INTERNATIONAL WORKSHOP ON
CAPACITY BUILDING & EDUCATION OUTREACH
IN ADVANCED GEOSPATIAL TECHNOLOGIES &
LAND MANAGEMENT

10-11 December, 2019
Dhulikhel, Kavre, Nepal
International Workshop on “Capacity Building and Education Outreach in Advanced Geospatial Technologies and Land Management”

Special Session on
BIM Technologies in Urban land management and development using Remote Sensing, Photogrammetry and Laser Scanning data: Managerial, Engineering and Educational Aspects

10-11 December 2019
Land Management Training Center, Dhulikhel, Nepal

WORKSHOP PROCEEDING

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Ganesh Prasad Bhatta
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Sanjeevan Shrestha
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Speech from Honorable Minister of Land Management, Cooperatives and Poverty Alleviation

Chair of the Inaugural Session of this International Workshop
Scholarly Vice-Chancellors of Kathmandu University and Nepal Academy of Science and Technology
Secretaries
Chairman and delegates of the co-organizers of this workshop
The invited scholarly professors as special speakers, National and International special guests, Workshop Participants, staffs and students of this training center and journalist friends
Namaskar and Warm greetings to you all!

I feel proud to inaugurate this International Workshop on Capacity Building and Education Outreach in Advance Geospatial Technologies and Land Management as the Chief Guest.
Since its establishment in 1968 as Napi Talim Kendra (Survey Training Center), this training center has been producing human resources and capacity development in the sector of Surveying and Mapping, and Land Management. Carrying forward this responsibility by conquering many obstacles, I am very pleased to know that LMTC has reached at this historical moment of organizing an international workshop for the first time. I would like to thank and congratulate the center family for being successful in organizing such an international seminar by bringing together distinguished scholars, professors, researchers, professionals and future students from all over the campus. The organization of an international level seminar within its own office premises is an exemplary work that I feel other departments should learn from.

Dedicated in manpower production and capacity development in the sector of Surveying and Mapping, and Land Management, it is of great pleasure that the training center is able to organize an international seminar on issues related to its jurisdiction.

In context of “Competent Civil Administration: Prosperity Development and Good Governance” being this year’s main slogan of Public Service and Good Governance being the highest expectation of the public, and Surveying and Mapping and Land Management being the backbone of infrastructure development; contemporary capacity building is indispensable and challenging to enhance the contribution of Surveying and Mapping, and Land Management towards nation building. It is highly relevant to organize such an International Workshop is such an important and challenging topic.

It is needed for the training center to completely transform the traditional technology based training methods into the latest technology based training methods. In my experience so far, we have not fully embraced technological development in the field of Surveying and Management, and Geomangement. In this regard, the center should be able to play an important role for technology transformation. Timely modification of the trainings provided by the Center, accordingly, the capacity development of the trainers and cooperation with the universities should be made more effective. In one hand, all participants will greatly benefit from the seminar through the exchange of experiences gained from the study, research, use and implementation of the latest technologies and concepts developed in the field of Surveying and Mapping, and Land Management. In the other hand, this workshop will play a vital role in the capacity building of the Center itself; and I hope that the workshop will guide the training center in fulfilling the nation’s expectations from the Center.
All the themes set for this workshop are important, among them the topics of International Cooperation and Curriculum Development are of more interest to me. Through intensive discussion amongst the invited scholars and guests, the center will surely receive guidance in developing the
curriculum in the focus area of the training center, and I am assured that this platform shall provide more opportunities for cooperation with national and international universities and related professional organizations.

As a pre-event of this seminar, I am happy to know that the workshop was organized yesterday to collect experts’ suggestions on the postgraduate level course of Surveying and Mapping area, which is being conducted on the Western Regional Campus Pokhara under Institute of Engineering Studies, Tribhuvan University. I am confident that the Center will continue this kind of cooperation with universities in coming days as well.

To make this campaign a success, the Government of Nepal, especially the Ministry of Land Management, Cooperatives and Poverty Alleviation has been involved in important campaigns including maintaining good governance, modernizing service delivery, ensuring availability of geographical information needed for infrastructure development and sustainable management of haphazard settlement. I believe this workshop shall be successful in building essential knowledge and capacity required to make this campaign a success.

In the coming days, this training center should continue organizing such programs and play a significant role in the capacity development of the government and private sector professionals working in the field of Surveying and Mapping, and Land Management. I am convinced this will help achieve the long-term vision of the “Prosperous Nepal: Happy Nepali” of the Government of Nepal. I would like to extend special thanks to the International Professional Organization in the field of Photogrammetry and Remote Sensing - ISPRS, the National Professional Organization of the same area - the NRSPS and the Professional Organization for Nepali Licensed Surveyors – NICS for assisting in organizing this important seminar. I extend my sincere thanks to all the participants, especially the Vice-Chancellors of Kathmandu University and National Academy of Science (NAST), and the distinguished university professors of different countries, who have contributed to the success of the seminar by accepting the invitation of the Center as special speakers. Likewise, I would like to extend special thanks to all the sponsors and supporters of the workshop, as well as the strategic partner of the workshop, Dhulikhel Municipality.

At last, with the belief that this two-day International Workshop will surely be fruitful, I wish for the full success of this event. As this International Workshop is being held when Visit Nepal 2020 is at our doorsteps, I extend our participating foreign guests to have a pleasant stay, especially at touristic Dhulikhel to be comfortable, successful and fruitful. Here, I conclude my inaugural address, hoping that you shall have lifetime experience here, and returning to your country of origin will encourage your relatives, friends and colleagues to visit us contributing to Visit Nepal 2020.

Thank You!
Messages from chair of Advisory Committee

It is indeed a matter of immense pleasure for me to have the privilege of conveying my message on the proceedings of the International Workshop on ‘Capacity building and Education Outreach in Advanced Geospatial Technologies and Land Management’. As the Secretary of the Ministry of Land Management, Cooperatives and Poverty Alleviation, Government of Nepal, my pleasure knows no bound congratulating Land Management Training Center (LMTC) for organizing such a wonderful event. I extend much thankfulness to the International Society for Photogrammetry and Remote Sensing (ISPRS), Nepal Remote Sensing and Photogrammetric Society (NRSPS) and Nepal Institution of Chartered Surveyors (NICS) for joining hands with LMTC as co-organizers in making this event a greater success.

It came to my knowledge that this is the first international workshop of this kind being held at LMTC. Pioneering such event of this magnitude and bring LMTC into recognition of international arena is admirable. I totally encourage LMTC for continual efforts for organizing such event in the days to come—especially to learn about state-of-art modern Geo-information and Land Management technologies and incorporate the knowledge obtained for updating syllabus, improvise training and teaching modes and techniques. I am confident this knowledge sharing shall ensure in production of competent human resources required for Surveying and Mapping and Land Management including Land Use Planning at all levels—Federal, Provincial and Local levels. It is commendable that the entire workshop is being held at the premises of the Training Center which portray great example of optimum utilization of own resources. Further, at this very event, LMTC has invited regional training centers in SAARC region aimed at flourishing network and collaboration to develop internationally accredited courses.

It feels good to see LMTC expanding its horizon every year. In the last fiscal year 2018-2019, LMTC issued its first annual publication named “Journal of Land Management and Geomatics Education”. This fiscal year, LMTC is organizing this international workshop. I would heart fully extend best wishes to entire LMTC team for even greater accomplishment in future endeavors and make a mark in National and International professional and academic sphere.

Last but not the least; I would like to extend heartiest thankfulness to the international participants for accepting the LMTC’s invitation to join this event, and warmest welcome in this beautiful Himalayan country. I am sure, you will enjoy the scenic beauty and kind hearted people of Nepal. Let me take this opportunity to bring into your, the International Participants’, kind information that the Government of Nepal is commemorating the Year 2020 as “Visit Nepal 2020” with aim to bring in visitors from all over the world. As this national campaign is on our footstep, I request all of you to spread mouth of words to your friends and families and inspire them to travel to Nepal. I wish a pleasant journey back home and happy reunion with your family and friends.

Thank you
Message from chair – Organizing Committee

Dear Distinguished Readers,

It's indeed a great honor and privilege for Land Management Training Center (LMTC) to host, and personally for me to be entrusted with the responsibility of chair of the Organizing Committee of, the International Workshop on Capacity Building and Education Outreach in Advanced Geospatial Technologies and Land Management.

I am short of words to express my happiness on the unprecedented gathering of dignitaries from different spheres of national as well as international life in the workshop. Gracious presence of Hon’ble Padma Kumari Aryal, Minister for Land Management, Cooperatives and Poverty Alleviation, Vice Chancellor of Kathmandu University Prof. Dr. Ram Kanth Makaju Shrestha, Vice Chancellor of Nepal Academy of Science and Technology, Dr. Sunil Babu Shrestha, including other eminent dignitaries in the workshop had enhanced the glory of the event and boosted up of our morale.

In addition to our scheduled sessions, special session on BIM Technologies in Urban Land Management and Development, and the pre-event entitled Workshop on Curriculum Development for MSc in Geomatics Engineering Course at Tribhuwan University; held on 9th December, jointly with Paschimanchal Campus (WRC), Pokhara had further added value to the workshop.

It was the first time for LMTC to organize this kind of event in its history. The center has proud history of bringing about innovation in the field of Geomatics and Surveying, and currently we are perpetually working hard in its transformation. We aspire to bring about such a transformation in three areas, firstly in its own capacity development i.e. in terms of the enhancing the capacity of its own training staff and its physical infrastructure; secondly, in terms of scope and content of the training courses, and thirdly by contributing through policy research in the areas of geoinformatics and land management. This Event aimed to contribute in the capacity development of LMTC’s training faculties and bring this institution in the light of the policy makers and professional community in the sphere of geoinformatics and land management.

The vision of LMTC is to be the “Center of Excellence in the sector of Geomatics and Land Management Education”. LMTC’s focus is three fold: firstly to develop human resources either by our own efforts or by collaborating with the universities, currently with Kathmandu University and Council for Technical Education and Vocational Training (CTEVT), secondly enhancing the capacity of the government staff working in the like field; by providing refresher courses, and thirdly by contributing to the policy reform through research activities. We believe the event remained catalyst in our bonding with the academia, research institutions and development partners.

It is so nice to mention that the event helped accelerating collaboration among national/international institutions, academia and professionals for mutual benefit through knowledge sharing and technology transfer. Special session on LMTC: Exploring Opportunities for Collaboration in LMTC’s Capacity Development remained fruitful. It was a close session and attended by Prof. Dr. Jaap Zebenbergen, University of Twente, The Netherlands; Prof. Dr. Prof. Dr. Ruizhi Chen from Uhan University, China; Dr. Sultan Kocaman from the Hacettepe University, Turkey; Prof. Dr. Candan Gokceoglu, Dean, Hecettepe University, Turkey; Prof. Dr. Kevin McDougall, University of Southern Queensland, Australia among other dignitaries.

The primary goal of the event was to provide forum for exchanging recent research achievements and novel ideas on cutting edge geospatial technologies and latest trends in geospatial education amongst multidisciplinary group of attendees. In presence of esteemed scholars, professionals and researchers from different part of the world, we believe, the goal has been achieved beyond its expectation.

Highly encouraging remarks from the Hon’ble Padma Kumari Aryal, the Minister for Land Management, Cooperatives and Poverty Alleviation, Government of Nepal, and Prof. Dr. Ram Kanth Makaju Shrestha, Vice Chancellor of Kathmandu University, motivated the LMTC team to work harder in the days to come. Enlightening Key Note Speeches from the Vice Chancellor of Nepal Academy of Science and Technology Dr.
Sunil Babu Shrestha, Prof. Dr. Jaap Zevenbergen, Prof. Dr. Ruizhi Chen and Dr. Sultan Kocaman remained in the center of attraction for the participants. Similarly, enlightening speeches from the BIM Speakers Prof. Dr. Karel Pavelka from Czech Technical University, Czech Republic and Prof. Dr. Roman Shults from Kyiv National University of Civil Engineering and Architecture, Ukraine were new to the national audience in the domain of BIM Technologies.

Prof. Dr. Kevin McDougall from the University of Southern Queensland, Australia remained mentor for LMTC staff, in his capacity of the Chair of Technical Committee. His affiliation as the Chair of the Technical Committee of the event helped us maintaining the quality of the technical sessions and presentations. His enlightening remarks of the opening of Day II equally remained a presentation of the audience’s interest.

I would like to acknowledge the all the dignitaries, I mentioned above, for extending their kind heart and supports to make the event a success. All the authors and presenters of the event deserve due respect and thankfulness from our side. I would like to thank International Society for Remote Sensing and Photogrammetry (ISPRS) (TC V / WG 7 and TC IV / WG 6), Nepal Remote Sensing and Photogrammetric Society (NRSPS), and Nepal Institution of Chartered Surveyors (NICS) for being on board with us as Co-organizers. Special thanks are due to the Chair of NRSPS Mr. Rabin K Sharma and the Chair of NICS Mr. Puny Prasad Oli for not only being happy to join us as co-organizers but also encouraging our team during its preparation. I would also like to thank Pashimanchal Campus (WRC) of Tribhuwan University for joining us as a partner of the pre-event of this international workshop.

Similarly, I would like to thank Trimble Inc., the Gold Sponsor of the event, which remains always supportive to us. I would also like to thank our local supporters ADMC Engineering Pvt. Ltd. and Geospatial Systems Pvt. Ltd, Technical Partner NAXA, developer of mobile app for the event, Academic Partner Kathmandu University, and media partner ‘Coordinates’ for their support in organizing this event. At the same time, I would like to extend heartiest thankfulness to the strategic partner of this event and the host of LMTC, Dhulikhel Municipality.

Last but not the least, I would like to extend heartiest thankfulness to the entire LMTC family, as included in the annex, including Director Mr. Rajendra Raut, Director Mr. Tanka Prasad Dahal, Director Mr. Lekhnath Dahal, Dr. Pradeep Sapkota Upadhyaya, Ms. Bhuwan Ranjit, Mr. Sanjeevan Shrestha, Ms. Laxmi Thapa, and Mr. Laxman Banjara, who has worked very hard to make this event a success and exemplary in its history.

Hope the content of the proceedings fulfills your interest. Enjoy going through the proceedings!

Thank you!
Message from chair – Technical Committee

On behalf of the Technical Committee for the International Workshop on Capacity Building and Education Outreach in Advanced Geospatial Technologies and Land Management, I would like to welcome all the keynote speakers, participants and other special guests to this workshop in Nepal.

The Technical Committee and team have worked extremely hard in reviewing over 60 abstracts submissions and undertaken the detailed peer review of approximately 40 full papers in order to determine their suitability for publication in either the ISPRS Annals or the ISPRS Archives and also for presentation as a paper or poster. There were 25 submissions received as the full papers for ISPRS Annals. The papers followed the ISPRS Guidelines and were peer reviewed by the professors, academics and professional experts in their related fields. Each paper followed a double-blind review process and the evaluation criteria were based on the ISPRS Review Guidelines. The reviewers focused on the papers’ innovation, scientific formulation, experimentation and validation, relevance and overall presentation. After the full review process, 17 papers were selected as being suitable the ISPRS Annals.

There were 40 submissions received as abstracts for ISPRS Archives. Again, the papers followed the ISPRS Guidelines and were peer reviewed by the professors, academics and professional experts in their related fields. A single reviewer was assigned for each paper and the evaluation criteria were based on the ISPRS Review Process. The review focused on the same five major criteria and after the review 16 papers were selected as suitable for the ISPRS Archives.

This International Workshop brings together experts which cover a variety of themes including: Advanced Geospatial Technologies, Land Management, Remote Sensing and Space Education, Curriculum Development for GIS Education Outreach, Spatial Data Infrastructure and Internet of things (IOT) and BIM. The Technical Committee acknowledges the efforts of all the authors and presenters and the high quality of the submissions.

In particular, I would like to recognise the efforts of the reviewers and Technical Committee Members namely Dr. Pradeep Sapkota Upadhyaya LMTC, Dr. Reshma Shrestha Kathmandu University, Dr. Jagannath Aryal University of Tasmania, Dr. Arun Pratihast Wageningen University and the Technical Committee Facilitators Er. Bhuwan Ranjit, Er. Sanjeevan Shrestha and Er. Laxmi Thapa. The Technical Committee also recognises the efforts of the International Workshop Advisory and Organising Committees, the International Program Committee, the Event Management Committee and the Secretariat.

I look forward to meeting everyone and a very successful and rewarding workshop.

Professor Kevin McDougall
University of Southern Queensland
Chair, Technical Committee
Message from Co-chair of the Workshop

Dear distinguished national and international participants,

It is my immense pleasure and honour to be one of the Co-chairs of the Organizing Committee for International Workshop on the ‘Capacity Building and Education Outreach in Advanced Geospatial Technologies and Land Management’ to be held from December 10-11, 2019 in Dhulikhel, Nepal. This event is organized by Land Management Training Center (LMTC) in collaboration with International Society for Remote Sensing and Photogrammetry (ISPRS) (Technical Committee V / Working Group 7 and Technical Committee IV / Working Group 6), Nepal Remote Sensing and Photogrammetric Society (NRSPS) and Nepal Institution of Chartered Surveyors (NICS). For your kind information, NRSPS is one of the Ordinary Members of International Society for Photogrammetry and Remote Sensing (ISPRS). Therefore, on behalf of NRSPS and in my capacity as the Co-chair of this workshop, I would like to heartily welcome to all the participants of the workshop in Dhulikhel.

Geospatial education and its applications are gradually increasing in Nepal. On the other hand, the geospatial technologies are developing in high speed in global context so in order to keep pace with the advancement of the technologies; capacity building should be one of the key factors. Therefore, the workshop aims to collect knowledge from the national and international researchers, renowned professionals and academicians regarding recent trends as well as result of the research projects of the geospatial domain, and to pass on such knowledge to not only the participants of the workshop but also to them who missed to participate due to some reason from multi-disciplinary organizations working with geospatial technology.

One more attraction of this workshop is a Special Session on Building Information Modeling (BIM) Technologies in Urban Land Management and Development.

I believe, this workshop is an ideal platform to exchange and share knowledge amongst the participants for enhancing and widen their horizon.

As the venue of this workshop is in Dhulikhel, this place is really a pleasant and attractive in the context of environment and natural beauty. Furthermore, this place is full of culture and ancient traditions. So, I believe, staying in Dhulikhel for the international participants could be a memorable one.

Finally, I wish for the success of the workshop.

Rabin K. Sharma
Co-chair, Organizing Committee of the Workshop
and
President, Nepal Remote Sensing and Photogrammetric Society (NRSPS)
Message from Co-chair of the Workshop

It is a great pleasure for us to organize International Workshop on “Capacity building and Education Outreach in Advanced Geospatial Technologies and Land Management” and a Special Session on “BIM Technologies in Urban land management and development using Remote Sensing, Photogrammetry and Laser Scanning data: Managerial, engineering and educational aspects” on December 10-11, 2019 at Land Management Training Center, Dhulikhel, Nepal and organized by Land Management Training Center in collaboration with International Society for Remote Sensing and Photogrammetry (TC V / WG 7 and TC IV / WG 6), Nepal Remote Sensing and Photogrammetric Society(NRSPS) and Nepal Institution of Chartered Surveyors(NICS).

The vision of International Federation of Surveyors (FIG) is that surveying is a modern profession acting worldwide for a better infrastructure for our society and planet earth. Vision FIG wants to keep, and even improve, its role as the premier non-governmental organization, that represents the interests of surveyors worldwide.

Manual technology is replaced by digital technology in Surveying. Survey works are now much easier, faster and accurate with these new methods. New technologies are being developed along with development of Information Communication Technology. The main objective of workshop is the Capacity building and Education Outreach in Advanced Geospatial Technologies and Land Management i.e. to cater exchange of recent achievements and ideas on geospatial technologies and latest trends in geospatial education amongst multi-disciplinary group of attendees. It is my expectation that it will assist to produce surveyors for a modern profession acting worldwide for a better infrastructure for our society and planet earth.

I would like to express our sincere appreciation to distinguish speakers, keynote speaker, speakers for BIM, paper presenters, sponsors and other partners for their contributions. I hope you all enjoy the stay in Dhulikhel, Nepal and wish happy journey back to your destination.

Punya P Oli
President,
December, 2019
Message From President of ISPRS Technical Commission V


Today, space technology touches essentially every aspect of our life as the phenomenal development has enabled the world to derive extensive benefits extending over natural resources management, disaster mitigation, communication, meteorology, education, health and entertainment, and so forth. The satellites from their vantage point in space are able to provide repetitive and synoptic coverage and the information and services offered from space sector has touched the lives of people to provide a variety of communication services across the world.

Remote Sensing and photogrammetry has made tremendous advances in the last two decades. There is almost no aspect of the modern civilizations that has not been touched by this technology. To cater to the growing demand of the technology and need of the nations to keep abreast of the demand of the technology, there is a urgent need to produce skilled manpower and also to enhance the capacity building of the different stake holders in the field of remote sensing.

I compliment the organisers of this Workshop for deciding to have a Special Session on Building Information Management (BIM) Technologies in Urban Management and Development using Remote Sensing, Photogrammetry as well as Laser Scanning data for managerial, engineering and education purposes. The BIM is an important essential element to be at the highest quality information to build eco-friendly urban infrastructure development including eco-system based disk risk reduction to realize the Sustainable Cities and resilient Communities as part of UN-SDGs.

To cater to this need, there is huge requirement for the scientists and academicians to deliberate ways to address the pressing need to enhance the capacity building of the nations and produce more number of skilled work force. I am sure that geospatial and academic community would find this conference professionally rewarding and use it as a platform to evolve solutions for the challenges that lie ahead of humanity.

I wish all involved in this event a great success in their endeavours.
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Organizer: Land Management Training Center

INTRODUCTION
Land Management Training Center (LMTC), under the Ministry of Land Management, Cooperatives and Poverty Alleviation, Government of Nepal was established in 1968. LMTC is the oldest and the only governmental institution continually and significantly producing human resources and enhancing capacity of the government personnel in the field of Surveying and Mapping, and Land Management since its establishments. The center has already produced more than 7,000 land professionals at different levels through various types of training courses.

LMTC has been conducting wide range of long and short term training incorporating state-of-art modern technologies. Moreover, LMTC has been collaborating to run academic courses with Kathmandu University (KU) and Council for Technical Education and Vocational Training (CTEVT).

VISION
To be the Center of Excellence in Land Management and Geomatics Education.

MISSION
To conduct academic courses, professional trainings, refresher courses and research in Land Management and Geomatics sector for the production of qualified and skilled human resources

OBJECTIVES
- To produce qualified and skilled human resources in the field of Surveying, Mapping, Geo-information and Land Management.
- To conduct and promote research and development activities in the field of Surveying and Mapping, Geo-information and Land Management.
- To establish collaborative relationship with national and international institutions for mutual benefit by knowledge sharing, professional trainings and technology transfer.

OUR FACULTIES/TRAINERS
Our courses are delivered by passionate and dedicated faculties/trainers who possess wealth of national and international experiences, and high qualification obtained from renowned national and international universities.

ANNUAL PUBLICATION
JOURNAL OF LAND MANAGEMENT AND GEOMATICS EDUCATION

OFFICIAL WEBSITE
www.lmtc.gov.np
**International Society of Photogrammetry and Remote Sensing (ISPRS) TC V/WG 7**

The international Society of Photogrammetry and Remote Sensing is a non-governmental organization devoted to the development of international cooperation for the advancement of photogrammetry and remote sensing and their applications. The society’s scientific interest includes photogrammetry, remote sensing, spatial information systems and related disciplines, as well as applications in cartography, geodesy, surveying, natural, earth and engineering sciences and environmental monitoring and protection. The scientific and technical work of the ISPRS is accomplished by 8 technical commission, namely

Commission I: Sensor Systems
Commission II: Photogrammetry
Commission III: Remote Sensing
Commission IV: Spatial Information Science
Commission V: Education and Outreach

**TC V/WG 7**

Under Commission V: Education and Outreach, ISPRS Working Group V/7 aims to promote global literacy and advance of innovations in geospatial technologies, mainly in photogrammetry and remote sensing for implementation in the educational process of civil engineers and architects through the development of multidisciplinary educational content that facilitate knowledge exchange between various applied sciences and organizations involved.

WG 7 is establishing and soliciting global collaborative network focused on the most efficient ways to integrate professionally and crowdsourced geospatial data into civil and architectural engineering operational workflows. To meet this challenge WG is planning to develop and promote worldwide educational content enabling to provide training and education for geospatial literacy and skills-sets development in civil engineering, environmental and architectural workforce. Special attention will be given to the low-cost close-range photogrammetry, UAS, LIDAR and open-sourced geospatial technologies suitable for the deployment by developing countries. To this end, group is planning to establish collaboration with United Nations University, European and US programs challenged in help to the developing countries.

Finally, WG shares educational content, develops novel educational components of training and education in photogrammetry and remote sensing for civil engineers and architects, organizes joint workshops, symposium and prepares results and recommendations.

**WG IV/6**

ISPRS WG IV/6 aims to promote the advancement of open standards, algorithms and system architecture related to spatial data infrastructure (SDI), the Internet of Things (IoT), sensor webs, and spatial decision support systems (SDSS). We will consider technologies, policies and people necessary to improve quality, reduce duplicity and encourage innovation in geospatial data access, sharing and use. Our goal is to elevate benefits of geospatial data to all levels of government, academia, private/non-profit sectors and individual citizens of our global community.

To this purpose, our WG will organize sessions and workshops exchanging latest developments in IoT, sensor webs, SDI and SDSS, as well as emerging technologies related to these areas of interest. We will promote publication opportunities in ISPRS Journal special issues, books, Annals/Archives, eBulletin and web/social media communication. Our members will liaison with related international efforts such as OGC Technical Committee, ISO/TC-211, Digital Earth, GEOSS, UNSDI, INSPIRE and GMES and collaborate with organizations such as the OGC Sensor Web Enablement, OGC SensorThings API, ISO/TC-211 working group, GSDI, FIG WGISS, ICA, W3C and EuroSDR. In these endeavors we will work closely with ISPRS WGs, especially within Commission IV (IV/4, IV/5, IV/7, IV/8 and IV/11), Commission I (Sensor Systems) and Commission V (Education and Outreach)
Nepal Institution of Chartered Surveyor (NICS)

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- To perform and to make performed activities for the welfare of the members of NICS.
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RESPONSIBLE LAND ADMINISTRATION: GEOINFORMATION AND MORE

Dr. J.A. Zevenbergen

KEY WORDS:

ABSTRACT:
In land administration we document the people-to-land relationships. This means we need to know the who, the how and the where throughout an area. Although the history land administration goes far back, the last decades the technological developments, both in geospatial techniques to collect ‘mapping data’, as well as overall ICT to collect, process, store, access and apply any kind of data, have been fast and (potentially) with large impacts. This is and will continue for sure. Examples are UAVs and (semi) Automated Feature Extractions. Technology also has potential side effects and needs to be contextualized for situation that it aims to support, as detailed in the fit-for-purpose approach. Large data sets also call for rethinking our broader ethical values as well. Finally, we need ‘change agents’ to make sure that we set up and/or run responsible land administration to contribute to smart land management.
THE CONTRIBUTION OF GEOMATIC TECHNOLOGIES TO BIM

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KEY WORDS: BIM, photogrammetry, laser scanning, cultural heritage, 3D documentation

ABSTRACT:
There are many definitions of the commonly used abbreviation BIM, but one can say that each user or data supplier has different idea about it. There can be an economic view, or other aspects like surveying, material, engineering, maintenance, etc. The common definition says that Building Information Modelling or Building Information Management (BIM) is a digital model representing a physical and functional object with its characteristics. The model serves as a database of object information for its design, construction and operation over its life cycle, i.e. from the initial concept to the removal of the building. BIM is a collection of interconnected digital information in both protected and open formats, recording graphical and non-graphical data on model elements. There are two facets: a) BIM created simultaneously with the project, or project designed directly in BIM (it is typical of new objects designed in CAD systems - for example in the Revit software) or b) BIM for old or historical objects. The former is a modern technology, which is nowadays used worldwide. From the engineer’s perspective, the issue is the creation of BIM for older objects. In this case, it is crucial to obtain a precise 3D data set - complex 3D documentation of an object is needed and it is created using various surveying techniques. The most popular technique is laser scanning or digital automatic photogrammetry, from which a point cloud is derived. But this is not the main result. While classical geodesy gives selective localized information, the above-mentioned technologies give unselected information and provide huge datasets. Fully automatic technologies that would select important information from the point cloud are still under development. This seems to be a task for the coming years. Large amounts of data can be acquired automatically and quickly, but getting the expected information is another matter. These problems will be analysed in this paper. Data conversion to BIM, especially for older objects, will be shown on several case studies. The first is an older technical building complex transferred to BIM, the second one is a historical building, and the third one will be a historic medieval bridge (Charles Bridge in Prague). The last part of this paper will refer to aspects and benefits of using Virtual Reality in BIM.

1. INTRODUCTION

1.1 What is a BIM?
BIM is a very popular acronym used in the last decade. The abbreviation BIM has been used more generally only since 2002 (Dekker, 2017). The principles of information modeling have been known since 1974 and in the last few years they have shifted from the theoretical level into practice. There are a number of definitions for BIM that differ in the use of the system itself. Building Information Modeling or Building Information Management (BIM) is a digital model representing a physical and functional object (building) with its characteristics. The model serves as a database of information about the building for its design, construction and operation throughout its life cycle, i.e. from the initial concept to the removal of the building. BIM is a collection of interconnected digital information in protected and open formats, a recording of graphic (2D, 3D) and non-graphic data about elements (elements) of the model. The 3D model itself is often mistaken as an information model of a building, even in professional circles. It is important to say here that BIM inherently includes not only its own information, but also rules for handling it; the 3D model is only one of many possible ways of presenting this information. The data must be compatible with used software systems and must be accessible to users, project participants, and must serve for the purposes of modeling, preparation and implementation, operation, maintenance and restoration of the building. The joined information creates a virtual model of the building, both spatial, time, cost, etc., from individual elements. These can be not only buildings, but also linear structures, bridges, etc. The basis of BIM is a 3D model of the object (building). And it can be a problem solved by using methods of geomatics or geodesy.

1.2 Using BIM for new constructed objects
Nowadays, buildings or constructions are already designed in BIM. However, it is used for larger buildings (constructions), using BIM for small houses or cottages is still in its infancy because of the input price and the maintenance of the system. Modern BIM brings long-term benefits in the definition and position of utility networks (power lines, water supply, sewerage, low - voltage networks), construction elements and monitoring their lifetime, resulting in cost savings, and keeps the building in good condition. System maintenance is a necessary part of BIM. Here, it is necessary to take into account the development of computer technology and software, which is very fast.

1.3 Using BIM for old or historical objects
In relation to older or even historical buildings or sites, there is a totally different approach (Pavelka,jr., Michalík, 2019). For older buildings or structures, we usually have classic 2D plans and cross-sections from the original construction documentation (Hůlková et al, 2016). This is a good basis for creating a new information system, but much other information (3D, materials, networks, etc.) needs to be added (Matoušková, Hůlková, Šedina, 2016). For historical buildings, there is either no solid documentation at all, or it was created purposefully during reconstructions and it is certainly not uniform or complete (Tuttas et al, 2014). Usually, it is better to create a completely new and accurate documentation, corresponding to today's requirements. Why should BIM be created for historic buildings? The answer is logical - when it comes to truly historic buildings, we try to keep them in good condition for a long time and we usually want to use them for living (Poloprušský, Fraštia, Marčíš, 2019). Many parts...
of historical buildings are unique or made by old technologies. This must be accepted from today's view on heritage care (Pavelka, 2017).

2. CONTRIBUTION OF GEOMATICS

2.1 BIM or 3D GIS?

From the perspective of geomatics or geodesy, BIM can be compared to 3D GIS. This parallel is suitable because similar tools are used in many cases for system creation and administration. In both cases, the basis is an accurate and credible 3D model, supplemented by thematic information.

2.2 Technology

In terms of technology, conventional geodesy can be traditionally used; but this is relatively slow. The aim is fast and if possible automatic 3D documentation of the entire building – inside and outside. Today, we have several options with full or partial process automation:

1) Advanced modern geodesy with semi-automatic devices (total stations often with a camera and scanning possibilities),
2) laser scanning (terrestrial stop and go technology), (Gleason, 2013),
3) mobile laser scanning (exteriors of buildings or linear constructions and bridges) using a special instrument mounted on a car equipped with INS (inertial navigation system), (Fig.2),
4) indoor mobile laser scanning (indoor parts of buildings) using hand-held equipment or a special trolley using an inertial unit, (Fig.3), (Kaijaluoto et al, 2015),
5) digital intersection photogrammetry (IBMR – image based modeling and rendering), aerial photos, drones etc. (Šedina, Housarová, Raeva, 2018).

2.3 Virtual reality

Virtual reality, like BIM, is again a very often used acronym. In modern manipulations with spatial data, the emphasis is often on visualization. Nowadays, Virtual Reality is used with success for data visualization. In this case, it is appropriate to say that this technology has come a long way in the last years. There is:

1) Augmented Reality (It is a term used for a real image of the world accompanied by computer-generated objects.). Using this it is possible to replenish real objects with non-existent elements.
2) Virtual Reality (It is about creating a visual experience that gives an impression of reality using devices connected to a computing unit that generates realistic perceptions for the user. It is commonly a stereoscopic imaging device in the form of special glasses with sensors for sensing their position. It is based on a 3D model of an object or surrounding reality with a texture in the computer memory), (Fig.4).

A significant benefit of VR is that someone creates a VR model and that others can browse or view it without being there. This is extremely important, for example, in the analysis of building structures and in archaeology or heritage care, especially in remote, dangerous or hard-to-reach places (Shirer, Torchia, 2017).
3. CASE PROJECTS

Here, we would like to show some examples how BIM or a general, common 3D information system of an object can be created and how it was developed.

3.1 Charles Bridge in Prague (beginning of BIM)

In 2004-5, the documentation of an important Czech and worldwide monument - historic Charles Bridge in Prague - was made. The methods of laser scanning and IBMR digital photogrammetry were not common at that time. Nevertheless, the bridge model was geodetically measured, the vector skeleton was defined by laser scanning, and the details and texture were created by single image digital photogrammetry. The resulting vector model in ACAD contained all the joints between the stone blocks and, finally, the model was covered with the texture from photos. Additionally, on one bridge arch and two pillars, historical and geological analysis of all stones was made. Each stone was identified by its type, origin, wear, defects, stonecutter marks, degradation, etc. (altogether 20 parameters), (Fig.5). Mouse clicking on a stone in the model will depict the related data (Fig.6). It was also possible to display its photograph with the near surroundings. It was already clear that for other experts this information would have to be concentrated in a 3D viewer. However, at the beginning of a new century, no suitable software for this project existed. A unique system was programmed in the laboratory of photogrammetry at the Czech Technical University in Prague that would now be referred to as BIM (Pavelka et al, 2016).

Figure 5. 3D model of Charles Bridge in Prague.
3.2 Dalal Bridge in Zakho (Iraq/Kurdistan)

After the success of the documentation and the development of a system for working with descriptive and spatial data, Dalal Bridge in Zakho, Kurdistan, Iraq, was similarly documented in 2008. This bridge probably has parts from the Byzantine era and was in very poor condition. Geodetic measurement and intersection photogrammetric work based on the Photomodeler software was performed in only three days. The documentation of the whole bridge with all stone blocks was carried out, and the analysis of damage to individual parts was also performed (Fig.7). Everything was entered into the above-mentioned 3D system. Unfortunately, this information and other facts were not used for the bridge repair, which did not much respect the historical originality of this object.

Figure 7 a, b. Dalal Bridge in Zakho (virtual model and vector model)

To a certain extent, it is tragicomic that everyone who saw the 3D-filled 3D system was thrilled. Unfortunately, none of the 3D information systems developed for both the above-mentioned bridges has been completed and used. They were ahead of their time and practice in restoring historical objects.

3.3 Nahúm’s shrine in Alqosh (using of VR in restoration process)

A modern, contemporary approach to the documentation and visualization of historic buildings was used for an important historical monument - the shrine and tomb of the Prophet Nahum in Alqosh (Iraq, Kurdistan), (Fig.8), (Pavelka et al, 2019). The shrine was in critical condition and close to a total collapse. In 2018, based on international activity and funding by Arch International (non-profit organization, “The Alliance for the Restoration of Cultural Heritage”, ARCH), complex 3D documentation of this object was performed using laser scanning and digital intersection photogrammetry (IBMR technology). At the same time, a static securing of the building was made, which was at risk of collapse. New possibilities of spatial documentation and visualization were used in this project. After the static securing of the construction and debris removal, another comprehensive survey was carried out, which showed further details. The resulting 3D models served as original documentation of various states of objects. While the rescue work was in progress, other experts could analyze the failures and discuss the next working steps using the 3D model and virtual reality, which allowed passing through an object without the need to re-visit the facility on-site. In the model, it is possible to measure distances, analyze the situation and virtually fill in non-existing collapsed parts, etc. (Fig.9). Based on a virtual reconstruction and remote consultations, the object was restored and today it is near completion, which is expected next year. After finishing all works, the last and final documentation will be made. The expert information system will thus contain not only three construction time levels, but also found artefacts, material, inscriptions and their translations, etc. Thanks to VR, we can look into the past viewing no longer existing condition of Objects.

Figure 8. A complex view on the Nahúm’s shrine, Alqosh

Figure 9. Virtually filled collapsed parts

3.4 Data transfer to BIM for elder building objects

The objective of documentation are not always historical objects or buildings. There are large numbers of buildings that need to be renovated due to modernization or reconstruction. It is expected that the reconstructed building will serve many years to come. Typical examples are offices or warehouses, production premises. Modern design companies are already working in BIM, and, in many countries, this is a requirement of the authorities. Therefore, it is necessary to convert the existing object to a BIM object and make the building design or the reconstruction project already in BIM. In simple constructions, today, laser scanning with automatic point clouds joining is used (Fig.10) (Pavelka,jr., Michalík, 2019). The process is even more modern and faster with hand-held indoor scanners. Their minor defect is less accurate results in terms of the absolute spatial position of the measured points, which is around a few centimetres.
4. CONCLUSION

The aim of the paper is to show how geomatics and geodetic methods can contribute to the development and digitization in construction. It is shown on examples, how the possibilities of spatial data conversion to BIM have been developed. Especially, new possibilities in the area of restoration of historical objects are mentioned. It turns out that as technology evolves, the transfer to BIM is becoming easier and will significantly increase the percentage of digitization in the construction industry in the near future. Converting a medium-sized object (hundreds of square meters) to BIM can be done in a few days or weeks. It depends on the details and requirements as well as the technique used.

ACKNOWLEDGEMENTS

This research was partially supported by a student’s Internal grant of the Czech Technical University Nr. SGS19/048/OHK1/1T/11 and partially by a grant of the Czech Science Foundation (GACR) Nr. 18-13296S.

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THE FUTURE OF AUTHORITATIVE GEOSPATIAL DATA IN THE BIG DATA WORLD: TRENDS, OPPORTUNITIES AND CHALLENGES

Kevin McDOUGALL

KEY WORDS: Spatial Data Infrastructure, Authoritative Geospatial Data, Big Data

ABSTRACT:

The volume of data and its availability through the internet is impacting us all. The traditional geospatial industries and users have been early adopters of technology, initially through the early development of geographic information systems and more recently via information and communication technology (ICT) advances in data sharing and the internet. Mobile technology and the rapid adoption of social media applications has further accelerated the accessibility, sharing and distribution of all forms of data including geospatial data. The popularity of crowd-sourced data (CSD) now provides users with a high degree of information currency and availability but this must also be balanced with a level of quality such as spatial accuracy, reliability, credibility and relevance. National and sub-national mapping agencies have traditionally been the custodians of authoritative geospatial data, but the lack of currency of some authoritative data sets has been questioned. To this end, mapping agencies are transitioning from inwardly focussed and closed agencies to outwardly looking and accessible infrastructures of spatial data. The Internet of Things (IoT) and the ability to interconnect and link data provides the opportunity to leverage the vast data, information and knowledge sources across the globe. This paper will examine the drivers of the “Big Data” phenomena and look to identify how authoritative and big data may co-exist.
CITIZEN SCIENCE AND GEOSPATIAL TECHNOLOGIES IN MODERN LAND MANAGEMENT

Sultan Kocaman
Hacettepe University, Department of Geomatics Engineering, Ankara, Turkey
Chair, ISPRS WGV/3 on Promotion of Regional Collaboration in Citizen Science and Geospatial Technology

KEY WORDS: Spatial Data Infrastructure, Authoritative Geospatial Data, Big Data

ABSTRACT:

The recent developments in geospatial technologies point out a new era for GIS with the advancements in data collection, analysis and presentation methods. Supported by mobile technologies, increasing data processing and management capabilities, advanced 2D/3D visualization platforms and artificial intelligence algorithms, GIS become extremely powerful for integrating geographical data from various sources. On the other hand, with the widespread use of ICT (Information Communications Technology), ordinary and even inexperienced citizens can utilize and benefit from geospatial technologies directly. GIS accessed from web and mobile platforms enables the participatory approaches for land use planning and development, land valuation and further land management practices. It allows citizens to contribute the decision making processes by sharing their data and opinion with the authorities, which can as well be associated with the concepts of VGI (Volunteered Geographical Information), crowdsourced data, participatory GIS, etc. In addition, Citizen Science (CitSci) draws attention for science oriented societies by ensuring participation of ordinary citizens to scientific processes based on their interest and abilities. The range of activities they may contribute range from biology to environmental monitoring to classification of galaxies, all of which having a spatio-temporal dimension.

The ISPRS WGV/3 emphasizes the increasing importance of citizen science both in scientific world as well as supporting the general trend in open science and open data. The geoinformation technologies play a key role within this research agenda and for achieving the 2030 Sustainable Development Goals of United Nations. National wealth is strongly dependent on land and its correct management is essential for sustainable development. Possible contributions of citizen science and geospatial technologies in modern land management will be discussed in this presentation. It is evident that one of the fundamental keys of sustainable development of nations is correct land management and planning. As the main conclusion of the presentation, the use of citizen science in land management may provide correct management and planning.
BEYOND GNSS: SUB-METER ACCURACY INDOOR POSITIONING USING SMARTPHONES

Prof. Dr. Ruizhi CHEN
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KEY WORDS: Spatial Data Infrastructure, Authoritative Geospatial Data, Big Data

ABSTRACT:
The recent developments in geospatial technologies point out a new era for GIS with the advancements in data collection, analysis and presentation methods. Supported by mobile technologies, increasing data processing and management capabilities, advanced 2D/3D visualization platforms and artificial intelligence algorithms, GIS become extremely powerful for integrating geographical data from various sources. On the other hand, with the widespread use of ICT (Information Communications Technology), ordinary and even inexperienced citizens can utilize and benefit from geospatial technologies directly. GIS accessed from web and mobile platforms enables the participatory approaches for land use planning and development, land valuation and further land management practices. It allows citizens to contribute the decision-making processes by sharing their data and opinion with the authorities, which can as well be associated with the concepts of VGI (Volunteered Geographical Information), crowdsourced data, participatory GIS, etc. In addition, Citizen Science (CitSci) draws citizen oriented societies by ensuring participation of ordinary citizens to scientific processes based on their interest and abilities. The range of activities they may contribute range from biology to environmental monitoring to classification of galaxies, all of which having a spatio-temporal dimension.

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GIS BASED MULTI-PARAMETER OPTIMAL PATH ANALYSIS FOR RURAL SCHOOLS

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KEY WORDS: Multi-parameter decision analysis, Optimal path, Geographic Information System (GIS), Spatial

ABSTRACT:

Using the Geographic Information System (GIS) technology, transportation and network analysis has become a straightforward application. An underlying problem in transportation and network analysis is to find optimal paths between different locations from sources to destination on a network. Sometimes this optimal path between source to destination has to be done in real-time. Several optimal path algorithms have been proposed by the researchers based on single parameter problem. In this paper, a multi-parameters based optimal path solution is proposed using GIS software for the travelling of children to schools. For these rural schools of Bara tehsil of Prayagraj district in India is selected. Three different parameters are taken to find the optimal path which is population density-based, travelling distance-based and travelling time-based optimal path. The developed optimum path is the least cost and satisfied by the other technical, environmental, economic and social criteria. This paper provides a solution if the government need to apply any policy that needs to visit each school. This paper will help the government in land management. On the basis of this paper, government can find schools which are not connected with road and can plan a new road to connect each school by road.

1. INTRODUCTION

Transportation is an essential aspect of child education. Most of the time there are several paths to reach the school. Selection of optimal path for transportation is the major issue for parents to send their children to school. The cost involved in transportation is a concern of the lower and middle-income group parents. Sometimes it hampers the child education that results in absenteeism and in worse case school dropout (Aggarwal, 2018). GIS can provide solutions that can help to reduce this problem.

GIS is can be defined as “a decision support system involving the integration of spatially referenced data in a problem solving environment” (Cowen, 1988). GIS can be used to develop a model that determines the optimal path for transportation (Ghose et al., 2006). It can be used as a decision support tool by students and school vehicle drivers to find the optimal path from sources to the destination (Singh et al., 2019). Using the multiple parameters based optimal path, the fastest route for a student to go and come from his home location to school location can be determined. This optimal path also can be followed by the school's bus drivers to receive students from their home location and drop out at the school using best optimal path. Based on the literature review there are many algorithms to find the optimal path (Pettit et al., 2018).

In this paper, the use of GIS is demonstrated in the identification of optimal path. The objective of the paper is to find the optimal path on the basis of population density, travelling distance and travelling time. As compared to shortest path application, multi-parameters based optimal path for rural schools of Bara tehsil using GIS software is more helpful. The database for Bara tehsil rural schools has been prepared and using GIS software optimal path from source to destination has been identified from the prepared database. Using GIS software the optimal path is to be calculated and the results were displayed. The user can view the optimal path based on these parameters. On the basis of travelling purpose user can choose the best paths. Many times the government wants to apply some policy that involves the visiting or surveying each school. This paper also provides a solution to this problem. Travel Salesmen Problem (TSP) is applied to find the optimal sequence to visit all schools. This also helps to identify whether there is road connectivity available or not.

2. STUDY AREA

Prayagraj district is in Uttar Pradesh state of India. It has been divided into eight tehsils, which are further divided into twenty developmental blocks. They are further divided into 1426 gram panchayat and then into 3095 revenue villages (Internet-1 2019). In all tehsils, except Prayagraj city, literacy rate is less than 60%. In Bara tehsil literacy rate is just 56.22%. As per Census of India (2011), there are 160,067 illiterate persons in Bara. This tehsil needs special attention to promote and support the literacy works. Therefore, Bara tehsil is selected as the study area.

* Corresponding author
Bara tehsil’s geographical extent is from 81.525°N, 25.029°E to 81.859°N, 25.357°E. It is divided into two developmental blocks, namely Shankargarh and Jasra. These two blocks are further divided into 326 revenue villages.

3. TITLE AND ABSTRACT BLOCK

This paper aims to identify multi-parameter based optimal path for rural schools. It highlights the potential use of GIS in the representation of available optimal path from source to destination. This optimal path will help the people living in rural area to find the best path to send their child in school and to return them to home in safely and timely manner. The methodology followed for this work is shown in Figure 2. This involves the creation of a GIS database of schools and road networks. Each of the school is located on the map along with road network connectivity.

4. DATA REQUIREMENT AND SOURCES OF DATA

The following data is required for this work.

4.1 School Location Data

There are 476 schools in Bara tehsil. Location of 476 schools is collected by field surveying. Minimum four satellites are required in GPS to calculate the (x,y,z,t), i.e. longitude, latitude
elevation of any place and time. The Trimble Juno 3B series handheld GPS is used for field survey to find the exact location.

![Methodology flow chart](image)

After the collection of data through GPS, data are transferred in Trimble field data (.SSF) format. When the data are transferred in .SSF format successfully then it is exported or converted into the ESRI point shapefile by using the GPS Pathfinder Office 5.60 software. Map in Figure 3 is showing the collected Bara tehsil schools which are overlayed on the village boundary layer.

Accuracy of the location collected by GPS field survey depends upon the accuracy of GPS instrument. The accuracy of the handheld GPS used in this survey work is 3 - 5 meters. Therefore, collected location may be displaced by this range. This minor displacement does not affect the output of this work. In the raw data only school and village name is given. During the survey, it was very difficult to find the school. With the help of local people each of the school is searched and surveyed.

### 4.2 Boundary Data

Boundary data is collected from maps. Prayagraj tehsil boundary map is generated from the Survey of India topographical maps. The toposheet number 63G, 63H, 63K and 63L are used to prepare Prayagraj tehsil boundary map. The scale of these maps is 1:2,50,000. These maps are first
georeferenced and then mosaiced. After this tehsil boundary of Prayagraj district is extracted by digitizing this mosaiced map. This digitized tehsil boundary map is shown in Figure 4. Bara village boundary map is prepared from NIC map. Bara tehsil village map is then georeferenced and digitized by using ArcGIS software. This village boundary map is shown in Figure 5.

4.3 Census Data

Population data of each village is collected from the census website of the year 2011. There are ninety six parameters in population data. Out of these parameters, nine parameters are used in this paper which are village name, village code, block name, total population, total male population, total female population, total literate population, literate male population and literate female population. Based on these parameters, attribute table of the village boundary layer is prepared.

4.4 Road Data

Road data of Bara tehsil is downloaded from OpenStreetMap (OSM) website (https://download.bbbike.org/osm/extract/planet_80.08,24.38_83.56,26.57.osm.shp.zip). This data is in shapefile format. The datum of this data is WGS 84. The spatial data type of this road is polyline. The road map is shown in Figure 6.

For the optimal path analysis, there is a need to assign the weight to the road data based on population. Therefore, splitting of road data is performed according to the village boundary. After splitting the road data with village boundary, village

---

Figure 4. Prayagraj district tehsil boundary map
Figure 5. Bara tehsil village boundary map
Figure 6. Bara tehsil road map
Figure 7. Bara tehsil road network map
population data is added in road shapefile attribute table. For the optimal path analysis, this polyline needs to convert into a network data type. This conversation is performed using ArcGIS software. The road network map is shown in Figure 7 where line is showing the road edge and point is showing the junction.

4.5 Bara Tehsil School Location with Road Network

In Figure 8, Bara tehsil village school location map is shown with village boundary and road networks connectivity. In this map, points are showing the school location and lines are showing the road network of Bara tehsil. From this map, it can be seen that in the rural area most of the schools are not connected with road.

5. LEAST COST OPTIMAL PATH

To apply the shortest path algorithm on road networks weight is need to be assigned. For this purpose literature review is performed. On the basis of this review, several parameters required for the optimal path as identified like travel time, travel distance, toll on route, quantitative information, qualitative information, number of turns, weather, time of day, congestion, safety, directness and comfort (Bowen and Ciyun, 2015; Li and Leung, 2011; Musliman, Rahman, and Coors, 2007; Papinski and Scott, 2011). However, in a rural area, some of these parameters are not required. To find optimal path from source to destination three parameters are selected which are population density, travelling distance and travelling time. Population density affects the traffic than any other factors. In rural area, many children go to school on foot so travelling distance becomes very important factor to find optimal path. Since the study area lies in a rural region, therefore travelling distance is selected as one of the parameter. Every student and their parents want to spend minimum time in commuting. Therefore, travelling time is chosen as one of the parameter. Hence, based on these three parameters combined weights are defined to find optimal path.

5.1 Population Density

To calculate population density (PD), first of all, the area of each village is calculated. For this calculate geometry tool is used which adds the area value in the attribute table of village boundary layer. In village boundary map attribute table, population data of year 2011 is added by joining the MS Excel file which is obtained from the census website. Using the following PD formula population density of each village is calculated in number of peoples in per km² area.

\[
    PD = \frac{\text{Total Population of Village}}{\text{Total area of Village}} \quad (1)
\]

A new attribute is added with the road layer to assign it a weight as per the population density. For this road layer, which is in shapefile format, is split by village boundary layer using the split tool of ArcGIS. After this population density attribute is added with each road based on the village in which it is falling.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Population Density (peoples in per km²)</th>
<th>Average speed (km per hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>0-200</td>
<td>60</td>
</tr>
<tr>
<td>2.</td>
<td>201-400</td>
<td>50</td>
</tr>
<tr>
<td>3.</td>
<td>401-600</td>
<td>40</td>
</tr>
<tr>
<td>4.</td>
<td>601-1000</td>
<td>30</td>
</tr>
<tr>
<td>5.</td>
<td>Above 1000</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 1. Average speed based on population density

Bara tehsil population density map is shown in Figure 9. This population density data is classified into five categories. Based on population density, the average speed limit in kilometer per hour is assumed as shown in Table 1.
5.2 Travel Distance

Travel distance is also taken as the weights that need to be added in the road attribute table. The coordinate reference system of road data is the geographic coordinate system. The datum of this data is WGS 84. To calculate travelling length, road data is converted from geographic coordinate system (GCS) to projected coordinate system (PCS) using ArcGIS Software. Then using calculates geometry tool of ArcGIS travel length of each road of Bara tehsils is calculated.

5.3 Travel Time

A new field is added in the attribute table by using following travelling time (TT) calculation formula.

\[ TT = \frac{\text{Traveling Distance}}{\text{Average speed}} \]  

(2)

Travelling distance is calculated in the previous section. The average speed of the vehicle is assumed based on population density of the village through which road is passing.

Figure 10. Optimal path map based on population density

Figure 11. Optimal path map based on travelling distance

Figure 12. Optimal path based on travelling time map

Figure 13. Optimal path based on combine weight map
5.4 Combined Weight

To calculate the optimal path based on above parameters a combine equation is defined. Because traffic is dependent mostly on population density so it is multiplied by three and then on travelling distance, so it is multiplied by two. Traffic in a rural area is affected very less by travelling time other than population density and travelling distance. So it will be same as actual travelling time. The following equation calculates combined weight:

\[
\text{Combined weight} = \frac{(3 \times \text{PD} + 2 \times \text{TD} + 1 \times \text{TT})}{6} \quad (3)
\]

where

- PD = Population Density in number of people in per square kilometer
- TD = Travelling Distance in meters
- TT = Travelling Time in seconds

Using the above equation combined weight is calculated. The attribute table is prepared for these parameters. Using networks analysis tool in ArcGIS, Bara tehsil road network is prepared. Using the new route tool in ArcGIS optimal path from source to destination is identified based on each parameter.

5.5 Travel Salesman Problem (TSP)

To visit all the schools starting from a particular point and then return to that particular location in order to find that there is road available or not TSP is used. Given a set of schools, distance, time and population density weight between every pair of school the TSP can find the least cost shortest possible route that visits every school exactly once and returns to the starting point. TPS helps to find that the road available or not available to reach a particular school.

6. RESULTS AND DISCUSSION

Using the above three parameters combine weight has been calculated and the attribute table of the above-mentioned parameters has been prepared. This attribute table data is a combination of school location data, village boundary data and census data of Bara tehsil. Road networks connectivity with school and find optimal path from source home location to destination school location and return from destination school location to source home location also identified. The different optimal path for the same source location and same destination location have been identified based on population density, travelling distance and travelling time which is shown in Figure 10, Figure 11 and Figure 12 respectively. Another map based on the combined map is also prepared which is shown in Figure 13.

Figure 14 is showing the output of TSP which is applied to the Bara tehsil schools. The points in red color are those schools that are not reachable by road. There are 36 schools in Bara tehsil villages which have no road facility and unable to reach by road. Therefore, based on the TSP problem, new routes required to connect every school of Bara tehsil from road can be identified through this analysis.

7. CONCLUSION

In the present paper, spatial analysis on the reachability of schools is performed. A spatial database is built that contains the school and road data of Bara tehsil. Optimal path analysis has been performed based on three parameters, i.e. population density, travelling distance and travelling time. A combined weight function is also given to find the optimal path. Many times there is a requirement to reach all the schools to distribute the food or any other material. This paper also gave the optimal route to visit all the schools by using the travelling salesman problem. This work will help the people to select the best possible path based upon their requirement. This paper will support the land administrators in planning. This paper will also help the government in the identification of locations where new roads need to be constructed so that every school will have the road connectivity.

REFERENCES


Internet-1: http://vlist.in/district/175.html (Accessed on 17 April 2019)
SPATIO-TEMPORAL ANALYSIS AND MODELING OF URBAN GROWTH OF BIRATNAGAR CITY, NEPAL

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KEY WORDS: Urban Growth, Image Classification, Spatial Metrics, Analytical Hierarchical Process, Multi-Criteria Analysis, Land Use Modeling

ABSTRACT:
Increasing land use land cover changes, especially urban growth has put a negative impact on biodiversity and ecological process. As a consequence, they are creating a major impact on the global climate change. There is a recent concern on the necessity of exploring the cause of urban growth with its prediction in future and consequences caused by this for sustainable development. This can be achieved by using multitemporal remote sensing imagery analysis, spatial metrics, and modeling. In this study, spatio-temporal urban change analysis and modeling were performed for Biratnagar City and its surrounding area in Nepal. Land use land cover map of 2004, 2010, and 2016 were prepared using Landsat TM imagery using supervised classification based on support vector machine classifier. Urban change dynamics, in terms of quantity, and pattern were measured and analyzed using selected spatial metrics and using Shannon’s entropy index. The result showed that there is increasing trend of urban sprawl and showed infill characteristics of urban expansion. Projected land use land cover map of 2020 was modeled using cellular automata-based approach. The predictive power of the model was validated using kappa statistics. Spatial distribution of urban expansion in projected land use land cover map showed that there is increasing threat of urban expansion on agricultural land. Neural Network (ANN), SLEUTH (Bihamta et al., 2015). Among them, CA model has been proven best for modeling urban pattern and phenomenon (Thapa & Murayama, 2011; Zhang et al., 2014). Many studies (Araya & Cabral, 2010; Bihamta et al., 2015; Tewolde & Cabral, 2011; Thapa & Murayama, 2011; Zhang et al., 2014) have shown that complex behaviour of urban change can be effectively simulated in the CA-based model. Its natural affinity with GIS and RS data gives more advantage to a user for simulating urban expansion. Moreover, its capability to integrate spatial multicriteria analysis (MCE) along with analytic hierarchical process (AHP) makes it more potential to model urban dynamics (Sakieh et al., 2014).

In this study, quantification and analysis of Biratnagar city’s urban growth changes and spatial pattern of urban area have been performed using an integrated approach of GIS and RS technique for the time period, 2004-2016. Similarly, probable urban growth area was simulated for future years using cellular automata (CA) model, using several factors affecting the urban growth and the past urban growth trend of the city. This study simulated and quantified the changing pattern of urban growth and future urbanization so that responsible authority could make it useful for implementing appropriate policies and monitoring mechanism for sustainable development. The paper is an example of reproducibility of existing technique of urban growth simulation in completely new study area (i.e. Biratnagar).

1. INTRODUCTION

Accelerating land use land cover (LULC) changes, especially urban growth has been profound these days, putting a negative impact on biodiversity, ecological process, thus creating a serious impact on the global climate change (Bihamta et al., 2015; Zhang et al., 2014). In last few decades, there has been substantial growth in urban areas, especially in the developing countries. According to United Nations (“World Urbanization Prospects,” 2014), 54 percent of people around the world were residing in the urban area, and two-thirds of world’s population is projected to be in the urban area by 2050. Due to increased availability of education, employment, services, production, sophisticated life, in developing country like Nepal, urbanization is considered as a usual phenomenon of economic growth as well as social change. But unplanned/haphazard urbanization may trigger many problems like urban sprawl, failing sustainable city development. Nepal is one of the least urbanized countries, but one of the fastest urbanizing country in the world, with the rate of urbanization of 3 percent (Bakrana, 2012). Among which, Biratnagar city is one of the densely populated areas and has a higher rate of urbanization after Kathmandu and Pokhara city.

There is a major concern on the necessity of exploring the causes of urban growth with its prediction in future and consequence caused by this for sustainable development. Due to rapid advancement in remote sensing (RS) and geographic information system (GIS) resources, tools and methods have enhanced researcher to apply the technique for monitoring and modeling urban sprawl, land use dynamics and urbanization effectively (Araya & Cabral, 2010; Tewolde & Cabral, 2011). Numerous researches has been conducted by several scholars focusing on the urban change phenomenon of urban sprawl using the utility of Cellular Automata (CA) Markov, Markov Chain, Artificial Neural Network (ANN), SLEUTH (Bihamta et al., 2015). Among them, CA model has been proven best for modeling urban growth changes and spatial pattern of urban area have been performed using an integrated approach of GIS and RS technique for the time period, 2004-2016. Similarly, probable urban growth area was simulated for future years using cellular automata (CA) model, using several factors affecting the urban growth and the past urban growth trend of the city. This study simulated and quantified the changing pattern of urban growth and future urbanization so that responsible authority could make it useful for implementing appropriate policies and monitoring mechanism for sustainable development. The paper is an example of reproducibility of existing technique of urban growth simulation in completely new study area (i.e. Biratnagar).

2. STUDY AREA

The study area (figure 1) lies in the south-eastern part of Morang district of Koshi region of Nepal. It consists of Biratnagar municipality and its surrounding VDCs (small administrative boundary) named as Tankinsuwar, Bajianthp, Ramganj
Belgachhi, Katahari, Matigachha and Buddhanagar. The geographic extension of the area is 26° 21’ 2.5” N to 26° 32’ 53.2” N in latitude and 87° 14’ 18.6” E to 87° 21’ 45.7” E in longitude. It covers an area of 149.126 sq. km. It is the second largest city next to the capital city, Kathmandu, and it consists of one of the biggest industrial areas in the country. It accounts for the highest growth rate of population among designated town in the country and there is a rapid change in land use.

3. DATA

Three Landsat TM satellite imagery with 30 m resolution, acquired in November 2004, October 2010 and October 2016 were used, obtained from the United States Geological Survey (USGS) (http://glovis.usgs.gov/) in the standard format. The image was projected into a World Geodetic System (WGS) 1984, Universal Transverse Mercator (UTM), Zone 45N coordinate system.

Landcover data, main roads, main rivers, topographic layers (contour and spot height) were obtained from Survey Department, Ministry of Land Management, Cooperatives and Poverty Alleviation, Nepal; whereas population data were obtained from the Central Bureau of Statistics (CBS), Nepal. Google Earth image (time slide) has been used for accuracy assessment.

4. METHODOLOGY

The study uses three techniques namely remote sensing, spatial metrics and land use modelling were employed.

4.1 Preparation of LULC Map using Remote Sensing

4.1.1 Image Processing: Firstly, pre-processing of acquired images was done using QGIS 2.16, which comprises a geometric transformation, radiometric correction, and image enhancement techniques to improve a quality of an image. Line stripping in Landsat 7 ETM+ (2004 and 2010) was corrected. Normalized indices such as normalized difference vegetation index (NDVI), normalized difference water index (NDWI), and normalized difference built-up index (NDBI) was prepared and used with other available bands in the layer stacking for better characterization of land use land cover type.

4.1.2 LULC Classification and Accuracy Assessment: A classification scheme with supervised classification was developed to obtain a broad level of classification to derive five LULC classes, such as urban area, water bodies, cultivation area, shrub/garden, and fallow land/industrial area. Support vector machine (SVM) classifier with radial basis function (RBF) kernel type was used to classify images. A focal majority filter was used to eliminate small and isolated area presented in a classified image. For accuracy assessment, sample points for each class were generated using stratified random sampling and checked against the google earth imageries. The reliability of classification was checked using overall accuracy metrics.

4.2 Spatial Metrics and Urban Sprawl Measurement

4.2.1 Spatial Metrics: Spatial metrics is a key parameter for the description of spatial structure and pattern, through spatial characteristics of patches, class and entire landscape (Herold et al., 2003). Quantification of change in urban structure can be accomplished by using information obtained from spatial matrices (Araya & Cabral, 2010). For this purpose, LULC map was reclassified into urban and nonurban areas, for a period of 2004 to 2016. Landscape heterogeneity for urban and non-urban classes was measured and analyzed using the FRAGSTATS tool. Seven spatial metrics (CA, NP, ED, LPI, MNN, AWMPFD and CONTAG) was selected (table 1) for analyzing urban changes due to their simplicity and effectiveness in depicting urban change (Araya & Cabral, 2010; Herold et al., 2003; McGarigal et al., 2002).

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
<th>Unit</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA- Class area</td>
<td>Total urban area in the landscape</td>
<td>Hectares</td>
<td>CA &gt; 0, no limit</td>
</tr>
<tr>
<td>NP- Number of Patches</td>
<td>Number of urban patches in the landscape</td>
<td>None</td>
<td>NP &gt;= 1, no limit</td>
</tr>
<tr>
<td>ED- Edge density</td>
<td>Sum of length of all edge segment involving the urban patch</td>
<td>Meter per hectares</td>
<td>ED &gt;= 0, no limit</td>
</tr>
<tr>
<td>LPI- Largest patch index</td>
<td>Percentage proportion of area of largest patch of urban</td>
<td>percent</td>
<td>0 &lt;= LPI &lt;= 100</td>
</tr>
<tr>
<td>MNN- Euclidean mean nearest neighbor distance</td>
<td>Distance mean value of all urban patch from the nearest neighboring patches of same</td>
<td>meter</td>
<td>MNN &gt; 0, no limit</td>
</tr>
<tr>
<td>AWMPFD- Area weighted mean patch fractal dimension</td>
<td>Area weighted mean value of the fractal dimension values of all urban patches, the fractal dimension of a patch equals two times the logarithm of patch perimeter (m) divided by the logarithm of patch area</td>
<td>None</td>
<td>1 &lt;= AWMPFD &lt;= 2</td>
</tr>
</tbody>
</table>
Table 1. Spatial metrics used in the study

<table>
<thead>
<tr>
<th>CONTAG-Contagion</th>
<th>Heterogeneity of a landscape, measuring extent to which landscapes are aggregated or clumped</th>
<th>percent</th>
<th>0 ≤ CONTAG ≤ 100</th>
</tr>
</thead>
</table>

4.2.2 Urban Sprawl Measurement Using Shannon’s Entropy: Urban sprawl is a complex phenomenon having environmental as well as social impacts (Sun et al., 2007). Due to its complex nature, there is no specific, measurable, and universally acceptable measurement method of urban sprawl. Shannon’s entropy with its integration with GIS is one of the effective methods used by several scholars (Araya & Cabral, 2010; Sun et al., 2007). Shannon’s entropy is used due to its toughness in urban sprawl measurement and its ability to measure the various patterns of urban area i.e. dispersed and concentrated over time (Yeh and Li, 2001). In this study, urban sprawl over a period of 12 years (2004, 2010 and 2016) has been determined by Shannon entropy calculation. The relative entropy is given by,

\[ E_n = \sum_{i=1}^{n} p_i \log \left( \frac{1}{p_i} \right) / \log (n) \]  

(1)

Where, \( p_i = x_i / \sum_{i=1}^{n} x_i \), \( x_i \) = the density of land development, which equals the amount of urban area divided by total amount of land in ith zone in the total of n zones.

The number of a zone is determined by a number of buffer zones around the city centre. In this study, this number is 13 having 1 kilometre of concentric rings around the main core area of the study area. This value ranges from 0 to 1 and determines the distribution of urban sprawl.

The difference in entropy between two time periods can be used to indicate the change in a degree of distribution of urban sprawl, which can be determined as:

\[ \Delta E_n = E_n(t + 1) - E_n(t) \]  

(2)

Where \( E_n \) = the difference of relative entropy over two time periods \( E_n(t + 1) \) = the relative entropy at time period \( t+1 \) \( E_n(t) \) = the relative entropy value at time \( t \) (Sun et al., 2007).

The difference of relative entropy over the period 2004-2010 and 2010-2016 were calculated.

4.3 Urban Land Use Change Modeling using CA-Markov

4.3.1 AHP Based MCE for CA-Markov Analysis: CA-Markov is combined cellular automata/Markov chain/multicriteria land use land cover prediction model that takes consideration of spatial distribution as well as spatial contiguity in a space (Sang et al., 2011). Urban sprawl modeling using CA-Markov process was mainly done by integrating Markov chain analysis with cellular automata. Markov chain analysis develops transition probability matrix of each land use land cover classes between t1 time and t2 time, describing the probability of land cover changes from one period to another (Araya & Cabral, 2010; Eastman, 2006).

The main disadvantage of this process is that it doesn’t consider the spatial behavior of each land use land cover classes over the space. This is the main factor where CA-Markov technique comes to play (Eastman, 2006). CA-Markov model is commonly used models among other LULC models due to its ability to model both spatial and temporal changes. Additionally, characterization of dynamics of LULC, urban sprawl, forest cover, plant growth etc. can be effectively done using CA-Markov model (Ghosh et al., 2017). CA-Markov analysis is backed up by using AHP based multi-criteria analysis to make the analysis more realistic by taking decision from the experts from various sectors influencing the urban land use change analysis. CA-Markov (combination of cellular automata with Markovian approach) predicts urban sprawl using Markov transition matrix, a suitability map and a neighborhood filter (Araya & Cabral, 2010; Eastman, 2006; Sang et al., 2011).

This study adopted CA-Markov chain analysis technique that is integrated within IDRISI software. Firstly, transition probability matrix for each LULC classes between 2004 and 2010 was prepared using Markov chain analysis. The suitability map for the urban area, agriculture and forest were generated using MCE-AHP process and that for water bodies and fallow land were generated with Euclidean distance function considering that closely existing LULC classes have more chance of changing into same classes. Here, socio-economic data (road network, settlement, land cover, population density, and water bodies) were integrated with biophysical data (DEM, slope) of study area through Multicriteria (MCE) technique, as an input for CA-Markov analysis. It is imperative to develop criteria for making decision to determine, which LULC classes are suitable for changing from one class to another with time and space including proximity from road, settlement, water bodies, socio-economic drivers (population density) as well as biophysical factors (DEM, slope) (R.R. Regmi, S.K. Saha, 2014). Depending upon the characteristics of each LULC classes with factors, a fuzzy rule is applied with each factor with fuzzy factor standardization (suitability of a contiguous range of 0 = least suitable to 255 = most suitable) for MCE in ArcGIS. For MCE-AHP process, weight for each factor for MCE has been computed from the AHP process. AHP process generally extracts from the measurement through pairwise comparison of each factor and relies on the judgment of experts to derive priority scales. The major strength of AHP is that it deals with judgmental consistency for subjective judgment done by experts (Thapa & Murayama, 2010). The consistency ratio of each AHP weight was tested and a ratio of less than 0.10 was accepted for decision making through multicriteria evaluation (Thapa & Murayama, 2010). In AHP process, each criterion of a factor was evaluated with pairwise comparison in decision support system tool in Idrisi. The suitability map of LULC classes of urban, agriculture and shrub were prepared by using the weights with different related factor map in ArcGIS environment.

4.3.2 Model Implementation, Validation and Projection: The predicted LULC map in 2016 using CA-Markov was accomplished with LULC map of 2010 as a base map with standardized group suitability map collection and Markov transition probability area matrix from Markov chain analysis and 5*5 contiguity filters.

Model validation is imperative in modeling process to assessing the performance of land use change model (Pontius et al., 2000).
In this study, this was done by comparing the result of simulation of LULC 2016 with reference LULC map of 2016 and calculating kappa variations, namely kappa for location (Klocation), kappa for quantity (Kquantity) and kappa for no information (Kno). Klocation defines success due to simulation’s ability to indicate location divided by the maximum possible success due to a simulation’s ability to specify location perfectly; Kquantity is a measure of validation of the simulation to predict quantity accurately and Kno shows the proportion classified correctly relative to expected proportion classified correctly by a simulation without the ability to indicate accurately quantity or location (Pontius et al., 2000; Tewolde & Cabral, 2011). More than 80% accuracy signifies that predictive power of the model is strong (Tewolde & Cabral, 2011). This means the model is good enough to predict future urban growth (for our case for 2020), assuming transition mechanism between 2004 and 2010 is going to be repeated.

5. RESULTS AND DISCUSSIONS

5.1 Land Use Classification and Accuracy Assessment

Using supervised with kernel-based support vector machine (SVM) classifier, LULC map of Biratnagar city for the year of 2004, 2010 and 2016 was prepared. LULC map contains five different class namely urban, water bodies, cultivation land, shrub/garden, and fallow land/industrial land. The maps showed that urban and cultivation land covered majority part of the study area.

To check the reliability of classification and to validate the result for further change analysis, the overall accuracy classification scheme was used. Overall accuracies obtained for the maps of 2004, 2010 and 2016 were 84.51%, 81.18%, and 84.3% respectively.

5.2 Analysis of Spatial Metrics

Spatial metrics and their variation were calculated for the urban areas for a period of 2004 to 2016 (table 2). The class area metrics show that there is a continuous expansion of urban area for the period of 2004 to 2016. Urban area increased by 468 hectares over a period of 2004-2010 and this increment nearly doubled in a period of 2010-2016. As study area contains a metropolitan city, it is a result of a common process which can be associated with the availability of resources, services, infrastructure, and trade.

The NP increased by 15 % over a period of 2004-2010 and decreased considerably (56%) in a period of 2010-2016, showing characteristics of urbanization as infill type. This signifies that urbanization was characterized by dispersion with a development of isolated and discontinuous built up area for the first period. In the second period, decrement indicates that these pre-existing isolated urban areas clustered together to form bigger patches. This kind of characteristics of urban growth is also confirmed by changing pattern of ED, with an increment (17%) in the first period and decrement (13%) in the second period. The LPI showed increased tendency over the study period, with an increment of 34% and 40% between 2004 to 2010 and 2010 to 2016 respectively. This indicates that the historical core area is still showing considerable growth.

There is a decrease in MNN for both periods i.e. 2004-2010 and 2010-2016, but by the small amount with 1% and 4% for the first and second period respectively. This reveals a decrease in distance between urban patches, hence towards agglomeration.

AWMPFD showed increasing trend over the period of 2004-2016, which also favors the argument toward urban growth. Nevertheless, this value is always slightly higher than 1, indicating moderate shape complexity. CONTAG decreased with 12% and 11% for the period of 2004-2010 and 2010-2016, which signifies that urban area is becoming more homogenous than previous, due to infill characteristics of urban growth trend.

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Year</th>
<th>Changes in Urban Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>2260.080</td>
<td>2727.540</td>
</tr>
<tr>
<td>NP</td>
<td>1250.000</td>
<td>1466.000</td>
</tr>
<tr>
<td>ED</td>
<td>42.135</td>
<td>50.523</td>
</tr>
<tr>
<td>LPI</td>
<td>7.342</td>
<td>11.091</td>
</tr>
<tr>
<td>MNN</td>
<td>69.799</td>
<td>69.091</td>
</tr>
<tr>
<td>AWMPFD</td>
<td>1.205</td>
<td>1.233</td>
</tr>
<tr>
<td>CONTAG</td>
<td>53.921</td>
<td>47.834</td>
</tr>
</tbody>
</table>

5.3 Urban Sprawl Measurement

The Shannon entropy of the urban areas in 2004, 2010 and 2016 was obtained as 0.824, 0.826 and 0.839 respectively (Table 3). All the values are above 0.5 showing a high rate of urban sprawl. Also, there is a continuous increasing trend of urban sprawl from 2004 till 2016. This confirms that urban growth is spreading over core urban area towards the surrounding rural areas. The spatial distribution of urban area (figure 5) over the period of 12 years showed that the there is significant growth of urban area in the north to south direction along major transportation network and around a periphery of the core area.

<table>
<thead>
<tr>
<th>E_s (Entropy during 3 study period)</th>
<th>ΔE_s (Difference in Entropy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.824</td>
<td>0.826</td>
</tr>
</tbody>
</table>

5.4 Land Use Modeling and Validation

Simulated LULC map of 2016 after modeling using CA Markov analysis shows reasonably similar spatial distribution to the real LULC of 2016 (figure 2). Validation has been done based on the kappa index of agreement. The K_{location}, which is analogous with overall accuracy, is calculated to be 85.09%. The model appeared to perform better in predicting specific location and quantity accurately (K_{location} = 0.8469 and K_{quantity} = 0.8013 respectively).
However, kappa statistics heavily depends on the reliability of suitability map collection, result from classification and contiguity matrix used.

5.5 Land Use Projection

A land use projection for the year 2020 was performed in the similar way, which is shown in figure 3. This shows that urban growth might continue to expand in future. The major growth in urban area is further expected to increase in the direction of north to south along the major transportation network. The extent of market centered urban area doesn’t seem to increase may be due to saturation of that area. The impact of the increase in urban area contributed in rapid reduction in the cultivation land.

6. CONCLUSION

The study analyses and models the trend of spatiotemporal change of urban of Biratnagar city and its surrounding areas using the combination of GIS, remote sensing, and modeling techniques. LULC maps of the study area for 2004, 2010 and 2016 were prepared by using supervised classification with kernel-based support vector machine (SVM) classifier. Accuracy assessment was done for validation of classification results.

The nature of urban area changes was quantified and analyzed using spatial metrics after urban areas were extracted from each LULC map. The result from spatial metrics in combination with urban sprawl measurement using Shannon’s entropy suggested that there is a high rate of urban sprawl and expansion over the study area. The spatial distribution of urban area suggested that significant growth of urban area in the north to south direction along major transportation network and around a periphery of the core area.

The validation result of a model using kappa degree of agreement showed satisfactory results, which allowed us to project LULC map for 2020. The result shows that urban area might continue
to grow. So, proper, and timely planning and actions should be implemented.

REFERENCES


MONITORING SPATIAL VARIATION IN TRIBAL POPULATION AT TAHSILS OF AHMEDNAGAR DISTRICT, MAHARASHTRA USING GIS TECHNIQUE

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KEY WORDS: Environment, Geographical Information System, Population, Socio-Economic, Spatio-Temporal, Tribal

ABSTRACT:
The tribal population represents a heterogeneous group scattered in different regions of India. The differences are noticed in language, cultural practices, socio-economic status and pattern of livelihood. The tribal population in India rapidly increased from 30.1 million in 1961 to 104.3 million in 2011. For same period tribal residing in rural area have increased by three times from 29.4 million to 93.8 million respectively. The tribal population resides in urban area is very less in number due to these people like to live in the remote areas of the proximity of natural environment. In Maharashtra, more than 47 indigenous tribes were dwelling at Sahyadri and Satpuda mountainous ranges. According to 2011 census, there are about 1, 05, 10,213 tribal populations living in Maharashtra, which constitutes 10.05% population of state. In Maharashtra, there is regional disparity in tribal population such as Nandurbar District has the highest tribal concentration while Dhule, Gadchiroli, Nasik, and Ahmednagar District have moderate tribal concentration. Therefore, present research work is an attempt to understand the Spatio-temporal variation in tribal population of Ahmednagar district using GIS technique during the period of 2001-2011. This study is to examine the tahsil-wise tribal population and identifying pattern of tribal population density in Ahmednagar District. The result shows that more than 80% of tribal population concentrated in Akole, Sangamner, and Rahuri tahsil due to hilly region, rugged terrain, river basin, and forest area. It is also demonstrated that the planning control, researchers and decision-makers should be focused on these areas for implementing policies and large numbers of tribal can be benefited.

1. INTRODUCTION
It is estimated that there are 370 million indigenous people living on the surface of the earth across 70 countries (Paltasingh and Paliwal, 2014). These tribes are located mainly in Central Africa, South America, Oceania, India and Australia. It is noted that, tribes are indigenous part of Indian subcontinent because India is one of the largest tribal population countries in the world (Ali and Das, 2003). The tribes constitute nine percent of the country’s total population, which ranks second in concern of tribal population world after Africa continent (Muzumdar, 1973). Tribal population in India is unevenly distributed. The tribal communities live in about 15 percent area of the country, in various ecological and geoclimatic conditions ranging from plains and forests to hills and inaccessible areas (Ambagudia, 2010). In 2001, Census enumeration tribal population was 8.43 crores and 8.2 percent of total population of the country. The tribal population of India, according to 2011 Census is 10.45 crores, constituting 8.63 percent of total population of country (Paltasingh and Paliwal, 2014).

In Maharashtra, several tribes are found i.e. Warli, Katkari, Kokana, Mahadeo Koli, Bhil, Thakar, Andha, Gond, Kolam, Oranon, Paradh, Halaba, and Tokre Koli dwell in certain pockets. Forests and Mountains play vital role of magnet for tribals. Therefore, majority of tribes were found in Sahyadri, Satpuda mountainous ranges (Kokate and Solunke, 2011). In Maharashtra, more than 47 indigenous tribes were dwelling. According to 2011 census, there are about 1, 05, 10,213 tribal populations living in Maharashtra, which constitutes 10.05 percent population of state. In Maharashtra, Nandurbar District has highest tribal concentration i.e. 69.3 percent of district's total population; while Dhule, Gadchiroli and Nasik Districts have moderate tribal concentration i.e. between 25-50 percent of district's total population. Districts Nashik, Thane, Nandurbar, Dhule and Jalgaon contribute more than 50 percent to the state's tribal population. Overall sex ratios among tribals are 977. The child sex ratio is 955; it is lowest in Kolhapur District (870) and highest in Gadchiroli District (985). Literacy rate among tribal’s are 65.7 percent and among males and females, 74.3 percent and 57 percent respectively.

Therefore, present research work is an attempt to understand the spatio-temporal variation in tribal population of Ahmednagar district during 2001-2011. This study is to examine the tahsil-wise tribal population and identifying pattern of population density in Ahmednagar District during 2001 to 2011. Ahmednagar District is socio-economically one of the developed districts in Maharashtra.

2. STUDY AREA
Ahmednagar District popularly known as ‘Nagar’ is one of the important district of Western Maharashtra, which is situated partly in the upper Godavari basin and partly in the Bhima basin. It lies between 18°2’ to 19° 9’ N latitudes and 73° 9’ to 75° 5’ E longitudes with the total geographical area of 17410.91 square kilometers (Wayal et al., 2016). Ahmednagar District is the largest district by area in the state of Maharashtra. Ahmednagar District has 1584 villages, 1 municipal corporation, 9 municipal council, 4041 grampanchayat, 18 urban centers and 1 cantonment board. The district is consisting of 14 revenue tahsils namely Nagar, Parner, Pathardi, Newasa, Shrirampur, Shenvoan, Rahuri, Rahata, Sangamner, Kopargaon, Akole, Shrigonda, Jamkhed, Karjat (Figure 1).
According to 2011, Census of India the total population of Ahmednagar District was 45,43,159 in which male and female were 23,42,825 and 22,00,334 respectively. Parner is the largest tahsil by area with 1930.28 square kilometers while Srirampur is the smallest taluka with 569.87 square kilometers in the district. It is bounded on the north by Nasik District, Aurangabad District to the northeast side, Beed District to the east, Osmanabad and Solapur District to the south, Pune District to the west and Thane District to the north-west (Narke and Kore, 2012).

Figure 1. Location Map of Study Area

3. OBJECTIVE

The main objective of the present research work is to understand the spatial variation in tribal population of Ahmednagar District.

4. MATERIALS AND METHODS

This study is based on secondary data obtained mainly from the publications of Census of India. The main census publications of different periods of time from where data has been collected include the General Population Tables, Socio Cultural Tables, District Census Handbooks of Ahmednagar Districts, Primary Census Abstract, Final Population Tables etc. In addition to the sources indicated above, information and data have been collected from the Gokhale Institute of Politics and Economics, Pune and Statistical Department, Ahmednagar District. The collected data has been processed and analyzed by using different quantitative, statistical technique. A large number of books, research studies including dissertations, published and unpublished works from different sources have been studied thoroughly for the present study. Relevant web sites were visited from time to time for authentic information and data.

The present research work is an attempt to monitor the pattern of tribal population density of Ahmednagar District during 2001-2011. Population density refers to the ratio between numbers of people to the size of land in a country (Rai, 1996). It is usually measured in persons per sq km with applying following formula (Trewartha, 1953; Clarke, 1965; Sundaram, 1985; Ghosh, 1998; Sawant and Athawale, 1994; Chandana, 2004):

\[
\text{Density of Population} = \frac{\text{Total Population}}{\text{Total Geographical Area}}
\]

Tahsils has been considered to be the most appropriate unit of study for which data are available. There were 14 Tahsils in the district in 2011.

5. RESULTS AND DISCUSSIONS

The District level distribution of tribal population shows wide variation. Ahmednagar district is habitat of 8.33 percent tribal population of Maharashtra (See in Table 1). The largest cluster of tribal population in Ahmednagar district lies in upper Mula and Pravara basin and partially in Godavari river basin and Western part of Sahyadri Mountain (Pawar, 2015).

The rim of Sahyadri continuously encourages aboriginals to settle and survive. Dense forest, Hill valley, rugged topography, steep slopes support tribal communities. Most of the tribal are concentrated in western part of Akole Tahsils. Out of total tribal population of district, more than 36 percent tribals inhabit in Akole Tahsil. In Akole Tahsil itself, out of total population 45.59 and 47.86 percent population consists of tribals in 2001 and 2011 respectively (See in Table 1; Figure 2 & Figure 3). Therefore, Government has declared Akole Tahsil as Tribal Sub Plan (TSP) area.

It is very interesting to note that more than 80 percent tribal population of district is concentrated in only 4 Tahsils like Akole (47.86 percent) Sangamner (10.59 percent), Kopargaon (11.37 percent) and Rahuri (10.54 percent) Tahsils in 2011 (See in Figure 3). Because of tribal population concentration are characterized by hilly, roughed terrain, forested and river basin. Distribution pattern of tribal population in Ahmednagar district is very uneven. In 2011, ten Tahsils mainly in South and East direction except Parner and Rahata falls in low percentage category (1 to 10 percent) of tribal distribution. In this first group Jamkhed with 1.43 percent, tribal population shows lowest in district. On the other hand, some parts of Shirrampur Tahsil stands on top with 6.80 percent tribes. Tahsils with less tribal population are characterized by relatively low altitude and thin vegetative cover area towards East and South of district. In next category Kopargaon, Sangamner and Rahuri Tahsil exhibit 11.37 percent, 10.59 percent and 10.54 percent respectively (See in Figure 3). Therefore, it comes into significant (10 to 20 percent) category of tribal distribution. These Tahsils are characterized by fluvial topography of Mula & Pravara basin and partially Godavari River basin. Rahuri and Sangamner are covered by Baleshwar range and Mula and Pravara basin.

Such hill valley landscape is supreme location for tribes. Godavari River flows through Kopargaon Tahsil and there are hardly any shrubs and vegetative cover, which support to tribals. This Tahsil is neighbor by Nasik District from West and North sides, which is well-known for its tribal population. This vicinity of tribal belt of Nasik is also important reason for high tribal concentration in Kopargaon Tahsil. In Ahmednagar District, only Akole Tahsil comes in important (20 to 50 %) percentage category of tribal population. Out of total tribal population of district more than 37 percent, tribal population resides only in Akole Tahsil. Scheduled tribe Population Density of Ahmednagar District was never cross the state average from the period of 2001 to 2011 (See in Table 2). In 2001, the ST population density in the region was 17.42 persons per sq km, which has increased to 21.72 persons in last decades. According to Census of India, the highest population density was observed in Akole (80.77 & 92.84 person per sq. km) Tahsil in 2001 and 2011 respectively due hilly region and lowest population density.
was recorded in Karjat Tahsil was 1.54 person per sq. km in 2001 and 2.30 per sq. km in 2011, due to plain areas (Table 2).

Similarly in 2001 the highest density was recorded in Akole Tahsil with 88.77 persons per sq. km followed by Kopargaon, Rahuri, Shiriramur, Sangamner Tahsils with 37.86, 26.97, 24.60 and 24.22 persons per sq. km respectively. In similarly Karjat Tahsil has recorded lowest density with 1.54 persons per sq. km after that, Jamkhed, Pathardi, Shevgaon and Shrigonda Tahsils (See in Table 2).

According to census 2011, tahsils-wise density clearly shows that Akole tahsils has recorded the maximum density with 92.84 persons per sq. km followed by Kopargaon, Shiriramur, Rahuri, Sangamner Tahsils with 47.41, 34.32, 32.88 and 30.29 persons per sq. km respectively. This is mainly due to the increase in irrigated area, expansion of infrastructural facilities, as well as the implementation of developmental activities. The Karjat Tahsil has recorded the minimum density with 2.30 persons per sq. km, later on Jamkhed (2.59), Pathardi (3.39) and Shevgaon Tahsils (4.54 persons per sq. km) due to undulating surface of low accessibility and developmental programmes are not properly implemented in these areas.

There is a found a high variation in spatio temporal changes in the tribal population density. The researchers observed that the death rate is rapidly declined in tribal region due to increase medical facilities in remote areas. Hence, population increased in tremendous proportion, as well as the density of population in tribal areas as affected. In 2001, the population density in the region was 17.42 persons per sq km, which has increased to 21.72 persons just in last one decade (See in Table 2).

6. CONCLUSIONS

The density of scheduled tribe population in Ahmednagar District is considered, the increasing trend from 2001-2011 is observed due to some operatic changes are occurs. It was noted that 17.42 persons per sq km in 2001, where as 21.72 persons per sq km. in 2011. Density of Tribal people is marked increasing trend since last 10 years. There is a great variation in tribal density pattern of Scheduled tribal population in the study area. Population distribution denotes the spatial pattern due to dispersion of population, formation of agglomeration, linear spread etc.

It is observed that, the tribal population is mainly concentrated in such areas, which are highly under forest that can provide sustainability to them. It is evidenced from the study; the tribal population is inhabited in hilly, rough and tough areas like Akole Tahsil. It is suggested that, socio-economic development planning should take place in those areas where the problem is serious and large number of tribal can be benefited. In the context, the result of the present research work proves of immense importance for planners, researchers, administrator, educationist and decision makers.

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Website Links
http://censusindia.gov.in/
https://mahasdb.maharashtra.gov.in
https://en.wikipedia.org/wiki/Talukas_of_Ahmednagar_district

**ANNEX**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Name of Tahsil</th>
<th>Geographical Area (km²)</th>
<th>Population Density (Sq. km)</th>
<th>Decadal Change in S.T. Population Density (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Akole</td>
<td>1505.08</td>
<td>80.77</td>
<td>92.84</td>
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<tr>
<td>2</td>
<td>Jamkhed</td>
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<td>3</td>
<td>Karjat</td>
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<td>2.30</td>
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<td>4</td>
<td>Kopargaon</td>
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<td>Nagar</td>
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<td>Rahita</td>
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<td>14</td>
<td>Shrirampur</td>
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<td>24.60</td>
<td>34.32</td>
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<tr>
<td><strong>District Total</strong></td>
<td></td>
<td><strong>17410.91</strong></td>
<td><strong>17.42</strong></td>
<td><strong>21.72</strong></td>
</tr>
</tbody>
</table>


Table 1. Distribution of Scheduled Tribe in Ahmednagar District

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Name of Tahsil</th>
<th>Total Population</th>
<th>S. T. Population</th>
<th>Decadal Change in Tribal Population (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Akole</td>
<td>266638</td>
<td>121566</td>
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<tr>
<td>2</td>
<td>Jamkhed</td>
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<td>1879</td>
<td>2.47</td>
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<td>3</td>
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<td>Shrirampur</td>
<td>256458</td>
<td>2712</td>
<td>26.41</td>
</tr>
</tbody>
</table>

Table 2. Changes in Tribal Population Density in Ahmednagar District (2001-2011)
IDENTIFYING AND MAPPING OF SLUMS IN PUNE CITY USING GEOSPATIAL TECHNIQUES

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KEY WORDS: Environment, Geospatial, Land Use, Migration, Slum, Urban

ABSTRACT:
In India, rapid growth of slums in urban areas, especially in metropolitan cities, has become a major problem for the planners and decision-makers. The slum expansion is mainly due to the rural-urban migration and pressure of the population on un-used, un-protected, and unsuitable public land. It leads to many issues like poverty, unemployment, lack of access to clean water, lack of durable housing, traffic congestion, environmental pollution, insufficient living area, inadequate sanitation, scarcity of land, inappropriate land use, skyrocketing land value and insecure tenure, etc. Planning controls are usually ineffective in slum areas due to lack of timely information and people having little regard for such things in the absence of any other alternative. In most of the municipal bodies, proper updated information/map of slums are not available, which, create a problem in the decision-making process. Thus, there is an imperative need to resolve above-mentioned issues with the help of Geospatial techniques. This paper aims to identify and mapping of slums in Pune City using Geospatial techniques. The slums were identified based on high-resolution satellite images such as Resourcesat-2 (LISS-IV) data with the help of visual interpretation and standard image processing techniques, i.e., image rectification, enhancement, and classification. Afterward, the database was created and labeled with the help of the GIS tool. In Pune, there is around 40 percent of the urban population resides in slums. Such a large proportion of slum population also adds to the burden of already scarce resources and on overall urban infrastructure. The entire slum population of the city was accommodated in a total of 477 slums of which 238 and 239 were declared and undeclared slums respectively. The most of the slums in Pune mainly occurred in the central part due to natural increases as well as migration. But, the peripheral areas it’s happen due to vacant land/open areas along to river, canal, railway line and hill slope. The study reveals that more than 200 slums are located near environmentally sensitive areas and encroachment activities are increased in southern part of the city i.e., Ambegaon Bk., Viththal Nagar and Warje areas.

1. INTRODUCTION
Urbanization is the physical growth of urban areas, which result in population growth, an increase of built-up area, high density of population, and also the psychological stage of the urban way of life. The urban population in the world is generally rising. It is expected to increase by 72 percent by 2050, from 3.6 billion in 2011 to 6.3 billion in 2050. By 2050, it is predicted that 64.1 percent and 85.9 percent population will be urbanized in developing and developed world respectively (United Nations, 2011). Urban population in India has increased more than six times during the last 60 years from 62.44 million in 1951 to 377.1 million in 2011. Presently, it is 31.16 percent of the total population (Census of India, 2011). In India’s three urban agglomerations viz. Greater Mumbai, Delhi, and Kolkata have crossed the 10 million mark in population, while the number of million-plus cities has been increased from 5 in 1951 to 53 in 2011 (Census of India, 2011). According to Government sources, a total of 65.49 million population living in 13.9 million households have been enumerated in slum reporting towns (2613) among States and Union Territories. The slum population enumerated was 17.4 percent of the total urban population of all the States and Union Territories in 2011 (Census of India, 2011).

The acute problem of slum formation is found not only in the big cities but, also in medium and small cities/towns in India due to rapid urbanization, poor housing planning and increasing migration of people from rural to urban areas (Jitendra Kumar, 2014). This has increased the demand for affordable housing in urban areas.

Hence, slums have formed mainly because of the inability of city governments to plan and provide affordable housing for low-income segments of the urban population (Ooi and Phua, 2007). Such dwellings are usually built in marginal areas such as along natural drainage channels, railway lines, hill sides, etc. Planning controls are usually ineffective due to lack of timely information and people having little regard for the absence of any other alternative (Kombe, 2005; Maktav and Erber, 2005). In most of the municipal bodies, proper updated information/map of slums are not available, which, create a problem in the decision-making process. Thus, there is an urgent need to adopt modern technology like remote sensing and Geographical Information System (GIS) for resolving the problem of slum areas (Sori, 2012).

2. STUDY AREA
Pune is the second-largest city in Maharashtra and one of the eight-mega cities of India regarding population, with a population growth of 7.8 percent during 2001-11 (Government of India, 2013). Pune city lies between latitudes 18° 25’N and 18° 37’N and longitudes between73° 44’E and 73° 57’E, and the geographical area is around 250.56 sq. K.m with a population of about 5.1 million composed of 76 general electoral wards. Based on Census of India 2011, these
wards are converted under 14 administrative wards by Pune Municipal Corporation (Figure 1). The city boasts of a strong heritage and culture with picturesque historical, religious, and natural zones and hence is called the “culture capital” of Maharashtra. Further, the city also processes the strengths in the educational sector with many educational institutes and a well-skilled labour force, for which it is considered as the “Oxford of the East.”

Pune attracts thousands of immigrants due to multiple variants of economic activities and most of them falling in the category of lower strata forming the poor or low-income group, who are forced to live in slums or slum-like conditions due to poor affordability. In 1951 the slum population was about 8 percent of the city’s population, which according to slum department of PMC, in 2011 gradually increased up to 40 percent (Figure 2). Such a large proportion of slum population also adds to the burden of already scarce resources and on overall urban infrastructure.

Subsequently, Survey of India (SOI) toposheets at 1:50,000 scale was used for the extraction of thematic layers: contours, drainage network, water bodies, roads, and rail network, forest areas and administrative boundaries, etc. Demographic details of the study area were obtained from the Census of India and various reports of Pune city, which is useful for the preparation of a demographic map. Ward map and administrative boundaries of the study area was collected from Pune Municipal Corporation (PMC).

In methodology involved several steps, i.e., image pre-processing, image classification, ground truth data collection and verification, accuracy assessment, post-classification, and post-processing (Joshi et al., 2002; Sur, 2004).

<table>
<thead>
<tr>
<th>Segment: Pune city</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topographical (OSM) Maps: E43H14 &amp; E43H15 surveyed in 2011, Scale 1:50,000</td>
<td>Survey of India (SOI)</td>
</tr>
<tr>
<td>Other data – i) Slum Population, ii) Slum Distribution (declared and undeclared slum) etc. iii) Ward Boundary Map</td>
<td>Primary Census Abstract for Slum, Census of India-2011 ESR 2016-17, PMC Revised City Development Plan for Pune - 2041 Pune Municipal Corporation (PMC) office</td>
</tr>
</tbody>
</table>

Table 1. Spatial and Non-spatial data

5.1 Image Pre-processing

Image pre-processing involves scanning, geo-referencing, and digitization topographical maps, satellite images, and other base maps. Firstly, topographical maps, e.g., E43H14 and E43H1415 scale 1:50,000 were geo-referenced using the UTM projection system and digitized thematic layers such as ward boundaries, road, railway line, river, forest, population density, declared and undeclared slums, etc. The remotely sensed image acquired by the Resourceat 2 (LISS IV) sensor with a spatial resolution of 5.8 m in November 2016, was used for visually interpreting the land use/land cover. Images were processed using slandered techniques like rectification, enhancement, band extraction, restoration, and image subset.

5.2 Image Classification

Image classification technique is based on spectral reflectance values with an assumption of the training data being normally distributed (Behanzin et al., 2015). The hybrid image classification approach effectively integrates supplementary information into the classification process. The classification scheme of land LU/LC is based on the classification scheme developed by NRSC/ISRO in 2015 (Arvêt et al., 2016). As per this scheme, remote sensing image was classified into mainly two classes, i.e., slums and non-slums areas.

5.3 Ground Truth Verification
Ground truth verification was done in problematic areas in the classified map of land use/land cover. Repetitive fieldwork was conducted using Global Positioning System (GPS) instrument.

5.4 Accuracy Assessment

Accuracy assessment was conducted based on the visual interpretation method supported by ground truth data collected in the fieldwork. Thus, to find out how accurate and useful the resulting classification, it is helpful to conduct an accuracy assessment, primarily, when resulting maps are going to be used for the decision-making process (Jensen, 2004). Quality measures derived from the error matrix, which is the cross-tabulation of referenced and classified data (Congalton and Green, 2008). It is used to assess the detailed image in terms of user’s, producer’s and overall accuracy as well as Kappa coefficient (Cohen, 1960; Lillesand et al., 2000; Jensen, 2005).

5.5 Post-classification

Post-classification process refers to the process of removing the error and improving the quality of the classified output. Furthermore, a post-classification smoothing was applied for present work. Corrections and modifications of doubtful areas are done based on ground intelligence, and the outline is given to final slum map of the study area is prepared.

5.6 Post-processing

The final step is post-processing that contains to prepare the output of the final map, which resulted from the classified image. Slum and non-slum areas of Pune city extracted from the various sources such as classified image, Google Earth image, and georeferenced topographical map. These extracted layers were overlaid on the administrative boundary layer. Finally, detailed mapping of a slum area in Pune city was prepared with the help of mined classified layer.

In addition to that, the slum map of the study area was overlaid on the 3-D model to find out which slums are vulnerable to environmentally sensitive areas. These findings of the research work are expected to help sustainable urban planning and measures to control future slum growth as well as minimizing impacts on the environment.

6. RESULTS AND DISCUSSIONS

6.1 Status of Slums

Pune attracts thousands of immigrants due to multiple variants of economic activities and most of them falling in the category of lower strata forming the poor or low-income group, who are forced to live in slums. The slum population in Pune city is more than 1.2 million people accommodating in a total number of 477 slums acquiring an area of 525 hectare which calculates to a density of 2398.5 persons per hectare (ESR, 2016-17). The density in slums (person/Sq.km) is more than six times that of the overall density prevailing in the rest of the city. As per the secondary information collected from Pune Municipal Corporation, there are 477 slums out of which 238 (50%) are declared and 239 (50%) being undeclared slums (Figure 2).

In Pune city, only 238 slums acquired the privilege of being declared as slums proclaiming that 50 percent of the city’s population resides in declared slums. However, by the various report, it has been revealed that not only 238 slums have a better provision of the basic services by PMC, but also the rest non-declared slums are being served by the corporation.

The number of slums in each ward varies depending upon many factors like employment opportunities, transport connectivity, vacant land or open land, etc. At present, the Bhavani Peth ward shows the maximum number of slum pockets, i.e., 62 followed by Dhole Patil Road, Hadapsar and Sangamwadi wards (Figure 3). It is also seen that the number of undeclared slums in these wards is also more than the declared slums. The least number of slum pockets is noticed in the Dhankawadi ward.

6.2 Slums Population

The growth of slums in Pune city is phenomenal; from a share of 8 percent of the total population in 1951, it has raised up to approximately 40 percent in the year 2011 (Figure 4). The main reason for such a significant increase is unaffordable pricing of house costs and sturdy economic activity in city jurisdiction. Such a large proportion of slum population also adds to the burden of already scarce resources and on overall urban infrastructure.

Figure 5 indicates that the growth of the slum population was higher than that of the total population. It is observed that during 1971, the annual growth in slum population was about 10 percent against the total growth in population at 3.5 percent due to the rural conditions, particularly, in 1966-67 and 1972-73 Maharashtra faced severe
droughts. It is likely that these brought a large number of migrants to Pune in search of livelihood. This trend continued further but at a slower pace and picked up again in 2001.

6.4 Slum Population Density

The total area occupied by the slums in Pune is approximately 525 hectares. Out of that, Sangamwadi ward has the highest slum area amongst all the wards, i.e., 85.99 hectares. The slum population density is calculated by dividing the slum population of the ward by area occupied by the slum in the ward. The density in slums (person/ha) is about six times that of the overall density prevailing in the rest of the city. The highest density is in the Dhankawadi ward, wherein the slum density is 2217 persons per hectare, followed by Sahakarnagar (2122) and Bhavani Peth (2058) ward (Figure 7). This highlights the amount of pressure on the infrastructure services and the living conditions of the slum residents. Such a high slum density also indicates high health and social costs. Based on the analysis, observed that around 50 percent of the slum population lives in unauthorized or not notified areas of the city.

6.5 Slum Tenement Density

A tenement is a multi-occupancy building of any type, but mainly a run-down apartment building or slum building. The tenement density is calculated by dividing the number of slum structure of the ward by the area occupied by the slum in the ward.
maximum tenement density is found in the Dhankawadi ward, i.e. 444 tenements per hectare followed by Bibwewadi (424) and Kasba-Vishrambagh (412) ward (Figure 8). In both cases, Dhankawadi ward shows high slum population density as well as tenement density.

6.6 Location of Slums in Pune

In Pune city there are 477 slums, out of that 356 (74.63%) slums are located on private land and reaming 121 (25.37%) slums are located on non-private land (Table 2). A very short proportion of slums are located on the land of Maharashtra Housing and Area Development Authority (MHADA), i.e., 3 slums (0.63%), Central Government (0.84%) and Pune Municipal Corporation (1.68%). A much higher proportion of the newer slums have come upon the railway track and along with the water bodies. Nearly (7%) of registered and unregistered slums are located along the railway line (Figure 9).

Slums have encroached rapidly public as well as private land. They are located mainly on the land judged unsuitable or unattractive for real estate development such as along natural drainage channels, railway lines, hillsides, etc. In Pune city, central areas of city found slums due to natural increases as well as quick migration from rural to urban areas. But, the peripheral areas it happens due to vacant land or open areas along the river, canal and hillslope.

![Figure 8. Ward-wise Slum Tenement Density](image)

### Table 2. Land Ownership Status of Slums

<table>
<thead>
<tr>
<th>Sr No</th>
<th>Administrative Wards</th>
<th>Owner wise Information of Slum</th>
<th>Total No. of Slums</th>
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<tr>
<td></td>
<td>PMC</td>
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<td>Mhada</td>
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<td>2</td>
</tr>
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<td>2</td>
<td>Kothrud</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Bibwewadi</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>Warje-Karvenagar</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>Dhole Patil Road</td>
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<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Hadapsar</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>7</td>
<td>Nagar Road</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Sangamwadi</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>Bhatvar Peth</td>
<td>2</td>
<td>4</td>
</tr>
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</table>

Figure 10 shows that some slums tenements are located in critical locations which need to be relocated to safer areas in order to develop these locations and also in the interests of the safety of slums dwellers. In Pune city, more than 200 slums are located near environmentally sensitive area and more than 3, 80,000 slum populations live in these slum pockets. The built-up area encroachment activity and vulnerable slum areas majorly observed in newly added area in PMC limit, i.e. Ambegaon Bk., Viththal Nagar and Warje, etc.

![Figure 9. Land Ownership-wise Distribution of Slums](image)

**Source:** MASHAL, 2011

**Note:** Areas highlighted in red indicate slum areas. Pune and Khadki Cantonment Board (PCB and KCB, respectively) are not included in the study area.
7. RECOMMENDATIONS

- There should be proper check and control by the government over vacant lands, and at the same time, people squatting on such lands should be provided affordable housing options.
- Slums located in the most environmentally sensitive and disaster-prone areas should be given priority in the provision of housing, specially focused on peripheral areas of Pune city like Warje, Ambegaon Bk and Viththal Nagar, etc.
- Slums which will be resettled should be placed within a distance of 1.5km preferably; so that the slum dwellers do not lose their livelihood.
- Zoning/Reservation of a certain percentage (10% to 20%) of land for Economically Weaker Sections (EWS) and Low Income Group (LIG) housing.
- Creation of housing stock of smaller size tenements (200 - 500 sq.ft.).
- Prevention of illegal settlements in the future.
- Slum-dwellers should be sensitized about the small family size through workshops and other measures.
- A vision of slum-free city can be achieved through implementation of Rajiv Awas Yojana. BSUP schemes, policies for Slum rehabilitation/redevelopment schemes through SRA rules and D.C. regulations.

8. CONCLUSIONS

In this research work, identifying and mapping of slums might be one of the most challenging tasks for all metropolitan cities due to rapid growth of population and speedy migration. Planning controls are usually ineffective in slum areas due to lack of timely information and people having little regard for such things in the absence of any other alternative. Thus the main contribution of this study is the quantification of uncertainties related to slum and mapping of slum areas using Geospatial tools like remote sensing and GIS techniques. Remote sensing data may be used for a rapid inventory of the location and physical composition of slums. In this study, various methods like image rectification, enhancement classification, and accuracy assessment are used because of more flexible, accessible and accurately deal with the large variability in slum areas. The present research also identified vulnerable slum areas using various factors like growth of slum population, slum population density, tenement density, and location of slums, etc. These findings of the work are expected to achieve the Million Development Goal of a slum-free city, measures to control future slum growth and eradicate the slums as well as minimizing impacts on the environment.

ACKNOWLEDGMENTS

I thank the Department of Geography, Sir Parashurambhau College, Pune for providing laboratory facilities. We express profound gratitude to Dr. Dilip N. Sheth, Principal, Sir Parashurambhau College, Pune. The author also thanks Prof. R. B. Bhagat, International Institute for Population Sciences, Mumbai for their advice and encouragement. The author also thanks to Dr. Ashok Chaskar, Dr. Sunil Gikwad, Dr. Manojkumar Devne, Dr. Suresh Deshmukh, Dr. D. B. Pawar, Dr. Nitin Ade, and Shri. Ganesh Dhawale for careful reading, insightful comments, and suggestions.


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UNDERSTANDING LINK BETWEEN LAND SURFACE TEMPERATURE AND LANDSCAPE HETEROGENEITY: A SPATIO-TEMPORAL AND INTER-SEASONAL VARIABILITY STUDY ON KABUL CITY, AFGHANISTAN

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KEY WORDS: Land Surface Temperature, Land Use Land Cover, Aerosols, Land Management, Kabul

ABSTRACT:

Satellite images were used to study temporal and seasonal patterns of Land Surface Temperature (LST) in Kabul, followed by establishing an interrelation with Land Use Land Cover (LULC) changes occurring in the city. LULC and LST changes were examined based on Landsat Thematic Mapper (TM) and Landsat Operational Land Imager (OLI), Thermal Infrared Sensors (TIRS). LST Maps were derived from the thermal band of Landsat images for decadal study (Winter/Summer: 2008-09 and 2018-19). Visible bands were utilized for supervised LULC classification in the same decade. Results showed that Kabul City expanded rapidly over the study period from 232.28 km2 to 371.08 km2 in one decade (2009-2019). Other land cover classes i.e. barren land, mountains and vegetation, were observed to be converted to urban class i.e. residential, commercial, and industrial. High LST zones of Kabul city consisted of mountains, barren land and urban areas. Notable difference of 3°C was observed between urban and vegetated lands. This study successfully identified the areas (i.e. district 12, district 13 and district 17) currently affected by rapid urban sprawl. The results also highlighted the changes in LST pattern caused by urbanization. The study will help the government, private sector investors and land planners to develop sustainable land management policies.

1. INTRODUCTION

Remote sensing (RS) plays a primary role in land management and planning by providing information on the physical characteristics of land, as well as monitor changes in allocation of land parcels to various uses. This may have a direct bearing on the land cover heterogeneity and prevailing environmental conditions of an area. Hence, such specific data procured through RS would influence land management by successful integration into infrastructure planning. Preparation of resource maps and inventory generation through acquisition of temporal information are key to efficient monitoring necessary in sustainable land management practices. Information on prevalent natural resources management system can be further reviewed with the help of thorough temporal analysis for reformation or formulation of policies and administrative procedures related to land management practices. Satellite images of Landsat, Spot, Modis, IRS etc. have been widely applied for sustainable land use and natural resource management, through change detection and monitoring environmental degradation on spatio-temporal scale. This has proved to be essential for urban planners in developing policy related to change in land cover as a result of anthropogenic activity; thereby, checking and controlling human activities and adverse impacts of rapid urban development. With increasing land scarcity, such applications are especially useful for land suitability studies. The rampant changes in land cover, i.e. deliberate conversion mainly by deforestation, for agriculture, urbanization; have been responsible for changes in regional and as well as global climate.

Land Surface Temperature (LST) is defined as the effective radiating skin temperature of the earth’s surface with reference to soil surface temperature for bare soil; canopy surface temperature for densely vegetated ground; temperature of vegetation canopy, vegetation body and soil surface for sparse vegetated ground (Khandelwal et al., 2018). The rapid pace of urbanization is responsible for major changes in the Land Use Land Cover (LULC) pattern over the past few decades. Another significant cause for LULC change is due to the growth in size and number of cities as a result of urban sprawl. Drastic conversion of classes like vegetation, water bodies, wasteland and agricultural land to the built-up areas is prevalent in several studies conducted over the last few years. The drastic rise in LST is strongly attributed to the LULC changes due to rapid urbanization leading to disturbed habitat unfit for humans and other living beings. LST being sensitive to various land surface features; can be used to extract information on different LULC types (Sinha et al., 2015). Use of historic and current spatial or attribute data in urban growth analysis, is an essential requirement for future scientific planning of cities and the establishment of political policies for substantial city development (Dadras et al., 2015). Numerous studies have been conducted on application of remote sensing for detection of seasonal and temporal changes in LST as well as LULC (Hathout, 2002); (Lambin et al., 2003); (Deng et al., 2009);(Shen et al., 2015). Significant variation in LST over various LULC types have been observed for Malda District in West Bengal, India by (Pal and Ziaul, 2016), which shows 2.75°C increase in LST on the rate of 0.114°C/year (1991-2014). The impact of LULC changes were obtained for land surface temperature in Karst area of China by (Xiao and Weng, 2007), reporting that Guiyang and Qingzhen in 1991 had a temperature...
of 291.1K and 288.6K, respectively. This increased to 294.2K and 292.9 K, respectively. However, the spatio-temporal transiency and non-uniformity in LST makes it very important to correlate this parameter with other stable environmental features like land cover and surface terrain attributes i.e. slope, aspect and terrain position (Fan et al., 2014).

The objective of the work outlined in the paper is to determine the dynamics of LST in relation to the LULC alteration over the past decade through spatio-temporal analysis for Kabul City, Afghanistan. The capital city of Afghanistan was selected as a case study, due its typical surface terrain conditions and semi-arid climate; necessitating one of very few researches conducted to study the seasonal and temporal variability of LST with suitable linkages to other influencing parameters like the land-use induced land cover change and elevation difference. LST has been retrieved from thermal images by the mono window method. Significant areas were identified for immediate attention with respect to continuous monitoring and developing mitigatory measures for efficient land management practices. The study aims to demonstrate application of RS and GIS for generation of thermal and land cover data for improving land management and policy formulation.

2. STUDY AREA

Kabul is the capital city of Afghanistan with 22 districts. Kabul is the political, cultural and intellectual centre. It is the largest city of Afghanistan with 36% urbanization. It is located between 34°39′N to 34°17′N latitude and 69°29′E to 68°54′E longitude, as shown in Figure 1. This study is conducted on an area of 1033.3 km² with a population of approximately five million with growth rate of 3.91% per year. Kabul city land surface has a texture of sandy soil and rocky mountains. This city is surrounded by mountains.

![Kabul City Map with District Number](image)

Figure 4. Kabul city map with district number

3. DATA USED

Data of Landsat-TM-5 and Landsat-8 OLI-TIRS are selected to detect changes of urban expansion and to evaluate the LST changes related to the urbanization expansion in Kabul. For the seasonal variability study of Kabul City, imageries were obtained for the most critical months of the seasons, December and July/August, representing both winter and summer season. Cloud free imageries were downloaded from United States Geological Survey (USGS) server, for the dates 10 December 2008 and 22 July 2009 Landsat TM-5 and for the dates 06 December 2018 and 03 August 2019 Landsat-8 OLI-TIRS with path 153 and row 36. OLI-TIRS has bands with resolution of 30m and thermal bands of 100m resolution while all bands of TM sensor have resolution of 30m with exception of thermal band which has a resolution of 120m.

4. METHODOLOGY

For extracting surface temperature from thermal band of Landsat images and classification of different land covers the following methodology has been used (Figure 2.).

![Flowsheet of detailed methodology](image)

Figure 2. Flowsheet of detailed methodology

4.1 LST Mapping

4.1.1 Clipping of Study Area

Clip is used to extract the study area. In this paper, the study area is clipped with city boundary provided by Kabul Municipality from the imageries downloaded from USGS.
4.1.2 DN Conversion to Spectral Radiance

It includes the conversion of pixel DN (Digital Number) to at-sensor radiance, subtraction of atmospheric illumination effects and sensor calibration. While comparing multiple images it is better to use spectral radiance rather than using DN values directly. The conversion is carried out with the following formula (NASA, 2011).

\[
L_\lambda = \left( \frac{L_{\text{Max}} - L_{\text{Min}}}{Q_{\text{Cal Max}} - Q_{\text{Cal Min}}} \right) \cdot (Q_{\text{Cal}} - Q_{\text{Cal Min}}) + L_{\text{Min}}
\]

where
\[
L_\lambda = \text{spectral radiance at the sensor’s aperture in } W/(m^2 \cdot sr \cdot \mu m)
\]
\[
L_{\text{Max}} = \text{spectral radiance that is scaled to } Q_{\text{Cal Max}}
\]
\[
L_{\text{Min}} = \text{spectral radiance that is scaled to } Q_{\text{Cal Min}}
\]
\[
Q_{\text{Cal}} = \text{quantized calibrated pixel value in digital number}
\]
\[
Q_{\text{Cal Max}} = \text{maximum quantized calibrated pixel value in digital number}
\]
\[
Q_{\text{Cal Min}} = \text{minimum quantized calibrated pixel value in digital number}
\]

It has been proved that radiation correction improves the accuracy of LST (Song et al., 2000).

4.1.3 Brightness Temperature

The spectral radiance converted from pixel DN values is then used to compute brightness temperature (i.e. blackbody temperature) under the assumption of unit emissivity and using pre-launch calibration constants (NASA, 2011).

\[
TB_K = \frac{K_2}{\ln(1+(K_1/L_\lambda))}
\]

where
\[
TB_K = \text{Effective at satellite temperature in Kelvin}
\]
\[
TB_c = \text{Effective at satellite temperature in Degree Celsius}
\]
\[
K_1 \text{ and } K_2 = \text{pre-launch calibration constants}
\]
For TM, \(K_1 = 607.76 \text{ and } K_2 = 1260.56\)
For OLI/TIRS, \(K_1 = 774.8853 \text{ and } K_2 = 1321.0789\)

4.1.4 Emissivity of Land Surface

The temperature obtained from equation (2) is for black body, which is different from the real land surface temperature. Therefore, emissivity correction must be applied. Land surface emissivity were estimated as follows: for with NDVI < 0.2, the emissivity was assumed as to be 0.98; while for NDVI > 0.5, the emissivity was assumed as to be 0.99; for those with 0.2 ≤ NDVI ≤ 0.5 (Wang et al., 2018) the emissivity was given as,

\[
\varepsilon = 0.004 \cdot \rho_v + 0.986
\]

where
\[
\rho_v = \text{the vegetation proportion obtained according to the equation (4)}.
\]
\[
P_v = \frac{(\text{NDVI}_{\text{min}} - \text{NDVI})}{(\text{NDVI}_{\text{max}} - \text{NDVI}_{\text{min}})}^2
\]

where
\[
\text{NDVI}_{\text{min}} = 0.2, \text{NDVI}_{\text{max}} = 0.5 \text{ were given in previous studies (Wang et al., 2018)}.
\]

Normalized Difference Vegetation index is computed with equation (5).

\[
\text{NDVI} = \frac{\text{NIR}-\text{Red}}{\text{NIR}+\text{Red}}
\]

For Landsat OLI-TIRS-8 this can be written as:

\[
\text{NDVI} = \frac{([\text{Band 5} - \text{Band 4}] / ([\text{Band 5} + \text{Band 4}])}
\]

For Landsat TM-5 this can be written as:

\[
\text{NDVI} = \frac{([\text{Band 4} - \text{Band 3}] / ([\text{Band 4} + \text{Band 3}])}
\]

4.1.5 Land Surface Temperature (LST)

LST was calculated from the Brightness temperature (Li et al., 2009) by applying emissivity correction as in equation (6).

\[
\text{LST} = \frac{TB}{1+\frac{TB}{L_\lambda}} \times 273.15
\]

where
\[
\lambda = 11.5 \mu m \text{ the wavelength of } \text{was emitted radiance};
\]
\[
\rho = h \times c / \alpha = 1.438 \times 10^8 \text{ mK}, \sigma = 5.67 \times 10^{-8} \text{ Wm}^{-2} \text{K}^{-4} \text{ was Stefan Boltzmann’s constant; and } h, c \text{ and } \alpha
\]

\[
\text{were the Planck’s constant, the velocity of light, the}
\]
\[
\text{land surface emissivity, respectively.}
\]

4.2 LULC mapping

4.2.1 Stacking of Visible Bands

Layer stacking is putting all layers above each other which is essential for classifying the different classes. For Landsat TM, the bands from one to five with resolution of 30m have been stacked together. For Landsat-8 OLI/TIRS the bands from one to nine with a resolution of 30m have been stacked together.

4.2.2 Supervised Classification

This paper follows the LULC classification system with four level 1 classes (Anderson, 1975). Two additional class of road and mountains were also included. Maximum likelihood classifier is used to classify the different classes. Supervised classification requires previously known sample to train the classifier and to classify unknown data.

4.2.3 Accuracy Assessment of LULC

To get the accurate results of LULC classification the accuracy assessment is performed on the images generated from supervised classification. 350 points have been taken on the classified image of each year (2009 and 2019) and compared with the ground truth obtained from the Google Earth images of the respective year. Post-classification refinements were applied to lessen classification errors caused by the similarities in spectral responses of certain classes such as barren land and urban (Harris and Ventura, 1995). Area of Interest (AOI) tool was applied to the classified image using visual analysis from Google Earth and local knowledge to split and recode these covers so to reflect their true classes.

4.2.4 LULC Map

The land use and land cover map show the different classes present on an area. LULC map gives a highlighted color to each class to distinguish between different classes. This paper use red for urban, yellow for vegetation, magenta for barren land, brown for mountains, blue for water and black for roads.
4.2.5 Analysis of Results

The change detection is the process of finding differences between two remote sensed images which are taken in different point of time (Zhang et al., 2016).

5. RESULT AND DISCUSSION

5.1 Seasonal Analysis of LST

The land surface temperature profile for Kabul City was prepared for analyzing the seasonal and temporal variability in different land use/cover classes. The built-up class (including residential, commercial, industrial and roads network) showed an increase of +1.45°C for summer season during the decadal analysis (2009-2019), as seen from (Figure 3 and 4). Similarly, the decadal study for winter season (2008-2018) showed that there was an overall increase of +1.66°C (Figure 5 and 6). The effect of anthropogenic activity can be assumed as an important factor for the overall increase in the surface temperature as observed through such decadal analysis.

A similar observation can be made to corroborate the above explanation. The temperature obtained particularly for the Industrial park located in district 9 shows increased winter temperature of +1.11°C for decade (2008-2018). Also, it was observed in the decadal analysis for summer season, that there was an increase of +2.9°C for decade (2009-2019).

In drier climates during summer, the net radiation intake increases resulting in intense surface warming effect. The absence of cloud cover and decrease in moisture available for evaporative cooling contributes to higher surface temperatures. Similar effects of cloud cover on surface temperature was previously reported by Feng and Zou (2019).

Kabul being partly cloudy in winters, in contrast to summers, may result in cooler surfaces. The city had experienced heavy snowfall in winter 2018. The distinct regions of low temperature were typically observed in barren lands and mountain peaks for the same year in winter due to thick layers of settled snow (Figure 6). This can be attributed to the higher albedo of snow, in comparison to the average albedo of land surface. In barren lands with sparse vegetation, lower evapotranspiration and greater radiation result in decreased latent heat and thereby warmer surfaces. The rapid heating of sandy soil (barren land) and rocky mountains showed highest temperatures in the range of 10.01-11.25°C in winter (2008-18) and 40.5-43.5°C in summer (2009-19) for these two classes relative to other classes.

The LST for significant urban areas (based on their contribution towards commercial, industrial, administrative, residential use) were analyzed for summer and winter season (Table 1). The boxes shown on LST maps provide spatial reference for these critical urban locations. Box one shows Kota-e-Sangi (commercial) area, box three shows Industrial park and box 4...
shows Arzan Qemat (residential) area. Similarly, Box 2 shows Shahr-e-Now (commercial), Wazir Akbar Khan (residential), Deh Afghanan (administrative), Old city (residential) and Manadawy (commercial) areas.

<table>
<thead>
<tr>
<th>Prime Points</th>
<th>Average Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shahr-e-Now (D 4)</td>
<td>34.85</td>
</tr>
<tr>
<td>Wazir Akbar Khan (D10)</td>
<td>32.55</td>
</tr>
<tr>
<td>Kota-e-Sangi (D 5)</td>
<td>34.00</td>
</tr>
<tr>
<td>Arzan Qemat (D 12)</td>
<td>34.28</td>
</tr>
<tr>
<td>Deh Afghanan (D 2)</td>
<td>32.78</td>
</tr>
<tr>
<td>Old city and Mandaway (D 1)</td>
<td>34.94</td>
</tr>
<tr>
<td>Industrial park (D 9)</td>
<td>37.32</td>
</tr>
</tbody>
</table>

Table 1. LST for major urban centers

The air quality status may have direct bearing on the LST of a city. The reported high levels of ambient air pollution in Kabul City may be attributed to use of low-quality, inexpensive, more polluting fuel sources by residents and local industries as a result of power rationing within the city (Sharkey et al., 2016). Additionally, emissions from open burning of biomass and from heavy vehicular traffic on unpaved roads, may contribute to black carbon type aerosols promoting radiation absorption. Such aerosols evaporate the atmospheric moisture enabling more solar radiation to reach the surface (Stofferahn and Boybeyi, 2017). Mineral and dust aerosols having diameter less than 10 μm, originate from barren lands or deserts (Lau et al., 2006). They have also been reported to exhibit absorbing characteristics by various researchers (Tarig and Ali, 2015), (Vandenbussche and De Mazière, 2017). These aerosols are found at lower altitudes (below 7 km) due to their size, in contrast to the mineral ash particles, that are found up to an altitude of 20 km (Tsamanlis et al., 2013). However, the overall effect on increase in LST may be influenced due to non-absorbing aerosols, as they will reflect more incoming solar radiation, thereby, cooling the surface (Seinfeld et al., 2016).

5.2 Temporal Analysis of LST

In 2019, the temperature for all classes of land cover were found to increase by more than +1.45°C. The most populated and central business areas of Kabul had an average increase of +2.46 °C in the last ten years (2009-2019). Old city (District 01) had an increase of +2.9°C. Deh Afghanan (District 02), Shahri Now (District 04), Kota-e-Sangi (District 05), Wazir Akbar Khan (District 10) and Arzan Qemat (District 12) had an increase of +2.63 °C, +1.42 °C, +1 °C, +3.78 °C and +3.01 °C respectively in the same decade (Table 1).

5.3 LULC Mapping

LULC maps were generated for 2009 and 2019 as shown in figure 8 and 9 respectively. Table 2 is showing the change in area which is obtained by the temporal analysis of the LULC map of the study area. As compare to year 2009 (Figure 8), the urban area is increased by 138.80 km$^2$ by the year 2019 (Figure-9). Also, there is a significant decrease in the barren land which mostly consists of rocky, stony and sandy region. It has decreased by 122.85 km$^2$ within the time period of 10 years. To study about the LULC conversion a transition probability matrix is also prepared which is shown in Table 5. It can be seen from the matrix that the conversion of other classes into the urban area is very high. The conversion of water, barren land, vegetation and mountain into the urban class is 26%, 36%, 21% and 12%, respectively. Therefore, it is clear that there is a rapid urban expansion in the Kabul city at the cost of natural resources like water and vegetation.

The accuracy of LULC classification for both the years was checked. The confusion matrices to compute the overall accuracy of LULC classification for 2009 and 2019 are shown in Table 3 and 4 respectively.
Figure 7. LULC map of Kabul with contour

Figure 8. LULC map of Kabul 2009

Figure 9. LULC map of Kabul 2019
5.4 Interrelationship between LST and LULC

The average LST per LULC class have been outlined in (Table 6). Of all the LULC classes, mountains and barren lands have been noted with highest average temperature, through decadal study. In arid environments, the top soil characteristics have an anomalous influence on the temporal changes in LST. Some of the land surface features have been observed to show same LST on a specific time period, but, exhibit significant variations at other time periods depending on the prevailing season (Shalaby and Tateishi, 2007). In general, urban or built-up areas had a temperature higher than the surrounding vegetation and water bodies, in summer season i.e. on 22 July, 2009. The LST profile is well known to be closely related to the percentage of impervious surface area in the urban class (Wang et al., 2018). However, some places near to water bodies or vegetation had temperature less than average urban temperature. Places near to Qargha lake had a temperature of 34.57°C. Minimum, average and maximum temperature of each season (summer and winter) for the year 2009 and 2019 is given in Table 7.

Table 7. LST of each season (All values in °C)

<table>
<thead>
<tr>
<th>LULC Class</th>
<th>22 July 2009</th>
<th>03 Aug 2019</th>
<th>10 Dec 2008</th>
<th>06 Dec 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>35.72</td>
<td>37.17</td>
<td>7.12</td>
<td>8.78</td>
</tr>
<tr>
<td>Mountains</td>
<td>40.51</td>
<td>43.47</td>
<td>10.01</td>
<td>11.25</td>
</tr>
<tr>
<td>Vegetation</td>
<td>31.95</td>
<td>34.5</td>
<td>6.46</td>
<td>7.78</td>
</tr>
<tr>
<td>Barren Land</td>
<td>39.15</td>
<td>42.85</td>
<td>8.63</td>
<td>9.84</td>
</tr>
<tr>
<td>Water</td>
<td>24.27</td>
<td>28.68</td>
<td>4.69</td>
<td>6.12</td>
</tr>
<tr>
<td>Road</td>
<td>36.9</td>
<td>37.23</td>
<td>8.04</td>
<td>9.31</td>
</tr>
</tbody>
</table>

6. CONCLUSION

In this study, by using multi-temporal Landsat TM and Landsat-8 OLI-TIRS imagery, an integrated approach of remote sensing and GIS has been used for assessment of urban expansion and its impacts on LST profile in Kabul city. Results showed significant increase in urban or built up area from 2009 to 2019. The change in land use land cover caused an increase of 1.45°C and 2.55°C in summer and an increase of 1.66°C and 1.32°C in winter, for built up area and vegetation, respectively. The LST profile of Kabul and its linkage to LULC maps has delineated critical areas undergoing adverse land cover transformation as reflected in terms of elevated surface temperatures. In case of the urban areas, this will be directly related to anthropogenic activities of development and
infrastructural growth. The findings of the study help to establish interrelationship between LST (temporal and seasonal variation) and LULC as well as other indirect influencing factors i.e. aerosol concentration and type, vegetation intensity, cloud cover and other local climatic factors. This would help in reforming prevailing land management practices and reframe any related policies for the city of Kabul.

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Khandelwal, S., Goyal, R., Kaul, N., Mathew, A., 2018. Assessment of land surface temperature variation due to infrastructural growth. The findings of the study help to establish interrelationship between LST (temporal and seasonal variation) and LULC as well as other indirect influencing factors i.e. aerosol concentration and type, vegetation intensity, cloud cover and other local climatic factors. This would help in reforming prevailing land management practices and reframe any related policies for the city of Kabul.


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CAPACITY DEVELOPMENT AND EDUCATION OUTREACH IN GEOINFORMATICS AND LAND MANAGEMENT: A CASE OF DEPARTMENT OF GEOMATICS ENGINEERING, KATHMANDU UNIVERSITY

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KEY WORDS: Capacity Development, Geoinformatics, Land Management, Geomatics Engineering Department, Nepal

ABSTRACT:

The capacity development and education outreach in Geoinformatics and Land management is very important for the development of any country. The aim of this paper is to highlight the existing capacity development and education outreach in Geoinformatics and Land Management at Department of Geomatics Engineering and draws attention of all national and international geospatial community for their contributions to promote capacity development and education outreach in Geoinformatics and Land Management sectors in Nepal. The desk study has been carried out for the study by reviewing literature and using secondary data sources. This study analyzes aspects, challenges and opportunities in collaborative efforts made by Kathmandu University and Land Management Training Center to become a center of excellence in these sectors. The study reveals that “To make Geoinformatics and Land Administration, a leader course in Nepal and also within the region”, Kathmandu University has to overcome various challenges. Some challenges may be addressed in the national level but some require collaborations and cooperation from international geospatial community. The result indicates that the capacity development and education outreach in Geoinformatics and Land Management sector helps to develop quality geospatial professionals which in turn may incorporate the entire South Asia region as a potential Geospatial and Land Management market. Finally, Kathmandu University, Department of Geomatics Engineering is committed to develop a centre of excellence in Geoinformation and Land management sector by providing quality education, research and development.

1. INTRODUCTION

The capacity development and education outreach in Geoinformatics and Land management is very important for the development of any country. Kathmandu University (KU) was established in November 1991 as an autonomous, non for profit, non-government, dedicated to maintain high standards of academic excellence, public institution through private initiative. The university is committed to develop leaders in professional areas through quality education with the vision “To become a World Class University devoted to bringing knowledge and technology to the service of mankind”. It is committed not only to develop leaders in professional areas through quality education but also develop as a centre of excellence. Long term presence of the university is also intended to benefit the local communities in terms of development of small scale business and community services (Ghimire, 2016). As silver Jubilee initiatives, it focuses on Quality, Innovation, Impact, Engagement, Equity and Identity. There is seven schools in the university: School of Engineering, School of Management, School of Science, School of Arts, School of Medical Sciences, School of Education and School of Law. School of Engineering has Department of computer science and Engineering, Department of mechanical Engineering, Department of electrical Engineering, Department of Chemical Engineering, Department of Civil Engineering and Department of Geomatics Engineering. Department of Geomatics Engineering is the youngest Department of School of Engineering and is officially established on March 26, 2019.

The aim of this paper is to highlight the existing capacity development and education outreach in Geoinformatics and Land Management at Department of Geomatics Engineering and draws attention of all national and international geospatial community for their contributions to promote capacity development and education outreach in Geoinformatics and Land Management sectors in Nepal.

2. METHODOLOGY

The desk study has been carried out for the study by reviewing literature such as journal articles, proceedings, reports etc. and is given in reference section and by using secondary data source such as brochure, report etc.

3. ASPECTS OF GEOMATICS EDUCATION

An aspects of Geomatics Education such as teaching/learning, vision, existing status of undergraduate Geomatics Engineering, existing physical facilities, status of graduate programs, ongoing research projects and capacity on organizing workshop are discussed in following subsections.

3.1 Teaching/ Learning

Kathmandu University (KU) in collaboration with Land Management Training Center (LMTC) has started undergraduate Bachelor of Engineering in Geomatics Engineering in 2007 and successfully running under the framework of Memorandum of understanding (MOU) between KU and LMTC. KU and LMTC also share the physical boundary and resources to promote undergraduate and graduate programs: Geoinformatics and Land Administration (Ghimire, 2015).
Mainly LMTC under the Ministry of Land Management, co-operatives and poverty alleviation is established to produce the skillful surveying, mapping and land administration and management professionals through trainings within the country. LMTC is offering two types of regular courses and several short courses; Basic Survey course and Senior and Junior Survey course.

Department of Geomatics Engineering offers Diploma in Geomatics Engineering started in 2015 in collaboration with LMTC and CTEVT, Bachelor in Geomatics Engineering started in 2007, Master in Land Administration started in 2013 and ME/MS in Geoinformatics is started from 2019. PhD program will be started based on need and availability of supervisors.

3.2 Vision

Department of Geomatics Engineering has set its vision “To become centre of excellence by providing quality education and research for leadership in Geoinformatics and Land sector in joint cooperation with government and other collaborating organizations.”
Department of Geomatics Engineering in KU and LMTC has set following future plan to fulfil its vision:

- To strengthen all levels of education in Geomatics Engineering to produce operational and managerial level highly qualified skilled human resources.
- To start MS by research in Geoinformatics and Land Administration and management.
- To enroll more PhD candidates in the field of Geoinformatics and Land administration and management.
- To strengthen and develop the intern opportunity for Geomatics Engineering students in related industries.
- To strengthen Geo Spatial Lab, photogrammetry and surveying lab and establish cartography lab.
- To carry out more research projects in collaboration with collaborating national and international organizations.
- To promote student/staff/faculty exchange program.

3.3 Status of undergraduate Geomatics Engineering

The undergraduate Geomatics engineering program was started in August 2007. Total 270 students are graduated as Geomatics Engineers and most of them are already employed in various government and non-government institutions. The first MOU between KU and LMTC under the framework of which, the Geomatics program had been started was completed with the intake of 2010 batch and a second MOU is completed in 2015 and third MOU with the intake of 2018 batch. Under first completed MOU, Ministry of Land Reforms and Management have provided financial support for 7 years for four batches. In this case 75% of total fee is waived for 24 students. Similarly, under the framework of second MoU, 2011, 2012, 2013 and 2014 batch students were enrolled in the course. The Ministry of Land Reform and Management had provided scholarships under various categories to number of students. In the second and third MOU, 100% tuition fee is waived for two students from government employee in the engineering services under survey group category, a 50% fee is waived for eight students from four Development Regions except the central regions of Nepal and 33% of tuition fee is waived for 10 students passing the Kathmandu University Common Admission Test (KUCAT) entrance exam on merit basis. The total graduated students are: 203 (8 Batches) and 9th batch is graduated this year. Currently, 150 (4 Batches) students are studying BE in Geomatics Engineering and fourth MoU provisioned 35% scholarship for 21 students based on inclusive provincial category (KU & LMTC, 2019).

3.4 Physical Facilities

The library facilities, sports facilities, computer Lab for computer programming, Geospatial lab, photogrammetry and surveying lab and conference lab for provision for e-learning are available at KU. The course syllabus of BE Geomatics Engineering program is consistently revised by the Subject Committee/Faculty board and academic council of KU with due consideration of feedback from students and stakeholders including industries every year. This engineering program have strong component of field survey training equivalent to 4.5 months in 4 years program and internship of one and half months

3.5 Graduate programs

Department of Geomatics Engineering has following two graduate programs and are discussed in following subsections.

3.5.1 Master in Land Administration

KU has started two year’s master degree program in 2013 in Land Administration in collaboration with LMTC and is successfully running at KU. The main aim of starting the master in Land Administration course is to produce graduate level highly skilled and qualified professionals in the field of land Administration and to conduct and promote research and development activities in the field of land administration and management. Land administration program at KU consists of multidisciplinary courses so that the intake will be from multidisciplinary background. The Government of Nepal has approved 100% scholarship to 5 candidates for government employee up to four batches. The financial aid is also available to selective full paying students in the form of graduate teaching assistantships as per the requirement of the Department.

3.5.2 ME, MS in Geoinformatics

Department of Geomatics Engineering has also started two year’s ME/MS degree in Geoinformatics from 2019 in collaboration with LMTC and is successfully running at KU. The main aim of starting the ME/MS in Geoinformatics is to produce graduate level highly skilled and qualified professionals in the field of Geoinformatics and to conduct and promote research and development activities in the field of Geoinformatics.

3.6 Research Projects

Department of Geomatics Engineering had carried out several research projects as follows and includes following activities.

1. Strengthening Geospatial Infrastructure and Research Capacity at Kathmandu University funded by NASA through ICIMOD
2. Developing Demonstration Model to Revive Springs for Enhancing Rural Water Security funded by Oxfam.

3. Land Surface temperature change analysis of Kathmandu Valley using Landsat images funded by UGC.

4. Developing Land Valuation model for Land Acquisition in Infrastructure Development. A livelihood perspective funded by NAST.

5. Estimation of Above Ground Forest Biomass and Carbon Stock Using UAV Images funded by NASA through ICIMOD.


7. Inspection of transmission line infrastructure for Bhaktapur-Baneswor-Patan-66kV.

8. Transmission Line Upgradation Project funded by NEA Engineering Company.


3.7 Training/Workshop/Refresher course

Department has organized following workshop and refresher courses:


12. Training for trainers in transparency in Land Administration, 2010


4. CHALLENGES

The major challenges of undergraduate Geomatics Engineering and graduate ME/MS in Geoinformatics and Master in Land Administration in Kathmandu University are highlighted as follows:

- Infrastructure development
- Hardware and software
- Faculty expansion visiting experts (national/international)
- Knowledge exchange programs

- Expansion of further higher education and job market (Bhattarai, 2009).

5. OPPORTUNITIES

There is an ample of opportunities for Department of Geomatics Engineering to become a centre of excellence in Geoinformatics and Land Administration Sector. Institutions like UT/ITC, University of Salzburg, Austria, Yildz Technical University, Turkey, ICIMOD, private and government agencies are willing to support Department of Geomatics Engineering to achieve its goal. Department of Geomatics Engineering has expectations for expert advice from national and international Geoinformatics and land administration community (Ghimire, 2011).

6. INTERNATIONAL COLLABORATION

Department of Geomatics Engineering has collaborations with following organizations:

- Faculty of ITC, University of Twente, the Netherlands
- University of Salzburg, Department of Geoinformatics, Austria
- Department of Geomatics Engineering, Yildiz Technical University, Turkey
- Changan University, China

7. CONCLUSIONS

Geoinformatics and Land Administration has become an emerging field as it directly deals with surveying, mapping and land management. Department of Geomatics Engineering, KU in collaboration with LMTC is playing crucial role for it. To become a centre of excellence in Nepal and also within the region in the future, Department of geomatics Engineering has to grab the opportunities and overcome the challenges. Some of the above mentioned challenges could be addressed in national level but some requires cooperation and collaboration from the international level. Therefore, it is essential to draw attention of all national and international Geoinformation and land administration and management community for their contributions to promote education and research and development in these sectors in Nepal.

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DEVELOPMENT AND IMPLEMENTATION OF INNOVATIVE EDUCATIONAL MODULES ON ARCHITECTURAL PHOTOGRAMMETRY FOR BACHELOR’S DEGREE CURRICULA IN ARCHITECTURE

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KEY WORDS: Architecture, 3D modeling, Architectural Photogrammetry, Curriculum

ABSTRACT:
Modern specialists in the field of architecture work exclusively in three-dimensional space. At the same time, their training completely ignores the state-of-the-art technologies associated with obtaining three-dimensional models of engineering structures. In such circumstances, the connections between the three key participants in the design and construction of engineering structures, namely architects, builders, and surveyors are broken. The main technology that allows obtaining three-dimensional models is photogrammetry. The purpose of the presented article is to determine the subject matter of close-range photogrammetry in solving architectural design problems. Based on certain architectural tasks, educational modules for the discipline of architectural photogrammetry of the bachelor educational level were developed. The peculiarity of the proposed program is that it is designed in such a way that it allows using the whole complex of the modern achievements in the field of automated image processing and the specifics of setting and solving architectural problems. At the same time, this program covers such modern technologies and concepts as UAV photogrammetry, digital photogrammetry, photogrammetric scanning, BIM, GIS, etc. Such an approach allows students without problems to learn several special knowledge, which is owned by surveyors and photogrammetrists. The approximate content of the course of architectural photogrammetry for bachelor students is presented.

1. INTRODUCTION

One of the topics of modern architects and civil engineers is the necessity to have a complex knowledge of the field of photogrammetric technologies. It was long years ago when both architects and surveyors used to use only “paper” technologies. They both used to work with paper drawings, create projects, and setting-out them on site. Since that time, a significant breakthrough in technologies has happened. Surveyors and photogrammetrists, particularly, have moved to digital technologies and using them for data gathering and output. The same things have been going with architects for the last twenty years. However, if, in the case of “paper” technologies, they were a common base for surveyors and architects, in a digital era, there is an issue in the understanding and treating of different data that provide architects and surveyors each other. Probably, the most famous example of such a dispute is a discussion about building information modeling (BIM) (Logothetis et al. 2015, Banfi et al., 2017, Han et al. 2017). For architects, BIM is, first of all, a detailed 3D model; on the other hand, for civil engineers, BIM is more than just a model. It is a passport of the structure with facilities, communications, loads, and even deviations from the project. At the same time, for civil engineers, the level of detail does not play such an important role for architects. The main demand is an accurate position of the structural elements and facilities, both absolute and relative. Somewhere in between is a place of surveyors. To be on the same page, surveyors have to understand the architects and civil engineers’ tasks and requirements. But, it does not mean that this is a peculiar problem of surveyors. Quite the contrary, to set up the tasks correctly, the architects must realize the surveyors’ opportunities and constraints. That is why it is badly needed for modern architects to be acquainted with state-of-the-art surveying and photogrammetric technologies. One of the ways to reach out to this purpose is to establish a special course for young students of architectural majors that will allow understanding the surveyors’ capabilities. From our experience, such a course that bears all the necessary components could be called architectural photogrammetry. The presented paper is a part of WGV7 research. Last years the works dedicated to the problem of the development and implementation of innovative educational modules on architectural photogrammetry for bachelor’s degree curricula in architecture had been published (Shults 2017, Shults et al., 2017, Levin et al., 2016, Kravchenko et al., 2016). But of course, these educational modules are based on some fundamental works such as (Luhmann et al. 2014). It is obvious that not the last role for this course plays ubiquitous low-cost technologies namely low-cost photogrammetry (Alessandri et al., 2019, Gaiani et al., 2019, Zacharek et al., 2017, Santisi et al., 2017, Ancona et al. 2015, Kersten et al. 2015, Hassani and Rafiee 2013) and UAV technologies (Azzola et al., 2019, Mutiyoso et al., 2017). So, the primary goal of the paper is curriculum development for the architectural photogrammetry course. This course will include the last achievements in photogrammetric science in conscience form. To start the curriculum development, it is necessary to identify common photogrammetric tasks.

2. ARCHITECTURAL PHOTOGRAMMETRY TASKS CLASSIFICATION

Any new course commences from concept development that we have done in the introduction. Then it follows learning objectives and ends up with a curriculum. To set the learning objectives, one has to understand general applications of architectural
Figure 1. Common applications of architectural photogrammetry

According to Figure 1, let us see more deeply to each of these applications and name a few of them. Landscape design may be the first or the last step of architectural design, depending on a project stage. Common tasks during landscape design are:
1. Drawing up plans for town planning documentation.
2. Creation of 3D models for a vertical design.
3. Creation of 3D models for projects of geoplastics.
5. Architectural measurements of the interior.
7. Architectural measurements of natural monuments and archeological sites.
8. Architectural measurements of structures.
9. Creation of archive of models of natural monuments.
10. Revealing hidden structures.

This list is no means exhaustive. However, it gives a general view of a problem and opens the ways how to organize the course content and its structure.

3. NEW EDUCATIONAL PROGRAM

According to the tasks mentioned earlier, the learning objectives, course items, and lab works content have been developed. The primary intention of the course the Architectural photogrammetry is to build up modern architects and scientists and to get them acquainted with a powerful tool for the solution of miscellaneous applied architectural and engineering tasks employing state-of-the-art photogrammetry. The course consists of five parts; it starts with a brief introduction about photogrammetry. Then follow basic concepts and math background. Keeping in mind that this course is intended for newcomers (first tear students), we have tried to put across the sophisticated math and used a basically geometric approach to present math background.

The educational program has the following items:
1. The basic concepts of GIS and BIM.
2. Introduction to architectural photogrammetry. Tasks classification. A brief history of the photogrammetry.
3. The basic math of architectural photogrammetry.
4. State-off-the-art digital cameras and software for data processing and modeling.
5. The main characteristics of digital cameras and calibration procedure.
6. A brief review of UAV technologies.
8. Calculation of the field surveying parameters and the anticipated accuracy.
10. Data processing.
11. Data integration.

Except for the theory, the major part of the program consists of lab works. These lab works in a complex look as a course project. The offered content of the lab works are:

Lab #1 Object description, conditions, and specific architectural requirements, preliminary accuracy calculation.
Lab #2 Fieldworks planning and deploy. For the real object of surveying, students calculate surveying parameters for different surveying methods (close-range photogrammetry, terrestrial laser scanning, UAV, etc.), study the technology of data capturing, plan and perform its measurements.
Lab #3 Non-metric camera calibration. The calibration carries out by software using plane test objects.
Lab #4 Fieldworks. For the chosen object (building, monument, sculpture, etc.)
Lab #5 Data processing and 3D modeling.
Lab #6 Terrestrial laser scanning of historical monuments. This lab includes just fieldwork that is based on preliminary information from lab 2.
Lab #7 UAV surveying of historical monuments. This lab includes just fieldwork that is based on preliminary information from lab 2. Lab #8 Data processing and integration. The aim of this work is data processing from labs 6 and 7, and its integration for complex 3D modeling.

Such a structure allows us to reach out to the course learning objectives. It means that upon successful completion of this course, students will be able to:

- analyze the results of photogrammetric measurements and assess data quality by standard statistical models;
- build charts, drawings, maps, 3D models by the results of photogrammetric measurements;
- apply the state-of-the-art photogrammetric equipment and software;
- set up and solve conventional architectural tasks;
- describe the architectural photogrammetry methods and opportunities.

Using this course structure, under supervising of ISPRS WGV/7 in Kyiv National University of Construction and Architecture, has been carried out a couple of projects. All of them were realized by university students. Let us have a look at some of them.

4. SAMPLE PROJECTS OF THE NEW EDUCATIONAL PROGRAM

The first project was done for a historical object in the center of Kyiv. The object was a building of Mariinskiy Palace that was built in the XVIII century. The main goal of this project was a creation of the facade horizontal drawings. To achieve this goal, photogrammetric surveying of the facade of the Mariinskiy Palace had been done (Figure 2).

Figure 2. Architectural measurements overlaid on the real structure

For surveying, a non-metric digital camera was used. On the facade, more than 100 reference points were measured by the total station. So that each imagery had 6-8 reference points at least. Photogrammetric modeling has been done by the educational version of PhotoModeler software. Camera calibration was done by PhotoModeler calibration tool and plane test object. The drawings were exported to AutoCAD for the final refinement (Fig. 3).

Figure 3. Architectural measurements of the façade

A similar project was accomplished for the main governmental building in Ukraine. It is a 10-story building of the Cabinet of Minister of Ukraine. This building was built before the Second World War. The same set of equipment and software was used. Again over 50 reference points were measured by total station. As a result, not only horizontal drawings were constructed, but also the 3D model was built (Figure 4) using PhotoModeler modeling tools. The final accuracy for both of these projects depends on the accuracy of geodetic measurements, surveying distances, quality of the calibration, and camera parameters. For the first object the final accuracy after adjustment was equal to 14 mm and for the second one 34 mm. Students have learned how to plan measurements, gathering data, processing and modeling data, and create the final product (drawings, 3D models, etc.).
houses with the aim of reconstruction and architectural design (Figure 5 and Figure 6).

For this project, students have used a non-metric digital camera, done its calibration, and processed data in PhotoModeler software. For the 3D model scaling, the Leica EDM was used. The necessary accuracy at the level of 5-10 mm was reached out. One of the things that students learned was the effect of bad camera geometry on the final results.

The more complicated and interesting project was accomplished last year. It is an architectural measurement of sculptures using different data sources and their integration. The sculpture (Figure 7, a) was surveyed by three different devices. The first data set had been got by terrestrial laser scanning using Leica C10 (Figure 7, b), the second one using scanner BLK 360 (Figure 8, a), and the third one using surveying from UAV DJI Phantom 4 (Figure 8, b).

For both sets of scanning data, the processing was carried out in the open-source software CloudCompare. The UAV’s data were processed in the educational version of AgiSoft PhotoScan software. To scaling the photogrammetric model, two different strategies were realized. For the first case, five vertical distances were measured by EDM. For the second case, the photogrammetric point cloud was exported to Cloud Compare and overlayed by point cloud from terrestrial laser scanning by Leica C10.

With the aim of comparison, all data sets were compared using the cloud to cloud algorithm. As a reference point cloud, the cloud created by Leica C10 was accepted. The results of this comparison are presented in Figure 9.
The root mean square error relative to the reference point cloud was equal to 11 mm for DJI Phantom 4 data and 21 mm for DLK 360 data. The key learning objectives for the students were gathering and processing UAV data, and integration of terrestrial laser scanning and UAV data.

The final project that it is worth to mention is drawing up plans for archaeological excavations and findings. The project was accomplished for the complex of fortified structures of the Second World War near Kyiv (Figure 10).

For the students, the key feature of the project was using coded targets for automatic imageries orientation. To scaling the photogrammetric model, ten vertical and horizontal distances were measured by EDM. Finally, the 3D point cloud (Figure 11) was generated by Agisoft Photoscan.

Summing up, it is necessary to point out a high quality of performed works and its high applicability to real architectural tasks.

5. CONCLUSIONS

First of all, it is necessary to point out that the effectiveness of the developed course of architectural photogrammetry was assessed very positively by employees of different architectural companies who were engaging our students for summer practice and part-time works. They proved students’ high skills in the field of architectural measurements and offered some useful suggestions that were accounted for in the course structure.

After the implementation of this educational course, the next step has to be the development of the course resources. Among such resources could be e-textbook, sample test data sets, and an online learning platform. To support this course, it is badly needed to organize seminars and workshops that would help to reach one of the primary aims of our work, namely the creation of liaison between architects and surveyors.

The results and experience that have presented above will be useful to students and teachers of other universities. The given concept and structure may help in the organization of new courses for other non-geospatial majors, e.g., civil engineering or the upgrading of current courses.

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EFFECTS ON GENDER BALANCE CAPACITY BUILDING IN GIT

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KEY WORDS: Capacity building, GIT, HKH, Gender

ABSTRACT:

The Hindu Kush Himalaya (HKH) region is among the most discrete and diverse region facing various ecological, environmental and socio-economic threats in terms of increasing demands for natural resources and its consequences in the form of overexploitation, disaster, droughts, extreme weather, and climate change etc. Geospatial information technology (GIT) with Earth observation (EO) data are effectively supporting the implementation of development agendas in HKH by providing extensive solutions to above-pressing issues by not only addressing them but also providing services in daily life. These technologies have effectively bolstered in time via innovation, creating jobs and confidence in people that supports filling the data and knowledge gaps in the region. However, the involvement and participation of women in GIT is mere in the region despite their vital role in environmental management and decision making. Realizing the issue, we acknowledged and implemented the twin challenges i.e. capacity building and gender equality for building the pathways to sustainable development via innovative steps and processes to bridge the gender imbalance in GIT workforce in HKH. For the purpose, we organized various capacity building trainings and workshops with a broad focus towards GIT applications in forest, agriculture, water management, drought and climate change along with the hands-on exercises. In addition, specific women focused training programs i.e. Empowering Nepali Women through Technology Training and Women in GIT were organized during 2017 and 2018 respectively. These efforts delivered optimistic results in terms of building confidence, decision making and more women participation showing an increment of ~5% participation by women in 2017-2018 fiscal year with respect to 2016-2017 fiscal year. In HKH nations with less social parity, the information delivered by this gender mainstreaming effort will have life-changing implications to achieve workforce parity.

1. INTRODUCTION

As one of the most diverse mountains, the Hindu Kush Himalaya (HKH) region serves to nearly 240 million population through various ecosystem services i.e. food, timber, fiber, fresh air and water, climate regulation, carbon storage, soil protection and the maintenance of aesthetic, cultural, and spiritual values (Hamilton 2015; Wester et al., 2019). However, the region faces multiple challenges in terms of various ecological, environmental and socio-cultural/economic securities due to the increasing demands of the natural resources (Wester et al., 2019). The unsustainable activities like overexploitation, rapid urbanization, land use land cover (LULC) changes and, habitat fragmentation has led to a profound impact on the sustainability and resilience of the region along with the threat to sustain the large population of the HKH region (Thapa et al., 2019; Wester et al., 2019).

Geospatial information technology (GIT) and earth observation (EO) data has played a vital role in addressing and mitigating the above pressing issues and have effectively bolstered via innovative technology, creating jobs and confidence in people. The application of GIT as a decision-making tool via data and information management, spatial data collection, quality assessment, processing and, modelling have revealed many new insights to knowledge gaps in ecology-environment interactions, agricultural analysis an natural disaster etc. (Ingole et al. 2015; Manfré et al. 2012; Ofori-Amoah, 2008). However, the effectiveness of GIT depends on the people who know the theory and applications of this technology, which is lacking in the developing countries (Merino and Carmenado 2012; World Bank 2005). Capacity building is the core strength of any sustainable development via enhancing and accelerating individual, institutional and infrastructure capacity and assisting to the use of advanced technology and innovations for decision making that provides options in bridging the science and policy gaps. In addition, despite the vital role of women in environmental management and decision making their involvement and participation in GIT is very low in Asia particularly in HKH region (Sherpa 2007; Mehta, 2007) that might lead to a large gender imbalance around the globe (Caitlin 2014). To overcome these challenges, a robust approach of capacity building (CB) is required that enhances the technical abilities of society and countries at individual, organizational and institutional levels to implement and achieve the development goals (Thapa et al., 2019; Chandler and Kennedy 2015). Recently, Thapa et al. (2019) developed a sequential work flow for capacity building highlighting four major tasks as Assessment, Design, Implementation, and Monitoring (ADIM).

SERVIR-HKH program, a joint development initiative of USAID and NASA, works on bridging these gaps in the HKH region (http://servir.icimod.org). The program supports CB activities for government institutions and other development stakeholders to incorporate GIT and EO data into decision making process. Wherein, the knowledge and information is

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delivered through national and regional platforms and collaborations through development of innovative, user-tailored analyses, decision-support products, and distinct trainings (SERVIR Global 2018). This paper addresses the gender balanced approach for the CB of HKH region.

2. MATERIALS AND METHODS

2.1 Capacity building strategy:

Our study area, the HKH region includes 8 member countries namely Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and, Pakistan (Figure 1). We followed the sequential CB workflow given by Thapa et al. (2019) that addresses four major tasks as assessment, Design, Implementation, and Monitoring (ADIM). Wherein, the capacity of the targeted institutions were assessed to identify gaps followed by design of CB workflow incorporating the selection of topic and subject matter experts (SMEs), curriculum and materials development, delivery methods, and execution plan. Further the implementation of the CB activities were carried out via various training programs during the years 2015 to 2019 in which gender balance among the participants are given high priority. The concern to bridge the gender gap urged us to introduce the gender strategy to mainstream gender and equity issues into GIT to provide equal opportunities to male and female in gaining and sharing knowledge and experience and to disseminate it via accessible opportunities. These issues are prominently addressed in the Medium-Term Action Plan 2018-2022 – ICIMOD (MTAP IV). For the purpose, we keep motivated our partners to respect gender equity and encourage providing equal opportunity of participation for all genders during training invitation and nomination process. We delivered the trainings in four categories (table1) as: 1) exposure and learnings (EL), 2) standard trainings (ST), 3) on the job training (OJT), 4) training of the trainers (TOT), with a broad focus towards GIT applications in forest, agriculture, water management, drought and climate change along with the hands-on exercises.

Special focus is needed to attract potential female students and professionals to adopt career in GIT field. Therefore, we offered special trainings designed for women participants exclusively to develop gender balance workforce in the HKH region. For the purpose, women oriented trainings i.e. Empowering Women in Geospatial Information Technology (GIT) were also organized. The evaluation of the trainings were done by a pre and post training survey based on participant’s self-knowledge on the subject and technical skill to understand the knowledge gain in different topics.

3. RESULTS AND DISCUSSION

3.1 Capacity building events

We organized different capacity building trainings in the region during October 2015 to September 2019. Overall, 62 trainings were organized under four major type as EL, ST, OJT and TOT as mentioned in methods section. Wherein, 1, 19, 19 and, 23 training events were organized in the fiscal year 2015, 2016, 2017, and 2018 respectively. As a whole, approx.1360 participants participated in these events including ~67% of participation by male and ~33% of the participation by females respectively (Figure 2).

3.1.1 Year wise capacity building analysis

Year wise statistics showed overall ~67%, ~62%, ~74% participation of male candidates for the fiscal year 2016, 2017 and 2018 respectively. On the other hand, female participation was observed as ~33%, ~38% and, ~25% respectively for the fiscal years 2016, 2017 and 2018. A significant gain of ~5% in the participation of women during the fiscal year 2017-2018 as compared to the year 2016-2017 was observed. This highlighted the successful approach of implementing gender strategy into the action plan of ICIMOD. We observed an overall drop of ~10% in the women participation during the fiscal year 2018-2019. This might be attributed to the irrelevant nomination procedure of the collaborating partners (Thapa et al., 2019). In addition, engagement of fewer women in GIT and EO based professions in the HKH region might have led to their lower participation.

![Figure 2. Year-wise comparison of the male and female participation (%) in capacity building events](image)

3.1.2 Service area based capacity building analysis

The broad topics chosen during the training covered applications of GIT and EO in the forest, agriculture, water management, drought and climate change. Wherein, the basic theory and hands-on exercises were designed for the participants to understand and implement the knowledge. These broad topics were categorized into five major categories as Agriculture and Food Security (AFS), Water Resources and Hydro-climatic Disasters (WRHD), Land Use Land Cover and Ecosystem (LULC&E), Weather and Climate Services (WCS) and, cross cutting (CC; Figure 3). Wherein, 8, 21, 13, 6 and 14 events were organized under AFS, CC, LULC&E, WCS and WRHD respectively (Figure 3). In these events maximum participation from female were observed in CC area (approx.48%) however, the least participation was observed under the service theme WCS (approx.17%).

![Figure 1. The Hindu Kush Himalaya region](image)
3.1.3 Training type based capacity building analysis

Based on the four types of CB trainings (i.e. EL, OJT, TOT and, ST) we observed overall 8, 5, 5 and 44 events were organized during the years 2015 to 2019. In these maximum participants were observed in the standard trainings. We observed the least participation of women in the OJT trainings showing only ~9% and maximum participation in the EL trainings with ~ 41%. In contrast, male participation was observed to be maximum for OJT trainings (~90%) and least participation for EL trainings (~58%) respectively (Figure 4). This statistics gives an insight of the differences in opportunities for male vs female participants that shows male participants are more into GIT and EO professions compared to female participants. While young women are looking for the opportunities to build their confidence and GIT as a career option via EL.

** EL: exposure and learnings; OJT: on the job training; TOT: training of the trainers; ST: standard trainings

3.2 Women focused program

Realizing the need to involve females in various thematic programs to opt for their career in GIT field we organized and supported various women oriented programs. For the purpose, training on “Empowering Women in Geospatial Information Technology (GIT)” was organized in 2018 and 2019 respectively. Overall, 84 and 40 women participants attended the training during 2018 and 2019 respectively and were benefitted. This training focused for women attained a massive attention from media under the headline “Empowering Nepali Women through Technology Training” and was a successful event in 2018.

As one of the innovative ways to promote women in science and technology we supported Miss Tech 2017, a massive national collaboration, focused on promoting women technopreneurship that takes place to solve the issue in the society faced by Women with the theme Mountain Women “Transformational Changes through Technology”. In this programme, 52 participants including 45 amateurs and 7 professionals collaborated, helping each other into inspiring creative and innovative solutions to the challenges. A total of 16 teams participated and they worked on solving challenges faced by women living in the mountains. This event was duly acknowledged in the media as “Women drive innovation at Miss Tech, 2017” under the news cover of “The Himalaya”.

These trainings not only provided more opportunities to the professionals working in GIT and EO field but also enhanced the confidence in the participants to opt this field for their career and is well evidenced.

3.3 Monitoring and evaluation

As an integral part of CB monitoring and evaluation serves the effective role in assessing the actual capacity build via trainings. Therefore, we conducted pre-and-post assessments for each type of capacity building activity. The pre assessment provides guidelines about the participant’s awareness and expectations on the capacity building content. Wherein, we provided the questions on the participant’s basic awareness of the subjects through self-assessment and then a technical session to assess their skill level. The post assessment provided the level of knowledge acquisition by the participants and feedback for the continuous improvement.

4. CONCLUSION

Although, innovations via GIT has led to a growing number of projects in various sectors to address and improve ecosystem sustainability, community infrastructure, public health etc. in the HKH region; the lack of human resources and capacity from individual, institutional and national level hinders the implementation in effective ways. Therefore, we presented a robust and simple approach ADIM designed by Thapa et al., (2019) to build the capacity of the region.

We conducted overall 62 capacity building programmes in the HKH region successfully via ADIM’s approach which clearly indicated its effectiveness in individual, institutional CB and in improving the gender gap in the GIT field of the HKH region. The specific programs for women identified the expectations and an opportunity for career options in GIT for the women participants. However, there is still much scope to improve the
activities in future. We believe, that the information delivered by this gender mainstreaming effort will have life-changing implications to achieve workforce parity in the HKH nations with balanced gender involvement.

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PREPARATION OF SYLLABUS OF GEOMATIC ENGINEERING

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ABSTRACT:

Accelerated development of a country depends on the available digital spatial data of the countries at larger scale or 0.5m or higher resolution which necessitate large number of qualified geomatic engineers. Technology of survey is changed to digital technology and precise mechanical or optical instruments, scale, ink, film, paper and manual instruments are phased out in 2014. Geomatic Engineering covers the areas of whole range of professional fields within global surveying community, here under surveying, cadastre, hydrography, engineering survey, urban planning, instrumentation, real estate valuation, mapping, geodesy, geospatial and quantity surveys. It also covers surveying of under, on and above the surface of the earth and other celestial bodies. The present techniques of acquiring data are by aerial /satellite imagery along with LIDAR, mobile scanning and field survey by total stations, GNSS, crowd sourcing. Web mapping is gradually replacing the paper maps. Preparation of syllabus need to assess long term development and needs of geomatic education as well as national and international employment situations. Some courses may be common to other engineering and other subjects. Course should not be repeated and total credit hours maintained below 180 credit hours for four years including the subordinate subjects. After the studies the courses of universities of other nations and requirements of stakeholders, detailed courses are designed. It is hard to satisfy all the requirements of stakeholders as well as university and councils. In this article, it briefly describe the method of development geometrics syllabus and approval processes in Nepal.
A COLLABORATIVE MODEL AND “KNOWLEDGE TRANSFER VEHICLE” FOR CAPACITY DEVELOPMENT: GEO-INFORMATION AND LAND ADMINISTRATION EDUCATION AT KATHMANDU UNIVERSITY JOINTLY WITH LAND MANAGEMENT TRAINING CENTER

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KEYWORDS: Capacity Development, Geo-information, Land Administration, Kathmandu University, Land Management Training Centre, Equity, Inclusiveness, Federalism

ABSTRACT:
Capacity Development is seen as a key component to bring effectiveness, efficiency and sustainability in any discipline. In this respect, the importance of capacity development has been highlighted by various scholars, both in the technical and managerial aspects of land management. Education in geo-information and land administration become very important to integrate with the overall management of land in the country context. Therefore, it becomes a dire need to think in these settings. Moreover, a conceptual approach is required, in order to cope with the various challenges that can come across while producing quality human capacity. Therefore, an innovative approach to capacity development has been adopted by Kathmandu University (KU) jointly with the Land Management Training Centre (LMTC). This paper seeks to describe the existing collaborative model of capacity development in geo-information and land management. The paper provides insight into how the model has served as “Knowledge transfer vehicle” by being able to outreach in seven provinces of Nepal. In addition, it reveals that the collaborative model has supported in “equity” and “inclusiveness” in providing educational opportunity and contributes to the transition phase of federalism and decentralization of the Land administration system in Nepal.

1. INTRODUCTION

1.1 Capacity Development:
Capacity Development (CD) is increasingly seen as a key component to bring effectiveness, efficiency, and sustainability in any discipline. In a general context, capacity development can be expressed as enhancing the ability of people to work in an effective, efficient and sustainable manner. Capacity development can be considered at three levels, the individual, organizational and institutional levels (Enemark et al., 2004; Samarakoon & Inomata, 2008). At the individual level, CD refers to the procedure of changing attitudes and imparting technical knowledge, developing specific skills, ability to knowledge exchange and accountability on the work (ownership). Similarly, at an organizational level, it is about enhancing the overall organization performance and functioning capabilities including the ability of an organization to adapt to change. The capacity development at the institution level is about the ability to support organizational changes. Besides, CD emphasizes the overall policy framework which consists of individuals and organizations that operate and interact with the formal and informal institutions. Therefore, for the proper functioning of the whole system, CD in all three levels is important.

1.2 A dire need for capacity development in geoinformation and land administration
A need for capacity development in geoinformation and land administration has been found as a global agenda. Further, the new lens through which to view the urgency of capacity development in various levels has been proposed. As highlighted by GEF-UNDP (2000), there is a global assessment of capacity buildings needs in biodiversity, climate change and land degradation at the institutional, organizational and individual levels. Similarly, Enemark (2005) has highlighted the necessity to capacity assess, capacity developing, and capacity development sustainability of land professionals in order to achieve a sustainable land administration system. A conceptual framework was developed by Enemark et al. (2004), to develop overall capacity in land administration.

![Figure 5: Enemark and Williamson (2004)](image)

The requirement to develop capacity in the sector of geo-information and land administration has been identified at the national level in Nepal. The market study was carried out in 2010 by Kathmandu University in order to assess to need for human
resources in land administration and land management. The study has highlighted the requirement of the skill human resources in the scenario of federalism. Nepal has six metropolises, 11-sub metropolises, 276 municipal councils and 460 village councils (Government of Nepal, 2019; Wikipedia, 2019b). In the transition phase of federalism, there is a need of immense human capacity in the sector of land administration and geoinformatics that facilitates in the three-tier government system (federal, state, local) and decentralization of land administration system.

To fulfill this necessity, the undergraduate program in geomatics engineering has been started in 2007 at Kathmandu University (KU). The graduate program in Land Administration in 2013 and the graduate program in Geoinformatics has been started recently in 2019. All the courses are offered jointly with the Land Management Training Center (LMTC) based on the Memorandum of Understanding (MOU). The MOU is defined as a type of agreement between two (bilateral) or more (multilateral) parties. Further, it articulates a convergence of will between the parties by indicating that there is an intended common line of action (Wikipedia, 2019a). In addition, the diploma level education was also started jointly with KU, LMTC and CTETV in which KU plays the role of facilitator. There are financial subsidies from the Nepal Government which has been allocated in each program.

1.3 Knowledge Transfer Vehicle

The main elements of the knowledge management process are knowledge acquisition, knowledge storage, knowledge transfer and utilization of knowledge. Among these four elements, knowledge transfer has huge importance. “Knowledge transfer” is the objective seeking communication of knowledge among knowledge sender and knowledge recipient. The recipient of knowledge should have a cognitive understanding and has the ability to apply knowledge. In order to obtain the smooth transfer of knowledge between the sender and recipient, the knowledge transfer mechanism is paramount. The particular knowledge transfer mechanism is the vehicles via which the knowledge is transferred. Taking into consideration of KU-LMTC collaborative model, the model has become a “Knowledge Transfer Vehicle” that supports the transition phase of federalism and decentralization of the land administration system in Nepal.

1.4 Aim of the study

The main aim of this study is to describe the existing collaborative model (KU-LMTC) for capacity development in geoinformation and land administration. The paper provides insight on how the model is being able to outreach by considering the vision of equity and inclusiveness and supportive in the transition phase of federalism and decentralization of the national Land administration system in Nepal.

The following section 2 describes the existing collaborative model between KU-LMTC. Then section 3 highlights the past and present scenario of geo-information and land administration education at Kathmandu University. Section 3 presents the analysis of the outcome of the model.

2. AN INNOVATIVE COLLABORATION BETWEEN
KATHMANDU UNIVERSITY AND LMTC

Collaboration is a concept in which two or more entity involves a target to achieve a common goal. In this era of rapid technological development, no single entity can have all the internal capacity and capabilities in the form of human resources, technical resources and financial resources (Powell et al., 1996). The collaboration can be on a different level such as individual, organizational. The collaboration between KU and LMTC is inter-organizational collaboration.

The KU is an autonomous, not-for-profit, self-funding public institution. It is governed by an KU Act on December 1991. It has its mission statement as “to provide quality education for leadership”. The vision is “to become a world-class university devoted to bringing knowledge and technology to the service of mankind”. Further, KU aspires to serve the nation with the norms like “from the campus to the community.” The University consists of seven Schools which are School of Science, School of Engineering, School of Arts, School of Law, School of Education, School of Medical Science and School of Management. The department of Geomatics Engineering is under the School of Engineering in which the education on geo-information and Land administration is taught. The niche of MOU between KU-LMTC is in producing quality human resources in Bachelors in geomatics engineering, Masters in Land Administration and ME/MS in Geoinformatics. All the mentioned programs are running under the Department of Geomatics Engineering (Kathmandu University, 2019).

Land Management Training Centre (LMTC), established in 1968 AD, under the Land Management, Cooperatives and Poverty Alleviation, is the governmental institution that have mandate to produce human resources and conduct evidence based policy research activities in the field of geo-information science. Apart from joint academic courses with KU, LMTC has been conducting two types of the training programs. One is long-term training programs which are senior survey Training, junior survey training and basic survey training. In addition to long term training, the center has been running short term flexible professional courses in geo-information and land management as per the requirement of capacity in the government organization (Land Management Training Center, 2019)

2.1 Human Resources:

The human resources refer here is about the expertise to deliver the lecture on different subject. The availability of qualified and skilled teaching faculties is a significant contributor to the quality product. Human resource sharing between KU and LMTC is one of the important pillars in which this collaboration is based on. The courses were designed in the “T” model (Ehlers, 2013). The horizontal bar if “T” denotes ability to act successfully across disciplines, context and systems. The vertical bar of “T” denotes in-depth knowledge in one field. For instance: project management, entrepreneurship, internship are courses offered representing horizontal bar of “T” whereas, spatial data acquisition (surveying, photogrammetry), spatial data analysis (GIS, digital image processing), spatial data storing (DBMS, SDI) and spatial data dissemination (WebGIS, cartography) are courses offered representing vertical bar of “T”. The capacity to deliver the “T” model courses are fulfilled from the expert of specific courses available at LMTC and KU by providing lectures to the undergraduate and graduate students.

2.2 Technical Resources:
Besides sharing human resources, other major pillar on which the MOU is based is the sharing of the technical resources. Technical resources, here, refers to the surveying equipment (Theodolite, Total Station, GPS etc),Geo lab which consists of computer hardware and software related to geo-information, photogrammetry equipment like unmanned aerial vehicle (UAV).

2.3 Physical Resources:

Physical resources refer to physical infrastructure like lecture rooms, seminar hall, library, student hostel. Under this collaboration, the third important pillar is the physical resource sharing.

3. SETTING THE SCENE: PAST TO CURRENT PATH OF EDUCATION AT KATHMANDU UNIVERSITY IN GEO-INFORMATION AND LAND ADMINISTRATION

Taking into consideration of need of capacity in handling geoinformation technology and its application in tackling land issues, the intervention on capacity building was made in 2007 A.D. The intervention was about developing a “Centre of Excellence” at Kathmandu University in producing human resources in the sector of geo-information and land management (KU & LMTC, 2007).

The MOU between KU-LMTC has been signed for the graduate program namely, Land Administration, in 2014. Under this MOU, the target was set to produce batches of 2014 to 2017. Before signing the MOU, the market study was carried out in 2010 which shows the need to strengthen the capacity of land professionals for supporting the federalism scenario of Nepal (Kathmandu University, 2010). After conducting the market survey, the detail implementation plan, including the role of the University of Twente, was prepared (KU -LA Implementation Committee 2012). Later, the MOU was signed between KU and LMTC for the implementation of the graduate program in L.A. Under the specific MOU, a 100% scholarship for 10 government employees was allocated. The financial support was provided by the Government of Nepal. Recently, the MOU was signed to produce a graduate in two programs (geo-informatics and land administration), from the batches of 2019 to 2022. The MOU reflects about providing 100% scholarship to the government employee considering the scholarships is provided for five government candidate in each program (KU-LMTC, 2019).

The undergraduate program in Geomatics Engineering was started in 2007 under the framework of MOU. Under the first MOU, the geomatics batches from 2007 to 2010 were produced in the geospatial field. 75% of the total fee is waived for 24 students (KU et al., 2007). Under the second MOU, the geomatics batches from 2011 to 2014 were brought into the market. The 100% scholarship was provided for two government employees who were in the engineering services under the category of survey whereas 50% scholarship was given for eight students from four development regions except for central regions and 33% scholarship was provided for 10 students based upon the merit score of entrance exam conducted by KU namely Kathmandu University Common Admission Test (KU-CAT) (KU-LMTC, 2011). Under the third MOU, the geomatics batches from 2015 to 2018 were produced into the market of geo-information. In this MOU, 35% scholarship was given to 20 students according to the merit list of KU-CAT and including all five development regions. However, the scholarship was provided to maximum four students in each development region (KU & LMTC, 2015). Recently, the MOU has been signed to produce batches of 2019 to 2022. The MOU explicitly consists of inclusive criteria as shown in Table 4 (KU-LMTC, 2019).

4 COLLABORATIVE MODEL AS A “KNOWLEDGE TRANSFER VEHICLE”

Figure 6 shows a conceptual framework of the collaborative model between KU-LMTC. The model is developed on the basis of MOU signed in 2019.

The collaborative model of KU-LMTC is a “Knowledge Transfer Vehicle” for educating geomatics engineering. Based on the MOU, the KU-LMTC shares the physical, technical and human resources as elaborated in sections 2.1, 2.2 and 2.3. With this joint effort, there are more than 220 geomatics engineers including LA masters graduate were produced from KU.

4.1 Inclusiveness:

The collaborative model is based upon the inclusive criteria. The inclusiveness has been defined in terms of gender, deprived community and ethnicity. Table 4 shows the inclusive criteria which are geographically inclusive as well because each quota for female, ethnic group and economically deprived is allocated for all province. Similarly, three intake seats based upon the score of the entrance exam has been distributed equally in all seven provinces.

<table>
<thead>
<tr>
<th>Inclusive Criteria</th>
<th>Number of Intakes</th>
<th>Scholarships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Employee of Nepal Government</td>
<td>4</td>
<td>100%</td>
</tr>
<tr>
<td>Inclusive Quota (3 from each province)</td>
<td>24</td>
<td>35%</td>
</tr>
<tr>
<td>Female-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethnic Group-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backward region/ Economic deprived-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Provisional Open Merit (3 from each province)</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Open Merit</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: The inclusive criteria and the number of intake from each province.
4.2 Supports federalism of the Land Administration System

The model further supports the decentralization of the land administration system of the country. The country needs a technical expert in 736 local level land offices i.e. 276 municipal councils and 460 village councils. The geographical equity criteria defined within this knowledge transfer model support in the transition phase of federalism.

ACKNOWLEDGMENTS

The authors would like to acknowledge Prof. Dr. Ram Kantha Makaju Shrestha (Vice Chancellor, Kathmandu University) for inspiring us to write the article.

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SAR – OPTICAL REMOTE SENSING BASED FOREST COVER AND GREENNESS ESTIMATION OVER INDIA

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KEYWORDS: ALOS PALSAR MOSIAC, Browning, Greening, LAI, SAR, Vegetation cover

ABSTRACT:

Indian natural forest has a high ecological significance as it holds much biodiversity and is primarily affected due to deforestation. The present study exhibits the forest cover change on Global Forest Non-Forest (FNF) data for India and greenness trend using MOD15A2H LAI product, which is the best product available till date. JAXA uses of SAR datasets for forest classification based on FAO definitions. Later, Forest Survey of India (FSI) used different definitions for forest classification from FAO and was to compare with JAXA based forest cover. The global FNF study exhibited that total forest cover was reduced from 568249 Km2 to 534958 Km2 during 2007-17 in India. The significant loss of forest cover (33291.59 Km2; by -5.85% change) was primarily evident in Eastern Himalayas followed by Western Himalayas. Whereas forest cover increase was observed in Eastern and the Western Ghats from 2007 to 2017. The state of forest report by FSI states an increase in the forest cover from 690889 Km2 to 708273 Km2 during 2007-17 by 2.51%. The difference in forest cover as estimated by JAXA global FNF datasets and FSI report is attributed to differences in forest cover mapping definitions by both the agencies and use of varied datasets (SAR datasets by JAXA and optical datasets by FSI). It is to note that SAR is highly sensitive to forest cover and vegetation’s as compare to optical datasets. Recent satellite-based (2000 – 2018) LAI product reveals the increase in leaf area of vegetation during 2000-18. It may be attributed to proper human land use management and implications of green revolutions in the region. The greening in India is most evident from the croplands with insignificant contribution from forest cover.

1. INTRODUCTION

Forest is the most essential and critical element of earth’s surface, and its dynamics on the landscape are driven by both human activities and natural processes (Morales-Díaz et al., 2019; Tucker and Richards 1989). The green leaves of vegetation play a crucial role in maintaining terrestrial carbon balance and also supports climatic systems as it amagamates sugar from water (H2O) and CO2 using the energy that leads to cooling of the surface by transpiring a large amount of water (Chen et al., 2019; Piao et al., 2003). The growth of vegetation in an ecosystem can be strongly influenced by climate change and human activity (Cavicchioli et al., 2019; Chu et al., 2019; Liu et al., 2019). Long-time change in greenness of vegetation are driven by multiple factors such as biogeochemical drivers i.e., fertilization effects of CO2, regional change of climatic factors as temperature, precipitation and radiation and varying rate of Nitrogen deposition or cycle change and land-use effects i.e., change in land use/ land cover (LULC) due to land management intensity, including use for fertilizers, irrigation, deforestation and grazing) (Wang et al., 2014). So, it is crucial to monitor vegetation changes because spatiotemporal changes can alter the structure and function of landscapes, subsequently influencing ecology and biodiversity and became an important issue in global biodiversity change (Li et al., 2012; Feng et al., 2012, 2011; Steidinger et al., 2019).

Greenness on earth’s surface can be monitored through various developed indices like Normalized Differential Vegetation Index (NDVI), Leaf Area Index (LAI), Enhanced Vegetation Index (EVI) and many more used by several researchers (Chu et al., 2019; Rani et al., 2018). LAI (one half the total green leaf area per unit horizontal ground surface) can be more efficient to monitor the greenness because it is one of the main driving forces of net primary production, water and nutrient use, and carbon balance and important structural property of vegetation (Breda, 2008; Fang and Liang, 2014).

Remote sensing is a beneficial technique for studying various earth observations on regional to a global scale. Optical remote sensing (ORS) data are widely used for the vegetation mapping by using a near-infrared and red band as it useful for vegetation mapping. As per current research knowledge, very less study has applied microwave remote sensing (MRS) datasets for vegetation mapping due to the requirement of robust hardware for processing. Major advantages of MRS over ORS is that it has day and night capabilities and penetration of cloud cover and can provide an image at any time (Woodhouse, 2005). There are various spectral bands at which SAR data is being captured. X-band is useful for various surface deformation and movement tracking activities (Lal et al., 2018), C-band is used for both ground surface deformation and vegetation studies, L-bands are used for vegetation studies primarily because of its higher penetration depth (Antropov et al., 2017; Kumar et al., 2019; Plank et al., 2017). By increasing the wavelength in SAR datasets, vegetation type classification accuracy will increase because of its penetration depth. Mapping a vast region with optical datasets leads to inaccuracies due to cloud cover data and have to be replaced with another time periods datasets, whereas by SAR datasets researchers can overcome these problems accuracies will be more.

* Corresponding author
With continuous availability of satellite-based datasets, the efforts to accurately classify forest types have increased over the year to correctly capture the real dynamism of any ecological landforms/landscapes. The ambiguity in management approaches for forest conservation raises the need to develop newer approaches with higher accuracies in mapping a forest region or types of forest region (Paneque-Gálvez et al., 2013). The trade-off between spatialtemporal datasets with spectral resolution and availability of cost determines the quality of forest or any land use classifications, unlike different types of spatial and spatial resolution keeps many advantages on species-level distribution mapping in forest region (Eisavi et al., 2015; Pu and Landry, 2012).

India is a country with diverse vegetation types and wildlife. Due to expansion of agricultural land, urban areas and various human-induced changes have caused extensive damage to Indian forests and results in loss of biodiversity hotspot in major regions: The Indo-Burma hotspot, Teral regions of Himalayas and Western Ghats (Datta and Deb, 2012; Deb et al., 2018; Myers et al., 2000; Reddy et al., 2019). To accent this mass and severe deforestation and degradation of ecology, the MoEF, as well as Indian Forestry Department, have declared major regions of forest regions as a biosphere, national parks, sanctuaries or reserve forest and increased the management for conservation in those areas.

Forest cover delineation is well documented in India by Forest Survey of India in Bi-Yearly report. Also, various researchers have documented for the degradations of forest and restoration of the forest from regional to global scale using remotely sensed data in past two decades and shown vegetation cover change or forest cover change ecologically it is transforming. Long term LULC changes has been mapped by Ramachandran et al., (2018) in the Eastern Ghats and identified as timber logging, dam construction, road/rail network and other developmental activities were the major drivers of forest cover change before the 1960s, and after 1960s anthropogenic pressure as increase in demand of land for urban development is a major driver for degradation. The three studies by Chakraborty et al., (2018); Kanade and John, (2018); Ramachandran et al., (2018) establish a relationship very rigorously and unambiguously that there is a significant reduction in green cover in different regions of national forest and habitat types in India. Forest cover loss in the Western Ghats shows that protected areas (PAs) were able to slow down the rate of deforestation about 32%. However, in areas with high population density, deforestation rates are higher even in the PAs (Krishnadas et al., 2018). As per recent Forest Survey of India report, it claims that Indian forest cover has been increased by 0.94% of total area (FSI, 2017), while some experts point out that government often keeps claiming that the green cover is increasing; but it is usually due to plantations and not due to expansion of forest covers (Padma, 2018). Apart from deforestation in India some studies also suggested that India is greening (Zhang et al., 2017) due to proper land use management as a direct factor whereas climate change and CO₂ fertilization as dominant indirect factors (Chen et al., 2019; Zeng et al., 2014; Zhu et al., 2016) by analysing Leaf Area Index (LAI) and Normalized Difference Vegetation Index (NDVI) from remotely sensed datasets. The objective of the study is to analyse the decadal change in the natural forest of India using PALSAR/PALSAR-2 mosaic and forest/non-forest (FNF) datasets by JAXA, which follows FAO definitions for forest mapping (Shimada et al., 2014) and comparing the results of forest cover with FSI reports. Later, the greening and browning trend from 16 days LAI datasets were also analysed to map the spatiotemporal variability in greenness in the Indian region.

### 2. STUDY AREA

India, located in South-East Asia, has been considered as a study area for above-said objectives. It is the seventh-largest country in the world can be divided physically into four regions—the Himalayan mountains, the Gangetic river plains, the southern (Deccan) plateau and the islands of Lakshadweep, Andaman and Nicobar. The lofty Himalayan mountain range borders India in the north and contains the nation’s highest peak. The Indus, Ganges and Brahmaputra rivers rise in the Himalayas. Southern India consists of a triangular peninsula, and much of this consists of a tableland, the Deccan plateau (Forster and Stallybrass, 1978).

![Figure 1. Biogeographic Zones of India](image)

For Forest area change mapping a Biogeography Zones were used and it consists of 13 different zones namely Western Himalayas, Eastern Himalayas, East Deccan, Deserts, North Deccan, South Deccan, Western Ghats, Central Highlands, East Coast, West Coast, Eastern Ghats, Eastern Plains and Northern Plains in India as shown in figure 1.

<table>
<thead>
<tr>
<th>Biogeographic Zones</th>
<th>Area in Sq. Km</th>
<th>Area Coverage in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Ghats (EG)</td>
<td>190190.61</td>
<td>5.80</td>
</tr>
<tr>
<td>Eastern Himalayas (EH)</td>
<td>218325.11</td>
<td>6.66</td>
</tr>
<tr>
<td>Desert (D)</td>
<td>217336.97</td>
<td>6.63</td>
</tr>
<tr>
<td>Western Himalayas (WH)</td>
<td>323331.91</td>
<td>9.86</td>
</tr>
<tr>
<td>Northern Plains (NP)</td>
<td>295662.01</td>
<td>9.01</td>
</tr>
<tr>
<td>Eastern Plains (EP)</td>
<td>208608.68</td>
<td>6.36</td>
</tr>
<tr>
<td>Central Highlands (CH)</td>
<td>368669.69</td>
<td>11.24</td>
</tr>
<tr>
<td>East Deccan (ED)</td>
<td>340963.67</td>
<td>10.39</td>
</tr>
<tr>
<td>North Deccan (ND)</td>
<td>330148.69</td>
<td>10.06</td>
</tr>
<tr>
<td>South Deccan (SD)</td>
<td>290539.84</td>
<td>8.86</td>
</tr>
<tr>
<td>West Coast (WC)</td>
<td>236748.98</td>
<td>7.22</td>
</tr>
<tr>
<td>Western Ghats (WG)</td>
<td>70702.95</td>
<td>2.16</td>
</tr>
<tr>
<td>East Coast (EC)</td>
<td>189307.70</td>
<td>5.77</td>
</tr>
</tbody>
</table>

Table 1. Area of different Biogeographic Zones considered in these study

### 3. DATA USED AND METHODOLOGY
Forest Survey of India forest cover datasets which are Bi-yearly released was used to analyse forest cover change with another dataset by JAXA, i.e., is Global forest and non-forest data. JAXA (Japan Aerospace Exploration Agency) used FAO definitions for forest mapping, which is purely different from FSI forest mapping definitions. Forest cover as reported in the SFR includes all the lands having trees with canopy density 10% and above and with the area having one hectare of the forest cover, which corresponds to the cartographic limit on a map at 1: 50,000 scale. It is taken in account based on the availability of cloud-free optical datasets, primarily it uses RESOURCESAT-1 datasets, but due to some limitations, another dataset like Landsat satellite or ESA based Sentinel 2A/2B data were also used (FSI, 2007). As per FAO, the forest is defined as land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10%, or tree able to reach these thresholds in situ. It does not include land that is predominantly under agriculture or urban land use. JAXA based global forest data used FAO definitions and used Synthetic Aperture Radar (SAR) datasets which can capture datasets at cloudy weather (JAXA, 2010; Shimada et al., 2014). Since, SAR signal has the problem in mountainous area and to overcome these issue all the raw scenes were calibrated using a published coefficient (Shimada & Otaki, 2010). “All scenes were ortho-rectified using the 90 m SRTM Digital Elevation Model (Shimada, 2010a, 2010b) and slope-corrected using these same data to account for the variation in the backscattering coefficient with topography” (Shimada et al., 2014). Global FNF data are available in Binary format as data and hrd extension with 0.1°X0.1° area coverage at 25m of spatial resolutions. For each year total, 1625 binary datasets covering over India were merged and converted into tif format. Biogeography Zones were rastered with a 25 m spatial resolution using ArcGIS 10.6 to match spatially with JAXA FNF data. Zonal summary used in Erdas Imagine for calculating the area of forest in different biogeographic zones, for comparison of forest area in different zones and analysing changes in the different time period. Later Overall forest area of India from FSI and JAXA were compared.

The MOD15A2H Version 6 Moderate Resolution Imaging Spectroradiometer (MODIS) Leaf Area Index (LAI) product is an 8-day composite dataset with 500 meter (m) pixel size were used for analysing the trend and long term of LAI in different seasons of India. Yan et al., (2016a), (2016b) comprehensively evaluated the quality of C6 MODIS LAI datasets against the ground measurement of LAI and also inter-comparison with other satellite LAI product and found that it is the highest quality LAI product available till date. Linear trend analysis of CDO (Climate Data Operator) was used for analysing greenness trend.

4. RESULT AND DISCUSSION

4.1 Analysing Forest Cover Change

JAXA global FNF data were used to analyse forest cover change in different biogeographic zones during the year 2007 and 2017. The study showed that the highest forest cover was present in Eastern Himalayas (24.07 %) followed by East Deccan (16.31 %) and Western Himalayas (11.50 %). These Statistics are with respect to the year 2017. But, when the area is analysed according to forest coverage in zonal wise as Eastern Himalayas have the highest coverage followed by the Western Ghats and East Deccan. These three zones have acted as a biodiversity hotspot, which has high ecological significance in natural forest. The JAXA Global FNF (2007, 2017) based decadal assessment of the forest cover reported a considerable reduction of 33291.59 Km² (1.02% area of India) forest cover (from 568249.47 Km² to 534957.88 Km²) during 2007-17. The significant loss in forest cover was observed in Eastern Himalayas (EH, 9.3%) followed by Western Himalayas (WH, 4.62%), East Deccan (2.29%), North Deccan (0.38%) and Central Highlands (0.31%). The decrease of forest in EH was also reported by FSI and attributed to shifting cultivation, rotational tree felling, diversion of forest land for developmental activities, submergence of forest cover, agriculture expansion, natural disasters (viz., flooding, earthquakes) and other pressures. North-East India also has a rich diversity in tree population, but many of the tree species are under threat. Since Western Himalayan region is the best-studied ecoregion in India, yet the region observed a significant (14946.71 Km²) decrease in forest cover during the last ten years (2007-17), primarily due to higher dependency of local populace on forest resources. In recent years, the stress on forests of the WH has become more intense due to unsustainable developmental activities as well as an increased frequency of natural disasters in changing climatic conditions (Tewari et al., 2017).

<table>
<thead>
<tr>
<th>Biogeographic Zones</th>
<th>2007</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Ghats (EG)</td>
<td>1.29</td>
<td>1.45</td>
</tr>
<tr>
<td>Eastern Himalayas (EH)</td>
<td>4.53</td>
<td>3.93</td>
</tr>
<tr>
<td>Desert (D)</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Western Himalayas (WH)</td>
<td>2.33</td>
<td>1.87</td>
</tr>
<tr>
<td>Northern Plains (NP)</td>
<td>0.21</td>
<td>0.26</td>
</tr>
<tr>
<td>Eastern Plains (EP)</td>
<td>0.63</td>
<td>0.63</td>
</tr>
<tr>
<td>Central Highlands (CH)</td>
<td>0.53</td>
<td>0.50</td>
</tr>
<tr>
<td>East Deccan (ED)</td>
<td>2.90</td>
<td>2.66</td>
</tr>
<tr>
<td>North Deccan (ND)</td>
<td>1.49</td>
<td>1.45</td>
</tr>
<tr>
<td>South Deccan (SD)</td>
<td>0.67</td>
<td>0.73</td>
</tr>
<tr>
<td>West Coast (WC)</td>
<td>0.87</td>
<td>0.87</td>
</tr>
<tr>
<td>Western Ghats (WG)</td>
<td>1.12</td>
<td>1.16</td>
</tr>
<tr>
<td>East Coast (EC)</td>
<td>0.75</td>
<td>0.79</td>
</tr>
</tbody>
</table>

Table 2. Overall forest cover distribution based on JAXA global FNF datasets

North Deccan, South Deccan and Central Highland have observed a minimal loss of forest in the last ten years due to conservation practices in the forest of above-said region unlike reason might be for deforestation due to population pressure and demand for timber etc. There is a high possibility to increase or consistent reliability in forest coverage in these zones of central India in case of successful implementation of effective conservation practices in the unprotected forests and protected forest (Krishnadas et al., 2018).

Although there are regions, where forest cover has been increased due to adoption of afforestation measures and implementation of proper land use management, which is primarily evident in Eastern Ghats (5004.64 Km², 2.63%) increase in forest area) followed by Western Ghats (1.92%, 1392.54 Km²), East Coast (0.74%), South Deccan (0.67%), Northern Plains (0.63%), Eastern Plains (0.10%) and Deserts (0.03%). These increase of forest may be attributed to plantation and conservation practices both within and outside the Recorded Forest areas.
The results of JAXA Global Forest-Non-Forest was compared with the (FSI) State of Forest Reports. The comparative reported an increase of ~17384 Km$^2$ of forest cover during 2007-17 (FSI, 2007;2017, Figure 4). On the contrary, JAXA Global FNF exhibited a decrease in forest area ~33291.6 Km$^2$ during the said period. The variation in the records/observation in forest cover may be attributed to differences in forest classification techniques, survey methods, minimum mappable unit and use of different satellite datasets as adopted by JAXA and FSI.

![Figure 2. Graph showing changes in forest cover in different biogeographic zones in India](image1)

![Figure 3. (a) Forest cover change map (b) Forest cover map of year 2007 (c) Forest cover map of year 2017. Comparison of forest cover between year 2007 and 2017 in (d) North-East India (e) North India (f) West Coast (g) Central India (h) East India and East coast.](image2)
Due to the limitations in scale, satellite resolution and mapping unit, it is not possible to discriminate natural forests by FSI as stated in SFR 2007. Also, it does not recognize the type of land ownership or land use and legal status of the land. Thus, all species of trees (including bamboo, fruits, coconut, etc.) and all types of land (forest, private, or community) are wrongly included in the forest. On the contrary, JAXA global FNF accounts mainly for the natural forest as it considered area of forest (as some part it also includes the land area behind natural forest) without agricultural, urban or land. One of the major advantages of JAXA global FNF is that it based on microwave SAR images, which are independent to seasonal and day-night limitations, which is classified based on backscatter threshold for forests of different climatic zones, with limited overestimate or underestimate. JAXA claims for 84% accuracy of global FNF datasets. As per FSI, it uses one-time optical datasets for entire India, which may have some limitations in terms of radiometric and atmospheric attenuation (viz., cloud cover, variation in scene contrasts, coarser grids size of temperature and rainfall).

The seasonal patterns of mean LAI indicated the maximum greenness pertaining to high LAI (5-7) was observed in autumn (September and October) and spring (March, April) due to rich vegetation growth after the monsoon. Evergreen forests of Western Ghats are multi-layered and complex in their architectural characteristics. These trees shed their leaves at a slow and steady rate throughout the year, which results in continuous decay and decomposition on the forest floor. The Eastern Ghats of India is a broken chain of hills that extends from Orissa to Tamil Nadu and dominated by deciduous forest (Reddy et al. 2014), and a similar pattern of mean is observed as SON have higher LAI values. Forest shed their leaves due to water availability in the dry season, i.e., during pre-monsoon season and result in a decline of LAI. Besides Ghats and Himalayan region mainly in agricultural dominated areas value of LAI changes with season to season due to change in agricultural patterns. The DJF and MAM season is a cropping season as seed sowing happens starts in December and harvesting starts between the last week of March to April. So, overall LAI value is higher in DJF as compared to the MAM due to growth of Rabi crop in DJF months and its whereas harvesting initiation during from mid-march harvesting starts that leadings to decrease of mean LAI value. Due to tropical hot and humid climate, entire Andaman & Nicobar Islands support very luxuriant and rich vegetation with unique tropical rain/evergreen forest canopy. The climate of Andaman and Nicobar Islands is highly favourable for the evergreen forest and mean LAI above two...
throughout the year. The trend of Agricultural dominated area was observed higher in DJF than that of MAM and it also coincides with LAI mean value. The overall decreasing trend and mean LAI value in JJA seasons is related with the sowing of Kharif crop in the last week of July, and its maturity in September. In Ghats and Himalayan range of India all four seasons exhibited positive trend and highest trend value observed in SON season followed by DJF and JJA. Least value of LAI trend was observed in the MAM season, and this may be attributed to the summer season. The minor contribution of lower trend of LAI may be attributed to cloudy pixel during monsoon season (JJA). Therefore, the overall trend of LAI exhibit that greenness is increasing due to mainly in agriculture dominated season and natural vegetation are also contributing to LAI increasing trend except for JJA seasonality, and other studies by Chen et al., (2019) also suggested that in India cropland alone contribute 82% of increase in leaf area and 4% of growth in forest which shows that there is little contribution of greenness. Thus, the above result shows that human land use is a dominant driver of greenness in India (Chen et al., 2019; Zhu et al., 2016), as cropland greening contributes the highest greening trend in 3 seasons with a minor contribution of forest in the Himalayas and Ghats area. The green revolution like hybrid mechanisation, crop insurance programme, multiple cropping irrigation, fertilization, hybrid seeds etc. have a significant role in the contribution of the increasing trend of greenness.

Indian satellite which is carrying optical sensors are capable for monitoring the forest cover in India, but it is restricted for the data having a cloud cover and can leads to misclassifications. Whereas, Indian satellite having SAR sensors (RISAT -1) are also capable for monitoring forest cover, but it does not cover whole India, and some of scenes are missing which cannot a real-time quality mapping of Indian forest. Indian upcoming satellite like NASA-ISRO Synthetic Aperture Radar (SAR) or NISAR having L (Foliage penetration) and S (Sensitivity to light vegetation) band which is primarily suitable for vegetation studies and can give a revolution in more accurate forest cover mapping and near real time forest watch as it has twelve days repeat pass with 3 – 10 meters’ mode-dependent SAR resolution which is primarily higher resolution then present Indian RISAT (C-Band) satellite.

5. CONCLUSION

India has an immense variety of forests ranging from tropical evergreen to dry deciduous forest and dominantly agriculture land. Forest Cover change has been analysed using JAXA global FNF datasets with 25 m spatial resolution between 2007 and 2017 and found that there is a huge decrease in a forest cover in India which is around 33291.59 Km². The major contribution is from the Eastern Himalayan zone (North-East part of India), and it is always a great issue for the continuous increase of Forest in EH. There is also a major contribution of Increase in forests of the Eastern Ghats and the Western Ghats to the nation and may be attributed to conservation practices. When overall forest cover area changes calculated form FSI report of 2007 and 2017, it shows that in India whole forest cover have increased, which is contradictory to global FNF datasets. Since both have different techniques to classify forest that leads to conflicting results. JAXA based global FNF data majorly accounts for natural vegetation. Thus, based on FNF data it can be concluded that Natural forest is decreasing. LAI, being a measure of canopy foliage content is key vegetation characteristic among the different forest types. The study investigated the spatiotemporal and inter-seasonal variations in LAI. Seasonal mean and trend analysis of LAI exhibited that trend of greenness is increasing as a major contribution of greenness from agriculture land and little contribution from the forest. Based on Seasonal trend, JJA has only negative/decreasing trends and rest all the season have positive/increasing trends. This study can tell us that Natural forest is decreasing and it has a significant loss of ecological significance, but greenness is increasing in India due to human use of lands for agriculture and attributes to human land use management in the greening of India. Primary importance towards forest conservation practices should be implemented strictly in the Eastern Himalayas region as it shows colossal loss of forests.

Limitations towards global FNF studies is that it assumes a constant backscatter value (-15 dB) to classify forest and non-forest in Indian regions (Shimada et al., 2014), but taking a constant backscatter value for monitoring diverse forest (covering tropical deciduous forest to tropical evergreen forest) of India which primarily forest type changes with change in latitude and climatic parameters. For different regions different backscatter value should be considered for FNF classification. Another limitation is that it classifies as per FAO parameterization which does not include a forest in TOF (Tree Outside Forest) which is good to map a natural forest and can employ for mapping an ecological significance any way’s in today’s generations forest regeneration or afforestation is primarily aimed for carbon sequestration (either in TOF or forest area) and mapping those forest is also required to have a regional watch for forest cover and their proper planning for future forest regenerations.

ACKNOWLEDGEMENT

We are thankful to anonymous reviewers for their careful reading of our manuscript and their insightful comments and suggestions. The first author is thankful to the Indian Institute of Science Education and Research Bhopal for proving an opportunity to do M. Tech Dissertation work. Authors like to acknowledge the Department of Science and Technology, Govt. of India grant number DST/CCP/NCM/69/2017. JAXA (Japan Aerospace Exploration Agency) for the free datasets of PALSAR/PALSAR-2 mosaic forest/non-forest (FNF), FSI for forest cover report and USGS for providing MOD15A2H datasets.

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ESTIMATING ABOVE GROUND BIOMASS OF *PINUS ROXBURGHII* USING SLOPE BASED VEGETATION INDEX MODEL

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KEY WORDS: Above Ground Biomass, Vegetation Index, NDVI, RATIO, TVI, CTVI, TTVI, *Pinus roxburghii*

ABSTRACT:

*Pinus roxburghii* is one of the important and most widely planted tree species in Nepal. Despite its large abundance and high economic values, limited studies on its AGB have been conducted in Nepal, especially using in situ non-destructive method. There are different methods to study the AGB. Regression equation based on the correlation between VI and AGB is cost effective method, and replicable in another sites of similar environment by just acquiring satellite images. Numerous methods have been developed to calculate VIs and each calculated VI shows different relation with AGB in different environments for same species. Therefore, there is a need to identify a most appropriate VI that has the highest correlation with AGB of *P. roxburghii*. The current study was carried out in Hattiban and Dollu community forests of Kathmandu district, using ResourceSat-2 imagery. In this study, Slope based VIs were used. Regression analysis between slope based VIs and AGB showed that relation between all VIs and AGB were significant. However, NDVI had the highest relation with AGB compared to others. Therefore, it was concluded that NDVI was the most appropriate VI to estimate AGB of *P. roxburghii*, and the regression equation with NDVI was used to estimate the AGB of *P. roxburghii* in the study area.

1. INTRODUCTION

Biomass is defined as the mass of living or dead organisms in a given area at a given time. It comprises of above ground biomass (AGB) and below ground biomass, but AGB is generally used to estimate the biomass because it accounts for the greatest fraction of total living biomass. AGB is defined as “the total amount of above ground living organic matter in trees expressed as oven-dry tons per unit area (tree, hectare, region, or country)” (FAO, 1997). There are different methods to study the AGB. The traditional destructive measurement method is expensive, time consuming, laborious and destroys forest (FAO, 2012). Ground based inventory using allometric equation is accurate, but it requires a large number of sample plots and also cannot measure the spatial distribution of AGB in large area (Anderson, 2007; Lu et al., 2004; Soenen et al., 2010). Hence, it is time consuming, labour intensive and costly. Integrating remote sensing data along with forest resource inventory (field data) is a cost effective method and provides a geo-statistical basis for estimating AGB of large area i.e. AGB of large area can be estimated by linking information derived from remotely sensed data to AGB values measured on the ground (Anderson, 2007; Zhu & Liu, 2014; Brewer et al., 2012).

Remotely sensed data comprises information of different spectral bands. Combination of red and near infrared (NIR) spectral bands produce vegetation indices (VIs), which have relationship with AGB (Brewer et al., 2011; Bajracharya, 2008; Lu et al., 2004) and are commonly used to estimate AGB using a regression equation (Dong et al., 2003; Lu et al., 2004; Zheng et al., 2004; Tucker et al., 1985, Bajracharya, 2008). Spectral radiances from red and NIR bands have distinct interaction with plants. The energy from red band is strongly absorbed by the plant pigments for photosynthesis, while energy from NIR band is strongly scattered by the internal structure of the leaves. This strong contrast between the amount of reflected energy in red and NIR bands helps to develop vegetation indices (VIs). Using this, different types of VIs have been developed (Eastman, 1999).

Although, VIs have relationship with AGB, the strength of the relation depends upon several factors such as background surface condition, amount of standing green biomass, atmospheric condition and local environment (Anderson & Hanson, 1992). As a result, different studies have reported different results. Sader et al. (1989) did not find NDVI as a reliable VI to estimate AGB. Sader et al. (1989) did not find difference in biomass in young tropical forest using NDVI and concluded that NDVI was not suitable for estimating AGB in uneven and mixed broadleaved forest. Similar result was reported by Hall et al. (1995). On the other hand, Anderson et al (1993) found a strong relation between NDVI and AGB in semi arid rangelands. Likewise, Mundava et al. (2014) found that VIs have strong relation with AGB in open plain land that refers to areas with periodic flooding with mostly annual grasses, while relation did not exist in Spinifex grass dominated areas. Lu et al. (2004) found a positive relation between AGB and VI (principal component, component1) in Pedras of Brazil, but in Altamira and Bragantina, they found a negative relation. This variation was accounted for difference in biophysical environment of study area as the relationship depends upon plant species and their local environment (Mundava et al., 2014; Lu et al., 2004). Since the relation between VIs and AGB for a particular species differs from one
VI to another, and from one place to another (different environment), one species shows higher relation on one VI, while other on another, depending upon the local environment. Hence, a need of identifying the best VI to quantify the AGB for a particular species at a particular site is highly felt. As such, the present study has focused to identify the most appropriate VI to estimate the AGB of *Pinus roxburghii*, a widely planted tree species with economic value.

In this study, Slope based VI has been used as it is used to study the status and abundance of vegetation cover and AGB (Eastman, 1999). The current study was carried out in Hattiban and Dollu community forests of Kathmandu district, using ResourceSat-2 imagery.

2. STUDY AREA AND MATERIALS

2.1 Study Area

The study area is located at Hattiban and Dollu community forests in Dakshinkali Municipality of Kathmandu district. It is about 18 km south of Kathmandu city. It covers an area of 3.69 km² (369 hectares), and extends between latitude of 27°36′43.142″ and 27°38′37.309″ North and longitude of 85°14′54.041″ and 85°17′13.3358″ East. The elevation of the study area ranges from 1505 m to 2037 m. The study area falls in subtropical bio-climatic zones, with maximum temperature of about 35.6°C in April and minimum of up to −3°C in January. The annual average humidity is 75% and the average rainfall is 1400 mm per annum. Most of the rainfall occurs in the months of June to August. The study area consists of different plant species that are not native to the area, and were planted during afforestation program. The southern aspect of the study area is dominated by *P. roxburghii*, while the northern aspect is mixed with broad leaved and *P. roxburghii*. *Schima wallichi*, *Castanopsis indica*, *Rhododendron spp.* are some of the plant species present in the area (DFO, 2014).

2.2 Data Description

Satellite imagery of 5 m resolution (ResourceSat-2, Scene ID: RS2-LISS4-24-Jan-2015-104-52, acquired on January 24, 2015) was obtained from India Space Research Organization. ResourceSat-2 is a “data continuity mission of ISRO (Indian Space Research Organization) with improved spectral bands of the IRSP6/ResourceSat-1” (ESA, 2016). Digital elevation model (DEM) of 1 arc-second (30 m resolution) (ID: SRTM1N27E085V3), of Shuttle Radar Topography Mission (SRTM) was used for orthorectification.

3. METHODOLOGY

3.1 Sampling

Based on equation proposed by Husch et al. (2003), a minimum of 34 sample plots was required at 95% Confidence interval (CI). Quadrant size of 10 * 10 m² as proposed by Oosting (1942) was used for the sampling. Taking sample plots greater than 10 * 10 m² was not possible in the study area as there were steep slopes. Within the sample plot, diameter at breast height (DBH) and height of *P. roxburghii* were taken because AGB calculation requires the data of DBH and height of the tree. Sample plots were laid only in areas where *P. roxburghii* is homogenously present.
3.2 Data Analysis

The data collected in the field were analyzed to calculate AGB of *P. roxburghii*. AGB was calculated from the volumetric and structural dimension of the trees. DBH and height are the major parameters for measuring AGB (Pokhrel, 2015). AGB of *P. roxburghii* of sample plots was calculated using equation proposed by DFRS (2014).

\[
\text{AGB} = \text{Stem biomass} + \text{Branch biomass} + \text{Foliage biomass}
\]

(1)

\[
\text{Stem biomass} = \text{Volume} \times \text{Density}
\]

(2)

\[
\ln(V) = a + b \ln(D) + c \ln(H)
\]

(3)

where \(\ln(V)\) = Natural logarithm to the base 2.71828, \(V\) = Stem volume, \(D = \text{DBH}\), \(H = \text{Tree height}\), \(a, b\) and \(c\) are coefficients (Sharma & Pukkala, 1990; DFRS, 2014).

Branch and foliage biomass were calculated using branch to stem biomass ratio and foliage to stem biomass ratio as proposed by MoFSC (1988).

3.3 Image Processing

3.3.1 Image Orthorectification

Ortho-rectification is the process of removing distortion due to terrain relief and off vertical imaging geometry. It creates an ortho-image that has features positioned as they would be in planimetric map. ResourceSat-2 image was ortho-rectified using Rational polynomial coefficient (RPC) supplied by image vendor, ground control points and DEM.

3.3.2 Atmospheric Correction

Atmospheric correction was done using COST model developed by Chavez (1996). The model uses cosine of sun zenith as an acceptable parameter for approximating the effects of absorption by atmospheric gases and Rayleigh scattering. The radiance is then converted to surface reflectance by correcting solar (includes corrections for sun elevation angle, amount of solar irradiance for the individual spectral bands and earth sun distance) and atmospheric effects.

Figure 9. Location of Dallu and Hattiban Community Forest.
3. 3.3 Vegetation Indices (VIs)

VIs are the combination of different spectral bands, usually red and NIR, of satellite data that produce a single image representing the amount of vegetation present. Low index value represents little healthy vegetation, while high value represents higher healthy vegetation. VIs are used to estimate AGB, monitor environmental changes and land degradation (Kogan, 1990; Kogan & Liu, 1996; Tripathy et al. 1996). In this study slope-based VI was used as it is applied to study the status and abundance of vegetation cover and AGB. Slope based VI is the simple linear combination that uses the reflectance of red and NIR spectral bands and focuses on the contrast between the spectral response pattern in the red and NIR portion of electromagnetic spectrum. The term “Slope based was coined because any value of the index can be produced by a set of red and NIR reflectance values that form a line emanating from the origin of a bi-spectral plot” (Eastman, 1999). Following are the slope based VIs used in the study.

3. 3.3.1 Ratio Vegetation Index

Ratio Vegetation Index (RATIO) was proposed by Rouse et al. (1974) to separate green vegetation from soil background. It is the ratio of NIR and Red bands (Equation 4).

\[ \text{RATIO} = \frac{\text{NIR}}{\text{Red}} \]  

(4)

The result clearly captures the contrast between the red and NIR bands vegetation pixel, with higher index values being produced by combination of low red (because of absorption by chlorophyll) and high NIR (as a result of leaf structure) reflectance. The index is susceptible to division by zero.

3. 3.3.2 Normalized Difference Vegetation Index

Normalized Difference Vegetation Index (NDVI) was proposed by Rouse et al. (1974) to produce a VI that differentiates green vegetation from soil. It is the difference between NIR and red bands normalized by the sum of those bands (Equation 5).

\[ \text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}} \]  

(5)

3. 3.3.3 Transformed Vegetation Index

Transformed Vegetation Index (TVI), proposed by Deering et al. (1975), modifies NDVI by adding a constant of 0.50 to all its values and taking the square root of the results. The constant is used to remove the negative NDVI values, while the square root is used to transform NDVI histogram into a normal distribution (Equation 6).

\[ \text{TVI} = \sqrt{\text{NDVI} + 0.5} \]  

(6)

3. 3.3.4 Corrected Transformed Vegetation Index

Corrected Transformed Vegetation Index (CTVI) was proposed by Perry & Lautenschlager (1984), which aims to correct the TVI. Adding a constant 0.50 to NDVI does not always remove negative values, therefore to remove the negative values, the (NDVI + 0.5) is divided by its absolute value ABS(NDVI + 0.5) and the result is multiplied by the square root of the absolute value (Equation 7).

\[ \text{CTVI} = \frac{(\text{NDVI} + 0.5)}{|\text{NDVI} + 0.5|}\sqrt{|\text{NDVI} + 0.5|} \]  

(7)

3. 3.3.5 Thiam’s Transformed Vegetation Index

Thiam’s (1997) found that resulting image from CTVI can be noisy due to over estimation of greeness, therefore he suggested using Thiam’s Transformed Vegetation Index (TTVI) that ignores first term of CTVI equation and uses ABS(NDVI + 0.5) (Equation 8).

\[ \text{TTVI} = \sqrt{|\text{NDVI} + 0.5|} \]  

(8)

3. 3.4 Image Classification

Object based classification was used to classify image. It involves segmenting an image into objects, and uses both spectral and spatial pattern for classification. Apart from imageries, image derivatives like PCA, VI, ancillary data like DEM were also used for classification in object based classification. Multi-resolution segmentation and CART Classifier algorithm were used for classifying the image. Land Use Land Cover classes—Agriculture, Barren land, Built up, Forest and Water bodies—were present in the area. However, the current study focused on P. roxburghii only, therefore, Forest class was subdivided into P. roxburghii and Broad leaved classes, and all other remaining classes were grouped into other class. The accuracy of the classified land use land cover was 87.18 %.

3. 4 Statistical Analysis

Correlation between VIs and AGB of P. roxburghii was calculated to show the relation between the two variables. Two variables are said to be correlated if change in one variable affects the other variable. If increase in one variable increases the other variable, then these variables are considered to have positive correlation. In contrast to this, if increase in one variable decreases the other variable or vice versa, then variables are considered to have negative correlation. The degree of relationship is represented by correlation coefficient (r) (Shrestha, 1996).

Regression analysis is used to show the relationship between dependent and independent variables, as well as predict or estimate the value of one variable (dependent) based on the value of another variable (independent) (Shrestha, 1996). Multiple R square explains the extent of variability in the dependent variable explained by all independent variable. It assumes all independent
variable affects the dependent variable. On the other hand, the adjusted R square explains the variation explained by independent variables that only affect the dependent variable. For a successful relation, the adjusted R square should be at least 0.5 (Mundava et al., 2014). Regression equation (model) was developed and used to predict the AGB (dependent variable) of the study area covered by *P. roxburghii* based on the independent variable, VIs.

### 4. RESULTS AND DISCUSSION

#### 4.1 Landuse Land Cover

Land Use Land Cover (LULC) of the study area showed that *P. roxburghii* occupied an area of 2.12 km² (57.45% of total area), broadleaved species occupied 0.63 km² (17.07% of total area) and other class occupied 0.94 km² (25.47% of total area). The accuracy of the classified land use land cover showed that the overall accuracy of the land use land cover was 87.18 %, with Kappa index of 0.7613.

#### 4.2 Statistics of Field Data

Analysis of field data showed that diameter at breast height (DBH) of *P. roxburghii* ranged from 11 cm to 65 cm, with mean DBH of 30.44 cm. The height of *P. roxburghii* ranged from 10 m to 33 m, with mean height of 22.68 m, while the volume of *P. roxburghii* ranged from 0.05 m³ to 5.21 m³, with mean volume of 0.9849 m³. AGB in the sample plots ranged from 2.284.02 to 13.259.91 kg per plot. The average AGB of the sample plots was 6,482 kg per plot.

#### 4.3 Correlation Analysis

Correlation analysis between slope based VIs and AGB showed significant correlation with correlation coefficient (r) above 0.7. The correlation coefficient in all of the VIs were almost same having relatively higher correlation (r =0.734) in NDVI.

<table>
<thead>
<tr>
<th>Slope based VIs</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>RATIO and AGB</td>
<td>0.731</td>
</tr>
<tr>
<td>NDVI and AGB</td>
<td>0.734</td>
</tr>
<tr>
<td>TVI and AGB</td>
<td>0.733</td>
</tr>
</tbody>
</table>

### 4.4 Regression Analysis

Regression analysis between slope based VIs and AGB (Table 2) showed that multiple R-square (r²) values were almost similar and ranged from 0.5348 to 0.5388. Similarly, Adjusted R square (adjusted r²) values ranged from 0.5207 to 0.5248. Mundava et al. (2014) noted that the adjusted r² value should be at least 0.5 for the regression equation to be significant and to predict the dependent variable. Hence, the adjusted r² value (0.5207 to 0.5248) showed that the relation between all VIs and AGB were significant.

However, NDVI was relatively more significant (r = 0.734, r² = 0.5388 and adjusted r² = 0.5248) for *P. roxburghii* in the study area. Similar results were also obtained by different researchers. Jin et al. (2014) found a significant relation (r² =0.60) between NDVI and AGB in grassland of Northern China. Zhu & Liu (2014) found a strong relation (r² =0.63) between NDVI and AGB in the senescing period, when vegetation attains maximum leaves and greenness, compared to other seasons. Edirisinghhee et al. (2011) also found a significant relation between NDVI and AGB in pasture land. Liu et al. (2006) compared the relation between different VIs and biomass in Oasis ecosystem, and found that NDVI had higher relation (r = 0.862, r² =0.743) with biomass. Dong et al. (2003) also concluded that NDVI and biomass has a statistically significant relation and the regression model can be used to estimate the biomass across spatial, temporal and ecological scales for relatively long time scales.

On the other hand, Heiskanen (2006) found Ratio (r = 0.90) to have better relation that NDVI (r =0.81) with AGB in mountain birch forest. Lu et al. (2004) also found similar results in Bragatina, where Ratio (r = 0.530) showed higher relation with AGB, compared to NDVI (0.459). Das & Singh (2012) studied the relation between VI and AGB in forests of Maharashtra, and also found Ratio to have higher relation (r² =0.785) compared to NDVI (r² =0.75). Anderson & Hanson (1992) studied the relation between VIs (Ratio and NDVI) and AGB in different months for two consecutive years and found that the Ratio had better relation with AGB than NDVI. In the month of July,

<table>
<thead>
<tr>
<th>Regression equation and Statistics</th>
<th>Slope based vegetation Indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equation</td>
<td>Ratio VI</td>
</tr>
<tr>
<td>Equation</td>
<td>AGB = -5251 + 3091 * Ratio</td>
</tr>
<tr>
<td>Multiple R-squared</td>
<td>0.5348</td>
</tr>
<tr>
<td>Adjusted R-squared</td>
<td>0.5207</td>
</tr>
<tr>
<td>F-Statistics on 1 and 33</td>
<td>37.93</td>
</tr>
<tr>
<td>P-value</td>
<td>0.000000604</td>
</tr>
</tbody>
</table>

Table 6. Statistical summary of regression analysis between slope based VIs and AGB
Figure 3. Regression analysis between slope based VIs and AGB—(a) between Ratio and AGB, (b) between NDVI and AGB, (c) between CTVI and AGB, (d) between TTVI and AGB, (e) between TVI and AGB
Figure 4. Slope Based Vegetation Index Models—(a) Ratio, (b) NDVI, (c) CTVI, (d) TTVI and (e) TVI
Ratio had the highest relation with AGB \( (r^2 = 0.44) \), while the relation was insignificant in the month of October. NDVI also had similar results. NDVI had the highest relation with AGB \( (r^2 = 0.36) \) in the month of June, while the relation was insignificant in the month of October. In July, \( r^2 \) for NDVI was 0.29. Mundava et al. (2014) compared the relation between NDVI and SAVI with AGB in different sites of Brazil, and found that in open plains, NDVI and SAVI showed same relation with AGB \( (r^2 = 0.6) \). Similar result was found by them in bunchgrass also. But in Spinifex dominated areas, SAVI showed no relation with AGB \( (r^2 = 0) \), while NDVI had very low relation with AGB \( (r^2 = 0.1) \).

The variation in relation between VIs and AGB could be attributed to the variation in biophysical environments of the study area because the strength of the relation between VIs and AGB depends on various factors, including plant species and their environment (Anderson & Hanson, 1992; Mundava et al., 2014 and Lu et al., 2004). As such, one species shows higher relation on one VI, while other on another, depending upon the local environment.

**4. 5 Estimating AGB**

Since NDVI had the highest relation \( (r = 0.734, r^2 = 0.5388 \) and adjusted \( r^2 = 0.5248) \) with AGB compared to other VIs, NDVI based regression equation was used to estimate the overall AGB of *P. roxburghii* in the study area. Based on the above regression equation, the total AGB of *P. roxburghii* in the study area was estimated to be 133,577,495.44 kg. The estimated AGB was cross validated with observed AGB from field using RMSE equation. The calculation resulted a RMSE of 41.49%.

**Figure 5. Relation between Observed and Predicted AGB**

**5. CONCLUSION AND RECOMMENDATION**

Statistical analysis showed NDVI had the highest relation with AGB \( (r = 0.734, \text{ multiple } r^2 = 0.5388, \text{ adjusted } r^2 = 0.5248) \). Therefore, it was concluded that NDVI was the most appropriate VI to estimate AGB of *P. roxburghii*, and the regression equation with NDVI was used to estimate the AGB of *P. roxburghii* in the study area. Based on the regression equation, it was found that the AGB of *P. roxburghii* in the study area was 133,577,495.44 kg. Cross validation of the estimated AGB with observed AGB from field showed RMSE of 41.49%.

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ESTIMATION OF FOREST COVERAGE IN NORTHERN REGION OF MONGOLIA USING SENTINEL AND LANDSAT DATA

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KEY WORDS: Remote Sensing, Forest Index, Forest Cover, Sentinel, Management

ABSTRACT:
This paper aims to apply Forest Index (FI) and to determine forest coverage in the study area. The study area (49°15’ to 49°10’ N and 104°05’ to 104°15’ E) is located in the northern region of Mongolia and consist of mixed forest. Larch forest (86.12%) is dominating in the study area. The Sentinel-2 satellite data for the years 2015-2019 were used in the research. The land surface temperature (LST) was produced from Landsat-8 OLI. FI methodology was applied for the Sentinel data in order to estimate larch forest coverage. The output map of forest coverage was compared with ground truth measurements and thematic map. The agreement between FI map and ground measurement was 85%. LST from Landsat and FI from Sentinel were sampled in to same size. The relationship between LST (Landsat-8) and FI (Sentinel-2) was reasonable (R=0.5). FI index and LST is applicable for different forest type in the region.

1. INTRODUCTION

1.1 Background

Forested areas, planted forests, bush and shrub stands, harvesting areas, the forested areas damaged by forest and steppe fire, pest insects and diseases, glades and the area extending to 100 meters beyond the outer edge of the forest, as well as seedlings and nursery areas to the land of forest fund (Government of Mongolia, 2012). Forest area belong to boreal zone in Mongolia. The northern boreal forests are part of the transitional zone between the Siberian taiga forest to the north and the grasslands to the south. These forests are mainly coniferous, mixed with some broadleaf trees (UN-REDD, 2017). Mixed forest is the basis for conducting research on various species of trees and bushes.

The regional or global scale, remote sensing techniques always offer an effective way for forest measurement and monitoring. Remote Sensing can be used to measure and monitor develop environmental policies and plans of the research areas (Enkhjargal et al., 2014). Nowadays many researches for forest cover mapping, forest type, forest degradation, fire of forest, inspected area uses active and passive remote sensing (Mitchell et al., 2017). In Mongolia, most research focused on using forest inventory statistics to estimate total forest area to further explore remote sensing or sources lacking image-based spatial information (Norovsuren et al., 2019) and small scale uncertainties still existed in some related researches. The main goal of this study was to map the change of forest area using satellite image data and the ground truth data.

The forest index (FI) is derived from three green, red and near-infrared (NIR) bands and an FI image can be classified into forest and non-forest map with a threshold (Ye, Li, Chen, & Zhang, 2014). Scatter plot of the spectral space NDVI is similar to that of the spectral space between LST and NDVI, by in-deep analysis (Yao, Qin, Zhu, & Yang, 2008). In comparison with the latest Landsat OLI/TIRS, Sentinel-2 has a better spatial resolution, better spectral resolution in the near infrared region, but does not offer thermal data (Kaplan & Avdan, 2017). The LST was produced from Landsat-8 OLI to better define forest coverage. Landsat-derived LST is also used for monitoring the forested areas, such as the correlation of LST with tree loss or the detection of changes in forest cover (Parastatidis et al., 2017; Rogan et al., 2013) (Parastatidis et al., 2017). It is possible to define the FI threshold by extracting the LST change. To extract forest cover from remotely sensed imagery, various methods have been proposed during the past decades. Some of these methods are based on supervised classification techniques to generate forest/non-forest classification aps, such as maximum likelihood (Bayarsaikhan et al., 2009), object-based classification and spectral index (Weih & Riggan, 2010). These VI are effective to distinguish vegetation from other non-vegetation land covers (e.g. water and impervious
surfaces), but difficult to distinguish forest from non-forest vegetation (Ye et al., 2014).

While remote sensing technology must help in providing information to satisfy the needs that forest managers have, remote sensing must be a cost-effective and easily understandable technology (Altangerel & Udval, 2019). This research aims to apply FI and LST in order to improve forest estimation map. A combination between the forest taxation inventory, LST and the forest index were used in the research.

1.2 Study area

The study area is Bulgan province is situated in the northern part of Mongolia borders with Russian Federation. Bulgan province is located in the taiga zone, forest steppe zone and steppe zone. Majestic high mountains of Bulgan, Buregkhangai and Dulaamkhan dominate in the northern part of the province. The north of the province is characterized by alpine forests, gradually blending in the arid steppe plains of the central Mongolian highland (Figure 1).

![Figure 1. Location map (b) The distribution of natural zones in Mongolia and (c) Khandagait soum in Bulgan province (c) the study area with the red color](image)

According to the Holdridge life zones system of bioclimatic classification Bulgan is situated in the boreal dry scrub biome (larch, birch and shrub) where larch is 86.12% and birch is 13.88%. According to our survey, the forest in Khandagait valleys covers an area of 11540 hectares and its elevation is between 1260m and 1570m (Norovsuren et al., 2019). This area has a subarctic climate where the annual average temperature is -1.3 degrees Celsius (29.7 degrees Fahrenheit) and total annual precipitation averages is 278.4 mm.

2. DATASETS

We used datasets; field data, FI data and Satellite Remote Sensing data in this research.

2.1 Field Data

The surveyed plots are located in areas where major disturbances, such as forest fire and clear cutting. The sampled stands differ for main type, leaf presence and type of field plots (size, shape, and number) (Laar, 2007). All ground data were collected during 2016-2019. In each plot, the following attributes were measured: diameter at breast (DBH) of living and dead stems (diametric number), leaf presence, and type of field plots (size, shape, and number) such as forest fire and clear cutting. The sampled stands were collected during 2016-2019.

### Table 1. Field measure data (2016-2019)

<table>
<thead>
<tr>
<th>Id</th>
<th>900x2 trees</th>
<th>High (m)</th>
<th>Diameter (cm)</th>
<th>Coronary diameter</th>
<th>Tree spacing</th>
<th>Type of tree</th>
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<td>3</td>
<td>Larix</td>
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<tr>
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<td>9</td>
<td>2.1</td>
<td>1.2</td>
<td>Larix</td>
</tr>
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<td>33</td>
<td>4</td>
<td>8</td>
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<td>16</td>
<td>2.9</td>
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<td>Larix</td>
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<td>4</td>
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<td>Larix</td>
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<tr>
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<td>Larix</td>
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<tr>
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<td>Larix</td>
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<td>9.2</td>
<td>2.3</td>
<td>3.6</td>
<td>Birch</td>
</tr>
</tbody>
</table>

Table 1. Field measure data (2016-2019)

2.2 Forest Inventory Data

The systematical national forest inventory (NFI) has been conducted nearly every ten years since the late 1950 and the last national forest inventory was conducted for the period 2013 (FDRE, 2018). The statistics of the national forest inventory in
Mongolia are based on large numbers of field plots and are the most important data sources for research on forest.

2.3 Satellite Remote Sensing Data

The multispectral bands visible Green (560 nm), Red (665 nm), and Near-Infrared (NIR) (842 nm) over years 2015-2019 were used in this research (Table 2). The satellite images were downloaded based on survey time, geographical extent and environmental conditions. Landsat 8 Operational Land Imager (OLI) image (September 2018, path 133, row 26) was downloaded from the USGS earth resource observation and science center (EROS) (http://glovis.usgs.gov/).

<table>
<thead>
<tr>
<th>Multispectral band (s)</th>
<th>Wavelength (µm)</th>
<th>Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sentinel-2</td>
<td>Band 3</td>
<td>0.537–0.582</td>
</tr>
<tr>
<td></td>
<td>Band 4</td>
<td>0.646–0.685</td>
</tr>
<tr>
<td></td>
<td>Band 8</td>
<td>0.767–0.908</td>
</tr>
<tr>
<td>Landsat-8</td>
<td>Band 10</td>
<td>10.60–11.19</td>
</tr>
<tr>
<td></td>
<td>Band 11</td>
<td>11.50–12.51</td>
</tr>
</tbody>
</table>

Table 2. Sentinel-2 and Landsat-8 NIR, TIRs bands: wavelengths, and time period covered.

3. METHODOLOGY

We used Remote sensing methodology for the middle-resolution satellite data. Assessment processed with the layer of the data such as Forest taxation data of the FRDC, Google Earth Pro and Bing map used SNAP and GIS software’s. We used forest index for the Sentinel satellite data when we define forest cover area of study map used SNAP and GIS software’s. We used forest index for the forest vegetation area. The reason of that we picked up Forest Index for our research. To make the process of forest cover mapping simple and rapid, a simple spectral index called forest index (FI) was proposed to highlight the forest land cover by a threshold in Landsat scenes. (Ye et al., 2014)

\[
FI = \frac{\rho_{NIR} - \rho_{red} - L}{\rho_{NIR} + \rho_{red}} \left( \frac{C_1 - \rho_{NIR}}{C_2 + \rho_{green}} \right)
\]

where \( L = 0.01 \), \( C_1 = 1 \), \( C_2 = 0.1 \)

The parameter L is a very small value and the introduction of which can effectively lower the NDVI of water while has little impact on the NDVI of vegetation. C1 and C2 are empirical parameters used to scale the function. Thus, the range of the FI is from minus infinity to 7. FI gives a positive value on forested area and vice versa negative value on the non-forested area.

Single channel (SC) is a commonly-used approach to estimate LST from the Landsat thermal infrared observations (Ndossi & Avdan, 2016). Among Landsat 5, 7 and 8, only Landsat 8 carries two thermal bands (Parastatidis et al., 2017), therefore the SC approach is used in this study for consistency. The LST was calculated using Equation (3) by (Natsagdorj et al., 2019).

\[
LST = \left( BT + w \cdot \frac{BT}{p} \right) \cdot \ln (e)
\]

where \( BT \) is the satellite brightness temperature (K); \( w \) is the wavelength of emitted radiance (11.5µm);
\[ p = \frac{h \cdot c}{s} (1.438 \times 10^{-2} \text{ m K}), \]

\( h \) is the Planck’s constant (6.626 \times 10^{-34} \text{ Js});

\( s \) is the Boltzman constant (1.38 \times 10^{-23} \text{ J/K}),

\( c \) is the velocity of light (2.998 \times 10^8 \text{ m/s});

\[ e = 0.0045P_v + 0.986, \]

\( P_v = (\text{NDVI}_{\text{min}} - \text{NDVI}_{\text{max}})^2 / \text{NDVI}_{\text{max}} - \text{NDVI}_{\text{min}} \)

is the proportion of vegetation.

Resampling is the technique of manipulating a digital image and transforming it into another form. (Baboo & Devi, 2010) This technique is used extensively in image processing for all applications, including medical, industrial and of course in remote sensing. Calculation of the new pixel value is performed by the weight of the four surrounding pixels. The bilinear interpolation is performed by the following (Equation 4).

\[ P(x, y) = P(1, 1) \cdot (1 - d) \cdot (1 - d) + P(1, 2) \cdot d \cdot (1 - d) + P(2, 1) \cdot d \cdot (1 - d) + P(2, 2) \cdot d \cdot d \] (4)

The equation 2 was applied for estimation forest cover using sentinel data analysis (Figure 3).

4. ANALYSIS

FI defined forest cover over years 2015-2019 using Sentinel-2. Figure 3 shows detailed information on NFI data.

![Forest cover map 2015 to 2019 for FI whit NFI](image)

However, some forest areas were also detected outside the NFI area suggesting that the boreal forest area for study area could be beyond the defined premises of the NFI.

![Field trip measured and forest cover validation map](image)

4. ANALYSIS

FI defined forest cover over years 2015-2019 using Sentinel-2. Figure 3 shows detailed information on NFI data.

![Field trip measured and forest cover validation map](image)

For the validation the output map FI (figure 3) was compared with NFI data using confusion matrix (Table 4). There is a good agreement with forest inventory data which is 85%.

![Confusion matrix and accuracy estimates](image)

Next, we applied LST for Landsat data. After that we made resampling LST FI from Sentinel-2 (Figure 5). Finally, we found and the relationship between LST and FI which is reasonable (Figure 6).
5. CONCLUSION AND RESULT

FI map was overlaid and compared on Inventory map. The validation result is reasonable (Table 4). These results indicate that the FI can effectively highlight forest cover. Advantage of using FI allow us to monitor forest for every 5 years and compare with NFI data. FI can also analyse seasonal change for different forest in the region. Overall, the research indicates that modern RS techniques and technologies are reliable tools for forest monitoring and management.

ACKNOWLEDGEMENTS

This research was partially supported by Asian Research Centre (ARC), Mongolia and Korea Foundation for Advanced studies and Mongolian Geospatial Association. The authors would like to gratitude the “Forest Research and Development Centre” in Mongolia and “Khanbuyan” community for their kind support. Authors are thankful for SENTINEL DATA CENTER for providing data.

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ESTIMATION OF ABOVE GROUND FOREST BIOMASS USING ULTRA HIGH RESOLUTION UAV IMAGES: A CASE STUDY FROM BARANDABHAR FOREST, NEPAL

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KEY WORDS: Forest Biomass, UAV, Image Segmentation, Visible-NIR Sensor

ABSTRACT:

Forest biomass is the sum of above ground living organic material contained in trees which is expressed as dry weight per unit area. Forest biomass acts as substantial terrestrial carbon sinks, they are estimated to absorb 2.7 Petagrams of carbon per year, as such accurate estimation of forest carbon stock is very important. The estimation of biomass is also important because of its application in commercial exploitation as well as in global carbon cycle. Particularly in the latter context, the estimation of the total above-ground biomass (TAGB) with sufficient accuracy is vital in reporting the spatial and temporal state of forest under the United Nations Framework Convention on Climate Change (UNFCCC), Reducing Emissions from Deforestation in Developing Countries (REDD). In this research, tree height, DBH and crown cover were measured using field instruments. Individual ultra-high-resolution UAV images acquired using customized Visible-NIR, were georeferenced and tree crown were extracted using multi-resolution segmentation. A regression equation between field measured biomass and Crown Projection Area (CPA) was developed. The paper presents results from Barandabhar Forest of Chitwan District, Nepal. RMSE of ortho-mosaic was found to be 18cm. While R² value of 89% was obtained for relationship between DBH and biomass, that of 61% was attained for relationship between CPA and biomass.

1. INTRODUCTION

Forest biomass is the sum of above ground living organic material contained in trees which is expressed as dry weight per unit area. Forest biomass acts as substantial terrestrial carbon sinks, they are estimated to absorb 2.7 Petagrams of carbon per year (PgC·yr−1), as such accurate estimation of forest carbon stock is important. The estimation of biomass is also important because of its application in commercial exploitation as well as in global carbon cycle. Particularly in the latter context, the estimation of total above-ground biomass (TAGB) with sufficient accuracy is vital in reporting spatial and temporal state of forest under the United Nations Framework Convention on Climate Change (UNFCCC), Reducing Emissions from Deforestation in Developing Countries (REDD) (UNFCCC, 2008).

Carbon stock is typically derived from above-ground biomass by assuming that 50% of the biomass is made up by carbon constituents. Various methods are available to estimate carbon stock of forest. The most accurate method is to use the destructive method; which involves cutting of trees, drying and weighing of their parts. This destructive method is often used to validate others, less invasive and costly methods, such as the estimation of carbon stock using non-destructive in-situ measurements and remote sensing (Clark et al., 2001; Wang, Hall, Scatena, Fetcher, Wu, 2003). Allometric equations developed on the basis of sparse measurements from destructive sampling are related to more easily collected biophysical properties of trees, such as diameter at breast height (DBH) and commercial bole height (CBH). The estimation of carbon over large areas using remote sensing is supported by correlating the reflection of canopy recorded at the sensor to the carbon measured directly or estimated indirectly on the ground (Chiesi et al., 2005; Gibb, Brown, Niles, Foley, 2007; Myeong, Nowak, Duggin, 2006; Tan, Fiao, Feng, Fang, 2007).

Various studies have evaluated the approaches to estimate biomass with the help of remote sensing. Remote sensing offers a potential solution to greater global consistency of estimates. Although biomass carbon (hereafter referred to as biomass) estimates derived from remote sensing may be less accurate at the plot scale than field (ground) measurements, remote sensing is technically capable of spatially continuous biomass estimates over the entire globe at some set level of spatial detail. Thus, it has the potential to eliminate inconsistencies due to differences in measurement programs between diverse countries or agencies. It could eliminate the need for sampling and extrapolation, which has been shown to constitute as much as 98% of total biomass estimation error. Most of the studies have used Radio Detection And Ranging (RADAR) (e.g., (Li et al., 2007; Sun et al., 2011; Tanase et al., 2014)), Light Detection And Ranging (LiDAR) (e.g. (Hudak et al., 2012; Vaglio Laurin et al., 2014)) and optical multi and hyperspectral data (e.g., (Morel, Fisher, Malhi, 2012; Vaglio Laurin et al., 2014)) in various forest ecosystem. These studies relate field-measured biomass values to train statistical or machine-learning methods in predicting

* Corresponding author
biomass by remote sensing predictors, and the majority report favourably on the accuracy of their biomass predictions.

The wall-to-wall estimation of forest biomass over large areas by ground-based measurements requires a dense network of inventory plots to reach good accuracies. In many regions, this is infeasible due to high costs, required man power and inaccessible field situations. This limitation is particularly evident in many sparsely populated areas with notable portion of natural forest ecosystems that are considered crucial for climate and biodiversity. Satellite images on other hand provides estimates over large area with reasonable accuracy, however, it is affected by the presence of shadow and clouds. Unmanned Aerial Vehicle (UAV) uses airborne platform and provides large scale forest measurement that can be used to estimate and validate the product derived from satellites. The study focuses on the applicability of UAV to estimate and validate the forest biomass. Tree biomass allometric equations are developed by establishing relationship between tree parameters such as CPA, DBH and wood density with above-ground biomass.

2. METHODOLOGY

Allometry, relates easily measured variable such as tree diameter, height to other structural and functional characteristics (Niklas, 1994). It is the most common and reliable method for estimating biomass, net primary production, and biogeochemical budgets in forest ecosystems (Gower, Kucharik, Norman, 1999). Practically, most allometry employs diameter at breast height (DBH) as the only independent variable, and develops an allometric relationship between DBH and component biomass (Gower et al., 1999). Some studies proposed to include tree height (H) as the second predictor and develop DBH–H combined equation to improve the precision of biomass estimates e.g. (Ketterings, Coe, Van Noordwijk, Ambagau, Palm, 2001).

In general, allometric equations for a tree species are developed using destructive sampling methods. The independent variables, such as diameter at breast height (DBH; 1.37 m above the ground), are measured for a representative sample (usually over a range of diameters or ages) of trees of a species. These trees are then felled and separated into different components including the main stem (trunk), stem bark, branches and foliage. The fresh weight of each component is measured. Since the intent is to determine dry biomass, the components are then dried in oven (throughout this article tree weight or biomass refers to the above-ground dry biomass).

However, some recent studies have outlined more statistically sound methods for using the sum of components for estimating total biomass. In either case, component or total weights are related to DBH using regression techniques. Since the variation of tree weight is heteroscedastic, that is to say the variation increases with increasing diameter, the use of simple linear regression becomes complicated. Traditionally, this problem is circumvented by taking the logarithm such that

\[
\log M = \log a + b \log D \quad (1)
\]

2.1 Study Area

Barandabhar Forest is located in Chitwan district of Nepal. The forest covers an area of 87.9km². Barandabhar, a 29km long forest patch, is bisected by Mahendra Highway, resulting in a 56.9km² area in the buffer zone of Chitwan Nation Park and 31km² under District Forest Office, Chitwan. The buffer zone area of Barandabhar Corridor Forest holds 48.016km² forest, 5.018km² grassland, 3.276km² shrub lands and 0.5km² of water bodies.

Barandabhar hosts Tropical forest types of Nepal, covering elevation ranges from 150m to 400m. The climate is subtropical dominated by the southeast monsoon. The average annual rainfall is about 250cm, with most occurring from June through September. From October through February, the weather is dry and cool with average temperatures of 25°C. From March to June, the weather is hot and temperature can reach as high as 43°C. The flora of Barandabhar forest is dominated mainly by Sal forest and partly by riverine, tall grassland and short grassland. A sample plot of 0.41km² (41 hectare) was used as test site near then Padampur (New) VDC. The selected area falls under District Forest Office, Chitwan as protected forest area. The location map of the project site is shown in Figure 11.

Figure 11. Location map of study area

2.2 Data Collection

During the field visit, data pertaining to tree allometry and forest cover were collected. Allometric data such as tree height, DBH and crown cover were measured using field instruments. Similarly, UAV was used to collect the images for the study site. The overall approach is shown in Figure 12.
2.2.1 Allometric Data Collection

After analysing the density of trees in the area, circular sample plots of 500m² were chosen to collect the data. So, a total of 11 plots were studied (Figure 13). The sample plots were navigated using GPS device. DBH and tree height were measured using DBH tape and Vertex instrument respectively. Field plot layout with orientation of trees relative to the North was recorded for identification of trees in image. Besides trees measurement in plots, few individual trees at random were selected and measured for validation purpose. Crown diameter was measured using 4 radii approach along different angular segments of the canopy (Figure 14). These angular segments are orthogonal diameter measurements (4 radii) suitable for computing crown diameter (Hemery, Savill, Pryor, 2005), from which crown projection area can be subsequently derived. The field orientation and extent data were used to interpret and digitize the crown area using visual image interpretation technique. The digitized data were then used for accuracy assessment of the delineated individual tree crowns from UAV image.

2.2.2 UAV Image Acquisition and Georeferencing

Ground Control Points (GCPs) were placed and measured before conducting aerial survey of the area. One meter by one-meter Red colour cloths were placed as GCP marker. Centre of the cloth was marked and 3D coordinates were recorded in WGS 84 coordinate system. The measurement was done with Differential Global Positioning System (DGPS) in static mode. Post processing of DGPS data was done in GeoMax Geo Office 3.21. A total of 27 GCPs were established and measured, 12 of which were used for geo-referencing while rest were utilized as check points for quality assessment.

UAV images were acquired with xnitnSonyA6000NDVI camera (LDP LLC, 2019). The camera’s NIR filter was removed and blue blocking filter was inserted. Therefore, it stores Red + NIR in Red channel, Green + NIR in Green channel and NIR in Blue channel. Red and Green channel information was computed and corrected using Python script. Captured images were geo-referenced with Agisoft PhotoScan.

2.3 Biomass Estimation

2.3.1 Field Based Estimation

Biomass of individual trees were calculated based on the field measurement. Individual tree height, DBH and wood density of the Sal (Shorea Robusta) species were used to calculate the biomass. The empirical formula as derived by (Chave et al., 2005) was used for biomass calculation. The equation used is:

\[
AGB = 0.0509 \times \rho \times (DBH)^2 \times H
\]

2.3.2 UAV Based Estimation

The georeferenced mosaic image was segmented and classified to extract individual tree crown (ITC) cover and regressed with field-based measurement for biomass estimation at plot and forest level. The first step was to segment the ortho-mosaiced image. It was carried out to separate individual tree crown cover. Segmentation was carried out in series of steps iteratively. Contrast split segmentation followed by multi-resolution segmentation was performed at different hierarchical levels in order to separate and delineate crowns of various sizes.

The contrast split segmentation was used for differentiating elevated surface area from ground area. The DSM was segmented into the bright objects (higher elevated objects) and the dark objects (lower elevated objects). The parameters such as the tile size, step...
size, class name for the bright and dark objects, minimum and maximum threshold were used while segmentation. Figure 15 shows the result of the contrast split segmentation.

In order to facilitate the appropriate scale for subset of image, ESP tool was used with series of trial and error approach at different scales. The customized algorithm ESP was used in eCognition to get the optimum scale parameters. Individual tree crowns can be delineated as objects through multi-resolution segmentation where the objects are polygons of roughly equal size exhibiting interior homogeneity (Changok, 2007). Most of single trees were delineated exactly at larger scale while smaller and connected trees were further segmented at smaller scale.

Hierarchical image segmentation approach helps to delineate tree more efficiently. It is difficult to extract all the trees at the first hit of multi-resolution segmentation. So, taking hierarchical approach into account, those that meet the first criteria are first assigned to one class and then the remaining ones are again subjected to re-segmentation using different parameters in an iterative way. Finally, the same multi-resolution segmentation algorithm is repeated with identical procedure but with different scale parameters until all of the tree crowns are delineated. Figure 16 demonstrates ITC delineation process.

The identified trees’ crowns were then related with individual trees collected during field enumeration. The matched trees in field and ITC from images were used to derive an allometric equation. Various parameters such as DBH, tree height, crown area, and biomass were plotted and regressed to determine significant relation

\[
D_{ij} = \sqrt{\text{Oversegmentation}_{ij}^2 + \text{Undersegmentation}_{ij}^2 / 2}
\]

(3)

\[
\text{Oversegmentation}_{ij} = 1 - \frac{\text{area}(x_i \cap y_j)}{\text{Area}(X_i)}, y_i \in Y_i
\]

(4)

\[
\text{Undersegmentation}_{ij} = 1 - \frac{\text{area}(x_i \cap y_j)}{\text{Area}(Y_j)}, y_i \in Y_i
\]

(5)

OverSegmentation and UnderSegmentation are in [0, 1], where OverSegmentation = 0 and UnderSegmentation = 0 define a perfect segmentation, where the segments match the training objects exactly. Similarly, performance of the regression was evaluated by measuring the deviation of the estimated versus measured total AGB. The mean across all sites was called average deviation (in %), and the standard deviation of Error across sites was the standard error (also expressed in %), and represented the overall predictive power of the regression (Chave et al., 2005).

\[
\bar{S} = \frac{100}{n} \sqrt{\frac{1}{n} \sum_{i=1}^{n} \left( \frac{\hat{Y}_i - Y_i}{Y_i} \right)^2}
\]

(6)

Where \( \bar{S} \) is the average deviation, \( Y_i \) = the observed biomass, \( \hat{Y}_i \) = the estimated biomass, \( n \) = number of observations

The deviation was calculated after the prediction was back-transformed to the unit values and corrected using a correction factor (CF). The log-transformation of the data entails a bias in the final biomass estimation (Baskerville, 1972; Duan, 1983; Parresol, 1999), and uncorrected biomass estimates are theoretically expected to underestimate the real value. A simple, first order,
correction for this effect consists of multiplying the estimate by the CF:

\[ CF = \exp \left( \frac{RSE^2}{2} \right) \] (7)

Which is always a number greater than 1, and where, here again, RSE is obtained from the model regression procedure. The larger RSE is, the poorer the regression model, and the larger the correction factor.

3. RESULTS AND DISCUSSION

3.1 Image Acquisition and Processing

A custom-made Hexa-copter was used as UAV platform for image acquisition (Figure 17). Its specification is presented in Table 7. Flight plan was prepared using DJI Ground Control Station software. An NDVI camera (xniteSonyA6000NDVI) from LDP LLC (LDP LLC, 2019) was used (Table 8). The images were acquired from 200m elevation with forward and side lap of 70% and 50% respectively. Root mean square error (RMSE) of orthomosaic obtained was found to be 18cm in planimetric and 46cm in vertical direction.

![Figure 17. Hexa-copter used for image capture](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension (motor to motor)</td>
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</tr>
<tr>
<td>Self-weight (including camera gimbal)</td>
<td>6.5 kg</td>
</tr>
<tr>
<td>Suggested payload</td>
<td>1.5 – 2 kg</td>
</tr>
<tr>
<td>Maximum thrust</td>
<td>20 kg</td>
</tr>
<tr>
<td>Propeller size and pitch</td>
<td>18 inch/6.1</td>
</tr>
<tr>
<td>Flight control board</td>
<td>Wookong-M (50 waypoints)</td>
</tr>
<tr>
<td>Flight time</td>
<td>Approx. 20 min</td>
</tr>
<tr>
<td>Flight mode</td>
<td>Manual &amp; Waypoint navigation</td>
</tr>
<tr>
<td>Maximum horizontal speed</td>
<td>25 m/s</td>
</tr>
<tr>
<td>Maximum vertical speed</td>
<td>5 m/s</td>
</tr>
</tbody>
</table>

Table 7. Specification of Hexa-copter

3.2 Crown Area Delineation

The comparison between the segmented individual tree crown (ITC) and digitized ITC were analysed using approach described in method section. The D value was 0.32 while over segmentation was 0.42 and under segmentation was 0.18. The lower D value can be result of various factors that governs the quality of the images. Resampling of image pixels from original image during image mosaicking and ortho-rectification results errors leading to poor quality of images. The error during the process leads in improper matching of the crown area especially in forested areas due to mismatching of points in overlapping areas.

Likewise, the error in individual tree crown delineation can also be attributed to sensor characteristics of consumer grade modified cameras. Consumer grade cameras have limited dynamic range CCD/CMOS sensors that forces the use of camera auto-exposure and prevents conversion of digital numbers into calibrated radiance values. In complex scenes, local differences in direct versus diffuse illumination may further obscure the changes of interest. Furthermore, consumer cameras apply non-linear transformations to the image data in ways that are beyond user control (Wüller, Gabele, 2007). It is therefore not possible to effectively correct for the changes in illumination and exposure.

Similarly, sensors in consumer-grades cameras are optimized for true-colour RGB recording, which negatively influences the separability of the three channels after infrared conversion. The band configuration is determined by additive rejection of the Bayer filter array and the installed long pass filter. This results in considerable overlap in sensitivity among the channels and prevents separate recording of red and infrared light. As a result, the bands are highly collinear.

3.3 Descriptive Statistics

Out of the 95 trees sampled in the field, most of the trees have diameter at breast height of 50-60cm showing matured trees in the study area. The DBH ranges from as small as 10-20cm to 80-90cm while the mean DBH lies in 50-60cm (Figure 18).
The number of trees were categorized under different classes according to their height. The maximum number of trees (i.e. 43) falls in height class of 20-30m and the least number of trees (i.e. 2) falls in height class of 40-50m (Figure 19).

Similarly, trees were categorized as per crown area. The study area was largely dominated by trees with crown area of 60-80m², while the minimum crown area was between 0-20m², the maximum was 180-200m² (Figure 20). The average value of crown areas of all trees was found to be 74.49 m².

### 3.4 Regression Analysis

Scatter plots of various variables such as DBH, tree height, crown area and biomass were used to analyse regression curves of the log-transformed models. Logarithmic transformations were used to simplify the regression procedure and satisfy the assumption of homogenous variance as discussed by (Bond-Lamberty, Wang, Gower, 2002).

The regression analysis between DBH and Crown Area shows significant relation, showing coefficient of determination of 0.60 (Figure 21). The lower value of coefficient of determination can be attributed to error in field measurement and individual crown delineation. Matured and overlapping trees might be a cause for the less value of the $R^2$ as crowns are difficult to identify in case of overlapping trees. As the study area is dominated by matured trees, tree crowns are subject to various extreme natural phenomena that might shape the crown inappropriately.

The relationship between DBH and above ground tree biomass (AGTB) shows significant correlation with $R^2$ value of 89% (Figure 22).

Similarly, the plot between the crown area and AGTB shows (Figure 23) that there exists linear relationship between them. The value of coefficient of determination was found to be 0.61. The lower value of $R^2$ is result of inappropriate crown area delineation from the image. The goodness of fit of our model was measured by comparing the estimated biomass versus the measured biomass. The average deviation was found to be 20.06 and standard error estimate of 0.2963 as per the method discussed in Section 2.4. As the log-transformed data entails a bias in the final biomass estimation (Chave et al., 2005), and uncorrected biomass estimates are theoretically expected to underestimate the real value. A simple, first order, correction factor was calculated to be 1.2011.
Figure 23. Relationship between Crown Area and AGTB

Errors in measurement of DBH can influence estimates of the allometric coefficients. For example, the ambiguity with which DBH has been defined in the past could be one source (Brokaw, Thompson, 2000). According to (Molto, Rossi, Blanc, 2013) a bias of ±10% in DBH estimates can result in ±20% or more bias in biomass estimates.

4. CONCLUSION AND RECOMMENDATIONS

UAV based approach is the most feasible method of above ground tree biomass estimation (AGTB), as it facilitates the ground-based measurement with satellite-based measurements. Unlike traditional destructive method, it is environmental-friendly, cheap and less time-consuming approach. Another benefit of this method is data can be taken periodically. Though satellite remote sensing is highly used in sectors like forestry and agriculture, the approach to estimate AGTB using UAV images is quite new. UAV images can give better result than satellite image as there is no problem of solar angle or shadow effect in UAV images.

The biomass estimates from the Barandabhar Forest shows that the biomass can be predicted with reasonable accuracy. However, precise field measurement of allometric data, spectral responsivity of camera system, ortho-rectification and individual tree crown delineation should be considered as vital in increasing accuracy. Similarly, spectral and spatial responsivity and separability of camera system used to acquire data has to be estimated as well.

The authors recommend that camera spectral and spatial responsivity should be carried out well in advance for finding out the errors associated the imaging system.

ACKNOWLEDGEMENTS

The project was supported by ICIMOD through Small Scale Application (SSA). The authors thanks ICIMOD for providing us funding to conduct the research. The authors acknowledge Dipesh Suwal, Shanghara Thapa and Sumesh K.C. for their tireless efforts during the field activities. We are also thankful to Sumesh K.C. for writing Python script for correcting reflectance values recorded by modified consumer camera.

REFERENCES


ESTIMATION METHODOLOGY FOR FOREST BIOMASS IN MONGOLIA USING REMOTE SENSING

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[Published in International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-5/W3, 7–12, https://doi.org/10.5194/isprs-archives-XLII-5-W3-7-2019, 2019]

KEY WORDS: Forest biomass, Allometric equation, Soil moisture, Satellite data

ABSTRACT:

The forest biomass is one of the most important parameters for the global carbon stock. Information on the forest volume, coverage and biomass are important to develop the global perspective on the CO2 concentration changes. Objective of this research is to estimate forest biomass in the study area. The study area is Hangal sum, Bulgan province, Mongolia. Backscatter coefficients for vertical transmit and vertical receive (VV), for vertical transmit and horizontal receive (VH) from Sentinel data and Leaf Area Index (LAI) from Landsat data were used in the study area. We developed biomass estimation approach using ground truth data which is DBH, height and soil moisture. The coefficient α, β, δ, γ were found from the approach. The output map from the approach was compared with VV and VH, LAI data. The relationship between output map and VH data shows a positive result R²=0.61. This study suggests that the biomass estimation using Remote sensing data can be applied in forest region in the North.

1. INTRODUCTION

Mongolia is a landlocked country and is situated in the central and semi-arid north-eastern part of Asia (Choimaa, et al. 2010). The forested area only amounts to 8 percent of the total territory of Mongolia (FCRD 2017). The northern part of Mongolia has taiga forest covers, which extend to Siberia in Russia in the North (Sata, Kimura and Kitoh 2007). The Mongolian forests are mainly coniferous, mixed with some broadleaf trees that grow on the mountain slopes between 800 - 2,500 m above the sea level (UN-REDD 2018). The Siberian larch (Larix sibirica Ledeb) is Mongolia's dominant tree species, which covers 80% of the country’s forested area (Jamsran 2004). The Mongolian forests have a low productivity and growth and are vulnerable to disturbance from drought, fire and plagues. Therefore, forests could easily lose their ecological balance such as the low natural regrowth rate, partly due to the boreal forests located in the northern hemisphere’s harsh continental climate (which significantly limits the vegetative growth rate and soil moisture contents (UN-REDD 2018)). The soil moisture plays a considerably important role in ecology and the forest ecosystem (Wen, Lu and Li 2015). The investigation of the soil moisture in different contexts, such as in agriculture, hydrology, meteorology, forestry and natural disaster management is important (Hosseini and Saradjan 2011). The forest biomass is one of the most important parameters for the global carbon stock modeling, yet it can only be estimated with great uncertainty (Mette, et al. 2002).

The global forest inventory and an accurate forest (above-ground) biomass estimation still are the critical missing parts in the global climate change discussion (FAO 2001). The leaf area index (LAI), in turn, is defined as half the total intercepting leaf area per unit ground surface area (Lauri, et al. 2017). So far, no equations have been empirically established so as to estimate the tree biomass in the Mongolian forests (Purevragchaa, et al. 2013). However, the Institute of General and Experimental Biology (IGEB) of the Mongolian Academy of Sciences (MAS) has carried out a biomass field survey on the main tree species of Mongolia (Dorjsuren 2017, MET 2016). The allometric models were based on the relation between the above-ground biomass (AGB), diameter at breast height (DBH) and the total height of tree (H) measurements (UN-REDD 2018).

The forest biomass cannot be measured directly from space (yet) but the remotely sensed greenness can be applied to assess biomass on decadal and long-term scales in regions of a distinct seasonality, as in the north (Renchin, et al. 2002). However, there are many studies which utilized the remote sensing technique to estimate the forest biomass. Multi-regression and neural models based on the thematic mapper (TM) imagery and 232 plots of forest inventory in the southern side of Xiaoxiang’an mountains have been established by Guo and Zhang (2003) to assess the forest biomass. The retrieval of the forest biomass using remote sensing data has received increasing attention for several reasons during the last decades. (Laurin, et al 2018) demonstrate the ability of remote sensing to spatially extrapolate the point field information on the forest parameters. Several researchers applied the synthetic aperture
radar (SAR) images in order to estimate the forest biomass. A study by (Renchin, Tsolmon et al. 2002) focused on the use of the JERS-1 SAR data to measure various properties, such as the total tree biomass, age and height, by means of a least-square method. This technique included both the modeling approach and empirical estimations of the forest biomass (based on the ground data). In another research, one looked into the models based on a large set of different vegetation indices and the multivariable models. The spectral satellite data include the medium spatial-resolution ranges from 10 to 100 m. More recently, the high spatial resolution data (IKONOS, QuickBird, WordView 2) have shown a high increase in availability. The improved accuracy in biomass estimation is reached when compared with the former two spatial resolutions. The main disadvantage is derived from their spatial resolution, which makes the data processing more time-consuming and thus better suited for local or regional scales (Lu 2006). The biomass estimation equations, also known as the allometric equations or regression models, are used to estimate the biomass or volume of the aboveground tree components based on a diameter at breast height (DBH) and the height data (Kebede et Soromessa 2018). The generality of the allometric equations can be evaluated either by comparing species within a region (or a broad vegetation type) or by comparing the same species appearing on various sites (Keith, Barrett et Keenan 2000). Most of the allometric models were based on the relation between the aboveground biomass (AGB) and diameter at breast height (DBH) and the total height of the tree (H) measurements. The species’ specific constant coefficients have also been employed. The biomass is found allometrically, generally on a species level, using the DBH alone or where available and generally more accurately, the DBH and height (Goetz et Dubayah 2011). The satellite radar is often proposed as the best tool so as to overcome the substantial spatial frequency and cost limitations of the allometric-based field surveys (Woodhouse, et al. 2012).

In this study, we have selected the boreal forested area which is located in the northern part of Mongolia. The vegetation index is enhanced by the strong reflectance of the near infrared (NIR) leaf internal scattering and the high chlorophyll absorption by the red wavelength region. The LAI can be utilized for the biomass estimation. Nevertheless, we used the LAI and backscatter coefficients for vertical transmit and vertical receive (VV), for vertical transmit and horizontal receive (VH) of the SAR images for the validation of the forest biomass in this research.

The objectives of the study are: Firstly, to estimate the forest biomass which is modified from the general equation using ground truth measurements in which the species’ specific coefficients of various trees (DBH, Height and soil moisture) can be found. Secondly, a need exists to correlate between the forest biomass and the VV, VH backscattering respectively. And thirdly, we aim to assess the relations between the forest biomass and leaf area index (LAI) derived from the Landsat 8 satellite data operational land imager (OLI). The innovative part of this research aims to consider the soil moisture measurements with the DBH and tree height and correlates with the LAI. The soil moisture measurements have been applied for this methodology, which have not been considered yet in previous studies.

2. STUDY AREA

The study area is located in the southern area of Khangal sum, a Bulgan province in the northern part of Mongolia (Figure 1). Bulgan is one of the northern provinces of Mongolia, located between the latitude 47° 14’ - 50° 23’ N and longitude 101°37’ - 104° 45’ E, in the territory of the Khangai mountain forest steppe zone. The north part (of this province) is characterized by alpine forests, gradually blending in the arid steppe plains of the central Mongolian highlands. Temperatures fluctuate between +38 °C in summer and -49 °C during winter. The average annual temperature amounts to -2.4 °C and the average precipitation ranges from 200 to 350 mm with a discontinuous permafrost. The soil type is sandy with semi desert features in the southern part, while fertile land mainly appears in the north for crop cultivation. The northern part of the province is characterized by alpine forests, gradually blending into the arid steppe plains of the central Mongolian highlands. According to the Holdridge life zones’ system of bioclimatic classification, Bulgan is situated in the boreal dry scrub biome (larch, birch and shrub), where larch measures 86,12 % and birch 13,88 % (FRDC 2016). The Ministry of Environment and Tourism (MET) forest report records 5 species of trees and bushes in the Bulgan province forests and 3 main forest types: Larch (Larix sibirica), Pine (Pinus silvestris), Cedar (Pinus cembra), Birch (Betula) and Poplar (Populus diversifolia).

![Study area of the southern side of Khangal sum](image)

3. DATASETS

3.1 Ground truth data

The ground truth data have been collected in the Bulgan province. We took 150 samples, which are the soil moisture data, diameter at breast (DBH) and height of the Larch and Birch in July and August, 2018. For the wood sampling, we collected the leaf presence and type of field plots (size, shape and number) and measured the DBH and height from the Larch and Birch. The forest biomass growth is high in July. We have gathered the soil moisture data during the ground truth in the Bulgan province. We used the soil moisture data in this study and measured the soil samples from all the corresponding different types of larch and birch wood loam soil. The water...
held tightly on the surface of the soil colloidal particles, is known as the soil moisture. It is essentially non-liquid and moves primarily in the vapour form, it cannot be separated from the soil (unless it is heated).

3.2 Synthetic Aperture Radar (SAR) images

Sentinel-1B is an imaging radar mission providing all-weather, day-and-night imagery at a C-band continuously. The Sentinel-1B SAR C-band data interferometric wide swath mode was used, with a 250-km swath width at a 5×20 m spatial resolution, an incidence angle between the 29.1 degree and 46.0 degree and the VH and VV dual polarizations. The scenes were multi looked (one look in range and four azimuth), geocoded based on the Shuttle Radar Topography Mission (SRTM) data and were radiometrically calibrated with a final pixel spacing of 10×10 m (Tsuyganskaya, et al. 2018).

3.3 Landsat 8 satellite data

The Landsat 8 satellite payload consists of 2 scientific instruments—the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). The OLI and TIRS designs incorporate technical advancements that improve the performance in the previous Landsat sensors (Irons, Dwyer et Barsi 2012). Landsat 8 data are nominally processed into 185 km × 180 km Level 1 terrain compressed GeoTiff file size, more than twice those of the former Landsat sensor L1T products. All the OLI and TIRS spectral bands are stored as geolocated 16-bit digital numbers in the same L1T file. The 100 m TIRS bands are resampled by a cubic convolution to 30 m and co-registered with the 30 m OLI spectral bands. An associated metadata file stores the spectral band gain and offset numbers that can be used to convert the digital numbers into the at-sensor radiance (W m−2 sr−1 μm−1) linearly (and to transform the OLI digital numbers into the at-sensor reflectance (unitless)) (Roy, et al. 2010).

4. METHODOLOGY

Biomass can be estimated using allometric equations. Generally, tree trunk is cylindrical for the volume calculation given as in the equation (1) does not hold for the majority of the trees. We selected equation 1 in order to calculate the tree trunk biomass in this study area. Where the V, R and H represent the trunk volume (m³), radius (m) and height (m). We modified the general equation (1), using the assumption that the tree trunk is cylindrical.

\[ V = \pi R^2 H \]  

We assume that tree volume can be in the equation (2). Where \( \alpha, \beta, \gamma \) and \( \delta \) illustrate the coefficients for the parameters regarding the general type of the tree trunk volume. \( R \) shows the radius of breast, \( H \) the height of trees, \( M \) the soil moisture, \( \alpha \) varies across the forest types. By solving this system, we will find the final solution \( \alpha, \beta, \gamma, \delta \) coefficients. In the equation (2) \( V, R \) and \( H \) demonstrate the trunk volume, dbh (in m) and height (in m). This equation is useful for various tree types.

The least-square method was applied in this study. The resultant tree coefficients can be utilized in the estimation of the total tree biomass. In this study, we assume that a regression model for the tree trunk biomass is as follows:

\[ V = \alpha R^\beta H^\gamma M^\delta \]  

In order to find the coefficients, we used a logarithm function and least square method in order to find the coefficients \( \alpha, \beta, \gamma, \delta \) that we need to solve the following unconstrained minimization problem equation (3). The least square method was applied in this problem concerning formula.

In here we \( \ln V = \bar{V}, \ln R = \bar{R}, \ln H = \bar{H}, \ln M = \bar{M} \) to indicate the function. Where \( V_i = \ln V_i; \alpha_i = \ln \alpha; \bar{R}_i = \ln R_i; \bar{H}_i = \ln H_i \) is a convex function reaching its minimum point.

\[ F(\bar{\alpha}, \bar{\beta}, \bar{\gamma}, \bar{\delta}) = \sum_{i=1}^{n} [\bar{\alpha} + \bar{\beta} \bar{R}_i + \bar{\gamma} \bar{H}_i + \bar{\delta} \bar{M}_i - \bar{V}_i]^2 \rightarrow \text{min} \]  

Equation (4) is obtained by taking the partial derivatives from where the error function (3).

\[ \frac{dF}{d\bar{\alpha}} = 2 \sum_{i=1}^{n} [\bar{\alpha} + \bar{\beta} \bar{R}_i + \bar{\gamma} \bar{H}_i + \bar{\delta} \bar{M}_i - \bar{V}_i] = 0 \]  
\[ \frac{dF}{d\bar{\beta}} = 2 \sum_{i=1}^{n} \bar{R}_i [\bar{\alpha} + \bar{\beta} \bar{R}_i + \bar{\gamma} \bar{H}_i + \bar{\delta} \bar{M}_i - \bar{V}_i] = 0 \]  
\[ \frac{dF}{d\bar{\gamma}} = 2 \sum_{i=1}^{n} \bar{H}_i [\bar{\alpha} + \bar{\beta} \bar{R}_i + \bar{\gamma} \bar{H}_i + \bar{\delta} \bar{M}_i - \bar{V}_i] = 0 \]  
\[ \frac{dF}{d\bar{\delta}} = 2 \sum_{i=1}^{n} \bar{M}_i [\bar{\alpha} + \bar{\beta} \bar{R}_i + \bar{\gamma} \bar{H}_i + \bar{\delta} \bar{M}_i - \bar{V}_i] = 0 \]

If we simplify (4), we noticed the system of (5). Then our model will be as follows in equation 5:

\[ n \times \bar{\alpha} + \bar{\beta} \sum_{i=1}^{n} \bar{R}_i + \bar{\gamma} \sum_{i=1}^{n} \bar{H}_i + \bar{\delta} \sum_{i=1}^{n} \bar{M}_i = \sum_{i=1}^{n} \bar{V}_i \]  
\[ \bar{\alpha} \sum_{i=1}^{n} \bar{R}_i + \bar{\beta} \sum_{i=1}^{n} \bar{R}_i \bar{R}_i + \bar{\gamma} \sum_{i=1}^{n} \bar{R}_i \bar{H}_i + \bar{\delta} \sum_{i=1}^{n} \bar{R}_i \bar{M}_i = \sum_{i=1}^{n} \bar{R}_i \bar{V}_i \]  
\[ \bar{\alpha} \sum_{i=1}^{n} \bar{H}_i + \bar{\beta} \sum_{i=1}^{n} \bar{H}_i \bar{R}_i + \bar{\gamma} \sum_{i=1}^{n} \bar{H}_i \bar{H}_i + \bar{\delta} \sum_{i=1}^{n} \bar{H}_i \bar{M}_i = \sum_{i=1}^{n} \bar{H}_i \bar{V}_i \]  
\[ \bar{\alpha} \sum_{i=1}^{n} \bar{M}_i + \bar{\beta} \sum_{i=1}^{n} \bar{M}_i \bar{R}_i + \bar{\gamma} \sum_{i=1}^{n} \bar{M}_i \bar{H}_i + \bar{\delta} \sum_{i=1}^{n} \bar{M}_i \bar{M}_i = \sum_{i=1}^{n} \bar{M}_i \bar{V}_i \]
Applying the ground truth data to (5), the respective coefficients and equation are dealt with as shown in table 1. Total biomass for the forest types, namely larch, birch, were estimated using the equation mentioned above. In order to consider the environmental factors like the moisture contents of various trees, the equation (2) can be modified using the above methodology. By modifying the equation (1), the forest biomass contents of various trees could be found.

5. ANALYSIS

Given the extreme continental climate of the region, the forests have a low growth rate and productivity, making them vulnerable to various disturbances (UN-REDD 2018). Most of the allometric models are based at breast height and the total height of the tree measurements. These approach used species’ specific coefficients found by the multi-purpose national forest inventory report (MET 2016). Our analysis relies upon a compilation to differ from the tree. We developed algorithms so as to estimate the total stand biomass and the shapes of the considered tree trunks. A least-square method was applied in order to establish the tree trunk shape coefficients, which were then used to assess the total stand biomass by means of ground data. Additionally, the soil moisture is enhanced by supplementary factors. We used the Sentinel-1B satellite data. The Sentinel-1B has been utilized in order to assess the forest biomass. A backscatter coefficient from the VV, VH polarizations was estimated for the larch and birch biomass. Leaf area index (LAI) were derived from the Landsat 8 satellite data operational land imager (OLI) afterwards. The innovative part of this research includes the consideration of the soil moisture measurement for the equation (2).

6. RESULTS AND DISCUSSION

All four types coefficients yielded estimates which approximate the measured dry weights of the stem and branch biomass. Most models had to be forced by the weighted regression (Choimaa, et al. 2010). A satellite radar is often proposed as the best tool so as to overcome the substantial, spatial frequency and cost limitations of the allometric-based field surveys. Our study area’s predominant forests are the Siberian larch (Larix sibirica) and Birch (Betula platyphylla). We selected 30 samples on larch and 18 samples on birch wood from the ground truth data. This study focused on the total tree biomass, radius, height and soil moisture contents using a least-square method. This approach included both a modeling approach and the empirical estimations of the forest biomass based on the ground data. The allometric equation performed in this study was used to calculate the biomass. It might also be applied to investigate the manner in which the trunk biomass is related to other soil moisture contents in stands. The tree shape coefficients $\alpha$, $\beta$, $\delta$ and $\gamma$ appear to be useful (tools) to estimate the stand biomass and will allow a refinement of the simple method from former studies. We developed the allometric equations. Most of the dependence DBH (D in equations), woods radius (R), height (H) and variables are obtained through calculations and measurements. The soil moisture measurements were applied for this methodology (which have not yet been considered in previous studies). These regression equations are related to AGB with the DBH, height (H) and wood density (R) individually (and in combination). In order to minimize the problems concerning the equality and inequality constraints, necessary conditions for the allometric equation extremum are being presented. These conditions apply when the constraints do not satisfy the traditional regularity assumptions.

Table 9. Coefficients and volume equations for the forests in the study area

<table>
<thead>
<tr>
<th>Forest type</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$\gamma$</th>
<th>$\delta$</th>
<th>Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larch</td>
<td>1.5</td>
<td>1.98</td>
<td>1.03</td>
<td>0.43</td>
<td>$V=1.5R^{1.98}H^{1.03}M^{0.43}$</td>
</tr>
<tr>
<td>Birch</td>
<td>2.9</td>
<td>2.07</td>
<td>0.85</td>
<td>0.23</td>
<td>$V=2.9R^{2.07}H^{0.85}M^{0.23}$</td>
</tr>
</tbody>
</table>

Figure 25. The relationship between the Larch biomass and the backscattering coefficient VH
Figure 26. The relationship between the Larch biomass and the backscattering coefficient VV

Figure 27. The relationship between the Birch biomass and the backscattering coefficient VV

Figure 28. The relationship between the Birch biomass and the backscattering coefficient VH.

In order to validate the model result (table 1), we measured the LAI from Landsat 8. The biomass from the model was compared with the LAI from the satellite data (R\(^2\)=0.55) for larch wood (R\(^2\)=0.56) for birch wood respectively (Figure 6 and 7). The leaf area index (LAI) is commonly used to characterize the structure and function of the forest ecosystems. The forest estimation results using recently launched Sentinel-1B SAR data are handled in this research. The forest biomass approach was developed and its relation with the Sentenil-1B SAR data has been established.

Figure 29. Relationship between the LAI and the Biomass of Larch wood

Figure 30. Relationship between the LAI and the Biomass of Birch wood

7. CONCLUSION

Forest research is vital for the Mongolian environment. The forest area accounts for 8 percent of the total territory of Mongolia, out of which 70 percent has deteriorated intensively by ageing, fire and insect infestations (FCRD 2017). The approach developed for this research could be applied to other ecological zones for various wood types.

ACKNOWLEDGEMENTS

This research was partially supported by the scholarship for mobility programmes at Ghent University, Belgium (ERASMUS-IMPAKT project). I thank Sentinel and Landsat data for providing me satellite data.

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Revised November 2019
ESTIMATING AND MAPPING CHLOROPHYLL-A CONCENTRATION OF PHEWA LAKE OF KASKI DISTRICT USING LANDSAT IMAGERY

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KEY WORDS: Water quality, Chlorophyll-a, Landsat 8, Regression model, Phewa Lake

ABSTRACT:

Water is a major component in the living ecosystem. As water quality is degrading due to human intervention, continuous monitoring is necessary. One of the indicators is Chlorophyll-a (Chl-a) which indicates algal blooms which are often driven by eutrophication phenomena in freshwater. Lakes should be monitored for Chl-a because Chla-a is related to eutrophication phenomena which are an enrichment of water by nutrients salt. When the environment becomes enriched with nutrients the excessive growth can lead to the death of fish. In this study, the Remote Sensing (RS) and Geographic Information System (GIS) techniques were utilized to determine Chl-a concentration of Phewa Lake of Kaski district. We used Landsat 8 satellite imagery for estimation and mapping of the Chl-a concentration. In-situ measurements from different sample points were taken and used to form a regression model for Chl-a and its concentration over the water body was calculated. The preceding year’s (2016) in situ measurement data of Chl-a concentration at a specific location were assessed with the one evaluated from the regression model thus produced for the succeeding year (2017) using Root Mean Square Error (RMSE) technique. As a result, we concluded that the estimation and mapping of Chl-a of a lake in Nepal can be done with the help of RS and GIS techniques.

1. INTRODUCTION

Water is one of the major components for the living creatures to survive. The water ecosystem, various types of resources valuable for the survival of the organisms are facing threat from a wide range of physical processes including land use/land cover change, pollution, global climate change as well as human interventions (Mushtaq and Pandey, 2013). Lakes and reservoirs store the part of these resources and satisfy both human requirements ranging from drinking water to recreation and environmental requirements to support high levels of biodiversity (Ismail et al., 2018). Due to the increased population growth, skyrocketing rate of industrial and urbanization sector as well as climate change, water quality is being deteriorated. These phenomena will continue to increase even more in the future, and many types of research have recognized declining water quality as one of the most crucial threats to society (Torbick et al., 2013). This led to a growing need for the monitoring of water quality parameters of lakes and reservoirs. Normally, water quality is evaluated in terms of its physical, chemical and biological parameters and recognizing the source of any possible pollution which might degrade water quality (Khattab and Merkel, 2013). Water quality monitoring using the primitive techniques dependent on in situ measurements followed by lab test of the collected water

Chlorophyll-a (Chl-a) is the major indicator of trophic state because it acts as a link between nutrient concentration, particularly phosphorus, and algal production. A eutrophication phenomenon is often related to Chl-a concentration (Han and Jordan, 2005).

Eutrophication, determined by the algal bloom, is an enrichment of water by nutrient salts that causes structural changes to the ecosystem, which causes degradation in water quality and depletion of fish species (Liu et al., 2014). So, regular monitoring and mapping of the Chl-a parameter are necessary.

Regular monitoring and estimation of the Chl-a parameter are being limited in Nepal using only in-situ measurements followed by lab test of the collected water samples. This technique may provide accurate measurements of the quality parameter. However, this technique is usually not economic, time-consuming and is unable to provide a state of water quality in terms of real-time spatial and temporal extent. To combat the problem, satellite-based Remote Sensing (RS) is a powerful approach for routine assessment of spatial and temporal variations in lake water quality parameters and may offer a suitable method to integrate water quality data collected from traditional in situ measurements (Giardino et al., 2001). The advantages that can be observed by this technique are numerous, but the most substantial one being the Chl-a concentration estimation over the whole lake (i.e. larger spatial extent) without requiring the time consuming and expensive field survey for sampling.

In such context, RS and Geographic Information System (GIS) can be very useful tools in estimating and mapping the Chl-a concentration of lakes in Nepal. RS imagery provides frequent wide coverage of water bodies and GIS provides the platform for efficient mapping and effective visualization. Landsat satellite has been the dominant source of satellite images for lake monitoring applications.

* Corresponding author
owing to its spatial resolution of 30m ground pixel size (Bartholomew et al., 2002). The cost-free and four decades-long historical archives of Landsat data open up the opportunity for the researchers to utilize such product in order to estimate various phenomenon such as Chl-a concentration. Several studies showed the feasibility of Landsat data for promising estimation of water quality parameters over the lake (Guan, 2009; Ledesma et al., 2019; Liu et al., 2014).

2.2 Data

Two types of data, satellite imagery and in-situ measurement for water quality, were used in this study.

2.2.1 Satellite Imagery: Level 1T processed images projected in WGS84 UTM zone 45N were downloaded from the USGS Earth Explorer which were, meaning that they have undergone systematic terrain calibration and geometric calibration. Images with less cloud cover were included in the analysis. Mostly water quality studies utilize only the visible and near-infrared (NIR) portions of the electromagnetic spectrum. Landsat 8 images from January 2016 to June 2017 were downloaded.

2.2.2 Water Quality Test: The water samples were collected from the area free of aquatic vegetation as such vegetation would falsify the true reflectance of the water. The pre-planning of field survey for the sample collected was planned on Google Earth imagery and their geolocation were recorded using handheld GPS from a boat. These water samples from different points were collected on narrow-necked bottles for measuring Chl-a.

<table>
<thead>
<tr>
<th>SN</th>
<th>Easting(m)</th>
<th>Northing(m)</th>
<th>Chl-a(mg/cu.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>201112.57</td>
<td>3124570.665</td>
<td>6.8</td>
</tr>
<tr>
<td>2</td>
<td>200970.22</td>
<td>3124208.712</td>
<td>4.1</td>
</tr>
<tr>
<td>3</td>
<td>200426.54</td>
<td>3124405.891</td>
<td>7.4</td>
</tr>
<tr>
<td>4</td>
<td>199904.49</td>
<td>3124614.532</td>
<td>5.2</td>
</tr>
<tr>
<td>5</td>
<td>199490.63</td>
<td>3124841.762</td>
<td>3.8</td>
</tr>
<tr>
<td>6</td>
<td>199196.00</td>
<td>3124864.193</td>
<td>3.6</td>
</tr>
<tr>
<td>7</td>
<td>199173.39</td>
<td>3125065.563</td>
<td>6.3</td>
</tr>
<tr>
<td>8</td>
<td>199250.43</td>
<td>3125531.549</td>
<td>3.8</td>
</tr>
<tr>
<td>9</td>
<td>199497.07</td>
<td>3126164.642</td>
<td>4.6</td>
</tr>
<tr>
<td>10</td>
<td>199622.58</td>
<td>3126034.000</td>
<td>5.2</td>
</tr>
<tr>
<td>11</td>
<td>200096.57</td>
<td>3125753.999</td>
<td>5.1</td>
</tr>
<tr>
<td>12</td>
<td>200111.62</td>
<td>3125466.403</td>
<td>4.6</td>
</tr>
<tr>
<td>13</td>
<td>200503.15</td>
<td>3125453.087</td>
<td>4.3</td>
</tr>
<tr>
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<td>200886.00</td>
<td>3125294.122</td>
<td>4.1</td>
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<tr>
<td>15</td>
<td>200748.05</td>
<td>3125083.932</td>
<td>5.5</td>
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<tr>
<td>16</td>
<td>201071.78</td>
<td>3124917.922</td>
<td>5.3</td>
</tr>
<tr>
<td>17</td>
<td>200976.78</td>
<td>3124035.931</td>
<td>5.8</td>
</tr>
<tr>
<td>18</td>
<td>201145.63</td>
<td>3123712.3</td>
<td>6.2</td>
</tr>
<tr>
<td>19</td>
<td>200866.87</td>
<td>3123795.968</td>
<td>5.9</td>
</tr>
</tbody>
</table>

Table 1. Geolocation of sampled point with Chl-a value
The water samples were collected in such a way that they have well-distributed i.e. 3 sample points per sq. km. (Zhang and Han, 2015), sufficient enough to capture the variability of Chl-a concentration and at a certain distance away from the banks so as to avoid the possible effect of the solar radiation reflectance of the lake bottom. The lake was infested with water hyacinth near the shorelines. Thus, water samples were collected away from those shorelines avoiding water hyacinths. The collected samples were taken to a laboratory for in-situ measurement. Chl-a samples were obtained from 1000 ml integrated sample bottles from which 300 ml were filtered through GF/c (Whatman 47 mm) filter paper. The Chl-a concentrations were determined according to methods by Carl J., (1967). The Chl-a concentrations from the laboratory analysis for the collected samples are represented in Table 1.

2.3 Image processing

To prepare the input satellite images for further processing, the following pre-processing steps were performed: radiometric calibration, atmospheric correction, image subsetting, and reflectance value extraction from 3*3 reflectance window. When the emitted or reflected electromagnetic energy is observed by a sensor, the observed energy does not coincide with the energy emitted or reflected from the same object observed from a short distance (Visual Information Solutions, 2009). This is due to the sun’s azimuth and elevation, atmospheric conditions such as fog, sensor’s response etc. which influence the observed energy. Therefore, in order to obtain the real irradiance or reflectance, those radiometric distortions must be corrected.

Each band of the satellite image was converted to top of atmosphere reflectance with sun angle correction using calibration coefficients provided in the metadata. Subsequently, the same image was subjected to atmospheric correction to avoid the possible effect of atmospheric conditions. Digital Number Image was converted to radiance value then surface reflectance using FLAASH in ENVI.

Next, the relationship between the in-situ measurements representing water quality parameter i.e. Chl-a in our case and mean reflectance values of satellite bands were established using the technique of regression analysis. The mean reflectance value was computed as the average reflectance values of a central pixel in a 3*3 kernel so as to remove the probable uncertainty in GPS measured geolocation of sample points (Guan, 2009). The selection of a nine-pixel window is based upon the assumption that water is heterogeneous and often in flux due to seasonal, solar, and meteorological factors.

Since some sample window had less than nine viable pixels (due to clouds), ratio of the number of viable pixels was generated which was used to compute each sample, by band, so we could independently determine an acceptable minimum value threshold for each individual study by sorting results based on this field and eliminating any windows with a lower completion ratio than desired.

Pre-processed images were converted into various band combinations which will be used for regression. Mostly the combinations were done for red (B4), green (B3), and blue (B2) bands.

2.4 Regression analysis

Regression analysis is a statistical technique that is used to find the relationship between the variable (Fisher, 1922). Multiple regression models were used to define the relationship between remotely sensed mean reflectance data obtained from 3*3 kernel earlier termed as the independent variable and the Chl-a concentration for the same point as the dependent variable. A large number of studies have examined single bands, band combinations including logarithmic, multiplicative, additive and band ratios as well (Ismail et al., 2018; Markogianni et al., 2017; Mushiaq and Ghosh, 2016; Wang and Yang, 2019) Markogianni et al. (2017) presented several types of band combinations to estimate mainly the Chl-a concentration in water bodies. Some of the band combinations used by the researcher were ratios of B1/B2, B2/B3, B4/B5; simple arithmetic band combinations like B1*B4, B2*B4, B3-B2, (B2+B4)/2, B2/(B1+B2+B3) and the logarithmic transformations like log(B1/B2), ln(B4/B3) and many more. The variables used in the aforementioned band combinations represent individual bands of Landsat 8. An approach to use a similar type of band combinations were made; a portion of which is reflected in table 2. The estimated relationships were followed by the computation of the coefficient of determination (R^2) between the mean reflectance values and Chl-a concentration parameters.

<table>
<thead>
<tr>
<th>Band combination</th>
<th>Regression equation</th>
<th>R^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>LogB2/LogB4</td>
<td>Y=314.21x^2-547.58x+241.06</td>
<td>0.212</td>
</tr>
<tr>
<td>B2*B4</td>
<td>Y=149.42x^2+156.67x+12.386</td>
<td>0.604</td>
</tr>
<tr>
<td>B4*LogB2</td>
<td>Y=-1572.6x^2+48.732x+9.2711</td>
<td>-0.395</td>
</tr>
<tr>
<td>Log(B2*B4)</td>
<td>Y=1.4045x^2-15.031x+28.138</td>
<td>0.589</td>
</tr>
<tr>
<td>Log(B2/B4)</td>
<td>Y=120.8x^2-4.98x+7.1506</td>
<td>0.129</td>
</tr>
<tr>
<td>B4+B2</td>
<td>Y=1156.1x^2-242.05x+14.767</td>
<td>0.500</td>
</tr>
<tr>
<td>B2*LogB4</td>
<td>Y=506420x^2+3864.5x+9.633</td>
<td>0.748</td>
</tr>
<tr>
<td>log(B4+B3*B2)</td>
<td>Y=1.1101x^2+6.5015+10.206</td>
<td>0.628</td>
</tr>
<tr>
<td>(B4+B2)/(B4+B2)</td>
<td>Y=0.0007x^2-0.0948x+2.9484</td>
<td>0.159</td>
</tr>
</tbody>
</table>

Table 2. Regression equations and R^2 values for various band combinations, where, B4=Red Band, B3=Green Band, B2=Blue Band

Furthermore, the established regression model was evaluated using the RMSE. The model with the maximum R^2 and a minimum RMSE value (i.e. derived as a difference between the predicted values and the observed field values) indicates the better model and hence that particular model was chosen for the estimation of Chl-a concentration. The associated R^2 and RMSE values of Chl-a are indicated in Table 2 and 3 respectively.

2.5 Mapping and visualization

Finally, the relationship with the band combinations resulting in the maximum R^2 was then selected to apply for estimating and mapping the spatial variability of Chl-a concentration over the study area. The selected and validated model (i.e. maximum R^2 and minimum RMSE) was henceforth applied to the entire study area showing the spatial as well as a temporal variation of Chl-a presented as a map on figure 4.
3. RESULTS AND DISCUSSION

Different band combinations tested to generate regression equation along with their associated $R^2$ value in order to find out the relation which best estimate the spatial variability of Chl-a concentration over the lake is mentioned in Table 2. Band combination of blue band and logarithmic function of the red band ($B2^2 \log B4$) gave the highest value of $R^2$ reflected as bold in the table. Figure 4 shows the scatterplot and regression line fitting the $B2^2 \log B4$ band combination.

Spatial and temporal variations of Chl-a concentration over the lake were then mapped using the highlighted regression equation $y=506420x^2+3864.5x+9.633$. The main reason to use this model was the highest coefficient of determination of 0.748 as well as the minimum RMSE value of 0.46 mg/cu.m associated with it.

Figure 3. Chl-a maps of Phewa Lake using band combination and quadratic regression for different months
Monthly Chl-a maps of Phewa Lake from the January 2016 to May 2017 were prepared. Higher cloud cover in the images of the rainy seasons like July and August made it impossible for the study to map the Chl-a concentration for those periods. Figure 4 shows all the maps produced for the Chl-a concentration of Phewa Lake.

Empirical method was chosen for the analysis. Other methods could allow achieving a good precision because they are developed based on the accurate spectral measurement and the radiation transmission theory. However, it seemed to be difficult to develop complex models due to the broad bandwidth of OLI data.

The concentration of Chl-a frequently changes and fluctuate according to the weather and climate. In the summer season, there is enough sunlight which results in a high value of Chl-a whereas in winter season there is less sunlight which results in less photosynthesis and consequently less Chl-a. When there is a shadow of the hills nearby lake there is a certain concentration of parameter and when there is no shadow there is a certain concentration of the parameter.

Looking at the Chl-a map, we can find that the concentration increases from April to July whereas decreases from September to February which indicated that there is fluctuation of Chl-a concentration due to seasonal changes. In the summer season and rainy season, there is a high concentration of Chl-a but in the winter season, there is less concentration of Chl-a. The data obtained has the RMSE of 0.458 mg/cu.m for Phewa Lake.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Date</th>
<th>In Situ Chl-a (mg/cu.m)</th>
<th>Obtained Chl-a (mg/cu.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>May, 2017</td>
<td>3.6</td>
<td>3.4</td>
</tr>
<tr>
<td>2</td>
<td>April, 2017</td>
<td>3.3</td>
<td>3.5</td>
</tr>
<tr>
<td>3</td>
<td>March, 2017</td>
<td>3.1</td>
<td>3.1</td>
</tr>
<tr>
<td>4</td>
<td>February, 2017</td>
<td>3.1</td>
<td>3.0</td>
</tr>
<tr>
<td>5</td>
<td>January, 2017</td>
<td>3.2</td>
<td>3.4</td>
</tr>
<tr>
<td>6</td>
<td>December, 2016</td>
<td>3.0</td>
<td>3.1</td>
</tr>
<tr>
<td>7</td>
<td>November, 2016</td>
<td>3.7</td>
<td>3.9</td>
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<td>8</td>
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<td>April, 2016</td>
<td>5.1</td>
<td>5.7</td>
</tr>
<tr>
<td>11</td>
<td>March, 2016</td>
<td>4.7</td>
<td>4.9</td>
</tr>
<tr>
<td>12</td>
<td>February, 2016</td>
<td>3.2</td>
<td>3.0</td>
</tr>
<tr>
<td>13</td>
<td>January, 2016</td>
<td>3.4</td>
<td>3.7</td>
</tr>
</tbody>
</table>

RMSE = 0.457009 mg/cu.m

Table 3. Monthly Chl-a concentration at 199497.066 N and 3126164 E along with the obtained value and RMSE for validation.

Phytoplankton, algae and other floating aquatic plant populations can exhibit significant spatial and temporal variation. The difference in the Chl-a concentration in the same month of the different year indicates that the growth of phytoplankton depends on the environmental condition and changes in time and space. The biggest influence on year-to-year differences in phytoplankton productivity is typical lake surface temperatures, wind patterns and, rainfall in the lake. Depending on rainfall, water flush from barrier gates, the concentration varies and dilution can cause phytoplankton’s growth. Thus, linking field measurements of Chl-a concentrations and signatures captured by remote sensing techniques in moving waters is not straightforward forward.

The limitation of the study was that the in-situ measurement was not taken on the exact date of the image captured due to lack of time and resources. Small sample size was also another limitation on this study. Greater number of uniformly distributed samples could produce a better result.

4. CONCLUSIONS

In this study, RS and GIS techniques were used to estimate and map the Chl-a concentration of Phewa Lake by using Landsat imagery by means of a regression model. Multiple regression analysis helped to create the best-fit regression model with $R^2=0.785$ which resulted out in generating reliable accuracy while assessing the efficiency of the model with in-situ measurement of certain fixed point with RMSE of 0.458 mg/cu.m.

Based on the various techniques and satellite sensors as discussed, it is seen that RS satellite imagery data can be successfully utilized for mapping the spatial variability of water quality parameter i.e. Chl-a over the lake. The present study concludes the efficacy of those imageries for establishing a cost-effective method for routine monitoring of lakes. Routine observation of lake water quality using remote sensing may be considered by different organizations as an alternative method to field survey for recording and processing water quality information for various works including fisheries. For developing generalized water quality parameters models, numerous studies are to be carried out considering variations of these parameters in different seasons.

ACKNOWLEDGEMENTS

Our sincere gratitude goes to Chief Officer, Senior Scientist, Suresh Kumar Wagle, Fisheries Research Division, for offering us this chance and providing us with his support to do this project.

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LEVERAGING CITIZEN SCIENCE TO ADVANCE INTERACTIVE SPATIAL DECISION SUPPORT TECHNOLOGY: A SWOT ANALYSIS

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KEY WORDS: Spatial Decision Support System, Planning Support System citizen science, participation, SWOT

ABSTRACT:

Over three decades, the Spatial Decision Support System (SDSS) concept has evolved significantly exploiting information technology to assist decision maker in a variety of fields of research, development, and practice. With the communicative turn in planning, which emphasizes public participation in all levels of planning and decision making, these technologies have further matured to support participatory planning by means of supporting diverse stakeholders in the decision making process. However, for multiple reasons, SDSS are still in the domain of expert, largely failing to incorporate general citizens in its use and applications. On the same note, citizen science as a method of inquiry is gaining much attention in recent years to engage general citizens in the scientific research, thereby also empowering them to participate in the decisions of the issues affecting them. As such, it seems likely that citizen science shows great promise for advancing SDSS for achieving broad citizen engagement in planning and decision-making. This paper discusses the strengths, weaknesses, opportunities, threats (SWOT) of integrating citizen science with SDSS by analyzing existing literature on SDSS and citizen science. In particular, we explore the integration of aspects of citizen science in Interactive Planning Support System (PSS), as one form of SDSS to support wider citizen engagement.

1. BACKGROUND

Many types of challenging problems faced by decision makers have a geographic or spatial component. Geographical information systems are often used for capturing, storing, manipulating, analyzing and displaying of spatial data - implying that geographic information systems implicitly are designed to support spatial decision-making. For many spatial problems, however, geographic information systems do not support decision-making effectively: analytical modelling capabilities are lacking and system designs are not flexible enough to accommodate the process of spatial decision-making (Densham & Goodchild, 1989). As such, there is an increasing interest in the development of computer based Spatial Decision Support System (SDSS), which is defined as “integrated computer systems that support decision makers in addressing semi-structured or unstructured spatial problems in an interactive and iterative way with functionality for handling spatial and non-spatial databases, analytical modelling capabilities, decision support utilities such as scenario analysis, and effective data and information presentation utilities” (Sugumaran & Degroote, 2010, p.37).

Over the decades the Spatial Decision Support System (SDSS) concept has matured significantly exploiting information technology to assist decision maker in a variety of fields of research, development, and practice. Literatures on SDSS show that advancement in technology had been fundamental in its evolution (Keenan & Jankowski, 2019). SDSS once utilized limited database, modeling, and user interface functionality, but technological innovations have enabled more powerful SDSS functionality.

With the communicative turn in planning theory, which is driven by interactive and interpretive process involving a dialogue between stakeholders (Healey, 1996), public participation is being considered as one of the important aspects in all levels of planning and decision making process. Politicians and planning theorists such as Walsch (1997), Forrester (1993), and Burke (1979) stress the need for public participation by explaining that the complex problems of planning require the widest possible range of input (Al-Kodmany, 2001). Following this paradigm SDSS technologies have further evolved from individual support to collaborative group support in spatial decision making, including different approaches and frameworks such as Collaborative SDSS (Jankowski et al., 1997; Jankowski et al., 2006), Group Support Systems (Turoff et al., 1993), and Planning Support Systems (Brail & Klosterman, 2001; Geertman & Stillwell, 2012; Klosterman, 1997).

1.1 Interactive Planning Support System

Of specific application of Planning Support System (PSS), is the development of so-called interactive PSS. An interactive PSS is hardware solutions in the form of digital table combined with geospatial mapping tools specifically dedicated to support group processes (Pelzer et al., 2014). Typically, an application of interactive PSS consists of interactive PSS tools and interactive PSS processes (Flacke et al., 2019). Interactive PSS tool usually consists of large-
scale horizontal, touch enabled screen such as MapTable, which allows stakeholders to stand around the table, and a suite of geospatial tool or GIS software for map-based interaction (Figure 1). In the present scenario, most of the interactive PSS tools usually make use of standard GIS software products such as ArcGIS, together with suitable extensions such as CommunityViz Scenario 360 (CommunityViz Scenario 360), adding dynamic capability on the tools. Interactive PSS processes, in its current form, usually consists of stakeholder workshops, either in the form of lab-based type of controlled experiments as in (Arciniegas et al., 2013; Döweling et al., 2016) or with stakeholders from the real world on the topic that is realistic (Flacke & De Boer, 2017; Pelzer et al., 2013; Shrestha et al., 2017).

The applications of interactive PSS are particularly tailored to support collaborative planning and mainly aims at increasing collaboration and participation of stakeholders while supporting complex planning tasks. Since more than a decade, interactive PSS are increasingly being developed and applied in various case studies related to urban planning (Pelzer et al., 2013), environmental health (Shrestha et al., 2017), energy planning (Flacke & De Boer, 2017). Research on application of interactive PSS shows that these technologies provide shared map interface to facilitate stakeholder engagement for discussing spatial problems, evaluating alternatives. The user friendly and dynamic interface and processes are argued to support exchange of knowledge and preferences between stakeholders (Flacke & De Boer, 2017), social learning (Shrestha et al., 2017), as well as contributing to higher quality plans (Pelzer et al., 2014).

Despite the many promising characteristics of interactive PSS for collaborative planning, the application of these interactive PSS are, however, often limited with few number of so-called experts discussing around the interactive PSS, excluding the involvement of broad citizen in its usage and applications. Even with respect to PSS usage by professionals in practice, research on so-called implementation gap of PSS shows that, these tools are being used in limited extent in practice (te Brömmelstroet, 2017; Vonk et al., 2005). Multiple reasons have been detected in its less uptake for facilitating stakeholder engagement with the interactive PSS, such as limited involvement of users in its development (Vonk & Litgenberg, 2010), mismatch between the tool and task to be supported, less user-friendliness, lack of experience and intention among practitioners to use the PSS tools (Vonk et al., 2005).

1.2 Citizen science as a method of inquiry

A separate field of citizen science is developing as a method of inquiry to involve general citizens, and other relevant stakeholders in scientific activities. A citizen scientist is a volunteer who collects and/or processes data as a part of scientific enquiry (Silvertown, 2009). It is a form of research collaboration involving members of the public in scientific research projects to address real-world problems (Cohn, 2008).

Citizen science emerged with the aim of voluntarily engage people to collect, categorize, transcribe or analyze scientific data to advance scientific knowledge. It is generally related to long-standing programs employing volunteer monitoring, and is often employed as a form of informal science education or outreach to promote public understanding of science (Brossard et al., 2005). Nevertheless, claims on benefits of citizen science activities show that citizen science activities are capable of cultivating behavior change, bringing awareness of the problems, stimulating transformative action and ultimately empowering them to participate in the decisions of the issues affecting them (Kimura & Kinch, 2016).

Active engagement in scientific work differentiates citizen science from other forms of public participation in scientific research where volunteers take less active roles (Wiggins & Crowthon, 2011). Most crucially, citizen science can also lead to the development of critical awareness of why social and political change is needed, and how it can be achieved. It is this active nature which separates citizen science from processes of consultation and other forms of civic participation. As such citizen science typologies to date have focused primarily on the integration of public participation in different steps of science research in the form of contributory, collaborative or co-created (Bonney et al., 2009).

Currently, this field is evolving quickly mobilizing people’s involvement in information development, social action and justice, and large-scale information gathering on various issues such as environmental monitoring, ecological monitoring, conservation management etc (Conrad & Hilchey, 2011). An increasing number and variety of citizen science projects are taking advantage of affordances of technology. New technologies such as mobile applications, wireless sensor networks, online gaming are showing great promise in citizen science activities to engage broad audiences (Clery, 2011), motivate volunteers (Sîrbu et al., 2015), improve data collection (Willett et al., 2010), corroborate model results (Snik et al., 2012; Van Brussel & Huyse, 2019), as well as increase the speed with which decisions can be made (Danielsen et al., 2010).

2. OBJECTIVE

Against this background, it seems likely that the development in citizen science activities provide valuable lessons to drive the development of interactive PSS towards broader engagement of citizens. However, to determine what aspects of citizen science can be integrated to drive interactive PSS towards citizen engagement, requires detail analysis on the strength, weakness, opportunities and threats of integrating citizen science aspects with interactive PSS. In this paper, we study the current research and applications of interactive PSS and citizen science activities regarding three aspects –forms of research, formats of engagement and technological development and present the SWOT analysis.

3. DATA AND METHODS

The research is exploratory, and is based on the literature study on interactive PSS cases and citizen science projects. These literatures
consist of the most relevant papers, studies and applications on interactive PSS and citizen science projects. We analyzed and structured the main issues regarding the citizen science activities and interactive PSS on three aspects: forms of research, formats of participant engagement and technological development. We then conducted SWOT analysis on each aspects for the interactive PSS.

4. RESULT AND DISCUSSION

After analyzing literatures on both interactive PSS and citizen science activities, following Strength, Weakness, Opportunities and Threat can be identified against three aspects—forms of research, formats of participant engagement and technological development—that could potentially be considered as lessons to advance interactive PSS for broad citizen engagement as presented in Table 1.

<table>
<thead>
<tr>
<th>Aspects</th>
<th>Strengths</th>
<th>Weakness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forms of research (community involvement at a core)</td>
<td>• Community issues at its core</td>
<td>• Motivation and willingness to adopt PSS tools is needed to be harvested</td>
</tr>
<tr>
<td></td>
<td>• Greater acceptance of PSS usage by the general citizen</td>
<td></td>
</tr>
<tr>
<td>Formats of participants’ engagement (hackerspace, maker space, living labs, gaming)</td>
<td>• Requirements in the design of the PSS tools can be identified</td>
<td>• Resource and time intensive in the form of training, logistics, and/or experience</td>
</tr>
<tr>
<td></td>
<td>• Create sense of ownership</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Task-technology fit</td>
<td></td>
</tr>
<tr>
<td>Technologies (open source, mobile apps, online web-platform)</td>
<td>• Open access, open source may reduce barriers related to off-the-shelf software use in PSS</td>
<td>• Integration with existing system architecture of PSS</td>
</tr>
<tr>
<td></td>
<td>• By leveraging mobile apps, web-based platform, PSS could evolve from same-time-same-place to different-time-different-place</td>
<td>• Privacy protection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Data quality control</td>
</tr>
</tbody>
</table>

Table 10. SWOT on each aspects

4.1 Forms of research

Citizen science projects show that citizen science activities include both community based monitoring, “a process where concerned citizens, government agencies, industry, academia, community groups, and local institutions collaborate to monitor, track and respond to issues of common community concern” (Whitelaw et al., 2003) and/or community based management, “where citizens and stakeholders are included in the management of resources” (Keough & Blahna, 2006). Direct community involvement to support community agendas and involvement of community from the early stage is the core objective of most of the citizen science activities, and can take the form of contributory, collaborative, or co-created projects. On the other hand interactive PSS are generally implemented either in laboratory with participants playing certain roles or with real world stakeholders, usually professional experts, under close to real world situations or context, resulting into limited usage of PSS by general citizens.

PSS scholars, therefore, need to consider community engagement at the core of PSS usage by embedding the PSS into the community based research activities and the broader social context by which the scientific question are collaboratively asked. Having community involvement at its core, PSS can be tailor made to address community issues directly. This may also result in greater acceptance of PSS usage and application by the broader citizens as one of its strength. However, in order for PSS tools to get adopted more widely and by diverse participants, PSS scholars should also need to concentrate on motivational factors for PSS users. This is the weakness that is also generally faced by citizen science activities (Rotman et al., 2012). By engaging community directly together with relevant organizations and agencies as in the citizen science activities, opportunities to forge partnerships can be built. As cooperative relationships with influential organizations may increase citizen participant motivation and passion (Schmidthuber et al., 2019) that may ultimately help in developing communities of practice for interactive PSS usage and applications. Nonetheless, community engagement is usually time and resource intensive.
4.2 Formats of engagement

Different hackerspace, makerspace, DIY activities, living labs, gaming etc in recent years are forming alternative networks in knowledge production and sharing and ultimately trending as way of engaging citizens in many of the citizen science activities for pragmatic response to various urban challenges. These hackerspace, makerspace, DIY activities, living labs/fab labs act as intermediaries and translational sites offering unique opportunities for bridging the gaps between knowledge based on experts/scientists and the everyday interests, practices and problems of general citizen in diverse local contexts (Kera, 2012). Moreover, these spaces offer co-designing activities (Jiang et al., 2016) that can potentially help in addressing digital illiteracy among the users.

In the current situation, most of the interactive PSS tools and applications are developed by developers, usually in research environment, with little to none involvement of users, or if any only the professional experts. Similarly, these are usually implemented in traditional workshop format. In this respect, the above forms of engagement can potentially drive early involvement of citizens also in the interactive PSS development. This can result in the early identification of the requirement for the design of interactive PSS, so that as an opportunity the tools and technologies can be adapted to the needs of the users rather than adapting their needs to technological exigencies. Also, by identifying requirements in the design and development of interactive PSS tools, technology can be better fitted to the task to be fulfilled by such technology, increasing their chances of wide adoption. Similarly, innovative uses of technology, for instance in the form of alternate and augmented reality games, context-aware games, games involving social networking, may expedite team formation, improve participants’ motivation, create a safer space to make their stake explicit. As a result citizen engagement is practiced through an open decision-making process, collaborative learning and knowledge exchange that happens in such spaces. In addition, early involvement in the development and usage of PSS application through such design spaces, may also create sense of ownership resulting into wider use and application of interactive PSS tools. Nonetheless, such engagement requires resources, time and space, which holds true to any kind of bottom-up processes and as one of the weaknesses. Thus, in order to embed interactive PSS development and applications with such form of engagement, great effort must be put into bringing coherence to the process, and overcome the weakness of lack of sufficient time, resources, and/or experience to allocate towards it. As for threat, while engaging broad citizens in co-design activities, tension may arise between the desire for simplicity and level of detail required to accomplish planning goals, when deciding how to represent complex real world issues in the interactive PSS tools.

4.3 Technological development

The speed at which new technologies are being emerged within scientific and citizen-science communities indicate that volunteers are more willing to adopt technology than ever before. In addition, open science movement in citizen science is redefining how the public engages with, and is engaged in science (Hecker et al., 2018). Open science engages with issues such as accessible data and publications, open evaluation and policies as well as developing its own tools. This includes open access, which is driven by the understanding that publicly funded research should be accessible to all members of society; sharing information and results for promotion of the open access publication model, establishing open data repositories, as well as developing open sourced tools and web platform. Technological development, such as the ubiquity of internet and mobile apps, open sourced software and web platforms, low cost of location devices, wireless sensor networks are driving forces in these regards. As a result, it is changing the way of involving citizen by opening up research throughout the process, from idea generation and planning to conducting the research and disseminating outputs. On the contrary, the technological development in interactive PSS shows that although the hardware solution is getting more and more advanced, but the software platform being used are usually off-the shelf software. This has resulted into less flexible tools and applications, which are not publicly available.

By leveraging the development of open source software, developers of interactive PSS can reduce the barriers being imposed by off-the shelf software and applications use in interactive PSS. Similarly, web-based platform, use of mobile applications can assist in the evolution of interactive PSS from its current format of same-place—same-time mode to different-time—different-place or same-time—different-place mode, resulting into more flexibility in its usage and applications. The use of mobile based applications, web based platforms, particularly in initial stage of planning, may provide opportunities to enlarge information source through data accessibility and sharing possibility and to incorporate citizen generated data and perceptions in the planning and decision making. Similarly, integrating such aspects in interactive PSS applications, it may provide opportunities to expand the use and applications of PSS across multiple spatial, temporal and social scales. As such, it might help in overcoming the limitations of current interactive PSS—as an expert driven tools or as one time application. Nonetheless, there remains weakness of how to integrate such technological developments in the current form of interactive PSS. Similarly, data quality issues is inevitable and is worth discussing when users perform data generation (Crowston & Prestopnik, 2013), so it is essential to verify data accuracy. Another weakness that is generally encountered when involving in digital communication is the privacy related issues (Drosatos et al., 2012). While using digital medium citizens’ ignorance of personal privacy and potential risk of personal information expose can cause users or stakeholder confliction. The different interest of citizen is unavoidable that may lead to algorithmic discrimination, and diminish citizen safety. While involving broad citizen with diverse background, violating personal privacy may hinder in openly public expression and motivation to participate and may cause unintended consequences. Therefore, systematic privacy guard is essential while employing digital medium of engagement. Similarly, threat of the integration of such technology with the interactive PSS could be related to the loss of social learning and depersonalization of decision-making. Although virtual platform provide flexibility and possibility of involving large number of people, but it may also replace the face-to-face interaction, which is essential to engender social learning and collective decision making. Moreover, increasing the users of virtual platform, data contributors, does not necessarily mean that they are actively engaged in the decision making process.

5. CONCLUSION

Despite the huge potentials in engaging stakeholders in collaborative planning, interactive PSS are far from being standardized tools in practice and is still in the exploratory stage of growth when it comes to broader citizen engagement. On the same note, citizen science
represents a new type of open movement, involving citizens in research activities in order to increase public understanding of science as well as bringing transformative potentials. As such, it seems likely that citizen science offers significant lessons on advancing interactive PSS for facilitating broader citizen engagement. Therefore, the goal of this research is to conduct the SWOT on integrating the aspects of citizen science activities with interactive PSS. In particular, we explored the three aspects in the domain of citizen science activities—forms of research, formats of engagement and technological development—in order to derive the strengths, weaknesses, opportunities, and threats of integrating these aspects in interactive PSS.

In general, we can conclude that in order to advance the interactive PSS towards broader citizen engagement, PSS scholars need to begin by changing the way research and operationalization of interactive PSS is being carried out in the present context. It needs to change from lab-based experiments or with few number of stakeholders working around the table in one time application into a long-standing activity embedded in community-based research and broader social context. Secondly, interactive PSS can benefit from different forms of intermediaries spaces such as hackerspace, makerspace, living labs/fablabs, in order to drive early involvement of citizens, for creating shared ownership of the tools through co-designing, thereby increase the acceptance. Thirdly, open science movement in citizen science domain and the availability of enabling technologies such as mobile based applications, web-platforms, gaming in variety of citizen science projects can offer huge potentials for interactive PSS to enlarge the information sources and incorporate citizens’ perceptions.

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SMARTPHONE-BASED VOLUNTEERED GEOGRAPHIC INFORMATION (VGI) FOR SLUM MAPPING IN POKHARA CITY OF NEPAL

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KEY WORDS: Informal Settlements, Volunteered Geographic Information (VGI), Crowdsourcing, Smartphones, Slum Mapping

ABSTRACT:

Informal settlements in urban areas are increasing rapidly throughout the world and regularisation of these settlements is being one of the challenging issues. Various study results have shown that conventional cadastral based information system approach and government managed institutional arrangements do not appropriately address land management issues of slum settlements. The aim of this study is to explore application of smartphone based Volunteered Geographic Information (VGI) and open spatial tools for slum mapping in developing countries such as in Nepal. A case of Pokhara Metropolitan city has been considered to explore the potential of utilization of smartphone based VGI and open spatial tools for slum mapping. Attribute and spatial data were collected using Smartphones and community-driven approach. Spatial and attribute data collected from 229 respondents of household’s surveys are integrated, analysed and interpreted and presented in this paper. Open Street Map (OSM) platforms and QGIS open source software have been used for slum mapping. These maps could play an important role in providing spatial information to the local government and planning authority in Nepal. This research paper concludes that smartphone based VGI and open portals such OSM have great potential to contribute to develop slum database and in providing information to plan various strategies, which aims at understanding, regularisation and upgrading slums.

1. INTRODUCTION

1.1 Background

For most of the developing countries, the regularisation and upgrading of informal settlements in urban cities have been a big problem for the government and to the local residence residing near such settlements. Nearly, 1 billion people reside in slums worldwide and it is predicted to increase up to 2 billion by 2030 (UN-HABITAT, 2013). Informal settlements are residential areas where 1) residents have no land tenure security, 2) lacks the formal basic services and city infrastructure such as supply of clean drinking water, health facilities, lack of electricity etc., 3) located in environmentally and geographically high risk zone and also housing may not fulfil building guidelines (UN-HABITAT, 2015).

In context of Nepal, informal settlement (Sukumbasi Basti) are relatively new and have only 20 to 30 years of history in major cities of Nepal (Paudyal and McDougall 2010). Nepal Government made several unsuccessful attempts to protect government or public land encroachment by informal settlements through forced eviction, while in the recent phase government has failed to address these issues through resettlement project in the surrounding of the urban cities (Brooks 2016). There are very few efforts from the government of Nepal to regularise slum settlements. After the restoration of democracy in 1990, a new high-level political commission Sukumbasi Samashya Samadan Aayog (SSSA) was formed in 1995 to work for landless people and informal settlements in Nepal. Later, this commission received 263,738 applications demanding for property rights and land ownership certificates. SSSA verified the applications and identified 54,170 families as a real informal settlements (Sukumbasi). To regularise these settlements, the commission had distributed land ownership certificates to 1278 families, while 10278 families received temporary land entitlement paper (Jagannath 2008). For addressing the issues related with informal settlement, Nepal government in its policy level has been working for legalisation, resettlement and regularisation and upgrading of informal settlement (Paudyal and McDougall 2010).

1.2 Role of VGI Managing Informal Settlements

The use of various GIS technology for urban planning has significantly been increased (Martinez 2009). As VGI uses bottom-up approach of spatial data collection, it helps the planner to understand and improve the quality of slum settlements (Hachmann, Arsanjani and Vaz 2018). VGI could play a vital role to collect enough information and can be useful for developing countries which has incomplete cadastral coverage and insufficient land records. An option to cadastral system can be developed using VGI for identification of land and land use (McLaren 2011).

1.3 Previous Research on Regularisation of Informal Settlements

Shrestha (2013) in his research “Squatter settlement in the Kathmandu Valley, Nepal” found that the informal settlements are due to a poor LA system, poor governance, low socio-economic growth and incapability to manage housing needs. Lack of public investment, lack of financing option and social exclusion are the major problems faced by settlers due to lack of land rights and land tenure.

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Hachmann, Arsanjani & Vaz (2018) has used spatial data for slum upgrading. During their research they investigated the implementation of Volunteered Geographic Information (VGI) and citizen science (CS) for collection of spatial information on informal settlements. They concluded that VGI and Citizen Science present powerful approaches to collect data on a larger scale and have potential to replace or complement Public Participation GIS (PPGIS) in slum upgrading practices. They urged that VGI could play an important role in providing more accurate and up-to-date spatial information through public participation (bottom-up approach) for urban planner which could be great help for understanding, regularisation and upgrading the realities of slum settlements.

Magigi and Majani (2006) in their research study found that involving slum settlers in decision making and educating them about local issues is an important aspect for regularisation of slum settlement.

1.4 Use of Smartphone and Open Data Kit

A case study of the Scottish crofting community employed Smartphone-based VGI approach for cadastral purpose (Duchateau & Mackaness 2017). CroftCapture, a location-based android application was tested by crofters and recorded boundary points, photographs and notes. Results have shown that such applications help to clarify boundary complexities from collected photographs and notes and help to record stories about crofts (agricultural units of under 50 hectares).

According to McLaren (2013) smartphone based VGI for land administration is in use and only little research has been done about its implications in recording land information for cadastral purposes. Further, McLaren et al. (2018) have developed a practical guide for implementing new technologies for land administration, including crowdsourced data and drone technology for data capture. This guide also offers a comprehensive overview of emerging trends in land administration through various case studies (Lengoiboni et al. 2019). Three popular mobile applications in land administration are USAID’s Mobile application for security of land tenure and Food, Agriculture Organisation (FAO’s) open tenure and Open Data Kit.

USAID has launched the Mobile Applications to Secure Tenure (MAST) initiative which uses smart phones/tablets and a participatory approach to efficiently, transparently, and affordably map and document land and resource rights (USAID, 2019).

Open Tenure was developed by FAO with financial support from the UK Department for International Development (DFID). It uses handheld tablets, and a community server to map and collect data on land tenure claims. It supports a crowdsourcing approach to the collection of tenure related details by communities. The data can then be viewed and moderated, and important documents and photos can be stored electronically (FAO, 2019). Open Data Kit is an android application which was developed at the University of Washington to use a smartphone as a data collection device. It is being used around the world to collect information in a cheaper way in places with insufficient infrastructure. Children from Rishi Aurobindo Colony, Kolkata, India have been mapping their own slum community using smartphone and Open Data Kit application with the funding of UNICEF (McLaren 2013).

This research paper has explored smartphone-based unconventional approaches such as VGI and Crowdsourcing for slum settlements mapping in Nepal. On the basis of collected spatial and attribute data using smartphone as a tool, it was explored that smartphone based VGI approach could contribute for regularisation of slum (Sukumbashi Basti) in developing countries such as in Nepal.

2. METHODOLOGY

The case study area is located in Pokhara Metropolitan City which is situated in Gandaki Province of Nepal. Pokhara is located 200 km West of capital city Kathmandu and is the largest city of Nepal in terms of area. There are large number of informal settlements in Pokhara, among which three settlements were taken as representative cases (Figure 1).

- Shanti Tole Informal Settlement (Ward 01)
- Pragati Nagar and Pragati Tole Informal Settlement (Ward 07)
- Simaltuda, Hanuman and Namuna Tole Informal Settlement (Ward 17)

![Figure 1. Location Map of Nepal, Kaski District and Pokhara Metropolitan City](image)

As illustrated in Figure 2, the research methodology focuses on spatial and attribute data collection using smartphone as a major data collection tool. The Questionnaire were prepared and field survey consist of house hold survey and slum mapping using smart phone device and open street map.

![Figure 2. Methodology Workflow](image)
2.1 Questionnaire Preparation

A questionnaire was designed to collect relevant attribute data from slum communities which consists of 30 questions related to personal information, socio-economic situation of slum settlers, basic infrastructure status, slum settler’s views on upgrading settlements as well as on property rights. First of all, all the questions were manually entered into the KoBoToolbox which is an open source survey tool for data collection. One of the advantages of using this tool is that it can be used in both online and offline mode.

2.2 Ethics Approval

Before undertaking the field survey, the ethics application was submitted to the USQ Human Research Ethics Committee through USQ Research Information Management System (RIMS) and ethics approval was obtained.

There was voluntary participation in the survey and the participants were informed and assured through a statement that participants' confidentiality would be maintained during data collection and presenting the research report. If any of the participant would be interested to see the research results, the summary of the results would be made available upon request. NextCloud was used for research data transfer and USQ’s Research Data Bank (ReDBank) was used to store, share and synchronise the research data during this research projects.

2.3 Field Survey

Field survey during this research was carried out using smartphones, which had improved the efficiency of work and minimised the risk of losing data. In addition to this, using these technologies also reduced the time for re-entering data collected in field and helped in post-processing of data as we directly obtained data in a digital tabular form. The main mobile applications used during the field survey were OSM tracker and KoBoCollect which are freely available on google play store and doesn’t require internet connection to operate. The locally trained/grassroots surveyors were involved during the data collection. Those grassroots surveyors were young adults from the slum settlements, trusted by the communities and educated and guided by professionals. A brief introduction about the aim of the research was provided to them and were made familiar with mobile phone application for data collection.

For this research study, Smartphone with OSM Tracker app had been used to collect the track of spatial data along with other attribute information such as house number, name of locality etc. from field and those data were used for further processing (to create a map). We had recorded various data using the tools available such as taking photos, recording voice, and taking notes which were available within the application feature. After the collection of spatial data, it was then uploaded into the OSM website (www.osm.org) using the JOSM editor application. In JOSM editor application, we had edited the collected spatial data using Bink and Maxar satellite imagery as a background layer. Finally, the information was uploaded into the site and it was saved.

Similarly, attribute data related to slum settlements were collected through household survey. Out of 33 wards in Pokhara Metropolitan City, three different wards were selected as representative case. The criteria for selecting these cases were location of slum settlement, size of slum settlement, and age of settlement. Informal settlement in ward 01 is located in the bank of Seti River (floodin/g risk area), ward 07 is located on the heart of Pokhara city and ward 17 is the largest informal settlement in Pokhara Metropolitan with 1080 households.

These three informal settlements were surveyed and the attribute data were collected via household survey using another mobile application named as KoBoCollect (v1.23.3k). KoBoCollect is a mobile application which allows us to perform survey through the questions designed in KoBoToolbox, when login credentials of KoBoToolbox are given to KoBoCollect. KoBoToolbox and KoBoCollect are interlinked applications i.e. questionnaire are created and hosted through KoBoToolbox and accessed through KoBoCollect mobile application and if questionnaire is updated in one KoBoToolbox, updated version of it can easily be accessed through KoBoCollect. The questionnaire was designed such that the spatial location (i.e. latitude and longitude) of all surveyed household was captured at the starting of the survey otherwise the form could not be proceed forward. When the household survey was completed, forms were marked and finalised on the mobile device. The finalised forms were submitted from KoBoCollect, those data were updated in KoBoToolbox website and could be visualised as illustrated in Figure 3. Then, the collected data were extracted in MS-Excel format from the KoBoToolbox application for further analysis.

3. RESULTS

3.1 Land Title and Household Survey

From the household survey, it was found that 96.96% (223 out of 229) of participants were occupying government land from many years and they do not have any kind of legal documents regarding the land ownership. While few (6 out of 229) were found to have restricted ownership of the occupied land, which was provided by High Level Commission formed by government of Nepal. In restricted ownership, settlers do not have full ownership right till the allocated time duration (it was found to be around 15 to 25 years). From Figure 4, it can be found that 110 (48.03%) participants were living in their current location from more than 15 years (in many cases more than 25 years). While 13.1% of participants were found to be residing in these settlements from less than five years. During the survey, they were asked about their property in other district of Nepal. It was interesting to see that 45 out of 229 participants (19.65%) responded that they do have land ownership in other part of the country. In addition to this, they added that they are residing as a slum as they cannot afford to buy a property in their current location.
location and are here because of natural calamities and lack of opportunities for earning in their previous location.

Figure 4. Duration of stay in the settlements (from sampled households)

During the survey, participants were asked about the procedure for land transaction in their current (informal) settlements. Interestingly, such occupied government lands are being bought and sold in presence of slum community leaders and members, with the mutually agreed locally signed deeds out of formal registry (signed and agreed by buyer and seller). From the sampled household survey of 229 respondents, 65.5% of participants responded that the land transaction has been done since these settlements were started. While 34.5% of participants responded that land transaction is not possible in their settlements. According to them, land transaction has been done with paperwork in presence of local slum community leaders, members and elders, signed and agreed by buyer and seller. But the buyer has to pay some fees to the local slum community before doing the transaction.

Figure 5. Agreement for land transaction

From the survey, it was found that informal settlements have their own cadastral map along with the record of area of land plot occupied by each family, which was prepared by Sukumbasi Samasaya Samadhan Aayog in 2009 but have not been legally registered in the official cadastre of government of Nepal till date.

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During questionnaire survey, majority of people (96 %, 220 out of 229) agreed that the condition of health service in their community is poor. They also added that high medical cost discourage them from visiting doctors. As an alternative to visit medical professionals, they prefered to go to quack doctor and traditional healers. From the survey, it was found that condition of water services in informal settlement is poor (as per the response of 89.86% participants).

Regarding shelter and settlement conditions, Sand Cement Block (wall material) and Tin (roof material) are used as primary building materials, which is easily available and inexpensive. From the survey, it was found that 83.84% (192) and 93.89% (2015) of participants had used Sand Cement Block and Tin to construct their houses respectively. Most of the houses in slum settlements were found to be poor, they are living in the same house since one-two decades. From the survey, it was found that 47.6% of houses were constructed before 2004. As per the questionnaire survey, 74 out of 229 responded that there is a risk of natural hazard. Flood, landslide and sinkhole formation are the major risk in these settlements.

During the survey, they were asked a question about relocation and it was interesting to see their response. As per their response, 145 (63.32%) were happy to relocate whereas 84 (36.68%) did not want to relocate from their current location. The key things they would be looking for relocated area are:

- Land ownership certificate along with house in the vicinity of city;
- Better employment opportunities;
- Availability of all basic facilities: Hospital/Health Post, School, Water, Road, Drainage, Sanitation etc.
From the survey, it is found that the participants (100%) are not aware of unconventional approaches such as VGI and Crowdsourcing. And they have never used smartphones for collecting data to prepare maps.

3.2 Slum Mapping

Slums are the most untraceable and un-surveyed parts of developing cities. Informal settlements mostly spotted as a blank spots: neglected and unmapped areas on most of the cadastral maps and planning documents. The edited and updated geographical data was published on OSM for slum traceability in three wards (Ward 01, 07, and 17) of Pokhara Metropolitan City as shown in Figures 8, 9 and 10. This has made it possible to record and visualise (number of houses count, road network status, tracing other infrastructures) of slums in these three wards of Pokhara Metropolitan City. Because of limitations of time and finance, attribute data of 229 participants were collected and appropriate data were successfully uploaded and added using OSM. And those data could be accessed and uploaded through the OSM site.

Figure 7. Informal Settlements in Pokhara Metropolitan City

Figure 7, illustrates the location of different informal settlements in Pokhara Metropolitan city. Red colour polygon represents the informal settlements in various parts of Pokhara city.

In Figure 8, 9 and 10, red colour housing data (polygon) indicates the houses surveyed during field visit. Out of 229 household surveyed, 30 were from ward-01, 52 from ward-07 and 147 from ward-17, all are shown by red colour polygon on Figure 8, 9 and 10.

Figure 8. Slum in Pokhara Metropolitan Ward No. 01

3.2.1 Before and After OSM Mapping

Figure 11 illustrates the comparison of study area of ward 07 before and after this research. Before this research, no housing data and other infrastructure of slum settlements were recorded on OSM. But after this research, every house and other infrastructures such as roads, temples, schools, community buildings were mapped. And attribute data collected from 229 sampled household were also entered and recorded on OSM.
After this research

Figure 11. Study Area (Ward 07)

3. 2.2 Overlay of Official Cadastral Map with Satellite Imagery

The main purpose to overlay cadastral map with freely available satellite imagery was to illustrate what is the status in the official record and what it looks like in the reality. As illustrated in Figure 12, yellow block indicates land parcels (ward 07) which is recorded in the official cadastral records of Government of Nepal (formal settlement). Whereas, the red block represents slum/informal settlement which is a vacant governmental land as per the official record (cadastral map) of Government of Nepal. However, there is a highly populated and dense settlements in field which has not been recorded in any official documents/maps. It was found that Informal settlement occupying the government, public and private lands, are neither legally recognised nor registered in official cadastre.

![Image of overlay of cadastral map with satellite imagery]

Figure 12. Overlay of Cadastral Map with Satellite Imagery (ward 07 along with some part of ward 09)

4. DISCUSSION AND CONCLUSION

Smartphone based VGI have been used in various part of the world for land administration, cadastral purpose and mapping. Smartphones can be effectively used for data collection and mapping in areas which lacks data and information such as informal settlement, as these technology are cheap and quick to use. The major problem in using smartphone for data collection and mapping is low accuracy. And in context to this study, locally trained/grassroots surveyors were involved during data collection. Those grassroots surveyors were young adults from the slum settlements, trusted by the communities and educated and guided by professionals. A short brief was given to them about the aim of the study and they were made familiar with mobile phone application for data collection.

In this paper, application of smartphone based VGI and open spatial tools were explored. Smartphone applications were used to collect spatial and attribute data. Likewise, the detailed study to identify the current status of the informal settlements was achieved through household survey. Informal settlements mapping was done using Open Street Map (open source mapping tool) and QGIS (open source software) using the collected spatial and attribute data.

REFERENCES


SCIDB BASED FRAMEWORK FOR STORAGE AND ANALYSIS OF REMOTE SENSING BIG DATA

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KEY WORDS: Big Data, Remote Sensing, Array Database, SciDB, Parallel Processing, Time series analysis

ABSTRACT:

Earth observation data of large part of the world is available at different temporal, spectral and spatial resolution. These data can be termed as big data as they fulfill the criteria of 3 Vs of big data: Volume, Velocity and Variety. The size of image in archives are multiple petabyte size, the size is growing continuously and the data have varied resolution and usages. These big data have variety of applications including climate change study, forestry application, agricultural application and urban planning. However, these big data also possess challenge of data storage, management and high computational requirement for processing. The solution to this computational and data management requirements is database system with distributed storage and parallel computation.

In this study SciDB, an array-based database is used to store, manage and process multitemporal satellite imagery. The major aim of this study is to develop SciDB based scalable solution to store and perform time series analysis on multi-temporal satellite imagery. Total 148 scene of landsat image of 10 years period between 2006 and 2016 were stored as SciDB array. The data was then retrieved, processed and visualized. This study provides solution for storage of big RS data and also provides workflow for time series analysis of remote sensing data no matter how large is the size.

1. INTRODUCTION

Laney (2001) defined big data as data characterized by the 3Vs: Volume, Velocity, and Variety. That is, they are large in size, speed of generation of new data is rapid and have variety of structure. Based on above definition Remote Sensing data can be termed as big data. The massive amount of earth observation data is now available in the archive which has been collected by different sensors for a long time. National imagery archives are storing terabytes of data every day and total stored imagery volume will grow to the order of Exabyte (OGC, 1999). Currently, this data is increasing at an exceptionally fast rate with the advent of the new sensor with varied spectral, spatial and temporal resolutions. These remote sensing data of large part of the world is big wealth to model the earth. It can be used to monitor environmental events, monitor natural disasters and study climate change. Other application area includes forestry, urban planning, land management, food security. However, these Big Remote Sensing (RS) data also poses the significant challenge of management, processing, and interpretation (Ma, et al., 2015). Recent research trends show the development of processing techniques for these data, such as time series processing methods to detect change (Verbesselt, Zeileis, & Herold, 2012), identify land cover (Clark, Aide, Grau, & Riner, 2010). Nevertheless, there is still big challenge in managing these data and fulfill high computation requirement to process them.

Generally, these RS big data are stored in files and most scientific data analysis methods for these data are file-based. But as the volume of the data increases, there arises the problem not only of data management but also of computational resource. Scientific community demands for the development of novel way in order to manage these enormous data and support distributed computation to meet high computational requirement of those data.

Relational database management systems (RDBMS) have been successful in addressing storage and analysis requirement of the varied business world from a long time. However, RDBMS are showing limitation when there is need of horizontal scalability and distributed computation (Jacobs, 2009), which is an essential requirement for RS data. Moreover, remote sensing data has an array like structure and it is advantageous to store the data in an array structure, to perform many RS operations. Cudre-Mauroux et al. (2010) demonstrate that the array-based database outperforms mature MySQL database for analysis Astronomical data. Thus array-based database with distributed storage and distributed computation has potentialities to manage and process big RS data.

SciDB is an open source multidimensional array based database and supports distributed storage, parallel processing, sparse array storage and user defined function and data types (Stonebraker,
Brown, Poliakov, & Raman, 2016). Planthaber et al. (2012) successfully tested SciDB to store and perform basic analysis on Modis Level 1 data. Appel & Pebesma (2016) have developed the workflow to store and retrieve three and four dimensional array of earth observation data in SciDB in an easy and reproducible way.

In this context, this study aims to develop SciDB based scalable solution to store multi temporal landsat image and perform time series analysis for change detection.

2. DATA USED

Image acquired by the Landsat Enhanced Thematic Mapper Plus (ETM+) sensor onboard the Landsat 7 satellite was used in this research study. This is a moderate resolution sensor built and operated by National Aeronautics and Space Administration (NASA). Landsat 7 was launched in 1999 and is continuously providing global data with 16-Day repeat cycle (USGS, 2016). Landsat 7 data collected after May 2003 have data gaps due to the failure of the Scan Line Corrector (SLC). This data is called SLC-off data. The data used in this study is SLC-off and has some missing scanned lines due to this hardware failure.

Image of the area between Nepal and India (WRS Path: 144, WRS Row: 040) was used. 148 image scene for different dates was used for the study.

Image captured between 7th July 2006 to 9th July 2016 and having cloud cover less than 80% was used for the experiment. There are 256 time series during the period.

3. METHODOLOGY

1. SciDB Database Setup

SciDB is currently supported only on Linux operating system. Interaction with SciDB server is done through iquery which is default SciDB client or by language binding using R or python. Two languages are available in SciDB: Array Query Language (AQL) and Array Functional Language (AFL). AQL is SQL-like query language whereas AFL is a functional language for SciDB. AQL is compiled into AFL.

SciDB itself has limited analysis capability but it can be extended using plugins that allow running script of powerful analytic language R and python inside SciDB array. R_exec (Lewis, 2016) plugin of SciDB provides a way to run R script inside SciDB arrays.

SciDB and other necessary plugins were installed using docker image of SciDB. (Appel, scidb-eo, 2016). The images contain SciDB, the scidb4geo extension for space-time arrays, a GDAL driver to upload and download Earth Observation datasets and r_exec plugin.

SciDB4gdal and SciDB4geo plugins were installed in order to facilitate conversion between time-service imagery to the multidimensional SciDB array and SciDB array to raster. Particularly SciDB4geo plugin (reference) stores spatial and temporal reference information of the time series satellite imagery to SciDB’s system catalog. SciDB4gdal is a GDAL driver implements read and write access to SciDB array. R_exec plugin was used to run R scripts inside SciDB chunks. Communication to the server was done by Secure Shell(SSH) protocol.

2. Loading Data to SciDB and Restructuring it

Data in SciDB are stored in an n-dimensional sparse array. SciDB array is created by specifying its dimensions and attributes of the array. For example a 3-dimensional SciDB array may have x, y and z dimensions with values (0,1,2,…,20),(1,2,3,…,50) and (alpha,beta,…) respectively.

SciDB divides the data into smaller portions called chunk and each SciDB instance is responsible for storing and running queries on chunk (SciDB User’s Guide, 2013). Because of this uniform distribution of storage and workload SciDB is able to deliver scalable performance on very large data sets.

The data was uploaded in SciDB using the gda_translate function of the gdalUtilities library in R interface. The date of the image scene was extracted from its name and the image was placed in multidimensional array accordingly.

Only two bands from the available image were loaded in SciDB separately and they were joined later to make a single array. The AFL query to join band 3 and band 4 is: 

store(join(LS3,LS4),LS)

The figure below represents storage of landsat image as SciDB array

![Image Storage as SciDB Array](image)

After that, the repart operator in AFL was used to restructure data in chunk size of 60*60*256. It means each chunk stores complete time series of 60 rows and 60 columns. To run change monitoring using the r_exec plugin it is necessary that each chunk contains complete time series. Thus it is necessary to set t dimension as 256 to encompass all the time series in a single chunk. It is recommended to store roughly 10 to 20 MB of data in each chunk to optimize the performance of the SciDB array (SciDB User's Guide, 2013).

Considering this, the value of row and columns was selected as 60.

3. Normalized Difference Vegetation Index (NDVI) Computation

Normalized differential vegetation index is the most frequently used index for vegetation studies. NDVI is calculated from the visible and
near-infrared light reflected by vegetation. Chlorophyll pigment present in plant leaf absorbs a major portion of the visible spectrum of light for photosynthesis. However, it does not absorb NIR and some portion of it is transmitted and rest is reflected. This reflected NIR is captured in remote sensing and used for the study of vegetation.

NDVI values range from +1.0 to -1.0. Very low values of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8). AFL was used to compute NDVI and store the file.

\[
\text{store}(\text{apply}(\text{between}(\text{landsat\_array\_repart},2150,2050,0,4250,4150,226), \text{ndvi},(\text{double}(\text{band1}\_2)+\text{double}(\text{band1})))/2, \text{ndvi\_WindowSize})
\]

4. Maximum NDVI Computation

Maximum NDVI is derived from the time series NDVI array. AFL was used to subset array into the desired size, compute maximum NDVI. AFL query to compute maximum NDVI array is:

\[
\text{store}(\text{aggregate}(\text{between}(\text{NDVI\_array},2150,2050,0,4250,4150,226), \text{max}(\text{ndvi}), \text{x}, \text{y}), \text{ndvi\_max\_WindowSize})
\]

5. Change Monitoring

Break for Additive Seasonal and Trend (BFAST) was used for detection of change from the data. BFAST allow “detection and characterization” of change in time series (Verbesselt, Hyndman, Newnham, & Culvenor, 2010). The BFAST monitoring splits time series data into history and monitoring period. From the data of historical period, it detects and models the stable history in order to detect disturbances within newly acquired data. Different models are available for modelling the stable historical behaviour. Also to determine the size of the stable history period, different methods are available.

BFAST package of R (Verbesselt, Hyndman, Newnham, & Culvenor, 2010) was used to monitor change from the time series data. Because there was too much cloud on some day, Landsat data was not available at every 16-days interval within our study period. So we have to first create regular time series objects using bfastts function in the BFAST package. This function link data with the date information and convert data of irregular date to daily time series. The start of monitoring period was chosen as 1st Jan 2012. A season-trend model with the harmonic seasonal pattern was used as a regression modeling to detect and models the stable history. Reverse-ordered CUSUM test (ROC) was used to determine the size of the stable history period. All other default parameters were used for the processing.

BFAST monitor function was run in SciDB using the r_exec plugin. The input for this operation was a SciDB array of NDVI values. R_exec works in each chunk and give the result for the chunk. For each chunk, we first split data apart. There are many options available for it in R such as the plyr package, data table package or tapply function in the basic package. We experimented with above three and found data table was fastest so used it. We then apply bfastmonitor function on the split data. Finally, we combined the output of the bfastmonitor function performed on split data together. The output of the operation is a 1-dimensional array with its row, column, breakpoint and magnitude value as attributes. We subsequently re-dimensioned the array into a two-dimensional array using row and column value.

4. RESULT

4.1 NDVI Computation

One of the primary output of the study was a three-dimensional array of NDVI value. NDVI not only detects vegetated area from non-vegetated but also can be used to derive vegetation health and other ecosystem dynamics. In this research, NDVI was also an input for subsequent experiments. SciDB automatically ignores cells in the array where values are missing and assign it as ‘NA’.

The figure 7 shows part of NDVI array visualized in R. The strips in the image are the missing scan lines.

![ Subset of NDVI array visualized](image)

Figure 33. Subset of NDVI array visualized

4.2 Maximum NDVI Computation

Finding the maximum value of NDVI at a particular location is the simplest form of time series analysis yet very useful to summarize the time series. It is also an input for other analysis such as to compute Vegetation Condition Index (VCI). This time series analysis gives a 2-dimensional array of maximum NDVI value observed over the chosen time period. This 2-dimensional array visualized using R is presented in the figure below. In this image, there are no strips of missing scanned line as seen in NDVI image because missing lines do not overlap in all image and are removed while taking maximum value.
4.3 Change Monitoring

Analysis to detect changes in SciDB array was performed using bfastmonitor function of bfast package. Bfastmonitor monitors change in time series by detecting disturbances in the end of time series. The output for this analysis was SciDB array with two values: the breakpoint detected with the date when this breakpoint is detected and magnitude of the median difference between the observed value and the value predicted by in the monitoring period. All the cells are assigned a value for magnitude regardless of whether the change is detected or not but no breakpoint date is assigned for the cells for which breakpoint is not detected.

The figure 4 shows the change of magnitude obtained from the function.

The red area in figure 4 represents the area where change magnitude is higher and green area of the figure suggest lower change magnitude.

Figure 5 shows the location of breakpoint detected with the year in which breakpoint is detected. It is important to note that all these changes might not be due to an actual change in the ground, which could be due to noise such as cloud in data of monitoring period. So further post processing is necessary but that is not the scope of our study.

5. CONCLUSION

System having distributed storage and horizontal scalability is the solution to ever increasing need of storage and computational requirement of remote sensing big data. In this experiment, we demonstrated a scalable solution for storage and management of multitemporal satellite imagery using SciDB. We also developed the workflow for performing for time series analysis on the image.

We also found that SciDB might not be the best solution for analysing small data as SciDB is not a mature system there is limited functionality. Also, initial system setup and data ingestion also requires time and efforts. Then again it has very good potential for management and processing of RS big data.

Further research can be conducted in the same research direction. It is necessary to investigate its applicability for running processes which requires more user interactions such as Supervised Classification. Another interesting area of study is the use of SciDB as the backend for web-based image processing system.

REFERENCES


REVISITING THE CURRENT UAV REGULATIONS IN NEPAL: A STEP TOWARDS LEGAL DIMENSION FOR UAVS EFFICIENT APPLICATION

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KEY WORDS: UAVs, Regulations, Geospatial Technology

ABSTRACT:

Unmanned Aerial Vehicles (UAVs) also known as drones, are an emerging geospatial technology that can facilitate data acquisition at various temporal and spatial scales. Notwithstanding, the wide application of UAVs globally, its wider application is found to be growing in Nepal as well. For instance, precision agriculture, forestry, topographical surveying, etc. It seems that there is a correlation between efficient use of UAVs in these sectors and the legal frameworks that regulate the use of UAVs. Therefore, it seems necessary to obtain holistic national view of UAVs regulations. Aligning with this necessity, this paper provides insight on existing legal provisions for UAVs in Nepal by highlighting the importance, impact, and limitations of UAV regulations. The criteria used in the framework to capture the present holistic legal dimension from literature in the web of science database are a) applicability b) technical requirements c) operational requirements/ limitations d) administration procedure e) human resource requirements and f) implementation of ethical constraints. The adopted methodological approach consists of exploratory case studies, systematic reviews of the concerned literature on UAVs regulations and the workshop on “Flight 4 Purpose” in which various UAVs application were discussed. The results show that the existing legal framework has both strengths and weaknesses for its use to capture the spatial data. The way forward is to harmonize the soft and hard regulations so that such geospatial technology can be applied for overall development and ultimately for the societal benefits.

1. INTRODUCTION

1.1 UAVs

Unmanned Aerial Vehicles (UAVs) also known as drones (Floreano & Wood, 2015), remotely piloted craft (Mulero-Pázmány et al., 2014), Unmanned Aerial System (UAS) (Puliti et al., 2015) refer to aircraft which fly without a human operator on-board. Despite of various terminology applied, this study has adopted the term UAV and Drone.

The UAV can be classified on the basis of aerial platforms. Mostly, there are four different types of UAVs, namely Multi-Rotor Drones, Fixed Wing Drones, Single Rotor Helicopter and Fixed Wing Hybrid Vertical Take-off and Landing (VTOL). These UAVs are used in accordance with purpose and accuracy of the work (Dalamagkidis, 2015).

Multirotor drones are the most common types of drones typically used in aerial photography, topographic mapping, 3D models aerial video surveillance, and so on. Whereas Fixed-wing drones are different in design and cannot hover like multicopter drones. It is mostly used in photogrammetric mapping and crop health monitoring. Looking to Single rotor drones, it resembles actual helicopters. Fixed Wing Hybrid VTOL are hybrid versions combining the benefits of Fixed-wing models (higher flying time) with that of rotor based models (Liu & Chen, 2018). The basic components of drones are remote controller, propeller, battery, GPS, landing gear, antenna, sensors, and display unit. The component’s size, model and usage vary with the types of drones.

1.2 Application of UAVs

Briefly exploring the UAVs development history, it is found that firstly it was applied in military applications. Later the use of technology has been expanded in other sectors. For instance, in 1986, the application of UAVs were tested for monitoring forest fires later on its application was found in weather forecasting, mineral exploration, coastal management, wildlife census and its tracking, forestry & agriculture (Raparelli & Bajocco, 2019), construction safety (Gheisari & Esmaeili, 2019), surveying and route planning (Desa et al., 2019). Notwithstanding its application on the technical aspect, its effective application has been seen in the humanitarian response (Meier, 2015). This initiative has highlighted very important application of the UAVs. Further, there is ongoing research on its applicability in obtaining land rights, land tenure security and in cadastre sector (Ramadhani et al., 2018; Stöcker et
al., 2019a; Stöcker et al., 2019b). It seems that the use of such a technology can be a boom towards good urban land governance.

Despite recent improvements in technological and operational capabilities related to UAVs, there exist challenges for UAVs operators as well as end-users including aviation authorities. The challenges are basically linked with having the effective and efficient legal framework that defines “Go”, “No Go”, “How to Go?”, “When to go?” and “Where to Go?.” (Stöcker et al., 2017). This raises the need to establish the UAV's regulatory framework that supports the smooth application in various disciplines.

1.3 The focus of the study

After understanding viable technical opportunities that UAVs can provide in social, economic, environmental management and governance aspect, the focus of this study is to obtain holistic national view of UAVs regulations in Nepal. This paper provides insight into existing legal provisions for UAVs in Nepal by adopting the existing framework developed by Stöcker et al. (2017). The criteria adopted in the framework varies from operational to administrative aspect including governance aspect like ethics. The single case on the use of UAVs in the humanitarian response is studied to explore how the flight procedure is regulated in Nepal. Since, the case was from 2015, to capture the present context on the UAVs regulation of Nepal, the content analysis of the government documents, blogs and more explicitly the data obtained from the workshop namely “Flight 4 Purpose” have been considered.

The following sections consist of methodological/analytical framework that guides this study. Section 3 provides the methods applied to collect data. Section 4 describes analysis and discussion and finally Section 5 highlights recommendations based on importance, impact, and limitations and way forward for improvement in legal framework which is further followed by concluding remarks.

2. METHODOLOGICAL/ ANALYTICAL FRAMEWORK

Based on Stöcker et al. (2017), the methodological framework to analyze the current Nepalese regulations on UVAs has been developed.

The criteria used in the framework to capture the present holistic legal dimension are a) applicability b) technical requirements c) operational limitations d) administration procedure e) human resource requirements and f) implementation of ethical constraints. The factors under the criteria are slightly modified by author based on characteristic of data.

2.1 Applicability of regulations

The criteria refer to the scope of UAV regulation. Under this criterion, one of the factors to evaluate applicability is ‘regulations that regulate the use of UAV based on the purpose’. Research, development work, fun, and recreational activities are a few examples of purpose. Similarly, weight of UAV and UAV flight permission based on land use type are other two criteria included in the framework to analyze applicability of UAV.

2.2 Technical Requirements

The criteria refer to essential instruments that are mandated for use of UAVs for spatial data collection. The regulations that regulate risk associated with UAVs flight by specifying risk-minimizing equipment is one of the factors under technical requirements criteria. The examples are instruments like parachutes, other special fail-safe instruments. Similarly, specific technical requirements like material of the blades, GNSS device, instruments attached to avoid collision of UAVs during a flight that is operated in Beyond Visual Line Of Sight (BVLOS).

2.3 Operational Limitations

The criteria refer to the UAV’s regulations that regulate and monitor the restriction of UAV flight in certain scenarios. The regulation like “No Fly Zones” based on the horizontal distance: for example, restrictions to distance from airports/airstrips, army camps, distance from people beyond UAV Pilot control, private property, army camps, jails, industrial buildings, nuclear power plants, hospitals, security-sensitive government buildings etc. is one of the factors for evaluating regulations over operational limits. Similarly, flight restrictions based on the flight height above ground and horizontal distance based on Visual Line Of Sight (VLOS), Extended Visual Line Of Sight (EVLOS) and Beyond Visual Line Of Sight (BVLOS) and are also the relevant factors that explain operational restrictions.

2.4 Administrative Procedure

The criterion refers to whether current regulations govern application procedure, operational certificate, need for registration, and need for insurance or not. Therefore, the factors included with this criterion are registration of platform, UAVs devices, flight approval from various sectors like National, Local, Police, landowner etc., compulsion of insurance policy to cover any harm/ damage by fight operation.

2.5 Human resource requirements

The criterion refers to either the current regulations govern the qualification of pilots and license to operate UAVs. In this criterion technical skills/ qualification of UAV Pilots like practical training, theoretical Knowledge, medical test, aeronautical test are the factors.

2.6 Ethical constraints

This criterion is one of the good governance components of UAV operation. It refers to the regulations that protect the use of information captured from UAVs. Within this criterion, data protection, privacy, data sharing policy are considered.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applicability</td>
<td>Regulations according to purpose, Regulations based upon the weight of UAVs, Regulations based on the characteristic of the site for flight (Area, Land Use Types etc.)</td>
</tr>
</tbody>
</table>
### Technical Requirements
- Requirements to include instruments like parachutes, other special failure and safety instruments, Specific technical requirements like the material of the blades, GNSS device, Instruments to avoid collision path that is operated (BVLOS, BVLOS, and EVLOS)

### Operational Limitations
- No Fly zones Based on the horizontal distance: For e.g. restrictions to distance from airports/airstrips, army camps, distance from people, property, military areas, jails, industrial buildings, nuclear power plants, hospitals, government buildings, etc.), Flight Restriction based on the Vertical Height, Horizontal Distance based on VLOS, BVLOS, and EVLOS

### Administrative Procedure
- Registration of Platform, UAVs devices, Flight approval, Insurance policy

### Human Resource Requirement
- Technical skills/ Qualification of UAVs Pilots: Practical training, theoretical Knowledge, medical test, aeronautical test

### Ethical constraints
- Data Protection, privacy, data sharing policy

Table 11. Analytical Framework based on (Stöcker et al., 2017) and modified by authors

3. METHODS AND DATA ON UAV LEGAL REGULATIONS

In this paper, the authors have applied case studies approach for data collection. The case studies design can be formulated as single-case and multiple-case design. The single exploratory case study approach is selected to collect data. Although Yin (2003) made a preference to make a choice of multiple cases as analytic conclusions derived from multiple case studies will be more powerful than one derived from single case study, the later one is selected. However, to overcome the weakness of a single case study approach, the workshop approach as one of the data collection approaches (Ørngreen & Levinsen, 2017) has been adopted.

3.1 Exploratory Case studies on UAVs Application on Humanitarian response after 2015 Nepal Earthquake

After massive earthquake in Nepal (25th April and 12th May in 2015), various humanitarian activities had been conducted in the early response and recovery stages. The deployment of UAVs to capture aerial images in order to plan humanitarian activities is one of the very effective actions taken in those periods. See Error! Reference source not found., the UAVs application on the recovery stages in which the local community was involved I identifying the buildings types and its damaged status, which seemed to be a very effective process for the informed decision making to avoid further human casualties and loss. This case has been studied considering legal regulations and its execution during the process of UAVs flight deployment and capturing images for the humanitarian responses.
3.2 Workshop as a means for data collection

An interactive workshop on “Flight 4 Purpose: Combating land tenure insecurity in Nepal’s remote and vulnerable areas using UAVs” was conducted at Kathmandu University jointly by the Department of Geomatics Engineering and Kadastr International. In the workshop, there were presentations and discussion related to UAVs application and existing regulations that govern the use of UAVs for the surveillance and capturing spatial data/images (Department of Geomatics Engineering, 2019; Dijkstra et al., 2019).

3.3 Data on the UAVs Legal Regulations

In this section, data on the existing UAV regulations have been presented which was collected based on the above-mentioned case studies, workshop and government documents on UAVs regulations: The content analysis (Mayring, 2004) approach has been adopted by considering the following government documents related to UAVs regulations.

- Remotely piloted aircraft (RPA) popularly known as ‘DRONE’ flight Act, 2019 (Ministry of Home Affairs, 2019)

3.3.1 Applicability of UAVs:

a) Regulations based upon the weight of UAVs:

The DJI Phantom 3 Advanced quadcopters were used. The weight of the UAVs is 1.28 KG. According to (Civil Aviation Authority of Nepal, 2015), the (drone) weighing less than 2 kg do not require permission from Civil Aviation Authority of Nepal (CAAN) while operating within the premises of the private property of the operator below 200 ft. above ground level (AGL)

The “Maximum Take-off Weight” (MTW) has been considered as a base for the categorization of UAVs and are categorized as follows.

<table>
<thead>
<tr>
<th>Category</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights</td>
<td>&lt;250 gm</td>
<td>250-2 kg</td>
<td>&gt;2 kg- 25 kg</td>
<td>&gt;25 Kg</td>
</tr>
<tr>
<td>Operations</td>
<td>Very low risk</td>
<td>Low Risk</td>
<td>Regulated, low risk</td>
<td>Regulated, high risk</td>
</tr>
<tr>
<td>Examples</td>
<td>Toy UAV/drones</td>
<td>DJI Phantom 4 Pro, Mavic 2 Pro</td>
<td>DJI Matrice series, DI Inspire Series</td>
<td>Industrial drones with payloads</td>
</tr>
</tbody>
</table>

Table 12. Categorization of UAV based on MTW

b) Regulations based on the characteristic of a site for flight (Area, Land Use Types, etc):

The binding rules of restriction area were not applied in the above-mentioned case and there were no such regulations to govern the
specific restriction area in the Flight operation directives 2015. However, the clauses 4.5 and 4.6 of the directives mentioned about the permission required from the concerned authority. The application of UAVs being applied for disaster relief activities, the local community such as the Community Disaster Management Committee (CDMC) of Panga was mobilized including the local people for the flight.

Later, the regulations by the Ministry of Home Affairs (2019) endorsed the risk-sensitive land use. The categorization as per the risk-sensitive land-use area where the flight is permitted are as follows:

- General: Non-settlement area, open space not included prohibited/preserved area
- Medium: settlement, community, protected/preserved area
- Sensitive: Government offices, hospital, religious, cultural, archaeological, airport strips, air space, close to airport, Military and security offices

c) Regulations according to purpose:

The UAVs flight was planned to capture images for disaster management purposes. In 2015, when the use of UAVs was a recent development, the need for the society for the early recovery seems to overrule the formal regulations to some extent. Moreover, the flight operation directives 2015 is silent regarding purpose.

Whereas under the Drone Related Flight Work Plan 2019 (Ministry of Home Affairs, 2019), the purpose of the flight has been categorized as

Research, disaster management, service, and development oriented project/program, culture/religious/recreational/tourism, general communication, military/security

3.3.2 Regulation followed under the Technical Requirements:

a) Requirements to include special failure and safety instruments

The case reveals that UAV was not equipped with any special safety instruments like Parachute. There were no such binding regulations regarding requirements to include the technical failure security instruments (Civil Aviation Authority of Nepal, 2015), as the application of UAVs is the recent development. The flight was operated in autonomous mode however, the flight paths were limited within VLOS.

b) Specific technical requirements GNSS device, blade material

The regulations of the Civil Aviation Authority of Nepal (2015) do not seem to bind the risk-minimizing technical factor. Besides, it is mentioned that UAV flight operators should be aware of the harm to others. In this case, the UAV's propeller was made of plastic.

The present regulation by the Ministry of Home Affairs (2019) specified about restriction to items that are risky such as explosive items, weapons, and nuclear weapons, transfer of animal and person via UAV.

c) Instruments to avoid collision (VLOS, BVLOS, and EVLOS)

The regulations do not explicitly mention incorporating technical instruments. The flight is allowed within VLOS only. Only the restriction on the frequency for flying without interfering the telecommunication and security is mentioned.

3.3.3 Regulations for the Operational Requirements and restrictions:

a) No Fly zones Based on horizontal distance:

During the emergency situation of disaster management, the case reveals that there was no such restriction to be taken into account seriously. There were no binding rules such as “No Fly Zones” is mentioned in the flight operation directives except it is mentioned that “if the operations need to be conducted in a Restricted or Prohibited area, approval from the concerned authority is required before applying to CAAN for flight permission”. The flight plan was scheduled for Panga. The area does not consist of flight sensitive zones like within buffer zone to airport, high-level government agencies, army camps, jails. Moreover, Civil Aviation Authority of Nepal (2015) does not mention the risk area very clearly.

The regulations endorsed by Ministry of Home Affairs (2019) have clearly demarcated the “No-fly Zone” above the personal property (land, house), public space, religious, cultural, archaeology, 5 km horizontal distance from international boundary, 1 km aerial distance from sensitive area/security offices, 5 km around airport area, 1000m aerial distance from special religious, high level government offices, president/prime minister residence, 1000m from main military and security offices, 300m other security offices.

b) Flight Restriction based on the vertical height, flight time

The specified endurance is limited to 15 mins, range within the horizontal distance of 300m the 100m altitude is maintained.

The Maximum flight above ground level is 200ft (see details in Error! Reference source not found.)

c) Flight based on the visibility

As per the guideline of (Civil Aviation Authority of Nepal, 2015), the flight was conducted within VLOS because it is not allowed to operate beyond VLOS.

3.3.4 Regulations that govern Administrative Procedure:

a) Registration of Platform, UAVs devices

The UAV used in the case of humanitarian response was brought by DJI. Later on the UAVs were donated to KU for use in academic purposes. The registration requirement of the UAV was not mentioned in Flight Operation Directives 2015.

At present, the UAV device needs to be registered and should obtain unique identification number (UIN). The procedure for registration is clearly provided. The required documents include identity cards like citizenship of individual/company, purpose of UAVs, specification of devices, VAT and Tax bill (purchased within country), customs clearance certificate (for imported drones). The UIN number is then attached to the UAV.
b) Flight approval (National, Local, local police, land owner)

Flight permission needs to be taken for each flight. The case reveals that the flight was conducted with support of CAAN. Besides, the local partner was involved during the flights. As stated in the Flight Operation Directives 2015, if the weight of the UAV is more than 7 Kg excluding fuel but including any articles must obtain permission of concerned authority, the UAV used in the case is only 1.28 kg. Moreover, the directive speaks about security clearance from the concerned authority is required prior to getting permission from CAAN. The case reveals that permission and cooperation are from the local authority as well.

Documents to be presented to get permission to fly are drone registration certificate, flight details including time, duration, purpose and location map (Google Map), authorization letter from local people/organization for foreigner/ foreign organization, UAVs pilots’ full information consisting of bio-data, citizenship copy, visa, valid visa (if foreigner pilot) and commitment letter of UAV pilot mentioning he/she will conduct the flight binding to the legal framework (Ministry of Home Affairs, 2019).

To obtain permission from the concerned offices, it must be assured about the criteria mentioned in section 3.3.3 are fulfilled. The granted permission to fly UAV cannot be transfer to others people/organizations.

Besides, the frequency in which the UAV flight is operating should not interfere with the frequency of telecommunication, national security, and CAAN.

c) Insurance policy to cover any harm/ damage by flight operation

The case does not reflect any evidence regarding the insurance policy. However, Drone flying Act 2019, regulates the insurance aspect. Basically, only drone of Category C and D should have third-party insurance.

3.3.5 Human Resource Requirement

Technical skills/ Qualification of UAVs Pilots:

The specific qualification of the UAV pilot has not been mentioned in the CAAN directives (Civil Aviation Authority of Nepal, 2015). However, the case reveals that the qualified person who was familiar with UAV technological and functional aspects has conducted the flight. Besides mapping activities in Panga, the team has given hand in training to develop capacity in UAV operation. The flight operation directive only mentions about the ‘remote pilot’ has the responsibility of himself or herself that flight can be safely carried out.

Whereas, the MoHA rules seem to have provided criteria required for UAV Pilots. For instance: age limit of 18 years and over, knowledge of radiofrequency, training on technicality of flight equipment, knowledge regarding take-off/ landing, knowledge of the area where the flight is being carried out. Despite the criteria set for UAVs Pilot, there is no provision of distributing license to the individual as given to the aircraft pilot. Rather, there is a provision of flight permission for a particular purpose valid for maximum three months and there is possibility to extend for three months if there is a valid reason to do so (Ministry of Home Affairs, 2019).

Ethical constraints:

Data Protection, privacy, data sharing policy

The case reveals that the data acquired has been used for research and disaster management purposes. The team printed orthomosaic, analyzed it and presented it to the community. The analog maps, as well as digital maps, were handed over to the CDMC. Figure 3 shows the handling of analog maps. Regarding privacy and ethical constraints of sharing spatial information, the CAAN Directives 2015 has mentioned that “any kind of filming or surveillance activities infringing the personal privacy shall be strictly prohibited”. However, the regulations do not spell regarding sharing, storage/ deposition of collected data.

4. ANALYSIS AND DISCUSSION ON EXISTING REGULATIONS ON UAVS:

a. Applicability of UAVs regulations:

The regulations are applicable as per the purposes of use, weight limits, and land-use types. Aligning this with the global study on UAVs regulation studied by Stöcker et al. (2017), the countries like Spain, Azerbaizan, Chile, South Africa also have already developed the regulations in this direction. For instance, Spain has weights limits categorization of 2/25/150 kg, Azerbaizan(20/150 kg), Chile (6 Kg), Colombia (25 kg), South Africa (7/20 kg) (Stöcker et al., 2017).

<table>
<thead>
<tr>
<th>Drone Catagory</th>
<th>Purpose</th>
<th>Flight Approval organization</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, B</td>
<td>Academic</td>
<td>required to inform local police / No permission required</td>
<td>Within premises academic institutions / Max. 200 ft AGL</td>
</tr>
<tr>
<td>A, B</td>
<td>Government activities</td>
<td>required to inform local police / No permission required</td>
<td>Max. 200 ft AGL</td>
</tr>
<tr>
<td>A</td>
<td>Recreational /ceremony</td>
<td>required to inform local police / No permission required</td>
<td>Within premises of personal property Max. 50 ft AGL/</td>
</tr>
<tr>
<td>A,B</td>
<td>Other purposes like business</td>
<td>District Administrative office of the concerned authority</td>
<td>Max. AGL 200 ft.</td>
</tr>
<tr>
<td>C, D</td>
<td>Permission required from Ministry of Home Affairs, Ministry of information and communication, Other related Ministry Coordination with District Civil Aviation offices</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 13. Flight Approval
However, the UAV’s regulations in Nepal in terms of applicability, need to formulate in more detail and clear in order to facilitate the implementation as each purpose might have different requirements. The general regulations might not fulfill the requirements to conduct flight for each purpose like academic, research, humanitarian response, recreational and tourism, media.

b. Technical Requirements:

Regarding the regulations for specific technical requirements, unlike in Chile and Colombia such as material used for blades, autopilot and recovery capabilities, GNSS devices, and other safety equipment like parachutes (Stöcker et al., 2017), the Nepal UAVs regulations does not seem to regulate in these factors. However, it reveals that there is a need to consider to define the specific technical requirements based on the purpose of the flight. Similarly, since the Nepal UAVs regulation allowed the flight within VLOS, there is not defined technical requirements regarding the collision avoidance capabilities. While, if the flight is allowed in EVLOS and BVLOS then the specific technical requirements need to be regulated to avoid severe accidents in the air.

c. Operational Requirements:

The regulations explicitly mention the restriction zones as “No Fly Zone”. Both flight operations directives of CAAN and UAV flight regulations have mentioned. The most prominent examples are no-fly zone near to the airport (air route), 5 km away from the international border (horizontal distance), Aerial radius from political, cultural, religiously, military and security-sensitive areas, etc. These rules are important to apply in terms of privacy of the people and also for security of sensitive information. The no-fly zone is found to regulate in many countries. In addition, the Netherlands and Japan seem to have made provision of on-line map service to identify no-fly zone (Stöcker et al., 2017).

Despite the restricted rules, the case of humanitarian response seems to overrule the UAV’s regulations to some extent. Further, according to Ministry of Home Affairs (2019), the UAV flight is restricted to operate immediately after a disaster. However, there is a provision to allow the flight to the national/ international expert by need assessment of the case by providing special permission. During this special permission period, the flight will be conducted under the surveillance of security officer.

This indicates that the hard rules might not be applicable in all cases. Therefore, the regulations should have provisions to accommodate soft rules depending upon a case by case approach for other purposes as well.

d. Administrative Procedure

The Nepal UAV regulations seem to clearly regulate as there is detail procedures of the registration process and obtaining flight permission. The requirement of UAVs registration is found in other countries as well for instance: Spain, Azerbaijan, South Africa, Rwanda (Stöcker et al., 2017) and USA (Gheisari et al., 2019). Besides having clear registration process at present, the use of UAVs which was donated for academic purpose is not clear. Since the case of humanitarian response reveals that UAVs are donated for academic purposes. To get those UAVs registered, all the required documents cannot be fulfilled. Similarly, there are almost clear regulations about taking permission but the duration of permission procedure is not clear. Moreover, the existing legal regulations (Ministry of Home Affairs, 2019) have mentioned provision of special permission to make UAV flight during disaster management. The unforeseen time frame to fulfill all the bureaucratic process can be serious hurdles on the effective and efficient response of UAV.

One of the strengths of the Nepal UAVs regulation is third party insurance for the Category C and D of the UAV types is must. This regulation is not seen in the study of (Stöcker et al., 2017). The point to be noted is that the study was carried out based on the data of 2014, 2015 and 2016 UAV regulations of various countries.

e. Human Resource Requirement

Regarding requirement of specific qualification of UAV Pilot, Nepal UAV regulation has described minimum standard norms applicable for general public. Whereas, there is no provision for evaluating the practical skill, aeronautical test, theoretical knowledge of the UAVs pilot and providing one-time license similar to the other vehicles and manned aircraft. The regulations of providing license and certification are found in many countries because pilot skills are one of important part that is associated with complexity and risk regarding flight plan and mission (Stöcker et al., 2017)

f. Ethical Constraints

The UAVs regulation of Nepal provides alert signals that it is necessary to consider by the UAV pilot to be aware that the flight mission does not hamper privacy of people, organizations, etc. It further mentions, the data captured should share with security department if needed. It seems that data privacy, use, and data sharing policy is still very weak. Although this criterion is not explicitly seen in other countries as well (Stöcker et al., 2017), it is important to think in this line for the effective and efficient application of UAV.

5. LIMITATION, RECOMMENDATION AND THE WAY FORWARD

This study has some methodological limitations because the single case of 2015 has been studied. Although the case studies are combined with other approaches like workshops and literature review, it is recommended to apply multiple variant cases on the UAVs application.

Based on the present study, it is recommended to concerned authority that the legal regulations have some shortcomings though Nepal legal regulations are found to be competent in the global framework. Basically, regulations need to be strengthened like duration of permission grant, clarity on concerned authority, registration of UAVs that are gifted or donated, data sharing and privacy, license, allowable to operate in EVLOS and BVLOS by defining explicit technical requirements, specific technical requirement as per risk categorization. The regulations like a restriction to fly over populated areas might be constrained to use the UAV for the study on urban land use planning.
Therefore, the way forward is to integrate hard laws such as government rules and regulations and also soft laws such as community awareness and industry self-control trends regarding use of UAVs. As it is already experienced that in the case like humanitarian response, a hard law might not be able to provide the effective use of UAVs. To do this, the participatory approach between government, private sector, and civil society groups are required.

ACKNOWLEDGEMENTS (OPTIONAL)

The acknowledgments go to Ms. Paula Dijkstra, Dr. Eva Maria Unger, Dr. Rohan Bennett for organising the Flight 4 Purpose workshop on behalf of Kadastar. Also the authors acknowledged an anonymous reviewer.

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VERSIONING – A METHOD TO DEVELOP AND MANAGE NATIONAL, REGIONAL, MUNICIPALITIES AND COMMUNITIES GEOSPATIAL DATABASES

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KEY WORDS: Versioning, Spatial Databases, Multi-level, Multi-scale, Unified Spatial Classes

ABSTRACT:

Some 12 years after the inauguration of the new Israeli new 3-D digital mapping effort in 1991, it became clear that success has brought new additional "problems". In the year 2003 some major ministries realized there is a real usage of the somewhat isolated what was called then, the National GIS. Only the Survey of Israel which developed and maintained the database and the Ministry of Housing, where the SOI was part of, made a use of the collected and already updated spatial database. All of a sudden, when the Ministry of the Interior engineers of the Development Division realized these sets of information may support their work both on planning and overseeing, it was clear there are multi-level usage and needs in terms of scale, resolution and visualization of the information embedded within the "National GIS" and the data layers each Governmental users, whether Ministries, authorities, Public companies and even large municipalities. Typically, a committee called the GIS Forum was established chaired by the Director General of the Survey. This committee came up with many important and unique decisions. Two of which were to change the name of the database from 'National GIS' to the 'National Topographic Database' (sounds much better in Hebrew). The second which is the most important and was adopted by the Israeli Government was that all governmental digital spatial work will be based on this national spatial database. Yet, the potential users came now from many echelons of the government and other actors of land management and development. This paper will describe the principals of Versioning Spatial databases that was used to enable using (almost) the same spatial database for multi-level users and tasks within the Country. Our Regional means the 6 regions within Israel and not the Middle East region of our close neighbours. That is, ours is a micro inner versioning which is more demanding resolution and accuracy wise but more accessible than the Macro Versioning, where resolution is less demanding yet coordination and cooperation are harder to find.
MAPPING URBAN TREES WITHIN CADAstral PARCELS USING AN OBJECT-BASED CONVOLUTIONAL NEURAL NETWORK

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KEY WORDS: GEOBIA, Machine Learning, Convolutional Neural Network, Urban Trees, Cadastral Parcel

ABSTRACT:

Urban trees offer significant benefits for improving the sustainability and liveability of cities, but its monitoring is a major challenge for urban planners. Remote-sensing based technologies can effectively detect, monitor and quantify urban tree coverage as an alternative to field-based measurements. Automatic extraction of urban land cover features with high accuracy is a challenging task and it demands artificial intelligence workflows for efficiency and thematic quality. In this context, the objective of this research is to map urban tree coverage per cadastral parcel of Sandy Bay, Hobart from very high-resolution aerial orthophoto and LiDAR data using an Object Based Convolutional Neural Network (CNN) approach. Instead of manual preparation of a large number of required training samples, automatically classified Object based image analysis (OBIA) output is used as an input samples to train CNN method. Also, CNN output is further refined and segmented using OBIA to assess the accuracy. The result shows 93.2 % overall accuracy for refined CNN classification. Similarly, the overlay of improved CNN output with cadastral parcel layer shows that 21.5% of the study area is covered by trees. This research demonstrates that the accuracy of image classification can be improved by using a combination of OBIA and CNN methods. Such a combined method can be used where manual preparation of training samples for CNN is not preferred. Also, our results indicate that the technique can be implemented to calculate parcel level statistics for urban tree coverage that provides meaningful metrics to guide urban planning and land management practices.

1. INTRODUCTION

There are two different approaches for image analysis namely pixel-wise and object-based (Castillejo-González et al., 2009; Lei et al., 2016; Lu, Weng, 2007). Pixel-wise image analysis method classifies each individual pixel to their most probable thematic class (Castillejo-González et al., 2009; Juniati, Arrofiqoh, 2017; Li et al., 2014; Weih, Riggan, 2010). Whereas, object-based image analysis first segments the image and classifies those individual segments to most appropriate thematic classes considering on spatial, spectral, geometrical and textural attributes (Blaschke, 2010; Weih, Riggan, 2010).

The use of Geographic Object Based Image Analysis (GEOBIA) for image classification and feature extraction has been increasing due to the introduction of user-friendly GEOBIA software packages such as eCognition, Orfeo Toolbox, Imagic, Spring etc. These GEOBIA software allows users to make their own rule sets based on the study area, available dataset and research objectives. The GEOBIA method considers the texture, shape, colour, size and relationship between contiguous pixels along with the spectral properties of an individual pixel (Benz et al., 2004; Blaschke, 2010). The basic steps behind image classification using GEOBIA follow an iterative process of segmentation and classification (Blaschke, 2010). This method overcomes significant limitation of pixel-wise method on high resolution image classification (Addink et al., 2013).

The GEOBIA method can give better accuracies than pixel-wise method during image classification especially for very high-resolution images. But there still exists some gap in this approach in order to meet the required level of accuracy.

Selection of scale parameter for image segmentation is a major challenge wherever segmentation and under-segmentation are likely to appear within same image (Ming et al., 2015). Also, Scale parameter selection and optimisation recently attracted attention of researchers (Belgiu, Drăgu, 2016; Drăguţ, 2010). Selection of scale needs to optimise high number of free parameters and requires domain specific knowledge (Jin et al., 2019).

The land cover classification with GEOBIA in urban areas could be challenging due to high diversity of land cover objects. For example, roof of various buildings might be of different materials in one hand whereas different features like roads and buildings might have similar characteristics in other hand. In addition, GEOBIA also has to interact with occlusion and shadows (Ehlers et al., 2003) which ultimately break image objects into finer objects and hence reduce the accuracy of the classification result. Extracting urban land cover features with high accuracy in an automated way is a challenging task and it demands artificial intelligence workflows for efficiency and thematic quality.

Convolutional Neural Networks (CNN) is one of the rapidly used deep learning neural network algorithms which is mainly designed for image classification (Fu et al., 2018; Zhang et al., 2016; Zhu et al., 2017). Kunihiko Fukushima first proposed CNN in 1988.
Deep learning approaches if integrated with OBIA may improve the overall accuracy of image classification. Hence, this research assesses the accuracy of image classification for OBIA, CNN and refined CNN (OBIA segmentation of CNN output) methods. As training of CNN requires a large number of samples, so it is not easy to prepare training data manually. However, on the other hand it is difficult to generate highly accurate training samples using automatic feature detection methods. Also, the classification obtained from automatic feature classification methods may not have better accuracies than manually prepared samples. But, in this research, we would like to classify the image using OBIA and train CNN with automatically classified OBIA output and assess and compare the accuracy of output to understand if it can improve the accuracy of CNN. Further, in order to filter the noise that might have been introduced due to erroneous training samples, we would like to implement the refinement algorithm to CNN output trained with automated OBIA output and test whether it can further improve the accuracy.

This method is experimented in an urban environment to test the performance for detecting urban trees. The classified output of urban trees is further overlaid with the cadastral parcel layer of study area in order to generate parcel level statistics. These metrics can be meaningful to guide urban planning and land management practices. The urban tree density map of cadastral parcels will have research as well as policy impacts. Further research on ecological abundance, foraging of birds and habitat mapping will be benefited by the density map produced in this research. In term of policy, the output from this research will inform urban planner and cadastral surveyors to bring in their planning of urban suburbia.

The organisation of the paper is as follows: in section 2, we present the location of study area, datasets used and adopted methodology. In section 3 the results are presented with maps, chart and tables. Section 4 presents the discussions from the results. And, section 5 presents conclusions and future works.
2.4 Preparation of Ground Truthing Dataset

The ground truthing dataset are prepared by using CHM and NDVI images for trees and grass classes, which then further used to generate samples in CNN workflow.

The image is segmented based on context, geometry and texture properties of trees and grass by using multiresolution segmentation algorithm with domain pixel level in eCognition software. The classification of the segmented objects into the trees and grass class is performed by defining threshold of CHM and NDVI value, assuming the NDVI value of trees and grass is more than 0.1 and by considering the height threshold for trees greater than or equal to 1.5 metres. The representative validation data (ground truth) for trees and grass classes are generated from the whole study area.

2.5 CNN Training and Classification

The overall analysis was done in a computer system having 64-bit operating system, 16 GB RAM and Intel (R) Core (TM) i7-7700 CPU @ 3.60 GHz processor. The CNN workflow of Trimble’s eCognition software Developer 9.4 (Trimble eCognition software, 2019) was applied for the tree’s extraction (Figure 3). The CNN workflow in Trimble’s eCognition software Developer 9.4 is based on Google TensorFlow API.

2.5.1 Generate Labelled Sample Patches for CNN Model: Labelled sample patches are created by considering different parameters including sample count, sample patch size and image layers. In this research, 8000 sample patches for each class are generated. The optimum sample size is determined to be of 22 x 22 pixels by trial-and-error method. Smaller sample size than the optimum ones, introduced multiple canopy detection errors whereas, larger sample size could not detect the smaller trees.

2.5.2 Create CNN Model: The CNN model is created with one hidden layer. The input image size is assigned the same as in sample generation. The hidden layer is based on the kernel size, number of feature maps and max pooling. As the even sized kernels will generate hidden units located between pixels and then are shifted to match pixel borders, old size kernels (13x13) is assigned with 40 number of feature maps. Max pooling using 2x2 filter with a stride of two in both horizontal and vertical direction is applied to reduce the resolution of the feature maps. Thus, the weight of 4 x 13 x 13 x 40 corresponds to the hidden layer kernel. The first factor (4) represents the number of image layer and the second and third factors (13x13) describe the number of units in the local neighbourhood, from which connection are forwarded into the hidden layer. The final factor (40) represents the number of feature maps generated. Therefore, 40 different kernels of 4 x 13 x 13 size is trained in this network. The only hidden layer of this network thus contains 27,040 different weights, that can be trained.

2.5.3 Train CNN Model: The model is trained based on labelled sample patches and model weights are adjusted using backpropagation. The learning rate of 0.0015 is assigned based on trial-and-error method. This parameter defines the amount by which weights are adjusted in each iteration of the statistical gradient descent optimization (Trimble eCognition software, 2019). Higher the value of the learning rate, faster the speed of training but the bottom of the optimal minimum may not be reached. While smaller values will slow down the training processing and may stuck in local minimum and end up with weights not even close to the optimal settings (Trimble eCognition software, 2019). A total of 5000 training steps are set in such a way that each training step uses 50 training samples.

2.5.4 Apply CNN Model: Heat map of tree class is produced after applying the trained CNN model to the input 4-band image. This map shows the likelihood of trees with corresponding probability value. The map is smoothed using a 7 x 7 gaussian filter and local maxima of the smoothed heatmap of trees is generated using morphology (dilate) filter of 3x3 pixels. A threshold value of 0.3 is set for the local maxima to delineate trees.

2.6 Classification Refinement

The heatmap obtained from CNN is segmented using multiresolution segmentation algorithm to classify trees and grass. The height threshold of 1.5 metres using CHM and NDVI threshold of 0.1 are applied to refine classification. The segmented tree objects are further refined using assign merge function, pixel-wise object resizing, and remove object algorithm using eCognition software. The tree objects sharing border with neighbouring trees are merged. Growing and shrinking mode with surface tension threshold and box size are applied consequently in pixel-wise object resizing algorithm to refine the shape of tree segments. Number of pixel threshold were used to eliminate smaller non-tree segments.

2.7 Mapping Per-Parcel Tree Coverage

The classified tree layer is overlaid with the cadastral parcel layer and hence the area and percentage of tree coverage area per-parcel is calculated. The percentage of tree coverage for each cadastral parcel is calculated as:

\[
\text{Percentage of tree coverage for a cadastral parcel} = \frac{\text{Total tree coverage area within the parcel}}{\text{Total area of that parcel}} \times 100\% 
\]  

2.8 Accuracy Assessment

The accuracy assessment of the classification outcome develops on the confusion matrix generated from manually digitised test data. The accuracy is assessed for three different methods of image classification i.e. 1) object-based image analysis (OBIA) and 2) convolutional neural network (CNN) and 3) segmentation of the refined CNN outcome. The refinement of CNN outcome is performed using pixel-wise object resizing (growing and shrinking) algorithm after applying minimum tree size threshold (pixel-area>4.5 square metres).

3. RESULTS

1. CNN Workflow Output

The output of CNN workflow is a probability heatmap representing the probability of tree in the test region (Figure 4.5). The probability
value in heatmap ranges from 0 to 1 where 0 being the least chance and 1 being the highest chance. The figure below shows the heatmap with red colour indicating the highest chance of being a tree whereas, blue indicating the least chance of presence of tree (Figure 6).

Figure 43. Before and after selecting the test region a) subset of the study area with ground truth of trees and grass b) selecting the test region within the subset.

Figure 44. Removing ground truthing of trees and grass from the test region.

Figure 45. a) Original RGB image of test region b) Probability heatmap of tree presence resulted from CNN with values between 0 to 1 (blue to red respectively) c) Smoothed heatmap reducing the noise effects. d) Smoothed heatmap implementing local maximum within 7x7 pixels.

2. Classification Refinement

The output of segmentation of heatmap obtained from CNN using multiresolution segmentation algorithm is presented in figure 7.

Figure 46. Refinement of the classification result from CNN a) Segmentation of local maxima heatmap result b) Segments with local maxima value >0.3, and NDVI value >0.1 and CHM value >2 to trees class which is represented by pink colour c) Merged trees class.

The shape of merged tree class segments is further refined using pixel-wise object resizing algorithm (Figure 8).
Figure 47. Resizing the classified objects, a) Image showing segments before merging b) Image showing segments after merging c) Image showing result of resizing of merged segments using pixel-wise object resizing (growing and shrinking) algorithm.

3. **Classification Accuracy Assessment**

The result shows that the classification outcome of refined CNN method gives the best overall accuracy of 93.2% with 0.85 kappa coefficient (Figure 9). Second to this classification method is the CNN with an overall accuracy of 92.3% and kappa coefficient 0.83. The OBIA method give the overall accuracy of 90.6% with kappa coefficient 0.80.

Figure 48. Overall accuracy and kappa coefficient of classification by OBIA, CNN and refined CNN.

4. **Classification results and visual assessment**

A final per-parcel urban tree coverage map of the study area was produced by overlaying cadastral parcels layer with the classification results of refined CNN outcome. The result shows that 21.5% of the study area was covered with trees.

To provide a better visualization, Figure 10 provides an overlay of cadastral layer with the urban tree layer and Figure 11 shows a classified per-parcel cadastral map of percentage of tree coverage. The cadastral parcels are classified into five different classes depending on the per-parcel percentage of tree area coverage. The percentage of tree coverage are classified as very high (>90%), high (60% - 90%), medium (30% - 60%), low (0% - 30%) and none (0%).

The tree coverage percentage result shows that two thirds of the parcel areas are covered by low density of trees. From the Table 1, highest sum area percentage (75.8%) of parcels have 2168 parcels with low density of trees (0% - 30%) but the very high tree coverage (>90%) are in 35 parcels which sums up 1.0% in total area. There are 514 parcels whose sum in area represents 17.6% of total area with the medium density of trees (30-60%). Only 4.6% of the parcels (88 in numbers) in area are covered by parcels with high density of trees (60-90%). The remaining 887 parcels representing 1.0% of sum area got no trees.

<table>
<thead>
<tr>
<th>Tree coverage class</th>
<th>Number of parcels</th>
<th>Percentage of parcel area coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high (&gt;90%)</td>
<td>35</td>
<td>1</td>
</tr>
<tr>
<td>High (60% - 90%)</td>
<td>88</td>
<td>4.6</td>
</tr>
<tr>
<td>Medium (30% - 60%)</td>
<td>514</td>
<td>17.6</td>
</tr>
<tr>
<td>Low (0% - 30%)</td>
<td>2618</td>
<td>75.8</td>
</tr>
<tr>
<td>None (0%)</td>
<td>887</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 14. Parcels level statistics in different tree coverage classes.
The land tenure type of tree coverage parcels (Table 2) shows that the authority land has 89 parcels but covers 29.9% of the total study area. This cadastral type has 30.5% of tree coverage which covers 39% of overall total tree coverage in study area. Similarly, there are 3707 private parcels covering 56.4% of the total study area with 18.8% of tree coverage which is half of the overall percentage of tree coverage.

<table>
<thead>
<tr>
<th>Cadastral Type</th>
<th>Number of parcels</th>
<th>Area of parcels (%)</th>
<th>Tree coverage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authority land</td>
<td>89</td>
<td>26.9</td>
<td>30.5</td>
</tr>
<tr>
<td>Casement</td>
<td>243</td>
<td>16.6</td>
<td>14.1</td>
</tr>
<tr>
<td>Private parcel</td>
<td>3707</td>
<td>56.4</td>
<td>18.8</td>
</tr>
<tr>
<td>Others</td>
<td>6</td>
<td>0.1</td>
<td>43.2</td>
</tr>
</tbody>
</table>

Table 15. Parcel level statistics in different cadastral types.

4. DISCUSSION

4.1 Integration of CNN and OBIA to Improve Image Classification Accuracy

This research demonstrates that the accuracy of image classification can be improved by using a combination of OBIA and CNN methods. Training CNN with automatically classified OBIA output of 90.6% overall accuracy (kappa coefficient 0.8) has improved the classification accuracy to 92.3% (kappa coefficient 0.83). Implementation of refinement algorithm to CNN output further improves the overall accuracy to 93.2% (kappa coefficient 0.85).

The results indicate that the overall accuracy of refined-CNN is better than CNN method alone even if it is computed by using automatically generated training samples (Table 3). Hence, this method can provide an alternative way to achieve improved accuracy in feature classification using automated OBIA output samples for training CNN.

However, object-based CNN method when trained with manually generated training samples if applied with very high-resolution multispectral imagery might produce better accuracy than this research (Csillik et al., 2018). But manual preparation of training samples might not be always feasible in terms of time and costs.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Type</th>
<th>Overall Accuracy (%)</th>
<th>Input Data</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>This study</td>
<td>Urban tree cover mapping</td>
<td>93.2</td>
<td>0.15m (R, G, B, and NIR band orthophoto), LiDAR</td>
<td>Object-based CNN; (CNN trained with automatically generated training samples using OBIA)</td>
</tr>
<tr>
<td>(Csillik et al., 2018)</td>
<td>Citrus tree identification</td>
<td>96.2</td>
<td>0.12m (R, G, Red edge, and NIR band UAV image)</td>
<td>Object-based CNN (CNN trained with manually generated training samples)</td>
</tr>
<tr>
<td>(Wang et al., 2018)</td>
<td>Identifying mango orchard flowering</td>
<td>86</td>
<td>VHR imagery and LiDAR data</td>
<td>R-CNN (CNN trained with manually generated training samples)</td>
</tr>
<tr>
<td>(Chen et al., 2017)</td>
<td>Identifying apples and oranges</td>
<td>83</td>
<td>UAV image</td>
<td>F-CNN (CNN trained with manually generated training samples)</td>
</tr>
</tbody>
</table>

Table 16. Summary of results from studies related to OBIA and CNN for vegetation analysis.

4.2 Tree Cover and Cadastral Types

The overlay of improved CNN output with cadastral parcel layer shows that 21.5% of the study area is covered by trees and this is more than that of urban tree coverage of many Australian cities including Melbourne (11% in 2012) and Sydney (15.5% in 2013) of Australia (City of Melbourne, 2012; City of Sydney, 2013). The private parcels which covers 56.4% of the study area has 18.8% of tree coverage which represents the half of overall tree coverage in the study area. But the authority land that covers 26.9% of total study area covers nearly 38.7% of total tree coverage (Figure 12). This means that the land owned, vested or managed by Commonwealth, State or Local Government authority has highest proportion of tree coverage. Having more urban tree coverage in study area means that the study area possesses wider social, aesthetic, climatic, ecological
and economic benefit from urban forest and trees. Also, the study area contributes to a better quality of living environment, for example by improving air quality and consequently the health of urban residents.

![Graph showing tree coverage area](image)

**Figure 5.1.** Percentage distribution of tree coverage area in different cadastral types.

## 4.3 Limitation of this Study

The main limitation in this research is the time difference between the used orthophoto (2015) and LiDAR dataset (2011). This could have introduced error in the analysis because the analysis uses CHM generated from the LiDAR dataset for identifying trees. This means, those trees that have been cleared in between the acquisition of LiDAR data (2011) and orthophoto (2015) may not have been classified as trees. On the other hand, those plantations done after the acquisition of LiDAR data and are taller than two metres during the orthophoto acquisition might not been classified as trees. Hence the result may have erroneously depicted the change in trees, planted, removed, or change in shape and textures.

## 5. CONCLUSIONS AND FUTURE WORK

The outcome of this research has two key contributions. First, the use of automatically generated training samples to train CNN model. Second, the application of combined CNN and OBIA method to map urban trees per cadastral parcel. In this context, this research demonstrates that the accuracy assessment of image classification can be improved by using a combination of OBIA and CNN methods. This spatial analysis can be used for multiple purposes including land management, urban planning and cadastral survey.

This research uses a simple CNN model with a single hidden layer. In future research, multiple hidden layers with a change in parameters can be applied and tested. Similarly, deeper CNN methods including Region-based CNN (R-CNN) and Fully-connected CNN (F-CNN) can be further tested for urban tree coverage mapping and tree species identification.

## ACKNOWLEDGEMENTS

We thank University of Tasmania for providing research facilities. We also thank Land Information System Tasmania for providing LiDAR point cloud and cadastral parcel datasets.

**REFERENCES**


POTENTIAL HABITAT MODELING OF WATER HYACINTH IN LAKES OF NEPAL USING MAXENT ALGORITHM

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KEY WORDS: Maxent Algorithm, Representative Concentration Pathway, Invasive Alien Plant Species, Water Hyacinth

ABSTRACT:

Invasive Alien Plant Species are spreading outside of their natural geographic range. Water hyacinth (Eichhornia Crassipes) is one of the most widely and rapidly spreading invasive species throughout the tropical and subtropical regions of Nepal. In the last decade, water hyacinth has become a chronic problem in many major lakes of Nepal which have affected the habitat aquatic plants and animals. Our study focuses on potential habitat modeling of Water hyacinth over the major lakes of Nepal using Maxent algorithm. Primary data used for modeling were 19 bioclimatic variables and Shuttle Radar Topography Model (SRTM) Digital Elevation Model (DEM). After preparation of the species distribution model, major lakes of Nepal were overlaid over the model to prepare potential invasive map. The performance and accuracy of potential habitat distribution model was evaluated using parameter Area under the Receiver Operating Characteristic Curve (AUC) which was within the range of 0.9–1. Validation of the model was done for the year 2015 with precision and recall, overall accuracy and F-measure and its values are 93% and 85%, 87% and 89% respectively. The model prepared for 2030 and 2050 shows the most suitable habitat for water hyacinth is in province 2 of Nepal and the moderately suitable habitat for this species is plain area of Province 4, 7 and 5. Similarly, the area of potential habitat has been increasing from current scenario to 2030 and 2050. From the potential invasion map, it can be observed that lakes in the Terai and Churey regions have the high risk of invasion of water hyacinth.

1. INTRODUCTION

Nepal’s biodiversity is a reflection of its unique geographic position, diverse climatic condition and the widest altitudinal variations where many species from anywhere of the world may find the suitable habitat and climatic condition in Nepal. An assessment was undertaken by IUCN Nepal during 2002-2003 about the invasive alien plant species (IAPS) and it has reported that that are at least 219 invasive alien plant species (Shrestha, 2016). Among them Eichhornia crassipes (water hyacinth) is the worst aquatic invasive plant species.

Water hyacinth (Eichhornia Crassipes) is an erect, free-floating, stoloniferous, perennial herb. It grows to 1m in height with buoyant leaves, which vary in size according to growth conditions. Water hyacinth is originally from South America and one of the world’s most prevalent invasive aquatic plants. Water hyacinth has invaded freshwater systems in over 50 countries on five continents. The vegetative propagation of water hyacinth is very rapid such that the two plants of water hyacinth could multiply to 120,000 in 120 days, while thirty offspring could be produced from two parent plants within 23 days (Verma, Singh, Ganesha Raj, 2003). If uncontrolled, it eventually blankets the water surface killing and displacing other aquatic plants and animals and creating a visually unappealing landscape. The presence of this alien invasive plant species may alter the aquatic habitat structure, by creating a homogeneous habitat, thereby negatively affecting biological communities (Thamaga, Dube, 2018).

Many environmental factors such as temperature, precipitation, soil and surface humidity plays an important role for the distribution of this species. Similarly, the change in climate has affected the growth and reproduction of plant and has become one of the dominating variables for determining the geographical distribution of plant species (Wei et al., 2018). So, the models predicting the potential geographical distribution of species are important for determining the invasion of species based on different climatic scenarios. Species distribution models (SDMs) are scientifically proven tools for assessing and predicting the impacts of climate change on flora and fauna. SDMs dealing with presence-only data might be more advantageous over presence/absence modeling methods, conditional to the suitability for the study such as Maxent (Phillips, Dudik, 2008). Maxent is a general approach for presence only modeling of species distributions, suitable for all existing applications involving presence-only datasets (Dube et al., 2015). This approach estimates the most uniform distribution (maximum entropy) of sampling points compared to background locations given the constraints derived from the data. The presence only data are good enough for species distribution modeling and the AUC scores obtained for predictions can be sufficiently accurate (Elith et al., 2006).

Over the last few decades, a lot of studies have been carried out species, quantifying economic and ecological impacts(Thapa et al., 2018). The studies were focused only on terrestrial invasive plant
species and its future prediction has not been practiced yet (Baidar et al., 2017). So, the major objectives of this study were i) to prepare the potential habitat modeling of water hyacinth in the lakes of Nepal in current and future scenario (2030 and 2050s) using Maxent algorithm; ii) to validate the potential habitat site of water hyacinth with current map using statistical measures; iii) to determine the important environment variables for the potential habitat of water hyacinth.

2. STUDY AREA

Nepal is a landlocked country located in South Asia with China in the north and India in the south, east and west. The country occupies 147,181 sq. km of land and lies in latitude from 26.4831 to 29.84121 and longitude from 80.33333 to 88.09436. Nepal has been one of the appropriate habitats for many invasive species. There is high concentration of IAPS on the southern half of the country (which includes Terai, Siwalik and Mid Hills running east-west) with tropical to subtropical climate (Shrestha, 2016). Growth of Water hyacinth has become one of the major problems over major lakes of Nepal and other fresh water bodies. In the last decade, water hyacinth has become a chronic problem in many major lakes of Nepal such as Phewa Lake, Khaste Lake, Ghodaghodi Lake, Bishazari Lake, etc. Figure 1 shows the study area along with major lakes of Nepal.

![Study Area: Major Lakes of Nepal](image)

Figure 52. Study Area: Major Lakes of Nepal

3. METHODOLOGY

3.1. Data Collection

The location information about the occurrence of water hyacinth was obtained from Google Earth platform. 146 sample points from different lakes and ponds were collected all over Nepal and the records were imported into Microsoft Excel and saved as “.CSV” format.

![Methodological Flowchart of Potential Habitat Distribution of water hyacinth](diagram)

Figure 53. Methodological Flowchart of Potential Habitat Distribution of water hyacinth.

We selected 19 bioclimatic variables from website (https://www.worldclim.org/bioclim) that may influence the distribution of water hyacinth. These bioclimatic variables have 30s (1 km) spatial resolution obtained from the world climate database for current year. Moreover, elevation is also major factor that affects the growth of water hyacinth. So, ASTER DEM of resolution 30 meter was downloaded from the website (https://search.earthdata.nasa.gov). Further the DEM was resampled...
to the resolution of 1 km. Figure 2 shows the overall workflow of this study.

To determine the future distribution of the water hyacinth under different climate trajectories, we used datasets of future climate from the Climate Change, Agriculture and Food Security (CCAFS) website (www.ccafs-climate.org). Representative Concentration Pathways (RCPs) (including RCP2.6, RCP4.5, RCP6.0 and RCP8.5) are four greenhouse gas concentration trajectories adopted by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (AR5). These pathways are used in climate modeling and research to describe four possible future climates, all of which are considered possible depending on how many greenhouse gases are emitted in the near future. However we selected RCP2.6 (the minimum greenhouse gas emission scenario) and RCP8.5 (the maximum greenhouse gas emission scenario) to model the potential habitat of water hyacinth in 2030 and 2050. All environmental data used in this model had a 30 second spatial resolution (also referred to as 1 km spatial resolution).

3.2. Current Habitat Distribution Modeling

Maximum entropy model (Maxent version 3.3.3) was used for the preparation of potential distribution model. This is well-suited distribution model for different species as it is easy to use as it works with presence only dataset. So, the sample points for this model where the species actually exist. For each species, 75% of the location point data were used as a training model, and the remaining 25% for validating the Maxent model(Zhang et al., 2018). The output of the Maxent was in ASCII format which was further transformed into raster format using the ArcMap tool in ArcGIS software for further analysis.

3.3. Determination of the key variables

After executing Maxent model for modeling current distribution Water hyacinth using 19 bioclimatic variables and SRTM DEM, the model resulted percentage contribution of each environmental variable for preparation of current distribution model. The variables which have contribution more than 0% were selected as key variables.

3.4. Validation

After preparing the current habitat distribution model, it is necessary to check the quality and accuracy of the model. For validation purpose, we prepared key bioclimatic variables of 2015 using precipitation data from CHIRP and land surface temperature (LST) from MODIS satellite imageries. Using these variables, potential habitat distribution model of year 2015 was prepared. Then the sample points were generated in the lakes of Nepal using stratified sampling method and calculated the true positive, true negative, false positive and false negative value in the specific area. With these values, overall accuracy, precision, recall and F-measure were calculated.

3.5. Future Potential Habitat Distribution Modeling

After using the current climatic data to model the spatial extent of suitable habitat for Water hyacinth, modeling projections were performed for four future climate scenarios (RCP2.6–2050, RCP8.5–2030, and RCP8.5–2050) to predict the extent of suitable habitat for the species in the future.

For evaluation of our output, several statistical analysis and tests were done. The robustness of evaluation for the Maxent model, threshold-independent receiver-operating characteristic (ROC) analyses was used. An area under the receiver-operating characteristic curve (AUC) was examined for additional precision analyses. The Jackknife test was used to assess the relative importance of the variables.

3.6. Area Calculation

The selected lakes were overlaid in the current and future habitat prediction model. Since the area covered by lakes was smaller than 1 sq. km, the raster model was resampled into 100 m and based on raster value of each pixel the habitat suitability area of each lake was determined.

4. RESULT AND DISCUSSION

4.1. Potential habitat distribution model of current year and its accuracy

Potential distribution of Water hyacinth for whole Nepal was done by using Maxent algorithm. Potential habitat distribution map was overlaid with provincial map of Nepal which would help to visualize potential habitat over different provinces in current year. The AUC training values were 0.973 and 0.96 for training and test sample points respectively, indicating the model performed well and generated excellent evaluation(Swets, 1988). Similarly, to validate the potential distribution model, the Maxent model was run for the year 2015. The sample points collected from Google Earth and environmental variables for the year 2015 were used to run the Maxent model. Figure 3 shows the potential habitat distribution model of current year in major lakes of Nepal and Figure 4 shows the potential habitat distribution model of 2015. Table 1 shows the shows precision and recall, overall accuracy and F-measures whose values are adequate as per the requirement of our study.

![Potential Habitat Distribution of Water Hyacinth in the Lakes in current year](image)

Figure 54. Potential Habitat Distribution of Water Hyacinth in the
Lakes in current year
4.2. Key Environment Variables

Using the Maxent model, the key variables that influence the potential invasion of water hyacinth were determined through the percent contribution values. Two variables digital elevation model and bio1 i.e., Annual mean temperature were identified as the variables conditions that contribute the most to water hyacinth’s potential distribution. Similarly, to get alternative estimates of which variables are most important in the model, a jackknife test was also run. The environmental variable with highest gain when used in isolation is Digital elevation model, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is bio14 i.e. Precipitation of driest month, which therefore appears to have the most information that isn’t present in the other variables. Table 2 shows the key variables that influence the invasion of water hyacinth are tabulated below along with its percentage contribution in current scenario. Figure 5 shows the jackknife test of different environmental variables.

![Figure 5. Potential Habitat Distribution of Water Hyacinth in 2015](image)

<table>
<thead>
<tr>
<th>Environment Variables</th>
<th>Percent Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Mean Temperature (BIO1)</td>
<td>10.4</td>
</tr>
<tr>
<td>Min Temperature of Coldest Month (BIO6)</td>
<td>7.4</td>
</tr>
<tr>
<td>Temperature Annual Range(BIO7)</td>
<td>2.1</td>
</tr>
<tr>
<td>Mean Temperature of Wettest Quarter (BIO8)</td>
<td>0.7</td>
</tr>
<tr>
<td>Mean Temperature of Warmest Quarter (BIO10)</td>
<td>2.7</td>
</tr>
<tr>
<td>Annual Precipitation (BIO12)</td>
<td>2.4</td>
</tr>
<tr>
<td>Precipitation of Driest Month (BIO14)</td>
<td>5.5</td>
</tr>
<tr>
<td>Precipitation of Warmest Month (BIO18)</td>
<td>3.2</td>
</tr>
<tr>
<td>SRTM DEM</td>
<td>65.8</td>
</tr>
</tbody>
</table>

Table 18. Key Variables along with its percent contribution

4.3. Potential Habitat Distribution in year 2030 and 2050 A.D.

From the important key variables, the potential habitat distribution model for year 2030 and 2050 was prepared. Selected bioclimatic
variables were defined by two Representative Concentration Pathway; they were RCP 2.6 and RCP 8.5 as these pathways defines extremities of emission scenarios of greenhouse gases over time. Using these bioclimatic variables along with SRTM DEM was used and following potential distribution maps were prepared. Figure 6 and 7 show the potential habitat distribution under RCP 2.6 and RCP 8.5.

![Figure 57. Potential Habitat Distribution under RCP 2.6](image)

![Figure 58. Potential Habitat Distribution under RCP 8.5](image)

![Figure 59. Potential Habitat Distribution of Water Hyacinth in the lakes of Nepal in year 2030 under RCP 2.6](image)

![Figure 60. Potential Habitat Distribution of Water Hyacinth in Major lakes of Nepal in year 2030 under RCP 8.5](image)

![Figure 61. Potential Habitat Distribution of Water Hyacinth in the lakes of Nepal in year 2050 under RCP 2.6](image)

![Figure 62. Potential Habitat Distribution of Water Hyacinth in the lakes of Nepal in year 2050 under RCP 8.5](image)

The model performance of future potential model distribution was analyzed based on its AUC value. The AUC value for both year 2030 and 2050 is in between 0.9-1 which shows that the model performs excellent and generate excellent evaluation (Baldwin, 2009). Table 3 shows the AUC value for year 2030 and 2050 under RCP 2.6 and 8.5 respectively.
Table 19. AUC value for year 2030 and 2050

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Year 2030</th>
<th>Year 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RCP2.6</td>
<td>RCP8.5</td>
</tr>
<tr>
<td></td>
<td>Training</td>
<td>Test</td>
</tr>
<tr>
<td>AUC Value</td>
<td>0.97</td>
<td>0.97</td>
</tr>
</tbody>
</table>

The potential distribution maps were categorized into four categories based on suitability: highly suitable (>60%), moderately suitable (60%-40%), Low suitable (40%-20%) and unsuitable (<20%). Zhang et al., 2018. Table 4 and 5 shows the potential habitat area of water hyacinth in the major lakes of Nepal in current and future scenario under RCP 2.6 and 8.5.

Table 20. Potential Area of Water Hyacinth in the lakes in current and future scenarios under RCP2.6.

<table>
<thead>
<tr>
<th>Lakes</th>
<th>RCP 2.6</th>
<th>Year 2030</th>
<th>Year 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rara</td>
<td>0.56</td>
<td>0.94</td>
<td>0.97</td>
</tr>
<tr>
<td>Phewa</td>
<td>0.97</td>
<td>0.97</td>
<td>0.94</td>
</tr>
<tr>
<td>Begnas</td>
<td>0.26</td>
<td>0.26</td>
<td>0.12</td>
</tr>
<tr>
<td>Bishajari</td>
<td>0.48</td>
<td>0.48</td>
<td>0.26</td>
</tr>
<tr>
<td>Gosaikunda</td>
<td>0.12</td>
<td>0.12</td>
<td>0.06</td>
</tr>
<tr>
<td>Ghodaghodi</td>
<td>0.12</td>
<td>0.12</td>
<td>0.06</td>
</tr>
<tr>
<td>Khaste</td>
<td>0.12</td>
<td>0.12</td>
<td>0.06</td>
</tr>
<tr>
<td>Rupa</td>
<td>0.12</td>
<td>0.12</td>
<td>0.06</td>
</tr>
<tr>
<td>Dashrath</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Table 21. Potential Area of water hyacinth in the lakes in current and future scenario under RCP8.5.

<table>
<thead>
<tr>
<th>Lakes</th>
<th>Total</th>
<th>Unsuitable</th>
<th>Low suitable</th>
<th>Moderately suitable</th>
<th>Highly suitable</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.04</td>
<td>0.07</td>
<td>1.2</td>
</tr>
<tr>
<td>Rara</td>
<td>10.56</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phewa</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Begnas</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bishajari</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gosapundha</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ghodaghodi</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Khaste</td>
<td></td>
<td>-</td>
<td>-</td>
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<tr>
<td>Rupa</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dashrath</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gangasagar</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The result shows that the major lakes of Nepal like Rupa Lake, Khaste lake, Phewa Lake and Begnas Lake which are situated in Province 4 have suitable habitat of water hyacinth and in the future scenarios these lakes have been shown as the major habitat of this species. Similarly, the water bodies which are situated in Terai region such as Dashrath and Ganga Sagar has the major suitable habitat of water hyacinth in current and future scenario and the area covered by the species from RCP 2.6 to RCP8.5 is increasing. This is because greenhouse gases emission under RCP 8.5 is more which results higher carbon contain in atmosphere and higher pollution contain in water bodies which enhance growth of water hyacinth.

From the potential invasion map, it can be observed that lakes in the Terai and Churey areas have the high risk of invasion. The hilly and Himalayan areas of Nepal are colored in mostly green and somewhat blue indicating lower risk of invasion. It is because water hyacinth is strongly damaged by frost, and the growth rate is greatly reduced at temperatures below 10 °C. This is reasonable with the sample points that we collected showed high level of presence of water hyacinth in plain areas that any other land cover. Plain areas are more affected because the weeds get the required temperature and moisture for its proper growth. Also the main reason behind its growth is water pollution; in these areas the pollution rate is very high which also influence its growth rate.

The potential invasion model prepared for current, 2030 and 2050 shows that major possibility of water hyacinth invasion in Rupa Lake, Begnas Lake, Phewa Lake, Khaste Lake which is situated in Province 4, Bis Hazari Lake in Province 3, Ghodaghodi Lake in Province 7 and Dasrat Pokhari and Ganga Sagar Pokhari in Province 2. The model prepared for 2030 and 2050 shows the most suitable habitat for water hyacinth is seen in province 2 of Nepal and the moderately suitable habitat for this weed is plain area of Province 4, 7and 5. Similarly, the area of potential habitat has been increasing from current scenario to 2030 and 2050. So, in the future scenarios the invasion rate of water hyacinth is very high which might pose a threat to the native ecosystems in Nepal.

5. CONCLUSION

This study indicates that the habitat distribution pattern of water hyacinth could be modeled through Maxent using its occurrence records and 9 environmental factors in current and future scenario. The result shows that the highly suitable habitat of water hyacinth has been increased under future climate change scenarios in (RCP2.6 and RCP8.5) in 2030s and (RCP2.6 and RCP8.5) in 2050s. The Terai and Churey range of Nepal have the highest invasion rate and the lakes within this area have been shown as the highly suitable habitat of water hyacinth.

Other environmental factors like are sunlight radiation, water contamination and wind speed that are need to be considered for predicting the suitable habitat of water hyacinth. So, incorporating these environmental factors on predicting the suitable habitat of water hyacinth is highly recommended for better analysis.

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SPATIAL BIODIVERSITY MODEL TO CHARACTERIZE BIOLOGICAL DIVERSITY USING R STATISTICAL COMPUTING ENVIRONMENT FOR NEPAL HIMALAYA

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KEY WORDS: Multi-criteria Decision Analysis, Spatial Biodiversity Model, Biodiversity Characterization

ABSTRACT:

Biodiversity characters of the landscape provide basis of prioritizing the sites in conservation effort. There is an urgent need for rapid assessment of existing biodiversity using state-of-art tools and technologies at large scale. The purpose of the study is to model and prioritize biological richness based on multi-criteria decision analysis (MCDA) for conservation priority and management planning. Vegetation type map for year 2017 was developed for generation of various landscape indices e.g. fragmentation, patchiness, porosity, juxtaposition etc. The Spatial Biodiversity Model (SBM) prepared for similar landscape of Uttarakhand, India which is scale, resolution and location independent for spatial biodiversity richness modelling was executed in R programming platform. Satellite data, non-spatial data and ancillary data were used to generate Biological Richness (BR) map which is categorized into 4 classes as low, moderate, high and very high (biiodiversity rich) including non-forest area to quantify BR area. The result shows that largest area is under very high biological richness class followed by high, moderate and low BR area. Overall accuracy and Kappa Statistics of LULC/vegetation type classification is 82.61% and 0.8013 respectively. The spatial regression analysis for final output validation has been made with ground based species diversity data where R2 value for Shannon-Wiener index and Margalef’s diversity index are 0.64 and 0.56 respectively. The results also re-emphasize the role of geospatial techniques in the quick appraisal of predicting biological richness. The study result is applicable in systematic inventory of biological resources, land use planning, conservation prioritization and policy support.

1. INTRODUCTION

Increasing human intervention and excessive exploitation of resources have resulted in great changes and provide alarming signals of accelerated biodiversity loss (Roy and Tomar 2000). Due to immense pressure on biological resources, mainly to drive the global economic engine, the global biodiversity is under tremendous threat (Gordon et al., 2011; Kersebaum et al., 2015). Climate change impacts are becoming increasingly evident in the Himalayan region (Shrestha et. al., 2012, Zomer et. al., 2014) which has profound implications for mountain communities (Ebi et. al., 2007), its biodiversity including major non-timber forest plants (Chitale et. al., 2018), ecosystem services (Beniston 2003), water resources (Immerzeel et. al., 2010), agricultural systems (Maikhuri et. al., 2001), and both regional and global climate processes. In the present scenario, with the extinction rate in most areas overtaking the process of biodiversity inventory, there is an urgent need for rapid assessment of biodiversity which is robust and is replicable over large area (Sing et. al., 2017). Landscape ecology seeks to understand the ecological functions of larger areas and hypothesizes that spatial arrangement of ecosystems, habitats or communities has ecological implications (Romme, Knight, 1982; Turner, 1987). Distribution of biodiversity is mainly a function of climatic conditions, edaphic and topographic regimes which are perfect for speciation (Beltrán et. al., 2014; Zhai et. al., 2015). The mosaic of natural areas and land use provide the scenario for loss of the endemic species due to reduced population size in the remnant patches as well as create conditions for exotic species to invade new areas (Prasad et. al., 2010; Roy et. al., 2016). This provides a unique opportunity to use the land use ad land cover (LULC) and the geographical variability of biodiversity to model the spatial distribution of the biodiversity.

There have been numerous approaches (Behera, Roy, 2010; Orsi et. al., 2011; Wilson et. al., 2016, Myers et. al., 2000; Roy, Tomar, 2000) to quantify the biological diversity using empirical approaches like biodiversity hotspots. Recently, the application of general ecological model (Harfoot et. al., 2014; Yu et. al., 2016) to simulate the global patterns of ecosystem structure and function to reflect the biodiversity has been used at a global level. But these models are generally coarse and are not able to capture the spatial variability of the biodiversity distribution. An innovative work was done by Roy et. al. (2012) to model the spatial distribution of biodiversity in Indian landscape in a GIS based model using remote sensing and ground based inputs. But this approach is scale dependent and also has some limitations to address the spatial distribution of biodiversity at high resolution and site specific variability in the specification process.

Hence, there is need for platform independent, open system model architecture with respect to the technological advancements and community participation for continuous upgradations of various scientific algorithms. In this study, we have modeled and prioritized pattern of biological richness through fragmentation and biotic disturbance gradients using spatial biodiversity model (SBM) in R programming platform (R Development Core Team, 2015) for conservation priority and other management decision. The SBM was successfully applied

* Corresponding author
in similar landscape of Uttarakanda State of India by Singh et al., 2017 as a platform independent solution using open system architecture.

2. MATERIALS AND METHODS

2.1 Study site

The study site is located in the western Nepal and stretched between 28°04’20” and 28°47’03” N and 83°07’00” and 84°42’40” E having geographical area of 6,042 Sq. km. The altitude of the landscape have an extreme topographic variation ranging from 346 m in south to 8,147 m in the North. It consists of world’s deepest gorge, the Kali Gandaki Gorge (6967 m deep). Fig. 1 represents the area selected for the study. Out of 19 districts under Chitwan-Annapurna Landscape (CHAL), current research site is in 3 districts viz: Myagdi, Kaski and Lamjung districts. The CHAL is a priority due to the urgency of conserving hydrological flows in the major river basin and of creating north-south corridors for seasonal migrations. In 1999, the CHAL was identified as a conservation landscape to maintain north-south ecological connectivity between Chitwan National Park (CNP) in the south and Annapurna Conservation Area (ACA) in the north. The landscape depicts high diversity of plants and is currently facing threats of degradation due to over-exploitation of natural resources as a result of anthropogenic pressure (Silwal et al., 2018). There hasn’t conducted similar study yet. Hence, the landscape is selected to characterize biological diversity for conservation prioritization and management decision.

2.2 Datasets and model

This study has utilized satellite Remote Sensing data, non-spatial data and ancillary data to generated vegetation type maps, forest fragmentation maps, disturbance maps, and biological richness maps in R statistical computing environment. The spatial biodiversity model (SBM) developed for similar landscape of Uttarakanda, India was used in this study. Geospatial analysis was carried out in R, ArcMAP, ENVI and ERDAS IMAGINE.

2.2.1 Satellite Remote Sensing Data

Landsat 8 Operational Land Imager (OLI) images of latest two seasons (April and November 2017) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) with 30m horizontal resolution were retrieved from USGS earth data portal (NASA/METI/AIST/Japan Space systems, and U.S./Japan ASTER Science Team 2018). Because of specified cloud free data were not available, the best available archived data i.e. below 10% cloud covered data were used.

2.2.2 Field inventory data and ancillary data

The phytosociological data of 86 geo-tagged field sample plots encompassing the different forest strata of Myagdi, Kaski and Lamjung districts was used for validation of the output of the study. The field inventory was carried and phytosociological data was generated for forest carbon assessment in CHAL, Nepal (ICIMOD 2016). The road network and settlement locations was created from OpenStreetMap using public participation on web. Census data was retrieved from https://geonode.wfp.org.

2.3 Model description and flowchart

The Spatial Biodiversity Model (SBM) established by Singh, et al. (2017) for Uttarakhand state of India was executed using R statistical computing environment which allows to include more user defined indices as per the requirements of the study landscape (R Development Core Team, 2015). The model has four different components i.e. (i) Input: Primary and secondary data sets e.g. vegetation types map derived from multi-season satellite data (Landsat 8 OLI), socioeconomic data e.g. road network, settlement locations, census data etc., field sample plot species data, DEM from ASTER GDEM data and user defined additional landscape parameters e.g. kernel size, vegetation type classes etc. (ii) Spatial Biodiversity Model (SBM): It is core engine having two level of data processing. Level 1 data processing includes computation of spatial landscape parameter and indices and terrain complexity parameters. Level-2 data processing includes derivation of Disturbance Index (DI) map using multi-criteria decision analysis and sensitivity analysis, (iii) Changing process: Output of DI, terrain complexity (TC), species richness (SR), biodiversity value (BV) and ecosystem uniqueness (EU) was used as input parameters to derive Biological Richness (BR) map of study area. (iv) Output validation: The validation was carried out based on spatial correlation method using field sample plot data.

Multi-criteria decision making (MCDM) and a wide range of related analytical techniques offer a variety of decision making processes to expose and integrate choices with available MCDM methods in order to solve “real-world” GIS-based planning and management problems (Karnatak et al., 2007). In this study, spatial landscape modelling approach was adopted based on highly suitable spatial landscape indices namely fragmentation (edge index), patchiness, porosity, interspersion, juxtaposition, biotic interference (road, settlement), population density, species richness, ecosystem uniqueness and biodiversity values using open source and platform independent environment. A spatial model incorporating ground based biodiversity attributes of the landscape elements, vegetation types/LULC patterns, disturbance regimes of the landscape and terrain complexity have been used to delineate the spatial pattern of BR. Overall research flowchart is presented in fig. 2.

2.3.1 Spatial landscape indices

The application of the spatial landscape indices is to quantify landscape pattern to reflect its capability to support specific ecosystem functions. Distribution of biodiversity is the function of the climate, topography and the external factor in the region. If topography and climate remain constant, variability in a landscape influences the distribution of biodiversity in space in which biotic interference plays vital role. Spatial indices provide...
The suitability of the indices i.e. fragmentation, patchiness, porosity, interspersion, juxtaposition, human disturbance, population density, terrain complexity, species richness, ecosystem uniqueness and biodiversity value was based on the evaluation of the importance in biodiversity distribution derived from available relevant literature. Spatial biological richness modelling was carried out for CHAL landscape of Nepal using landscape indices and it was first and historic work in this domain till date. The suitable spatial indices was designated and implemented using R programming language and statistical computing environment.

2.3.2 Analytic hierarchy process

Analytic hierarchy process (AHP) is a decision-making technique utilized for solving complex problems, with many parameters of interrelated objectives or concerned criteria (Rimba et al., 2017). Based on separability analysis of different communities in various vegetation types, associated topographic variability, and socio-economic parameters, a knowledge base of weightages for computation of landscape indices e.g. juxtaposition is developed by normalizing it using AHP (Chen et al., 2013; Karnatak et al., 2007; Prakash, Barua, 2015; Saaty, 1977). The developed model is run after parameterizing the above mentioned inputs (Fig. 2) to generate the various landscape indices required for level-2 processing.

The level-2 data processing of the model includes derivation of DI map using AHP based multi-criteria decision analysis for generation of BR map. At this stage, the model derives fragmentation (edge index), patchiness, porosity, interspersion, juxtaposition, human disturbance (Euclidean distance: road, settlement) and population density as landscape parameters. However, additional user defined parameters can also be included based on study area and availability of data sets. The linear combination of weights and landscape parameters are used to compute DI of study area. The model also computes the variability in terrain complexity using parameters such as slope, aspect and elevation which are derived from ASTER GDEM.

As an intermediate result, the DI is computed via linear additive method which is given below:

\[ DI = Fr \times Wt + Pa \times Wt + Pr \times Wt + Ir \times Wt + It \times Wt + Ed \times Wt + Pd \times Wt \]  

(1)

Where, \( Wt \) (t=0-1.0) are the weightages computed through AHP.

Finally, the BR map is computed via linear additive method:

\[ BR = TC \times Wt + SR \times Wt + EU \times Wt + BV \times Wt + DI \times Wt \]  

(2)

where, \( Wt \) (t=0-1.0) are the weightages computed through AHP.

According to Equation (2), BR input parameters have been selected based on the study objectives, data availability and spatial scale as the base parameter for the model. Moreover, there is a facility in SBM to include new parameters, as per user requirement. Thereafter, all judgments have been made by the decision maker and all pairwise comparison matrices have been determined to quantify AHP process. In order to derive a significant interpretation of the consistency ratio, the threshold value of evaluation criteria was computed following Saaty’s (1980) principle.

2.4 Pre-processing satellite images

Layer stacking is the process of “stacking” images from the same area together in order to form a multilayer image and spectrally image enhancement. For layer stacking, of the OLI sensor with individual bands from 2 to 7 was extracted and stacked respective row and path spectral bands. The study area is present in zone 45 of Universal Transverse Mercator (UTM) coordinate system, World Geodetic System (WGS) 84.

Image enhancement is the technique by which the low contrast of satellite images is improved to make the image more interpretable. ‘Standard deviation stretch’ is the algorithm to enhance image contrast and the spectral behavior of the satellite imagery. The magnitude of the enhancement depends on the standard deviation value defined by the analyst. The ‘Standard deviation stretch’ algorithm was used to improve the image contrast to identify the classes (Hashimoto et al. 2011). An interval value between –2.5 to +2.5 standard deviations from the mean of the existing pixel values was used in this study. This stretched the values to the complete range of output screen values. In addition, the study used the contrast brightness utility of ERDAS IMAGINE to enhance visual details of the satellite images.

2.5 Vegetation types classification approach

The vegetation type can be defined as an embodiment of unique physiognomy, structure, and floristics (intrinsuc factors), influenced by the climate, topography, and anthropogenic factors (extrinsic factors). Champion, Seth’s (1968) classification scheme follows a hierarchical approach wherein climatically driven forest ecosystems systems with distinct physiognomy and phenology are primarily classified as type groups. These type groups are further subdivided into sub-groups based on dominant compositional patterns and region and location specific formations controlled by edaphic and disturbance conditions. Stanton (1972) recognized 35 forest types on the basis of detailed floristic studies and classified into 10 major groups in Nepal. The existing classification systems precisely used ground data in deciphering the patterns of species assemblages but did not provide the explicit spatial boundaries of these assemblages. Such spatial explicit boundaries of vegetation types are important for studying the patterns of vegetation diversity and long-term monitoring. The delineation of such boundaries for larger spatial extents based on geospatial tools and field information have become time and cost effective. Two-season Landsat 8 OLI images of 2017 were utilized optimally to map the vegetation types depending on the forest
phenology, i.e., leaf fall and peak growth seasons. Satellite data pertaining to the time windows of November and April were used to take into account the phenological variations required for delineation of different vegetation types.

The on-screen visual interpretation technique using maximum likelihood classification (MLC) and support vector machine (SVM) classifiers were selected for the land cover classification of OLI data. The Google Earth Map and altitude zone maps were used to define classes. Wherever necessary, field data were used to delineate the vegetation type and locale-specific classes. The MLC has been the most popular parametric classifier used for remote sensing data classification (Foody et al. 1997; Jia et al., 2011). The MLC assumes that a hyper-ellipsoid decision volume can be used to approximate the shape of the data clusters. Moreover, for a given unknown pixel, the probability of membership in each class is calculated using the mean feature vectors of the classes, the covariance matrix and the prior probability (Duda, Hart, 1973). The unknown pixel is considered to belong to the class with the maximum probability of membership. The SVM classifier is the most widely used non-parametric statistical learning classifier with no assumptions made regarding the underlying data distribution. This method typically performs better in land cover classification studies (Pal, Mather, 2005; Pal, Foody, 2012, Foody, Mathur, 2004). The surface reflectance value of bands 2, 3, 4, 5, 6 and 7 of OLI data were used for land cover classification using MLC and SVM classifier.

2.6 Vegetation types classification accuracy

To validate the land cover classification performance using OLI data, the classification results using the MLC and SVM classifiers were assessed via visual observations and quantitative classification accuracy indicators. Randomly selected sample pixels were used to quantitatively assess the land cover classification accuracy. The total sample pixels used for the classification accuracy estimation were 6150 pixels for forest, 3607 pixels for snow, 1580 pixels for water body, 386 pixels for built up area, 278 pixels for agriculture, 680 pixels for barren land and 1679 pixels for reject class e.g. shadow and cloud. The overall classification accuracy, producer’s accuracy, user’s accuracy and Kappa statistics were then estimated for quantitative classification performance analysis (Congalton, Green, 1999, Foody 2013, Tso, Mather, 2001, Foody 2009).

2.7 Model validation

The spatial BR map can be validated with ground based species diversity information (Shannon-Wiener index) of the study landscape. The phytosociological data collected by ICIMOD as part of Forest Carbon Assessment in CHAL landscape project using RS and GIS (ICIMOD, 2016) was used to compute the Shannon-Wiener index (Shannon, 1948) for individual field plot (80 permanent sample plots representing cold alpine semi-desert to sub-tropical humid climates) of 15.45 m radius plots for tree, 5.64 m radius sub-plots for saplings, 2.82 m radius sub-plot for shrubs and 1 m radius sub-plot for counting regeneration/seedling. Correction for the slope was applied whenever required. Shannon-Wiener index values were plotted against BR map values and correlation coefficient for herbs, shrubs and tree diversity was observed. The higher the $R^2$ values, the better the model fits user’s field data. The regression curve represents the actual condition reflecting variation in the compositional structure of the plant species communities with the varying levels of the BR index map.

3. RESULTS

3.1 Vegetation types and land use

The sum total of vegetation types and land use for 2017 consist of 13 classes viz: Tropical Moist Deciduous Forest, Subtropical Broadleaved Hill Forest, Sub-Tropical Pine Forest, Montane Wet Temperate Forest, Himalayan Moist Temperate Forest, Sub-alpine Forest, Dry Alpine Scrub, Barren land, Agriculture, Built up area and Settlement, Waterbody, Snow and reject class (Shadow and Cloud). The predominance of forest land is evident, constituting 50.80% of the total geographical area followed by snow (17.11%), agriculture (15.22%), barren land (15.09%), settlement (0.99%), waterbody (0.58%) and reject class (.20) (Fig. 3).

![Figure 3. Vegetation types and land use map of 2017](image)

3.2 Species composition in forest types

Tropical Moist Deciduous Forest is distributed in the southern belt of Lamjung and Kaski districts along the Siwaliks where dominated species was Shorea robusta. The sub-btropical broad leaved forests is dominated by Schima wallichii and Castanopsis indica and associate species are Phylanthus emblica, Lagerstroemia parviflora etc. (Silwal et al., 2018). Subtropical pine forests are characterized by Chir pine (Pinus roxburghii). In Monte Wet Temperate Forest, dominated species in lower mountain region are Quercus lamellosa, Castanopsis tribuloides, Lauraceae spp. whereas Quercus semecarpifolia, Acer spp and Rhododendron spp. dominated in the upper area. Pinus wallichiana, Abies spectabilis and Tsuga dumosa dominated in the Himalayan Moist Temperate Forest. Abies spectabilis, Betula utilis and Rhododendron species are the key species of the Sub-Alpine Forest. Common species of the Dry Alpine Scrub are Juniperus spp. and Rhododendron spp in the study landscape.

3.3 Forest Fragmentation index
The derived map is representing forest and non-forest area. The moving window size of 11x11 pixel was used to model fragmentation map using R statistical computing platform. The computed forest fragmentation (edge index) map (Fig. 4) has integer values ranging between 0 and 100. Based on natural breaks classification, fragmentation map is categorized into 4 classes as low (dense forest), moderate, high and very high including non-forest area to quantify forest habitat fragmentation and increase in forest edge within the study area. Low class corresponds to dense forest and very high class is highly fragmented landscape. Shrinkage of core forest patches is the biological diversity indicator of increasing forest degradation and fragmentation. The highest percentage of geographical area is covered by dense forest and followed by moderate fragmentation, high fragmentation and highly fragmented forest area.

### 3.4 Disturbance index

The prediction of the spatial pattern of landscape disturbance map is an important requirement for characterizing biological diversity. The computed DI map (Fig. 5) has integer pixel values ranging from 0 to 100. On the basis of the natural breaks classification, the DI map is categorized as forest, low, moderate, high and very high for identifying the spatial characteristics and extent of anthropogenic disturbance affecting the forest in study area. The forest corresponds to very low disturbed class and very high is highly disturbed region. The derived DI map is depicting the regions of high disturbance as well as forest edges. DI map showed that highest percentage of geographical area is under low disturbance class and followed by moderate disturbance class, high disturbance class and very high disturbance class respectively.

### 3.5 Biological richness

The biodiversity value, species richness and ecosystem uniqueness were generated with the field sample plot data and knowledgebase. The terrain complexity data was computed as weighted function of aspect, slope, elevation and their weighted spatial variability. The BR map is computed as linear weighted additive method of biodiversity value, species richness, terrain complexity, ecosystem uniqueness and DI.

The computed BR map has integer pixel values ranging from 0 to 100. Based on natural breaks classification, BR map (Fig. 6) are categorized into 4 classes as low, moderate, high and very high including non-forest area to quantify the biodiversity rich area. The BR map predicted highest area under very high BR class, followed by high BR class, moderate BR class and low BR class. Statistics of percentage of area distribution is depicted in bar graph (Fig. 7).

### 3.6 Accuracy assessment

The overall accuracy of the vegetation type classification, assessed on the basis of field sample plot data was 82.61% and Kappa Statistics of 0.8013. The spatial BR map is validated with...
ground based species diversity information (Shannon-Wiener index and Margalef diversity index) of the study area. The phytosociological data collected from field as part of Forest Carbon Assessment of CHAL level using RS&GIS (ICIMOD 2016) was used to compute the Shannon-Wiener index (Shannon, 1948) and Margalef diversity index (Margalef, 1958) for individual field plot (86 sample plots representing the different ecosystem of the study area). The Shannon-Wiener index values and Margalef’s diversity index value have been plotted against BR map values separately and the correlation coefficients for the tree diversity have been observed to be 0.64 and 0.56 as shown in Fig. 8 (a) and (b) respectively.

4. DISCUSSION
Shrinkage of core forest patches is an indicator of increasing fragmentation. The loss of biodiversity has been attributed to the destruction of habitat, isolation of fragments of formerly contiguous habitats and edge effects within a boundary zone between forest and deforested areas. With increase in the anthropogenic degradation of the natural areas, there is a need for periodic and rapid assessment of the biodiversity distribution across the landscape. CHAL is considered significant for biodiversity conservation because of its floristic richness and high level of endemism. A national level study carried by Reddy et al. (2017) show that the land cover legend for 2014 is consisting of 21 classes, i.e. tropical dry deciduous sal forest, tropical moist deciduous sal forest, subtropical broad-leaved forest, subtropical pine forest, lower temperate broad leaved forest, upper temperate broad leaved forest, lower temperate mixed broad leaved forest, upper temperate mixed broad leaved forest, temperate needle leaved forest, subalpine forest, planation, tropical scrub, subtropical scrub, temperate scrub, alpine scrub, grassland, agriculture, water bodies, barren land and settlements. Current study assesses 13 LULC classes including 7 forest types where about 50% area is under forest in the landscape. According to the study of Reddy et al., 2017, the predominance of agricultural land is evident, constituting 28.2% of the total geographical area followed by forest (26.8%). The overall loss of dense forest is high as compared to open forest. The loss of an area of 1768 Km² (6.9%) of dense forest was found from 1975 to 2014 in Nepal (Reddy et al., 2017). Tropical deciduous sal forests show more spatial changes followed by Subtropical broad leaved forest from 1975 to 2014 in Nepal. Regarding the historical fragmentation, the total number of forest patches increased from 1930 to 2014. (Reddy et al., 2017). Current research finding shows that more than 18% forests of the landscape is affected by anthropogenic disturbances, which in turn affect the biological richness of the landscape. This study found that the main cause of disturbance in forest is anthropogenic activities i.e. grazing, lopping, felling for timber extraction, forest fire, forest road and encroachment in the study landscape which is in line with DFRS, 2015. This has resulted in the fragmentation of the landscape and the loss of many endemic species. The progressive fragmentation might have significant ecological implications for species dependent on interior regions of forest patches (Echeverría et al., 2006).

5. CONCLUSION
Proper documentation of biological resource is essential for conservation and sustainable use of natural wealth in the benefit of mankind (Tangle, 1990). This study provides spatial information on fragmentation, disturbance and biological richness of study site. Approximately 50% area is under forest which ensure high potential of biodiversity in the landscape. Fragmentation and disturbance area under high to very high class is about 15% and 5% respectively and still greater than 18% area is under BR area.

6. RECOMMENDATION
The existing databases on floristic and detailed ecological and edaphic databases relating to selected few study areas are not geo-spatially linked. The absence of a spatially linked database of plant population structure, population dynamics, and abiotic driving and driven variables and other limiting factors makes it difficult to characterize, monitor and conserve species. Nepal is representative of the land cover diversity in the Hindu Kush Himalayas region. The HKH region has been identified as a blank spot for data by the Inter-Governmental Panel on Climate Change, indicating the need to develop regional database and sharing mechanisms (Sharma et. al., 2010). In this context, this study provides spatial information on fragmentation, disturbance and biological richness of study site. Result of this study is expected to contribute in systematic inventory, conservation prioritization and management decision of forest resources in the study landscape. Finally, up scaling of the similar research covering large extent in Nepal and beyond the boarder is recommended.

ACKNOWLEDGEMENTS
The first author gratefully acknowledges Centre for Space Science and Technology Education in Asia and the Pacific (CSSTEEP) for financial support during the study. The authors are thankful to the Director, Indian Institute of Remote Sensing, ISRO and CSSTEEP Dehradun, India for his support during the study. The authors are thankful to ICIMOD for providing the field data.

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COMPARISON AND SUITABILITY ASSESSMENT OF SLOPE CALCULATION ALGORITHMS ON DIFFERENT TERRAINS USING AERIAL SURVEY

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* Corresponding author  


KEY WORDS: ANOVA, Post-Hoc, IBM SPSS, Slope Calculation Algorithms, Aerial Survey, QGIS

ABSTRACT:

Digital Elevation Models are one of the important datasets of any Geographic Information System (GIS) and so are the parameters derived from them. One such parameter is slope, whose accuracy can have a significant effect on many engineering and construction works. This paper addresses the eight-slope calculation methods that are currently available to calculate slope value from a DEM and compares how these methods work on different slope range and values. These methods were applied to calculate slope from DEM of 30m. To determine the method that calculates the most accurate slope value for a particular slope range by comparing them with actual slope value is the main objective of this paper. The methods 2FD, 3FD, 3FDWRD, Average Neighborhood, Constrained Quadratic Surface and FFD has given similar results across all slope range while the algorithms that appears to yield the most varying results are Maximum Max and Simple D. In addition, it is observed that the choice of algorithms is more important when grade slope is less than 10 percent. However, for terrains with above 10 percent slope, the choice of algorithms seems less important with only a difference of approximately 0.5 gradient.

1. INTRODUCTION

Geographic Information Systems (GIS) offer a cost-effective way to analyze and inventory Digital Elevation Model (DEM). Aerial survey is one of the many ways to obtain field data for the DEM generation and has been used during the research. Different parameters can be derived from DEM, and one such parameter that has been used in this project is slope. Slope is a metric that is essential to describe surface processes, including overland flow, sediment transport and soil erosion and needed during locating a hydropower plant. The application of slope is endless. The accuracy with which the slope of an area is calculated and used for any projects can have an impact on the output of those project.

There are several different mathematical computational algorithms used to calculate slope from a DEM. The analysis of the different slope calculation methods is an essential as it may create vast effects on many engineering and construction works. Every slope calculation method is different from the other and its working mechanism may suit for certain slope range over others. Eight Slope calculation methods has been used in the project to calculate the slope from DEM. All eight algorithms are developed using different techniques and considerations so the question arises whether they give different slope values while calculating slopes of different terrains or they give same results across different terrain surfaces? Therefore, this project compares the results of the slopes generated applying different algorithms using statistical testing and assess the suitability of each algorithms in different classified slope surfaces. Among many methods of slope calculation, the ArcGIS uses the Average neighborhood method to calculate the slope from DEM. It uses a 3×3 cell size and the cell window contains eight neighboring elevations.

1.1 Slope Calculation Methods

At every point in a DEM the slope can be defined as a function of gradients in the X and Y direction:

\[
\text{Slope}_{\text{radian}} = \arctan\left(\sqrt{f_x^2 + f_y^2}\right)
\]

Where, \( f_x \) is slope in x-direction and \( f_y \) is slope in y-direction

The key in slope estimation is the computation of the perpendicular gradients \( f_x \) and \( f_y \). Different algorithms, using different techniques to calculate \( f_x \) and \( f_y \) yield the diversity in estimated slope. The common approach when estimating \( f_x \) and \( f_y \) is by using a moving 3×3 window to derive the finite differential or local polynomial surface fit for the calculation. Methods 1, 3 and 4 are methods based on approximation of differential operators by finite differences. Method 2 compares the central elevations with its eight neighbors, adopting the largest. Eight methods used for calculating slope from DEM obtained after processing of images obtained from aerial survey are:

All these methods work on a moving window of DEM. Let’s assume the cell size of the DEM be 9.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 63. 3×3 window with numbered cells
In the following mathematical equations of slope, zi (i=1, 2,.. 9) is the elevation value in cell i.

1.1.1 Second-order finite difference (2FD): The rate of change in the x and y-direction for the central cell or cell 5 is given by:

\[ f_x = \frac{(z6-z4)}{2g}; \quad f_y = \frac{(z8-z2)}{2g} \]  

(2)

Where \( z2, z4, z6 \) and \( z8 \) are the elevation values of cell 2, 4, 6, 8 and \( g \) = cell size.

1.1.2 Maximum Max (Downhill slope) (Dr. Ashraf, 2012). The slope of the central cell or cell 5 is calculated by:

\[ \text{Slope} = \arctan \left( \max \left( \frac{z5-z3}{L_j} \right) \right) \]  

(3)

Where \( j = 1, 2, 3, 4, 6, 7, 8, 9 \)

\( L_j = \Delta x = g \), when \( j = 2, 4, 6, 8 \) in the orthogonal direction;

\[ L_j = \Delta x \times \sqrt{2} = g \times \sqrt{2} \), when \( j = 1, 3, 7 \) and 9 in the diagonal direction.

1.1.3 Simple difference (Simple-D) (Jones, 1998). The rate of change in the x and y-direction for the central cell or cell 5 is given by:

\[ f_x = \frac{(z5-z1+2(z6-z4)+z9-z7))}{8g}; \quad f_y = \frac{(z7-z1+2(z8-z2)+z9-z3))}{8g} \]  

(4)

Where, \( z1, z2, z3 \) and \( z7, z8, z9 \) are elevations of cell 1, 2, 3 and 7, 8, 9 respectively and \( g \) = cell size

1.1.4 Average Neighborhood (ArcGIS Algorithm) (Horn, 1981). The rate of change in the x and y-direction for the central cell or cell 5 is calculated with the following formula:

\[ fx = \frac{(z3-z1+2(z6-z4)+z9-z7))}{4g}; \quad fy = \frac{(z7-z1+2(z8-z2)+z9-z3))}{4g} \]  

(5)

(6)

Where, \( z1, z2, z3 \) and \( z7, z8, z9 \) are elevations of cell 1, 2, 3 and 7, 8, 9 respectively and \( g \) = cell size

1.1.5 Three-order Finite Difference Weighted by Reciprocal of Distance (3FDWRD) (Unwin, 1981). The formulas for the slope calculation using this method is as below:

\[ fx = \frac{(z3-z1+\sqrt{2}(z6-z4)+z9-z7))}{4g}; \quad fy = \frac{(z7-z1+\sqrt{2}(z8-z2)+z9-z3))}{4g} \]  

(7)

(8)

1.1.6 Three-order Finite Difference, Linear regression plan (3FD) (Sharppack & A. and AKin, 1969). The formulas for the slope calculation using this method is as below:

\[ fx = \frac{(z3-z1+z6-z4+z9-z7)}{6g}; \quad fy = \frac{(z7-z1+z8-z2+z9-z3)}{6g} \]  

(9)

1.1.7 Frame Finite difference (FFD) (Chu & Tsai, 1995). The formulas for the slope calculation using this method is as below:

\[ fx = \frac{(z3-z1+z9-z7)}{4g}; \quad fy = \frac{(z7-z1+z9-z3)}{4g} \]  

(10)

1.1.8 Constrained Quadratic Surface Quad Surface (Wood, 1996)

\[ F(x,y) = ax^2 + by^2 + cxy + dx + ey + f; \quad AX = Z = F(x,y) \]  

(11)

Where, A has been defined (see fig. 4), X stands for unknown vector of parameters (see fig. 3) and Z is the elevation vector (see fig. 2). The number of equations is more than the unknown parameters, so there is no “true” solution. We use the least-squares method to determine the indices of the constrained quadratic surface.

\[ A^TAX = A^TZ; \quad X = (A^TA)^{-1} A^TZ \]  

(12)

It is then relatively easy to estimate the \( fx \) and \( fy \) values at the center of the \( 3 \times 3 \) window.

\[ fx|x=0, y=0 = d \]

\[ fy|x=0, y=0 = e \]

Where, 5, 4 and 2 are elevations of cell 5, 4 and 2 respectively and \( g \) = cell size

1.2 ANOVA Test
An ANOVA test is a way to find out if survey or experiment results are significant. In other words, it helps to determine whether to reject the null hypothesis or accept the alternate hypothesis. Basically, while testing groups to see if there’s a difference between them (Stephanie, 2019).

1.2.1 One-Way ANOVA: The One-Way ANOVA ("analysis of variance") compares the means of two or more independent groups in order to determine whether there is statistical evidence that the associated population means are significantly different. One-Way ANOVA is a parametric test. The variables used in this test are known as: Dependent variable. (slope) and Factor (algorithm).

1.2.2 Level of Significance: The level of significance is defined as the probability of rejecting a null hypothesis by a test when it is really true. Generally, it is denoted by \( \alpha \) and should be as low as possible. For our project, level of significance that we used is 0.05.

1.2.3 Confidence Level: Confidence level is an index of suresty in the data. It is expressed in percentage and it is defined 95% for our project. 95% confidence level indicates can be 95% certain that it really true. Generally, it is denoted by ά and should be as low as possible. For our project, level of significance that we used is 0.05.

1.3 Post Hoc Test
Post hoc tests are designed for situations in which the researcher has already obtained a significant omnibus F-test with a factor that consists of three or more means and additional exploration of the
differences among means is needed to provide specific information on which means are significantly different from each other (Stevens, 1999).

2. METHODOLOGY

2.1 Study Area

The study area for the project was chosen to be within the premises of Kathmandu University, Dhulikhel, Nepal. The study area consists of varying slopes and land cover. The area of the study area is 97335.51 m². The study area was selected so as to meet the project objectives.

2.2 Workflow

2.2.1 Image Processing: Different software are available for processing of images captured from drone survey. DTM, DEM and DSM can be generated using such software. The reports of the processing can be obtained after the processing. Pix4D mapper was used for the image processing.

2.2.2 DTM Generation: Digital Terrain Model is generated after processing the images. DTM is further used for analysis and derivation of results.

2.2.3 Calculation and Analysis: Depending upon the range of slopes, the algorithms can produce different results. Thus, the terrain was classified into six different groups based on slope range. The purpose was to make the result of the analysis applicable for general purposes. Owing to this, the slopes were divided into continuous interval of slopes.

Table 22. Slope Classification

<table>
<thead>
<tr>
<th>Class</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Little or none</td>
<td>Little or no slope: 0 - 4 % gradient.</td>
</tr>
<tr>
<td>2</td>
<td>Gentle</td>
<td>Gentle slopes: 4 - 10 % gradient.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>Moderate slopes: 10 - 15 % gradient.</td>
</tr>
<tr>
<td>4</td>
<td>Steep</td>
<td>Steep slopes: 15 - 30 % gradient.</td>
</tr>
<tr>
<td>5</td>
<td>Extremely steep</td>
<td>Extremely steep slopes: 30 - 60% gradient.</td>
</tr>
</tbody>
</table>
All eight algorithms are developed using different techniques and considerations so the question arises whether they give different values while calculating slopes of different terrains or they give same results across different terrain surfaces.

To decide this, we considered a hypothesis test with null and alternate hypothesis as:

Null: The final slopes are not affected by the algorithms used
Alternate: The final slopes depend on the algorithms used.

Analysis of variance (ANOVA) is a statistical technique that is used to check if the means of two or more groups are significantly different from each other. ANOVA checks the impact of one or more factors by comparing the means of different samples (Singh, 2018). ANOVA test can be computed manually but for small volume of the data only. But the data we work ranges up to 250000 for a single slope class. Thus, used IBM SPSS Statistics to conduct ANOVA test.

95% confidence interval and level of significance as 0.05 was considered. It indicates if the level of significance after applying ANOVA test is less than 0.05 then the null hypothesis is rejected and accept alternate hypothesis which concludes that slopes are dependent on the algorithms used. Major components involved in ANOVA test are within group variability and between group variability.

After deciding whether the means of the slopes from different algorithms are significantly different or not, it is followed by Post Hoc test. The Post Hoc test provides the difference between the mean, standard error and significance between the mean slopes calculated from different algorithms. Similarly, after the Post Hoc the Means Plot provides visualizations to the Post Hoc test.

2.2.4 Accuracy Analysis of slopes with ground calculated slopes:

Ground survey was conducted using Total Station to calculate the Ground slopes that was further used to validate the slopes calculated after applying the algorithms on classified slope divisions. The sample points required to validate the slope were calculated considering the rules for the sample calculation. The sample areas on the ground were defined for all six slope classes in the extent that they meet the sampling rule. The elevation data were taken within the sampling area and slopes were calculated from the elevation data and used as the reference value for the suitability assessment of the algorithms for each slope class. Algorithm with the lowest RMSE will be the most accurate method for that specific slope class. Each sample area on the ground includes area of (15*15) m².

To check the accuracy of the slopes calculated using all eight algorithms, a ground survey was carried out using Total Station. For all six slope classes, sample points were calculated using the sample calculator. The sample area on the ground was selected so as to meet the sampling rule and required sample points. The sample areas each covered an area of 15m*15m on the ground. The sample areas were staked out on the ground and elevation data within the sample area were observed and further processed through GIS and slopes for each class were calculated. The mean slope for each sample area was considered the most probable value of the slope for that slope class.

The mean of the sample was used to tally with the mean slope calculated using algorithms. The RMSE was used as the measure to analyze the slope accuracy.

3. RESULT

ANOVA Test for Class 1: The ANOVA test was significance which indicates that at least two algorithms among the eight algorithms were different for Class 1.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>N</th>
<th>Subset for alpha = 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000</td>
<td>3000</td>
</tr>
<tr>
<td></td>
<td>4000</td>
<td></td>
</tr>
<tr>
<td>3FD</td>
<td>21904</td>
<td>1.381</td>
</tr>
<tr>
<td>3FDWRD</td>
<td>21904</td>
<td>1.383</td>
</tr>
<tr>
<td>AvgNeighbourhood</td>
<td>21904</td>
<td>1.385</td>
</tr>
<tr>
<td>FFD</td>
<td>21904</td>
<td>1.394</td>
</tr>
<tr>
<td>ConstrainedQuadSurface</td>
<td>21904</td>
<td>1.416</td>
</tr>
<tr>
<td>2FD</td>
<td>21904</td>
<td>1.434</td>
</tr>
<tr>
<td>SimpleD</td>
<td>21904</td>
<td>2.983</td>
</tr>
<tr>
<td>MaximumMax</td>
<td>21904</td>
<td>3.092</td>
</tr>
</tbody>
</table>

Mean plot of Class 1:

Figure 69. Mean slopes of each algorithm for class 1

ANOVA Test for Class 2: The ANOVA test was significance which indicates that at least two algorithms among the eight algorithms were different for Class 2.
Post Hoc Test Class 2: Following ANOVA test, post-hoc test was done to find out the difference among the different algorithms. The following table from Tukey’s Post-Hoc test show that the slopes calculated using Maximum Max and Simple D was significantly different from all other algorithms with mean values, significantly higher than the rest of the algorithms while 3FD, FFD, 3FDWRD, Average Neighborhood, Constrained Quadratic Surface and 2FD didn’t produce significantly different results.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>N</th>
<th>Subset for alpha = 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>FFD</td>
<td>21904</td>
<td>9.377</td>
</tr>
<tr>
<td>3FD</td>
<td>21904</td>
<td>9.379</td>
</tr>
<tr>
<td>3FDWRD</td>
<td>21904</td>
<td>9.381</td>
</tr>
<tr>
<td>AvgNeighborhood</td>
<td>21904</td>
<td>9.385</td>
</tr>
<tr>
<td>ConstrainedQuadSurface</td>
<td>21904</td>
<td>9.396</td>
</tr>
<tr>
<td>2FD</td>
<td>21904</td>
<td>9.418</td>
</tr>
<tr>
<td>SimpleD</td>
<td>21904</td>
<td>10.096</td>
</tr>
<tr>
<td>MaximumMax</td>
<td>21904</td>
<td>1.000</td>
</tr>
<tr>
<td>Sig.</td>
<td>21904</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Mean Plot of Class 2:

Figure 70. Mean slopes of each algorithm for Class 2

ANOVA Test Class 3: The ANOVA test was significance which indicates that at least two algorithms among the eight algorithms were different for Class 3.

<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>4.168</td>
<td>7</td>
<td>595</td>
<td>.040</td>
</tr>
<tr>
<td>Within Groups</td>
<td>2612906.183</td>
<td>175224</td>
<td>14.912</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2612906.351</td>
<td>175231</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Post Hoc Test Class 3: Following ANOVA test, post-hoc test was done to find out the difference among the different algorithms. The following table from Tukey’s Post-Hoc test show that the slopes calculated using Maximum Max was significantly different from all other algorithms with mean values, significantly lower than the rest of the algorithms while all the other algorithms produced similar results and weren’t significantly different from one another.

Mean Plot Class 3:

Figure 71. Mean Slope of each algorithm for Class 3

ANOVA Test Class 4: The ANOVA test was insignificant which indicates that no two algorithms were significantly different for Class 4.

<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1843.903</td>
<td>7</td>
<td>263.419</td>
<td>.000</td>
</tr>
<tr>
<td>Within Groups</td>
<td>638226.747</td>
<td>175224</td>
<td>3.642</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>640070.691</td>
<td>175231</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Post Hoc: The post-hoc wasn’t required for class 4 because the ANOVA was insignificant. The results that the algorithms produced weren’t significantly different from one another.

Mean Plot Class 4:
ANOVA Test Class 5: The ANOVA test was significance which indicates that at least two algorithms among the eight algorithms were different for Class 5.

ANOVA Test Class 6: The ANOVA test was significance which indicates that at least two algorithms among the eight algorithms were different for Class 6 algorithms while the rest of the algorithms had no significant differences.

Post Hoc Test Class 5: Following ANOVA test, post-hoc test was done to find out the difference among the different algorithms. The following table from Tukey’s Post-Hoc test show that the slopes calculated using Maximum Max was significantly different from all other algorithms with mean values, significantly lower than the rest of the algorithms while the rest of the algorithms had no significant differences.

Table 30. ANOVA Test Result for Class 5

<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1123.789</td>
<td>7</td>
<td>160.541</td>
<td>27.760</td>
</tr>
<tr>
<td>Within Groups</td>
<td>10232007.565</td>
<td>175224</td>
<td>58.384</td>
<td>175231</td>
</tr>
<tr>
<td>Total</td>
<td>10231330.876</td>
<td>175231</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 31. Tukey Test Result for Class 5

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>N</th>
<th>Subset for alpha = 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>MaximumMax</td>
<td>21904</td>
<td>37.153</td>
</tr>
<tr>
<td>FFD</td>
<td>21904</td>
<td>37.389</td>
</tr>
<tr>
<td>3FD</td>
<td>21904</td>
<td>37.393</td>
</tr>
<tr>
<td>3FDWRD</td>
<td>21904</td>
<td>37.394</td>
</tr>
<tr>
<td>AvgNeighbourhood</td>
<td>21904</td>
<td>37.394</td>
</tr>
<tr>
<td>SimpleD</td>
<td>21904</td>
<td>37.396</td>
</tr>
<tr>
<td>2FD</td>
<td>21904</td>
<td>37.399</td>
</tr>
<tr>
<td>ConstrainedQuadSurface</td>
<td>21904</td>
<td>37.399</td>
</tr>
</tbody>
</table>

Table 32. ANOVA Test Result for Class 6

<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>102256.982</td>
<td>7</td>
<td>14900.837</td>
<td>175224</td>
</tr>
<tr>
<td>Within Groups</td>
<td>14698418.563</td>
<td>175231</td>
<td>85.430</td>
<td>175231</td>
</tr>
<tr>
<td>Total</td>
<td>15071624.444</td>
<td>175231</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 33. Tukey Test Result from Class 6

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>N</th>
<th>Subset for alpha = 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>MaximumMax</td>
<td>21904</td>
<td>83.038</td>
</tr>
<tr>
<td>ConstrainedQuadSurface</td>
<td>21904</td>
<td>85.919</td>
</tr>
<tr>
<td>SimpleD</td>
<td>21904</td>
<td>85.929</td>
</tr>
<tr>
<td>FFD</td>
<td>21904</td>
<td>85.954</td>
</tr>
<tr>
<td>3FD</td>
<td>21904</td>
<td>85.955</td>
</tr>
<tr>
<td>3FDWRD</td>
<td>21904</td>
<td>85.956</td>
</tr>
<tr>
<td>AvgNeighbourhood</td>
<td>21904</td>
<td>85.956</td>
</tr>
<tr>
<td>2FD</td>
<td>21904</td>
<td>85.958</td>
</tr>
</tbody>
</table>

Sig. 1.000 1.000
Mean Plot Class 6:

Figure 74. Mean Slope of each algorithm for Class 6

3.1. Suitability Assessment

Figure 75. RMSE plot for slope class 1

Figure 76. RMSE Plot for slope class 2

Figure 77. RMSE Plot for slope class 3

Figure 78. RMSE Plot for slope class 4

Figure 79. RMSE Plot for slope class 5
The suitability assessment for the algorithms depends on their RMSE value. The RMSE was calculated using the mean slope for each algorithm and ground calculated slope. Algorithms with the lowest RMSE value was the most suitable algorithm for that slope class and the algorithm with largest RMSE was the least suitable algorithm for that slope class. The RMSE plot above represents the RMSE for each algorithm while applying in each slope class. Thus, suitability was derived from the plot and algorithms and has been ranked according as the suitability.

4. CONCLUSION

The analysis of slope algorithms was done in two different ways: comparison among the results of the slope algorithms and RMSE calculation of each algorithm’s result with the ground measured slopes. The assessment of slope calculation algorithm was done for six different slope classes. Following are the conclusions obtained for each of the classes.

Class 1(0 – 4 grade slope)
From the ANOVA and post-hoc test, it is seen that all algorithms except Maximum Max and Simple D gives similar results to the rest of the algorithms. The values for those two were drastically higher than the other algorithms. From the RMSE calculation result, the 3FDWRD produces the least error and simple D produces the highest error. Thus, the best algorithm for this class is 3FDWRD.

Class 2(4 – 10 grade slope)
Similar to class 1 result, it is seen that all algorithms except Maximum Max and Simple D gives similar results to the rest of the algorithms from the ANOVA test. The values for those two were drastically higher than the other algorithms. From the RMSE calculation result, the FFD produced the least error and Maximum Max produced the highest error. Thus, the best algorithm for this class is FFD.

Class 3(10 – 15 grade slope)
From the ANOVA and post-hoc test, it is seen that all algorithms except Maximum Max gives similar result. The values for those Maximum Max were slightly lower than the other algorithms. However, the difference among all other algorithms aren’t statistically significant. From the RMSE calculation result, the Maximum Max produced the least error and Constrained Quadratic Surface produced the highest error. Thus, the best algorithm for this class is Maximum.

Class 4(15 – 30 grade slope)
From the ANOVA and post-hoc test, it is seen that all algorithms give similar result and theirs is no significant difference among algorithms. However, values for those Simple D were slightly lower than the other algorithms and the values for Constrained Quadratic Surface were slightly lower than the other algorithms. From the RMSE calculation result, the 2FD produced the least error and Maximum Max produced the highest error even though all of the RMSE were similar to each other. Thus, the best algorithm for this class is 2FD.

Class 5(30 – 60 grade slope)
From the ANOVA and post-hoc test, there is significant differences among algorithms though they are small. Values for the Maximum Max algorithm were slightly lower than the other algorithms. From the RMSE calculation result, all the algorithms have similar resulting slopes. However, Maximum Max produced the least error and Constrained Quadratic Surface gives the highest error. Thus, the best algorithm for this class is Maximum Max.

Class 6(60 above grade slope)
From the ANOVA and post-hoc test, there is significant differences among algorithms though they are small. However, values for those Maximum were slightly lower than the other algorithms. From the RMSE calculation result, all the algorithms have similar resulting slopes. However, Maximum Max produced the least error and Simple D gives the highest error. Thus, the best algorithm for this class is Maximum Max.

The algorithms 2FD, 3FD, 3FDWRD, Average Neighborhood and Constrained Quadratic Surface and FFD has given similar results across all observation while the algorithms that has been observed to producing varying results are Maximum Max and Simple D. In addition to this, it is observed from the above results that the choice of algorithms is more important when grade slope is less than 10 percent. However, for terrains with above 10 percent slope, the choice of algorithms seems less important with only a difference of approximately 0.5 gradient slopes. However, the results from Simple D and Maximum Max has been observed to be more fluctuated. This may be due to the fact that among all algorithms these two are the only algorithms that calculate center cell to adjacent cell slope. Even among these two maximum maxes is the only algorithm that doesn’t calculate the x-slope-component and y-slope-component like all the other algorithms and just takes the max slope out of the slopes calculated from center to all surrounding cells.

The conclusions drawn from this project can be used for any general slope calculation purposes. That may include disaster management, hydrological and environmental analysis, suitability assessment, construction and land trainings and other similar projects.

REFERENCES


International Workshop on “Capacity Building and Education Outreach in Advanced Geospatial Technologies and Land Management”, 10-11 December 2019
Land Management Training Center, Dhulikhel, Nepal
NOCTURNAL AND DIURNAL TRENDS OF SURFACE URBAN HEAT ISLAND INTENSITY: A SEASONAL VARIABILITY ANALYSIS FOR SMART URBAN PLANNING

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KEY WORDS: Urban Heat Island, Impervious Surface Area, Landsat, In-situ Data, Land Management

ABSTRACT:

Land management in the limited environment of city regions with immense population pressure is a challenging task. To achieve the goal of sustainable smart cities, reliable spatial information needs to be incorporated in land governance policies. In this study, Landsat 8 satellite bands were processed to derive the land use characteristics which are causing the development of urban heat islands at certain locations. To assess the prolonged effects of heat-trapping in cities, night time temperature data was obtained through in-situ data collection with error within 1°C. Much higher intensity of urban heat island was observed during the night. The maximum increase of 1.67°C was noted from day to night temperature for the same heat island. Seasonal analysis between winter and summer months was also carried out. The results suggested that for both day and night summer months produced more critical heat islands with maximum intensity up to 3.48°C; while in winter the heat island intensity did not exceed 2.18°C. Through comparative analysis between two cities with varying extent, urbanization and population pressure, it was observed that the maximum intensity of day time temperature was greater in a bigger city and heat islands were less fragmented. Heat islands covered an area of 10.39 km² over Prayagraj and 28.29 km² area of Kolkata. The temperature patterns obtained during day and night were statistically validated with the index of impervious surface area, at the significance level of 0.05.

1. INTRODUCTION

Land management in the limited environment of city regions with immense population pressure is a challenging task. To achieve the goal of sustainable smart cities, reliable spatial information needs to be incorporated in land governance policies. In this study, Landsat 8 satellite bands were processed to derive the land use characteristics which are causing the development of urban heat islands at certain locations. To assess the prolonged effects of heat-trapping in cities, night time temperature data was obtained through in-situ data collection with error within 1°C. Much higher intensity of urban heat island was observed during the night. The maximum increase of 1.67°C was noted from day to night temperature for the same heat island. Seasonal analysis between winter and summer months was also carried out. The results suggested that for both day and night summer months produced more critical heat islands with maximum intensity up to 3.48°C; while in winter the heat island intensity did not exceed 2.18°C.

The focus of this study was to analyze the driving forces resulting in land use change patterns and their effects on local temperature. The study is performed on two major cities of India, Prayagraj and Kolkata. These two cities are undergoing different levels of urbanization. Local temperature profiling was performed in both study areas. Day time UHI was mapped with satellite data and the night time temperature data was collected through field surveys. Handheld temperature sensors were utilized for in-situ data collection. The overall Land Use Land Cover (LULC) patterns for both cities were matched with the spatial pattern of UHI. Among urban land covers, the presence of concrete surfaces affects the Land Surface Temperature (LST) pattern the most. Therefore, Fractional Vegetation Cover (FVC) and Impervious Surface Area (ISA) indices were derived to statistically validate the spatial pattern of UHI formation. Seasonal analysis was performed in Prayagraj to find out the season with a comparatively more critical UHI scenario.
Most of the UHI studies are carried out by using satellite data. They quantify and analyze day time UHI (Weng et al., 2019; Zhao et al., 2010). Some of them also studied the night time UHI effect (Soltani and Sharifi, 2017; Tiangco et al., 2008). To assess the thermal characteristics of the city center, the resolution of night time satellite data was not satisfactory. Therefore, to map the night LST for this study, in-situ data collection was carried out. The objective of the study was to compare diurnal and nocturnal UHI patterns for two cities with considerable differences in size, population and infrastructural development. Also, the seasonal UHI intensity was assessed. Spatial patterns of UHI, for both day and night, were validated with location based land cover characteristics. All areas were identified where smart urban designs need to be implemented. Thus, the study aimed to demonstrate the utilization of remote sensing and field survey in environment protection and land management policies, by obtaining thermal and land cover data.

2. DESCRIPTION OF STUDY AREA

The study included the city of Prayagraj belonging to the Indian state of Uttar Pradesh. Situated at the confluence of Ganga, Yamuna and Saraswati rivers, it is one of the oldest cities in India. Currently, Prayagraj witnessed drastic growth in built-up, especially during the occasion of Ardh Kumbh Mela. The spread of impervious surfaces was rapid, which might have resulted in the development of thermal hotspots. As the study deals with urban heat islands, only the main city region of Prayagraj was taken, which extends from 25°24’N to 25°30’N and from 81°47’E to 81°53’E. This study region covers an area of 66.54 km². To compare the results with another city of greater extent and urban development, Kolkata was taken. Kolkata is the capital of the Indian state of West Bengal and is one of the major cities of eastern India. This city is also located beside the river Ganga. As the urban area in Kolkata covers its entire district, the whole of Kolkata district was considered for UHI analysis. Kolkata extends from 22°27’N to 22°37’N and from 88°14’E to 88°28’E. The area is 188.06 km². Both the study areas are shown in Figure 1.

![Figure 1. Location and extent of study areas](image)

3. DATA CHARACTERISTICS

3.1 Remote Sensing and Map Data

Satellite images of Landsat 8 with OLI/TIRS (Operational Land Imager & Thermal Infrared) sensors, were obtained from U.S. Geological Survey. The thermal band was used for day time LST map generation. Maps of land cover characteristics were derived from other band combinations. To focus on the current UHI and land use scenario, summer and winter season images of the year 2019 were taken for Prayagraj. For Kolkata, satellite images of the year 2018 summer season were utilized as in-situ temperature data collection was carried out at the same time. Other than satellite images, Survey of India topographical maps were utilized as reference data in this study.

3.2 In-situ temperature measurement

To generate the night time LST pattern, temperature data was collected. Handheld devices were used for data collection, where Bme 280 Digital Sensor Module Kg501 was mounted. The device had accuracy of ±1°C. Temperature measurements were started after 11 pm for each sampling schedule; because by this time, the anthropogenic activities nearly stop. Hence, the observed temperature pattern reflected locations with a high rate of heat-trapping.

4. METHODOLOGY

The procedures applied to achieve the results are shown by the flowchart in Figure 2.

4.1 Night Time LST Pattern by In-situ Temperature Measurement

A total of 30 data points, fairly distributed over the study area were selected for Prayagraj and they are shown in Figure 3. The data was collected on one cloud free day in the first week of April 2019, representing summer season and on one cloud free day in the first week of January 2019, as winter season. The extensive LULC study was performed through field survey and image analysis. Hence, it was made sure that the points cover different types of land use classes. Another set of 20 points were decided for error checking, after interpolation. Night time LST maps were prepared by interpolation. In this case, Ordinary Kriging was used as the interpolation technique.

![Figure 2. Distribution of locations in Prayagraj for in-situ temperature measurement at night](image)
Kriging provides more reliable interpolation as specific values of spatial autocorrelation of sample points are considered (Setianto and Triandini, 2013; Van Beers and Kleijnen, 2003). After generating a spatial LST profile, the errors for interpolation were checked. Temperature values obtained directly by in-situ measurements at those 20 points of checking were compared with LST values obtained after interpolation, at the same points. The value of Root Mean Square Error (RMSE) was computed to assess the quality of night time LST profile. The highest temperature pockets present at night time LST profile were identified as UHI locations.

In the case of Kolkata, a similar approach was adopted. On a cloud free night in the first week of April, 2018 field data collection was carried out. A total of 28 points were used for night time temperature data collection as shown in Figure 4. A small scale previous field study indicated summer to be the critical season for UHI. Hence, only summer temperature of Kolkata was analyzed as a reference to the study in Prayagraj.

4.2 Day Time UHI Zoning from Satellite Imageries

Thermal bands of two seasons for Prayagraj and one for Kolkata were processed to generate LST maps. At first, the pixel Digital Numbers (DN) were converted to spectral radiance as per the globalized methods provided by NASA (NASA, 2011). Mono window algorithm was applied to determine the temperature in Kelvin as per the formula outlined by Qin et al., (2001). Lastly, the Kelvin temperature values were converted to the Celsius temperature of the land surface. Each LST map was categorized into five classes, representing zones of very low temperature, low temperature, moderate temperature, high temperature and very high temperature.

![Figure 3. Flow chart of methodology](image_url)

![Figure 4. Distribution of locations in Kolkata for in-situ temperature measurement at night](image_url)
This generalization was done as the images are of different places and seasons and hence showed varying ranges in the LST profile (Dutta et al., 2018). The highest temperature zone was considered an urban heat island. The intensity of UHI (UHI<sub>t</sub>) was calculated as the maximum difference between the LST of the heat island and the average LST of the land surface (Zhao et al., 2010).

### 4.3 LULC Categories

The spatial characteristics of UHI can be explained by the LULC pattern of a city region. LULC maps can be simply developed by processing satellite images (Abd El-Kawy et al., 2011; Punia et al., 2011; Sobrino and Raissouni, 2000). Maximum likelihood supervised classification was applied on stacked satellite imageries. Six classes of land use land cover as, urban, vegetation, water, open land, bare soil and sand were identified for Prayagraj. For Kolkata, the five LULC classes were dense urban, mixed urban, open field, vegetation and water. The UHI locations were matched with the LULC categories to understand the type of land use which are suitable for thermal hotspots. To quantify this, an average temperature of major land use classes were noted for both cities.

### 4.4 Validation of UHI with Land Cover Parameters

The spatial dynamics of urban built up over both cities was used to statistically validate the observed LST pattern. Many researchers have shown the presence of built-up surface and low vegetation concentration leading to the creation of urban heat islands (Connors et al., 2012; Rasul and Ibrahim, 2017). To analyze the cause of heat island formation, Pearson’s product moment correlation coefficient between impervious surface area and LST was computed. The analysis was carried out for both day and night at the pixel level, for the entire spatial extension. To generate the ISA map, firstly, FVC map was prepared (Carlson and Arthur, 2000). FVC map was developed using the scaled Normalized difference Vegetation Index. As ISA and FVC vary inversely in urban areas, ISA maps were prepared using the FVC maps. The ISA maps were then downsampled to 100m with nearest neighbor resampling. The LST and ISA maps were then vectorized to point files before calculating correlation values.

### 5. RESULTS AND DISCUSSION

#### 5.1 Night time LST of Prayagraj

The night time LST of Prayagraj for winter and summer months are shown in Figure 5. In winter, only one major heat island can be observed at the centre of the city, around civil Lines area (a). High rate of anthropogenic activities at this place can be the reason behind heat-trapping till late night. The maximum intensity was 2.18°C. On the contrary, the areas close to river channel were cooled down by land breeze at night. The overall temperature pattern has little variation. In contrast, the night time LST profile of summer depicted much more variation in LST profile. Maximum UHI of 3.48°C was observed at the central city region. Four major heat islands were clearly visible. The distinct UHIs were at north the Teliarganj area (a), at east Govindpur residential area (b), at center the Civil Lines area (c) and towards south around Hazrat Ganj (d). Comparing the intensity values with the winter UHIs, it can be said that, in summer nights the problem of heat trapping is more critical. The UHI observed at night, for both seasons, were higher than day time UHI. It showed that certain locations were at high risk even at night. The accuracy of night time field survey was assessed through RMSE between observed and interpolated LST values. In winter the RMSE was 0.40°C and in summer the RMSE was 0.84°C.

#### 5.2 Day time UHI of Prayagraj

The day time LST profile and the identified UHI zones in winter, for Prayagraj, have been shown in Figure 6. The UHIs identified by very high temperature zones, were spread all over the city region. Heat islands covered a total area of 9.47 km<sup>2</sup> in winter. A major heat island in the north west part, over urban areas of Kamlanagar (a) and Teliarganj can be clearly seen. It was marked with 1.85°C of UHI. Towards north, over congested parts of Mumfordganj (b) and Old Katra another heat island was identified. Here intensity of UHI was 1.21°C.

![Figure 5. Night time LST profile of Prayagraj for winter and summer, 2019](image-url)

The dense residential area of Govindpur (c) and Rajiv Nagar in the east was a major heat island area with intensity of 1.59°C. At the center of Prayagraj City, Civil Lines (d) was another UHI with...
1.26°C intensity. Other distinct UHIs can be found at the southern parts of the city. 2.04°C of UHI was marked at the UHI formed near Sangam area (e), Prayagraj Junction (f) and the old commercial zones at its south were other UHIs with 1.7°C of intensity. Towards west, a linear pattern (g) of UHI can be found with intensity of 1.81°C. The linear shape of this heat island was probably due to the high concentration of urban places and anthropogenic activities beside railway line present here.

The summer day time LST and UHI pattern was quite similar to the winter month, for most parts of the city. The patterns are shown in Figure 7. One major difference was the extensive heat island forming over Hazrat Ganj (a), in the southern parts of Prayagraj. The UHI cover increased to 10.39km², covering 15.61% of the total area. The UHI in this southern commercial area was 1.99°C.

5.3 LULC pattern of Prayagraj

The land use land cover pattern along with percentage area cover of each category, over Prayagraj is shown in Figure 8. An area of 38.56 km² was covered by urban built up. In comparison, vegetation was covering only 13.7 km² area. The LULC pattern explained the spatial characteristics of the LST profile. Extensive built up areas in southern parts, at south east and over central parts match with the UHI locations. The most prominent dense built up was at south, around Hazrat Ganj (a). Comparing with Figure 6 and Figure 7, this area was marked with high temperature in both seasons. In contrast to the urban areas, the patches of vegetated land were all marked with low temperatures. From Figure 6, Figure 7 and Figure 8, it can be observed that the old cantonment area towards north (b), Chandra Shekhar Azad Park (c) at center and at west around Dhoomanganj (d), vegetation was present resulting in low temperature values.
It matched with previous results that, summer UHI condition is more critical in this city.

<table>
<thead>
<tr>
<th>LC Classes</th>
<th>e Day Time LST in Winter</th>
<th>e Day Time LST in Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>17.8°C</td>
<td>34.1°C</td>
</tr>
<tr>
<td>Field</td>
<td>18.3°C</td>
<td>35.3°C</td>
</tr>
<tr>
<td>Vegetation</td>
<td>17.7°C</td>
<td>32.9°C</td>
</tr>
<tr>
<td>Soil and Sand</td>
<td>18.7°C</td>
<td>35.8°C</td>
</tr>
</tbody>
</table>

Table 1. Average LST of major LULC classes

5.4 Impact of impervious surface on LST pattern

To map the major land cover parameter of built up, firstly, FVC map was prepared. Both the FVC and ISA maps are shown in Figure 9. Urban built up identified by the ISA map matched with the spatial pattern of urban class from Figure 8. The FVC map showed presence of vegetation in areas of low built up.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Day Winter</th>
<th>Night Winter</th>
<th>Day Summer</th>
<th>Night Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISA-LST</td>
<td>0.245</td>
<td>0.485</td>
<td>0.664</td>
<td>0.588</td>
</tr>
</tbody>
</table>

Table 2. Correlation coefficients between ISA and LST

5.5 Night time LST of Kolkata

The temperature data collected in summer, 2018 was interpolated to generate the night time LST map for Kolkata. The map is shown in Figure 10. The LST pattern depicted the presence of one major heat island at central parts of Kolkata. The heat island was present on the central business district (a) of the city. The rate of anthropogenic activities is very high over this zone, leading to the UHI problem at night. The maximum intensity of UHI noted here was 2.43°C.

5.6 Day time UHI of Kolkata

The summer day time LST and the UHI zones for Kolkata are shown in Figure 11. Overall heat islands covered 28.29 km² area. While in case of Prayagraj only the central commercial urban area was considered, for Kolkata entire district was taken for the study. Still the percentage cover of 15.04% by UHI was similar to that of Prayagraj City. It shows the urbanization in Kolkata is widespread and problem of UHI is spread over a greater extent. Among the major heat islands observed in day, one was towards north around Dharmatala - Sealdah Station area (a). This is the central business district of Kolkata City and high UHI of 2.47°C was noted here. The most distinct UHI was present in the western parts of the city, near Garden Reach (b). Maximum UHI of 4.05°C was found here. Other patches of heat islands were over urban centers of Ballygunge, Kalighat, Tollygunge (c) in south. The value of day time UHI in Kolkata was much higher than that observed for Prayagraj. Also the heat islands were less fragmented than UHIs of Prayagraj. In case of Kolkata, larger patches of UHI were distinct.
5.7 LULC pattern of Kolkata

The LULC pattern of Kolkata is shown in Figure 12. The district has a very high percentage of land covered by dense urban and mixed urban. Urban areas covered 114.68 km$^2$ of the city. In contrast, vegetation covers only 7.48 km$^2$ of total area. The LULC pattern explained the spatial distribution of UHIs over Kolkata. Comparing with Figure 11, it is clear that, over urban built up LST is high and UHIs were located at dense urban areas. In contrast to this, the boundary region of the district is covered by vegetation and open fields. These areas have formed low temperature zones. Water bodies also result in cool islands within cities. Towards east the effect of water on creating low temperature zone is very prominent.

The average LST of the LULC classes in Kolkata are listed in Table 3. The average LST values were highest for dense urban areas. The LST was 1.33°C higher than the average in vegetated land. The mixed urban and fields also showed higher LST pattern than green areas. These values depicted that, the LST pattern within a city region varies greatly with land cover characteristics.

<table>
<thead>
<tr>
<th>LULC Class</th>
<th>Average Day Time LST in Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense Urban</td>
<td>28.68C</td>
</tr>
<tr>
<td>Mixed Urban</td>
<td>28.46C</td>
</tr>
<tr>
<td>Open Field</td>
<td>28.29C</td>
</tr>
<tr>
<td>Vegetation</td>
<td>27.33C</td>
</tr>
</tbody>
</table>

Table 3. Average LST of major LULC classes

5.8 Impact of impervious surface on LST pattern

Similar to Prayagraj, ISA map was prepared for Kolkata City from FVC map. These maps are shown in Figure 13. The maps depicted the dominance of built up surface all over Kolkata City. The correlation coefficients between ISA and LST of Kolkata are shown in Table 4.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Day Summer</th>
<th>Night Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISA-LST</td>
<td>0.656</td>
<td>0.417</td>
</tr>
</tbody>
</table>

Table 4. Correlation coefficients between ISA and LST
The values were significant at $\alpha_{0.05}$. It validated that, urbanization is the cause of heat island growth in case of Kolkata also.

### 6. CONCLUSIONS

The study successfully outlined a set of techniques to identify high risk locations in cities, where sustainability and welfare is challenged. These areas were marked with compact residential or commercial areas with lack of vegetation, resulting in the phenomenon of UHI. For Prayagraj, these locations were listed in Table 5 and for Kolkata city these were listed in Table 6.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Locations</th>
<th>Max. UHI day</th>
<th>Max. UHI night</th>
<th>ISA</th>
<th>FVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hazrat Ganj-Kareli-Prayagraj Junction-Johnston Ganj</td>
<td>+1.81°C</td>
<td>+3.48°C</td>
<td>+0.19 &gt; mean ISA</td>
<td>-0.20 &lt; mean FVC</td>
</tr>
<tr>
<td>2</td>
<td>Central Civil Lines area</td>
<td>+1.09°C</td>
<td>+2.18°C</td>
<td>+0.20 &gt; mean ISA</td>
<td>-0.13 &lt; mean FVC</td>
</tr>
<tr>
<td>3</td>
<td>Old Katra</td>
<td>+0.93°C</td>
<td>+0.62°C</td>
<td>+0.17 &gt; mean ISA</td>
<td>-0.15 &lt; mean FVC</td>
</tr>
<tr>
<td>4</td>
<td>Teliarganj-Phaphamou</td>
<td>+2.16°C</td>
<td>+1.94°C</td>
<td>+0.17 &gt; mean ISA</td>
<td>-0.16 &lt; mean FVC</td>
</tr>
<tr>
<td>5</td>
<td>Govindpur</td>
<td>+1.77°C</td>
<td>+1.64°C</td>
<td>+0.18 &gt; mean ISA</td>
<td>-0.16 &lt; mean FVC</td>
</tr>
</tbody>
</table>

Table 5. List of high risk locations in Prayagraj

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Locations</th>
<th>Max. UHI day</th>
<th>Max. UHI night</th>
<th>ISA</th>
<th>FVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dharmatala</td>
<td>+2.47°C</td>
<td>+2.43°C</td>
<td>-0.33 &lt; mean ISA</td>
<td>-0.32 &lt; mean FVC</td>
</tr>
<tr>
<td>2</td>
<td>Garden Reach</td>
<td>+4.05°C</td>
<td>+0.71°C</td>
<td>-0.21 &lt; mean ISA</td>
<td>-0.18 &lt; mean FVC</td>
</tr>
<tr>
<td>3</td>
<td>Kalighat-Tollygunge</td>
<td>+1.72°C</td>
<td>+0.68°C</td>
<td>-0.16 &lt; mean ISA</td>
<td>-0.14 &lt; mean FVC</td>
</tr>
</tbody>
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Table 6. List of high risk locations in Kolkata

These areas urgently need landscaping with increase in vegetation cover. Adaptive planning needs to be incorporated in these zones to mitigate UHI intensity and size. The roofs, walls of the buildings here can be used for vertical gardening, green façade and green roof creation. The analysis suggested stronger UHI effects for summer season, at night time. Simultaneous sampling from large number of points with higher accuracy sensors will help to generate night time LST surface of better resolution. The methodology to utilize satellite data for providing valuable support in land management strategies has been described. Modified land system architecture should be of priority to management committee for developing sustainable urban societies.

### ACKNOWLEDGEMENTS

Authors would like to thank Shubham Maurya, Anubhav Tiwari, Prabhat Kumar, Piyush Kumar Singh, Prakash Singh, Pradeep Singh, Saptak Banerjee, Upasana Datta and Shantanab Datta for their support in in-situ night time LST data collection.

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LAND MANAGEMENT PROBLEMS IN NEPAL: REPERCUSSIONS OF LAND USE POLICY AND IMPLEMENTATION GAPS IN REGIONAL AND URBAN PLANNING

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KEYWORDS: Land management, Land use, Policy and implementation, Land development, Regional and urban planning

ABSTRACT:
In lieu of advancement in human civilization from nomadic age to quest for welfare capitalism in recent days, land resources have been one of the most sought after assets for subsequent socio-economic development. The concept of land, once only geo-political has evolved to be interdisciplinary with developmental and managerial aspects in regional and urban planning worldwide making the facets of land management more complex than ever. In the context of modern Nepal, governance in systematic land management appeared during mid-1960 only with establishment of Ministry of Land Reform (MoLR). This paper aims to provide constructive criticism upon institutional fragmentation, and fragile policy and implementation gaps in land use administration which have been bewildering the concepts of regional and urban planning in Nepal. The recitation of this work is primarily based on selected literature review of relevant research on land use planning along with two representative case studies in national context and in international scenario as well. Despite rigorous efforts, the issues of competence in land administration, migration and syndicate in urban real estate remain as the major problems in land management in Nepal. Also, the new state restructuring of federal Nepal has already upraised the challenges in land resources planning for local governments who but seem muddled up in constructing rural economy and strategic urban plan for regional development. Nevertheless, these concerns in regional and urban planning can be addressed through practice of sustainable land management with thoughtful consideration of ambiguities in land use policy and implementation.

1. INTRODUCTION
As a definite property, land resources have economic as well as physical definitions varying from geological resources to biodiversity. Essentially, land has a spatial dimension which offers point of departure in development planning resultant to regional and urban planning. In both the concept of regional and urban planning, land use management is mutually associated with development of growth centres and built environment of a particular urban or urban-oriented areas. In global pursuit of Sustainable Development Goals (SDGs), almost 10 out of 17 goals are directly or closely related to features of land resources, of which 6 goals again indicate interdependence in important facets of regional and urban planning (UN, 2019). In this interdisciplinary context, land management becomes the key tool in achieving shared goals. This relates to the areas of providing the relevant geographic information in terms of mapping and databases of the built and natural environment, and also providing secure tenure systems, systems for land valuation, land use management and land development (Enemek, 2010).

1.1 Status of Land Management in Nepal
Although the conventional system of land management in Nepal dates back to 1870s, regulatory means for land management in modern Nepal was lately introduced in 1962 only with formulation of Land Survey and Measurement Act (MoLCPA, 2019). The Ministry of Land Reform and Management has featured 62 acts being related to land management, among which at least eight acts are directly related with land management issues (MoALC, 2018). Recently, Government of Nepal has passed a bill related to land use which again may have some inconsistencies in regard to regional and urban planning sector.

In this preface of land use management, it is necessary to understand the characteristics of land cover in Nepal. Again, the perspective of land cover fulfills with the concept of land use only. Recalling the implementation of land use policy in Nepal, National Land Use Project was set up in 2000. One of the major objectives of the project was to identify and zoning the land for housing, urbanizing, industrialization and other non-agricultural processes in the existing municipalities and urban-oriented rural areas as well as to balance the environment and sustain the system by preserving and developing water, forest and living treasure. But the much needed Land use Act 2019 came forth retrospectively in September 2019 only.

In current scenario, land cover dynamics of Nepal ranges from set aside areas for reserves by wetlands. 44.47% enclosed by forests to 1.15% occupied by built-up areas (Forest Research and Training Centre, 2019). The land cover data shows that while 28.68% of land is spared to bare soil, rock, ice and other unmanaged land, only 21.88% of land is occupied by arable and tillage land and agro-forestry systems. Likewise, 2.60% of land is swamped by grasslands and 1.22% of land is reserved by wetlands.

Figure 1. Current land cover status of Nepal.
The newly formulated Land use Act 2019 features formation of Land use Council in federal, provincial and local levels of governments. It suggests preparation of land use program including 11 different areas such as: industrial corridors, special economic zones, national projects, inter-provincial projects, protectable natural and physical heritages of national importance, places of religious and cultural importance bearing international identity and humanitarian beliefs, school or other educational areas, roads, health institutions, areas with irrigation canal, sensitive areas in terms of national security, areas having disaster risk, protected areas for environmental cleanliness and bio-diversity conservation, and other required areas (House of Representatives Nepal, 2019).

In the Act, several legal provisions has also been advised for upgrading land records and administration system, determination of land taxes and valuation, change in land use and restrictions in fragmentation of land. Hopefully, the Land use Act has introduced an enthusiastic concept of land bank in land management. On the other side, the government is still struggling to expand its capacity in offering digital land surveying and administration services to general public.

### 1.2 Directions in Regional and Urban Planning in Nepal

Ironically, Nepal is both the least urbanized country in South Asia, with about 17% of its population living in urban areas, and the fastest-urbanizing country, with an average urban population growth rate of about 6% per year since the 1970s (Muzzini, Aparicio, 2013). But, with new state restructuring of federal Nepal, it is ambiguously depicted that the country constitutes these singularities truthfully present the fabrication in regional and urban planning in Nepal.

![Figure 2. Urban population growth rate of Nepal.](https://example.com/urban-population-growth-rate-nepal)

In an overview of regional and urban development in Nepal, issues of land use policy and approaches for regional and urban planning are explicitly not mutually exclusive. Difficulties in land management has instinctively become special problem in spatial planning in rural and urban areas of Nepal, and in reciprocal means, the later has instigated new challenges in land governance thereafter. Therefore, a dialectical process is necessary to examine and address the uninvited hurdles in the path of both sustainable land management and sustainable urban development.

### 2. THE COMMON DENOMINATOR

There is a well-known mathematical principle that to simplify a given problem at hand, a common or mutual denominator is required. Similarly, here in case of problems in land management, and regional and urban planning, we have land use as a common factor. Physical aspects of regional and urban planning are largely related to land use and development which itself is an indispensable aspect of land management and governance. In context of Nepal, statutory practice of land use and zoning regulations have not been implemented objectively in the apparatus of land administration which has shaped irregularities and invited challenges and problems in land management. Particularly, migration from rural to urban areas for various reasons and unusual investment in urban real estate has brought about terrible regional imbalance in national economy of Nepal which have confronted land use policies and regional and urban development strategies. In order to avoid these complications, we need to match legal provisions in land management with standard norms and values in regional and urban planning.

### 2.1 Land use Planning in Nepal

Land use is one of the inescapable aspects in land management for guide to effective planning of land resources in order to realize intentions of regional and urban development. Either in land reform policies or in land development plans, land use planning has remained as key of implementation measures in land
administration in Nepal. As we look into periodic planning history of land management in Nepal, from 1960s to 70s during initial days of periodic planning in Nepal, reforms in land management were introduced with emphasis in agricultural productivity. Periodic plans of 1970s and 80s also intervened in land management systems mainly for conservation and protection of forestry and natural resources.

Major turn in land use planning in Nepal arrived with Eighth Five Year Plan (1992/93 - 96/97) which identified land use plan as a long-term basis program in order to address the problems in land management. The subsequent Ninth Five Year Plan (1997/98 - 2001/02) was focused in sustainable development for preservation and extension of ecological sectors of mountains, hills and lowlands using land and natural resources. It was followed by the Tenth Five Year Plan (2002/03 - 2006/07) with objectives of land use sector to create service-oriented and informative land administration by development of sustainable land use management for increasing land productivity (Sharma, 2012). Main objectives of above mentioned plans were to implement land use planning based on maps prepared at various levels and identification and classification of land for agriculture, forestry, industrialization and urban settlement extension. Formulation of land use policy, discouragement in use of arable land for non-agricultural purposes or unproductive activities, and development of National Geographic Information System was also envisioned by the five year plans. Almost in all later fiscal plans of Government of Nepal, one particular agenda has always found its place: formulation of an appropriate act related to land management or land use policy in order to stop use of potentially arable land in unproductive urban real state. This issue of land use is still in debate whilst National Land use Policy (NLUP) was formulated in 2013 which was repealed and a new Land use Policy (LUP) was adopted again in 2015 (MoLRM, 2015).

LUP 2015 has clearly stated in its background that in the context of Nepal, on account of fast growing population, internal migration, unmanaged and rapid urbanization, among others, encroachment over arable lands, forests, government and public lands, various natural resources is rampant these days, and the protection thereof has poised a challenge now (MoLRM, 2015). Policy No. 1 of LUP statuses classification of entire land of the country into 11 different land use zones (LUZs): agricultural zone, residential zone, commercial zone, industrial zone, mines and minerals zone, cultural and archaeological zone, river and lake-reservoir zones, forest zones, public use and open space zone, building materials (stone, sands, concrete) excavation zone, and other zones as specified as per necessity, for example, vulnerable/hazardous zones. While LUP promises to discourage the trend of keeping land fallow and rampant fragmentation it also envisions a hygienic, beautiful, well-facilitated and safe human settlement along with a planned and sustainable urbanization of the country.

To remember, the newly formulated Land use Act 2019 also has similar features comparing it to LUP 2015. But, there exists incoherence in some parts of both the policy and act making it susceptible to being less comprehensive. Despite the fact that numerous land management acts and regulations have emphasized on public awareness on land use and the long-term impact thereto, there lacks sufficient co-ordination beforehand among and between inter-disciplinary institutions and local stakeholders regarding the subject and content of proposed bills on land use planning resulting to complications in its effective implementation.

2.2 Land use Norms and Standards in Planning Practice

Be it a small scale project of rural infrastructure development in small towns or a new town development project aimed at urban land development, land use norms and standards are crucial parameters in implementation of the concerned project. Development planning is intended to guide appropriate land use pattern and vice versa in foundations of planning practice. Fundamentally, regional and urban planning method is anticipated so as to follow the process in which land asset is considered a primary tool. In the process, land is first equipped with proper services or facilities as a prerequisite for proposed infrastructures to be built. Then only comes the ownership of the infrastructure by people, and the project is assumed to be operational. But in case of Nepal, the process is just the opposite wherein the socio-economic dimension of people or public usage comes first which attacks land assets secondly and the rest of development follows thereafter. This unusual phenomenon of unreasonable takeover in the process has emerged as a major problem in planning practice in Nepal.

Framework for regional and urban planning in Nepal has become vague as there exists dilemma regarding whether the pattern of land use should be guided or decided by social institutions or the government agencies to implement it. As population is increasing due to aspirations of urban economy and also due to urban-oriented rural agglomerations, change in land use pattern is expected, especially mixed-use pattern are noticed at most. Rural areas are continuously evolving from agrarian societies to service-oriented and commercial economies, and at the same time, urban settlements are also seeking for expansion due to transformation in commercial and industrial sector triggered by development in means of transportation. This spontaneous occurrence has created transition in land use pattern in both rural and urban areas of Nepal. We need to wisely address this issue as the spatial arrangement of economic activities is not random, it is but the result of decisions made by our own social institutions including families, business, and government itself. Some of the factors determining land use are: land use plans and maps, infrastructure, information system, zoning, bye laws, building codes and conservation, budgeting and fiscal incentives, population, demand for land for different uses, and territorial rights (Joshi, 2019).

Land use pattern is often guided by form and hierarchy of settlements. Human settlements in Nepalese context are sparsely populated in wide range with some rural municipalities having population around 15,000 to metropolitan cities accommodating population of approximately 1,000,000 (Central Bureau of Statistics, The World Bank, 2013). Given the skewed distribution of population in both rural and urban areas, delivery of basic infrastructures is an initial step in planning method.
services and facilities have also become unmanaged and unequal challenging regional and urban planning practice in Nepal. This has occurred mainly due to inaccuracies and complications in land use planning of above-mentioned disorganized settlements. Nevertheless, Government of Nepal (GoN) has tried to shape a path for sustainable urban development with some plans and projects of developing regional centers which would eventually disseminate the significance of land use planning.

One of the commendable steps by GoN towards setting up necessary codes in planning practice is preparation of Planning Norms and Standards in 2015. With an objective of facilitating urban designers, planners and policy makers to identify and forecast essential infrastructure need of urban areas, it asserts in understanding of urban form and land use in order to ensure balance between them with recommendation of land use norms and standards (MoUD, 2015). It has arranged a hierarchy of urban areas into 5 classes: metro city, sub-metro city, city, sub-city, and market center which are based on population and guided by infrastructure, land use and urban form.

### Table 1. Types of land use for Market Center.
© Planning Norms and Standards, 2015

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Broad Classification</th>
<th>Sub-classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Natural Resources Area (60%)</td>
<td>Agricultural forest/Community forest/Water bodies</td>
</tr>
<tr>
<td>2.</td>
<td>Settlement Promoted Area (40%)</td>
<td>Mixed (Residential cum Commercial/Residential/Institutional (Office complexes)/Industrial (Agricultural initial processing industries that are linked to the industries of the cities)</td>
</tr>
</tbody>
</table>

### Table 2. Types of land use for City.
© Planning Norms and Standards 2015

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Broad Classification</th>
<th>Sub-classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Natural Resources Area (40%)</td>
<td>Urban agriculture/Water bodies/Open spaces/Public land</td>
</tr>
<tr>
<td>2.</td>
<td>Settlement Promoted Area (60%)</td>
<td>Mixed (Residential cum Commercial/Residential/Rural residential/Commercial/Institutional/Industrial (Production with heavy processing)/Recreational/Park</td>
</tr>
</tbody>
</table>

### Table 3. Types of land use for Metro City.
© Planning Norms and Standards 2015

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Broad Classification</th>
<th>Sub-classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Natural Resources Area (30%)</td>
<td>Urban agricultural area/Water bodies/Recreational areas/Open spaces/Public land</td>
</tr>
<tr>
<td>2.</td>
<td>Settlement Promoted Area (70%)</td>
<td>Urban core area/Mixed (Residential cum Commercial/Commercial/High residential/Medium residential/Low residential (Rural)/Urban expansion area/Institutional/Industrial (Service-oriented: Tourism/IT/Logistic/Display, etc.)/Heritage/Religious</td>
</tr>
</tbody>
</table>

As suggested by the Planning Norms and Standards 2015, the land use is basically categorized under natural resources promoted area and settlement promoted area. The norms for the land use for urban areas explains the types of specific uses allowed with each land use and the percentage adequate for each land use whereas standards explains the specific standards for each land use such as distances from the main road, water bodies, minimum land parcel sizes, etc. which govern the form of the urban areas. The percentage for the allocation of natural resources and settlement promoted areas in the hierarchy of urban areas differ from 55-80% and 20-45% respectively. The percentage of natural resources and settlement promoted areas have been set in reference to the existing urban form, but since the built-up areas for the urban areas of Nepal is quite less, the percentage of settlement promoted areas has been taken with consideration to other developing countries.

### 2.3 Cross-cutting Issues and Repercussions

After a brief introduction of land use planning in Nepal and land use norms and standards in planning practice in singularity, the embedded problems in land management in Nepal related to regional and urban planning has come to surface. It is evident that the cross-cutting issues are around land use planning, yet another hidden factor to be considered is the attitude of both government and general public in acceptance of the plans and policies related to land management. For the government, problems in land management seems to be sole concern of MoLCPA whereas challenges in regional and urban planning are directed to Ministry of Urban Development (MoUD). In the formation process of relevant strategies, other ministries and departments are dodged. Sometimes, plans and policies on land management and development come indifferent to overlapping agencies which are short of adequate participation and feedback from general public and local stakeholders. In some cases, guidelines are drafted along with participatory planning process, which are again surprisingly not acknowledged by the general public.

For instance, MoLCPA has initiated a program, Freed Agricultural Bonded Laborer Rehabilitation Program (FABLP) which provides a parcel of land or new housing or financial aid for maintenance of existing houses of the laborers. But, the beneficiaries are not ready to move to allotted sites rather they insist that a housing plot be allocated for them in market centers where the housing conditions are already in chaos.
It is sometimes a matter of utter disgrace that stories of corruption in selection of land parcels are heard wherein both the government officials and beneficiaries, and land brokers are involved. This has challenged both the aims of government to alleviate poverty and set up planned settlements in rural areas of Nepal.

Also in case of urban poor, back in 2012 Department of Urban Development and Building Construction under MoUD purchased 4,070 square meters of land from Ichangu Narayan Land Pooling Committee and built 227 housing units in 2014 for squatters and urban poor residing in informal settlements along the Bagmati River in Kathmandu Valley which amounted NRs 230 million to GoN (The Kathmandu Post, 2019). But in vain, the housing complex has remained vacant for almost five years as the squatters are reluctant to move in. In a case study of land readjustment of Ichangu Narayan Housing Project (Shrestha et al. 2017), the research concluded that there lacked participation of landowners in the planning process, and also there was lack of policy implementation of accommodating low-income groups. On the other hand, a similar housing project in Kirtipur led by a non-government organization, Lumanti, is reported to be successful. This tragedy in urban housing has raised some serious issues of institutional fragmentation among MoLCPA and MoUD in implementation of sustainable land management in urban context.

Besides the examples of small projects in rural and urban context, there are similar tragedies in various national level projects deemed crucial in the context of regional and urban planning in Nepal. As GoN is planning several new towns across the nation, it has introduced the concept of smart city development at different places. It is ridiculous to know that while the government is lagging behind in preparing proper land use plans and integrated urban development plans for various municipalities, it has declared ambitious program for smart cities void of justified indicators for smartness of a city. Without pre-planning, it is unsure of managing smart cities, but with stubborn nature of government in co-ordination among inter-linked organizations in fields of regional and urban planning, it is more than sure that we are going to get dumb cities.

Also in case of new town development projects, the outcomes are uncertain if they would fulfill the objective of controlling internal migration from rural regions to urban areas. GoN has conceptualized that the developed new towns would consequently accommodate a population of 100,000 with adequate urban amenities and services. However, due to difficulties in land acquisition and abnormal delays in prerequisite infrastructure set up, targets of achieving regional balance seem faraway. In lack of appropriate land management and land administration in the project areas of new town development, people are unwilling to avail land for development, rather they are holding or involved in brokerage and trading of lands for speculation purpose. This has been unnecessarily appending the project and people are continuously moving to near urban areas with better economic opportunities which has retrospectively triggered internal migration. Now with new state restructuring of federal Nepal, formation of all the TDCs have been revoked and its property has been transferred to respective municipalities. This annulment of TDCs might not be desirable, but in last years, even TDCs were convoluted in overpoweringly distributing much valued government and public lands to different persons or organizations for vested interests which was ruthlessly against the norms and values of TDCs themselves. It is hard to believe but there is no more government and public land left with local governments in Nepal for future development purposes.

Another problem in both land management and spatial planning is encroachment of government and public open spaces. Previously, there was an autonomous Town Development Committee (TDC) in almost all municipalities which had some portion of land under its jurisdiction which was a kind of land bank for government and public purposes. In its planning provision, the land would be used for government institutions, community or urban service centers, bus parks, sports facilities, recreational parks, emergency operation centers, public open spaces, and etc.

Now with new state restructuring of federal Nepal, formation of all the TDCs have been revoked and its property has been transferred to respective municipalities. This annulment of TDCs might not be desirable, but in last years, even TDCs were convoluted in overpoweringly distributing much valued government and public lands to different persons or organizations for vested interests which was ruthlessly against the norms and values of TDCs themselves. It is hard to believe but there is no more government and public land left with local governments in Nepal for future development purposes.

Apart from the deterioration of government and public land from local authorities, public open spaces have been equally encroached by the general public. lands of various religious trusts, protected areas such as national parks, grasslands and community forests have been overtaken by the squatters, victims of natural disasters including landslides and flood. These issues are often fabricated by political interests whereby nobody seems to suggest for proper land management solution for the affected ones. Not only the homeless or landless people, but people with tenancy of adequate land are also involved in intruding barren and
fallow land around them. Building bye laws are followed with little or without consideration of legal provisions in most of the rural and urban municipalities. Public open spaces called as breathing spaces for adjacent settlements are of being squeezed by both the government and general public.

Figure 8. Land use Map with Physical Development Plan 2014 of Rajpur Governmental Area under Dipayal Silgadhi Town Development Committee in Doti district. © Bhupendra Jung Keshari Chand, 2019

3. CASE STUDIES AND IMPLICATIONS

The urgency of any problem is determined by its specific nature pertaining to its planning and implementation methodology. Also, in case of land management problems in Nepal, resolution lies within its policy and plan formulation and respective implementation thereafter. In modern days, traditional arm-chair planning has become almost outdated, and public participatory planning approach has emerged as a new paradigm in substantial result-oriented planning practice. In context of Nepal, Integrated Action Plan (IAP) is in exercise since long period of time whereby all the associated implementing agencies, partners and local stakeholders actively take part in the planning process from beginning of a project to its end. While the participatory planning process has come to be successful for many non-governmental organizations in Nepal, is has but become less effective in standings of government-initiated projects. It can be inferred from the government lead projects that decision-making is the key process wherein community participation is either kept in set back or the public themselves keep at distance during the process. With the help of some relevant case studies, fulfillment or fallacies in planning and implementation course can be well understood. A brief insight into both regional and international case studies in participatory land use planning and implementation project, and capacity building for sustainable land management would present some applicable findings in local as well as global perspective.

3.1 Participatory Land use Planning and Implementation in Designated Districts of Nepal

In 2015, a report on Participatory Land use Planning and Implementation (PLPI) in designated districts: Surkhet, Nawalparasi and Morang in Nepal was prepared by UN-Habitat Nepal in association with United Nations Development Program (UNDP) and International Organization for Migration (IOM) supported by UN Peace Fund Nepal (UNPFN) along with some local non-governmental organizations. The basic objective of the project was to carry out participatory land use planning and its implementation in the Latikoli, Amrout and Jhorahat Village Development Committees (VDCs) of Surkhet, Nawalparasi and Morang districts respectively and to assist in the compilation of legislative framework and land use planning and implementation guidelines for replicating participatory land use planning beyond project districts and VDCs. The project reportedly achieved 21 outcomes in preparation, data collection and analysis, land use planning, implementation of VDC land use plan, monitoring and evaluation, and capacity development and training (UN-Habitat Nepal, 2015).

The project was based on both top-down and bottom-up planning approach with technical or professional inputs and inclusive community participation. It also formulated district level land use plans of Surkhet, Nawalparasi and Morang districts in accordance with NLUP 2013 which provided a periodic vision on addressing the needs of rezoning or reallocation of land resources resulted by increase in migration, urbanization, industrialization, unplanned settlements, agro-farming systems, and use of forestry in respective districts. The report has strongly asserted on necessity of integrating district land use plan along with long-term or periodic development plan and annual development plan of the district by respective District Co-ordination Committees (DCCs).

Figure 9. Land use Map of Amraut VDC. © UN-Habitat Nepal, 2015
Land use plan of selected VDCs were prepared by using participatory planning approach with rigorous involvement of community and local stakeholders. The project prepared compiled land use maps including zoning maps, soil map, land capability and suitability map, cadastral superimpose and planning maps, also presented alternatives to sustainable land management such as land consolidation which were submitted to local Land Revenue Office and Survey Office as well.

3.2 The Governance of Land use in the Netherlands: The Case of Amsterdam

Apart from issues of capacity building and participatory planning approach in land management, ineffectuality in regional and urban planning across the globe has emerged as one of the major contests for land use planning. Similar could be the case in devising appropriate governance for land use in the Netherlands. Amsterdam, in the Netherlands along with its adjacent municipalities, have great regional as well as economic importance. Currently, dynamic growth of Amsterdam City has been asking for mixed-use and multiple land use pattern otherwise which would create chaos in urban housing and further expansion of the city. Also, transforms in transportation and rising tourism industry in urban core of Amsterdam has been challenging land uses of the city.

However, it is more than fulfilling to know that the Netherlands has self-binding strategic spatial plans for each level of government. The Spatial Planning Act 2008 is the main framework legislation for any sort of spatial planning in the Netherlands where structure plans and land use plans are the two major types of spatial plans. Again, the structure plans are self-binding meaning that the plans of an upper level government are not legally obligatory on that of a lower level government. This provision makes the framework documents flexible in order that they can serve the needs and interests of each level of government and community as it requires (OECD, 2017).

The national structure plan of the Netherlands constitutes a strategic spatial vision for development, on the very basis of which the national government used to intervene in urban planning by determining percentages of built-up areas in city cores, and outlining national buffer zones for implementing restructure plans. But with recent changes in governance of land use in the Netherlands, the national government only focuses on urban transportation system, and acts in accordance with local and regional authorities. The structure plan of Amsterdam city envisions radical spatial development of its land with objectives of encouraging urban population, expansion of mixed-use zones, and enhancement of quality of public open spaces guided by legal instruments of land use plans with active planning method. There is a new framework legislation in development in the Netherlands anticipated to come with integration of multiple rules and regulations mutually related to governance of land use such as natural resources, water bodies, real estate, and etc. which would ultimately facilitate the decision-making process in spatial and urban development projects.

3.3 Policy and Implementation Gaps

It is a coincidence that major turn in both land management system and in regional and urban planning in Nepal emerged simultaneously along with the Eighth Five Year Plan (1992/93 - 96/97) which identified land use plan as a long-term basis program in order to address the problems in land management, and it also had a separate chapter on urban development aimed at regional balance. Despite having a fate of twin policies from single periodic plan, consecutive developments in plans of land management and that of regional and urban planning seem to have taken different paths in singularity.

In current scenario, LUP 2015 and NUDS 2017 remotely complement each other. There are more than enough existing acts and regulations related to land use planning, but due to lack of inter-departmental co-ordination, institutional fragmentation, and unnecessary duplication of responsibility in government mechanism, implementation of sustainable land management in contemporary issues of regional and urban planning has become a long, faraway and almost impracticable goal to achieve. The recent Land use Act 2019 again seems to be formulated in isolation from various other institutions or organizations related to land development works. The act is largely based on traditional usage of land resources such as agriculture, hazard or disaster risk, and environmentally sensitive zones, etc. whereas it has remained silent in case of urban expansion areas. Despite the concurrent problem of land acquisition in several projects of national pride, no any provisions for such scenarios has been suggested in the act.

From the multi-axial issues of institutional fragmentation among inter-linked bodies to necessity of special provisions in land management and land administration in places of national level projects, may it be devoid of justified parameters and indicators or tenacious attitude in encroachment of government and public land, the utmost tool for appropriate intervention is policy refining at last. But with astonishment, even policies are incoherent in context of land management in Nepal. As it has been discussed earlier that a new Land use Policy (LUP) was framed in 2015 subsequently retracting the NLUP 2013 of Nepal. Though both the policies are mostly similar, some strategically important appendices on definitions of land use from 2013 have been entirely removed from the 2015 version. In NLUP 2013, detailed in-clause basis and criterion for determination of 6 different definitions and zones for respective land use has been illustrated in Appendix No. 1. Whereas in the updated LUP 2015, the detailed appendix has been omitted with basic definitions of 11 different land use zones only. Whether this change was just an alteration or may it be intentional, such immaturity and inaccuracies in policy re-writing is more than likely invite obstacles in its implementation.

Apart from conventional policy interventions, some technical tools such as Computer-aided Designs (CAD), Building Information Modelling (BIM) Technology, appropriate use of
Information and Communications Technology (ICT), Geoinformatics, and etc. can also bring about continuous evolution in land management and land administration as well. For instance, unnecessary fragmentation of land could be controlled by designing a special software for plot division which would be programmatically based upon pre-set parameters or bye laws related to land administration of given municipal area. Similar uses and advancement in Geographic Information System (GIS) software can also assist in digital land management and land administration services. Another important step to control and protect land resources for future urban expansion is that an autonomous body such as former TDCs or an independent planning commission having legal rights with single-door system of operation be reformed in each local levels which would devise, regulate and monitor overall structure plan of particular local authority aimed at regional and urban planning and subsequent development.

4. CONCLUSIONS

There is an urgent need of an integrated act on land use planning which would contain mutual aspects of both socio-economic and physical dimensions in land management and land administration, and in regional and urban planning sector. It comes as an important lesson from the case study of governance of land use in the Netherlands that the local land use plans be self-binding whereby local level government practices its own legislation independent to the federal government. This practice would be meaningful only if the local governments have attained required technical and institutional capacity with long-term vision for spatial development of their land resources. Likewise, from the case study of participatory land use planning and implementation, it is evident that community driven sustainable land management projects are prospective to become fruitful in sensitization of land use planning among the general public and local stakeholders Equally important is an integration of relevant building bye laws with rules and regulations of land administration of a municipal area. It is seen that non-professional land brokers and surveyors with limited knowledge of planning are involved in illegal plotting of land making it vulnerable to degradation in long run. This needs to be restricted and legal practice of land development must be assigned to planning professionals only.

As the research of this paper is particularly focused in relevancy of land use in land management, and regional and urban planning in Nepal, the study work is limited to general background and interdisciplinary aspects only rather than the explanation of broader concepts of land management, and regional and urban planning. Also, methodology of the research is based on constructive criticism on existing policy and implementation gaps with relevant literature review, and the presentation is more discussion-oriented rather than being result-oriented.

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E-CAD: WEB-BASED INFORMATION SERVICE FOR LAND MANAGEMENT

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KEY WORDS: Dynamic Web Platform, Spatial, GeoDjango, Mapping Server, Administrators, Spatial Operation

ABSTRACT:

The status quo of the land management and information system in Nepal is a far cry from where the developed world stands. Paper-based system is still the spine of this system which is tedious, less accurate and difficult to store and update. So, there is a need for a digitized system providing country’s land authorities with a powerful tool that creates a unified platform for the creation of an accurate spatial database, timely maintenance and updating of the database in a dynamic web platform. The database including spatial data of land features can be utilized to create a web-based thin-client mapping application which meets the needs of all the stakeholders (government authorities from Survey Offices, Land Revenue Offices, Land Reform Offices, etc.). This paper shows the use of open-source software for the creation of a web mapping system including QGIS, PostGIS extension of PostgreSQL for spatial database, HTML for markup, CSS for styling, JavaScript, Leaflet, Open-Layers for client-side scripting and Geo-Django for backend designing. The developed methodology can be utilised for the preparation of an interactive thin-client web mapping server that enables general users to dynamically view data, zoom, pan and search from the database and obtain land information. The login system enables administrators with various access to upload, verify and edit data along with performing various spatial operations while the super admin is entitled to access to the PostgreSQL database. The major finding is that the use of a thin client application for a land information system is beneficial for all stakeholders. It is also a measure of the performance of land authorities allowing better planning, preparedness, and allocation of resources.

1. INTRODUCTION

Land is important because humans not only live but also perform all economic activities on land. Besides, Land also supports wildlife, natural vegetation, transport, and communication activities. Most of our basic needs and requirements are obtained from land. Land is a nonincreasing factor of production that houses an increasing population. A great percentage of man’s activities depend on land. The quests for land ownership, registration, transfer of ownership, etc. are concepts that affect land management. Estimations show that about 70% of people-land relationships worldwide are not documented, whereas the population grows and the pressure on land and natural resources increases. These results in many land conflicts and competing claims on land.

Land Information System can be defined as a geographical information system for cadastral and land-use mapping, typically used by local governments. It consists of land records and associated attributes as well as spatial information. Land records include land resources, land use, environmental impact, and fiscal data. It basically deals with legal boundaries of land tenure. LIS provides a base layer capable of integration into other geographic systems. Mainly LIS uses cadastre as a primary document. Hence, it consists of two components i.e. spatial data and non-spatial data. Spatial data refers to the data related to location or position of an object in geographic data e.g. map whereas non-spatial data describes the spatial data e.g. field books, registers, etc. LIS considers land parcels as key features. The parcel is only considered as a property after the rights and restrictions acclaimed to the owner. LIS guarantees land ownership and security of tenure. Concept of LIS and the cadastral system was first developed in Europe to support taxation. The Western LIS concept nourished the multipurpose role of the cadastral system. The Dutch Cadastral System enabled the web to the parcel-based system. It consists of a pre-modeled database with ISO standards. The system is capable enough to handle spatial and attribute data in web browsers. It has a Web-based query facility as well as a login facility for data security. It also combined an online verification facility (Tuladhar, 2005). The concept of LIS was first introduced in Nepal in the 8th periodic plan by the government. The Implementation of Land Information System in Nepal Project was carried out, in close co-operation with the Swedish counterpart Swede Survey. The map-based land recording system was started after the establishment of Cadastral Survey in Bhaktapur district in 1980 B.S. The Survey Goswara was established in Kathmandu in 1996 B.S. The Survey Department and the Department of Land Revenue were established respectively in 2014 B.S. and 2016 B.S. After the Land Survey and Measurement Act, 2019 B.S., came into effect, the maintenance of a map-based land records system was taken into practice. The general objectives of this act were preparation of up to date land-ownership records that were essential for the collection of land revenues, collection of the tenants and land mensuration works (esp. needed for land reformation program). In the meantime, the software was designed named DLIS to acquire and manage non-spatial data (Ministry of Land Management, 2019).

The advent of the Internet has seen a number of Geographic Information Systems utilizing its potential to disseminate Geographic Information. Web-based GIS comprises of relatively small pieces of software or components, which perform particular GIS operations, namely Cartographic Visualization. However, it is still a tedious task for the collection and maintenance of the database due to a multi-tier system for data acquisition. In the current day and age where the internet has
vastly simplified this process, the old multi-tier system is a hindrance to an effective management system. Thus, a thin client-based application is best suited for this purpose. This also serves as a justification for the selection of web-based thin-client application creation as described in this paper. The overall paper describes the indispensability of a web-based cadastral information management system in ensuring a much more informative and users’ participatory cadastral information system for land management.

2. METHODOLOGY

The succeeding sub-sections describe all the procedures required for developing digital information system. Figure 1 summarizes all the work procedure followed to develop the system. Additional geo-data like orthophotos, digital elevation model (if available) along with development plans are needed for the betterment of the system.

![Figure 1. Workflow diagram](image)

2.1 Data Collection

Data is a fundamental part of any management tool. Spatial information with its attribute value was collected in .mdb format. Verification of data is a must. For that, satellite images along with OSM were collected. Cadastral plan for area of interest provided the validation of information obtained from .mdb file.

2.2 Data Processing

- Shapefiles were extracted from Microsoft Access Database File (.mdb) format using Microsoft Access Database Engine in QGIS.
- Extracted shapefile had Nepal_87 Transverse Mercator coordinate system. The coordinate system was changed to WGS_1984 UTM Zone 45N and spatial adjustment for each layer of shapefile was performed.
- Unwanted information was removed from the attribute table.

2.3 Map Preparation

The map to be published on the website was prepared from shapefiles (parcel.shp, hydro.shp, building.shp, transportation.shp) obtained from Microsoft access database (.mdb) format. Using QGIS, which is a free and open-source cross-platform desktop geographic information system application that supports viewing, editing, and analysis of geospatial data, map was prepared using various tools. OpenStreetMap was added as a base map for the verification of the data. Before that, we also connected QGIS with our database so that any changes in data made on QGIS could be automatically modified in the database system.

2.4 Back-end design

Back end deals with the inner mechanism of data along with the front end. It is used to store, create, manipulate the data. Django, a high-level Python Web framework, was used for the creation of the backbone of the website. A project with the name ‘e-CAD’ was created along with applications ‘pages’ & ‘shapefiles’. First one was for creating the front end of the website & later one was for processing the shapefiles.

- Database was connected with Django by defining the engine required. Spatial database was connected with the Django project as well as with QGIS.
- Apps required for project, for example: third party apps and own created apps were defined in ‘settings.py’.
- The ‘admin.py’ file was used to display models in the Django admin panel. Also, admin panel can be customized using ‘admin.py’ file.
- Admin homepage can be accessed by entering URL ‘http://127.0.0.1:8000/admin/’ or ‘http://localhost:8000/admin/’.
- For each shapefile, models were prepared. Models are the definitive source of information for our data. They contain the essential fields and behaviors of the data used. Each model maps to a single database table.
- Unicode_literals was used to speed up the porting process. Models were imported from a database of Django. MultiPolygonField, not being supported by ‘django.db’, ‘gis models’ was imported from ‘django.contrib.gis.db’.
- A Parcel class including various fields with field type id was defined. Field type filters the exact type of data required by field. Likewise, Building, Transportation & Hydro classes were also defined along with various fields and their types.
- To import data, Layer-mapping was used. It helped us to load all the information stored in a shapefile to the model developed. All the function interacting with the operating system was imported by import ‘import os’. The ‘django.contrib.gis.utils’ module contains various utilities that are useful in creating geospatial Web applications. One of them is the LayerMapping class that provides a way to map the contents of vector spatial data files into GeoDjango models.
- Each key in the ‘parcel_mapping’ dictionary corresponds to a field in the ‘Parcel’ model. The value is the name of the shapefile field that data will be loaded from. The location of ‘parcel.shp’ was provided by defining ‘parcel_shp’.
- All fields which correspond to each other were imported with layermapping.
- Similarly, ‘building_mapping’, ‘transportation_mapping’ & ‘hydro_mapping’ were defined for importing fields from respective shapefiles.
- All the basic requirements for setting up back-end like URL, ADMIN, VIEWS were set up.
The system is supposed to be dynamic. Dynamic in the sense that our model should update the information if we change something in frontend.

Also, for data to function and be processed according to the requirement of user, we changed our shapefile to GeoJSON.

Serializers allow complex data such as query sets and model instances to be converted to native Python data types that can then be easily rendered into JSON, XML or other content types.

Doing so, we were able to achieve API. API is a set of functions and procedures allowing the creation of applications that access the features or data of an operating system, application, or other service.

2.5 Front-end design

Front-end web development is the practice of converting data to graphical interface for the user to view and interact with data through digital interaction using HTML, CSS, JQUERY, TURF & JavaScript.

- Front-end design started by designing the homepage.
- In login page, three different login sections were made for different kinds of users: administrative users, authentic users and normal users.
- Three different pages were developed for redirecting each users after login which display the parcel including building feature, hydro feature, transportation feature along with Satellite_streets map as default with:
  - default zoom:16
  - default bound: [[27.63404, 85.51547],[27.62401, 85.52434]]
- Icons were prepared for various functions like zoom in, zoom out, geolocation, measure, search and buffer.
- Geolocation function shows current location of user and measure tool gives coordinates of a point, distance between two drawn points and area of drawn polygon.
- Floating widget was made for selection of base map and map layers.
- Buffer function was made for buffering transportation & hydro feature with default buffer radius of 5m.

After designing both back-end & front-end, they should be connected. It should be ensured that every element gets connected so that the front-end shows exactly the same feature it asks for. By using leaflet plugins, HTML & CSS, web pages were created that display map feature, login pages and home pages.

3. DEVELOPED WEB GIS PLATFORM

Following items provide a brief description of the interactive web map application thus created:

- While accessing 'localhost:8000/home' or http://127.0.0.1:8000/home, the user is directed to homepage containing button labelled with ‘e-CAD’.
- After clicking the button, one is directed towards the login section. There are three login sections, each for three different kinds of users as seen in figure 2.
- Considering data security, each type of users have been provided with different permissions. A base map has been added for the user’s convenience. Users can select among different base maps. Similarly, there is a choice of selection of data layers too.

![Figure 2. Login Sections for different kind of users](image1)

- Admin users can see all the information about the features included. They can use spatial functions and also edit the data. They can update, split or add the information of features. If required they are able to create new features too.

![Figure 3. Admin View of the webpage.](image2)

- Some spatial functions like zoom in, zoom out, buffering(default radius of 5m), geocoding, area calculations, distance calculations, coordinate view, search window, scale bar along with mini-map have been introduced.
- When a feature in the map is clicked, a popup window appears with detailed information about that feature as shown in figure 5. It shows the information of parcel...
along with its area, east parcel, west parcel, north parcel, south parcel, parcel key.

Figure 5. Operation to locate the position of the clicked point

Figure 6. Distance between two drawn points on the map

Figure 7. Area of the drawn polygon on the map

- Normal users don’t need any ID to login. They only need to submit the purpose form for their visit to the website.

- Data can be added from the admin site and all the required information can be saved.

- Building, transportation and hydro also can be added/modified in a similar way as in figure 8.

- Only administrative members can access the admin page.

- An interactive secondary homepage has been added so that admin can visit the page they require.

- Authentic users are able to see their information i.e. one can obtain detailed information of the parcel only if he owns it.

- Authentic users have to use their citizenship number and date of birth to log in.

- Normal users can just view the map. They can neither use spatial functions nor obtain detailed information.

Figure 8. Adding/Modifying parcel data to the database

Figure 9. Viewing information by authentic user

4. CONCLUSION

Management of land information is imperative at present in Nepal. Hence, Web-based and Information System provides the country’s land authorities with a powerful tool which creates a unified platform for all the stakeholders and concerned individuals and organizations which can be utilized for creation of accurate spatial and non-spatial database, timely maintenance and updating of the database in a dynamic web platform. It also provides government officials with easier analysis of geospatial data. This system implements the OGC Web Services: WMS and WFS in order to achieve the visualization of static and dynamic spatial data respectively and the various spatial operations on those data to perform simple spatial and statistical analysis. This paper is an example of how better data dissemination can be achieved of spatial and non-spatial datasets for various stakeholders with different access. It is also a measure of the performance of land authorities allowing better planning, preparedness, and allocation of resources. Alongside with this, land valuation, utility management, land taxation can be appended in this system. Data dissemination to the general people also would be easier for both the stakeholders and public.

REFERENCES

**APPENDIX**

**Map Interface**

The map can be added using a leaflet. Leaflet is the leading open-source JavaScript library for mobile-friendly interactive maps. Leaflet content delivery network (CDN) can be started in our HTML file as:

```html
<link rel="stylesheet" href="https://unpkg.com/leaflet@5.6.0/dist/leaflet.css" />
<script src="https://unpkg.com/leaflet@5.6.0/dist/leaflet.js"></script>
```

Division of map can be stated as:

```html
<div id="map"></div>
```

Styling of map division is followed using cascading style sheet (CSS) as:

```html
<style>

body {
   width:100%;
   height:100%;
   background-image: linear-gradient(to right bottom, #333333, #ff0000);
}

html, body, map {
   width:100%;
   height:100%;
   margin: 0;
   padding: 0;
   float: right;
}
</style>
```

Mapping parameters like zoom control, maximum & minimum zoom level as well as bounding is set as:

```js
var map = L.map('map', {
    zoomcontrol: true, minZoom: 3, maxZoom: 15);
map.fitBounds([[27.63004, 85.52947],[27.64083, 85.52634]]);
```

Now, the shapefiles that are imported in databases from Django models by running `load_shp.parcel_run()` are added to the map. The creation of `.json` file made it possible to pull API wherever required. It is then bounded and added to layer as:

```js
var layer_shapes = new L.geoJSON.AJAX({
    url: 'parcel_13.json',
    onEachFeature: function (feature, layer) {
        layer.bindPopup('Parcel: ' + layer.feature.properties.id + ', Area: ' + layer.feature.properties.area + 'sqm');
    },
    style: function (feature) {
        return {fillColor: '#555555', weight: 2, color: 'red'};
    }
});
map.addLayer(layer_shapes);
```

Similarly, building, transportation & hydro is added to layer as done for parcel.

For operating buffering on a transportation feature of 5m, a button is created which buffers the feature on click. It is removed by double-clicking the same button.

```js
var toggle = L.marker(leafletCenter, {
    icon: new L.Icon.
    color: 'red',
   พฤติกรรม: 'add-buffer',
    onmouseover: function() {
        view.overlay.addLayer(layer_shapes.parcel_9);
    },
    onmouseout: function() {
        view.overlay.removeLayer(layer_shapes.parcel_9);
    }
});
```

A small division is added to the bottom right side of the map. It shows the ESRI World Imagery of the place which is represented by cursor in main map division.

```js
L.control.mousePosition().addTo(map);
var baseMap = {
    'ESRI_WorldImagery': L.tileLayer('https://server.arcgisonline.com/ArcGIS/rest/services/World_Imagery/MapServer/tile/{z}/{y}/{x}',
    maxZoom: 20,
    id: 'mapbox.satellite',
    accessKey: 'pk.eyJ1IjoiamFyZGVvcmRyIiwiYSI6ImNra3JrYnlwajJyemZvNTp1bWd2OGl1c2MifQ.NEoia2m02ph--vQzZcKgTQ');
);
map.addLayer(baseMap);
L.control.layers(baseMap, {}, {collapsed: false}).addTo(map);
```

To add a base map layer in our map, variables must be initialized for the required number of base maps.

```js
L.control.layers().addTo(map);
```

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APPLICATION OF ANALYTICAL HIERARCHY PROCESS TO ASSESS THE IMPACT OF THE LAND USE REGULATION ON THE LAND MARKET IN NEPAL

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ABSTRACT:

The impact of the introduction of land use control on the Nepalese land market is a function of various impact factors across economic, social, environmental and institutional dimensions. However, diversity in the unit of measurement of the land market outcome across these dimensions and the associated impact factors, and stakeholders’ perceptual variation on the level of their importance always challenges the identification of the impact on the Nepalese land market. The objective of this study was to measure the impact of the introduction of land use control in the Nepalese land market through the application of multi-criteria decision making (MCDM), in general and, Analytical Hierarchy Process (AHP), in particular. The multidimensional impact scenario was framed in the hierarchical structure of the AHP, placing the four dimensions and fourteen identified impact factors at various level. These hierarchical alternatives were prioritised, their weights were calculated and passed through consistency checking. Finally, these weights were synthesised with the stakeholders’ rating over the actual land market outcome experienced in the land market. The study found that the economic dimension of the Nepalese land market received the highest score of importance or weight of 33.1% whereas the social dimension receives the lowest 17.6%. The environmental and institutional dimension receives weights between these two extremes: 27.9% and 21.4%. Among the impact factors, the study found that consideration towards risk in the land use zoning receives the highest score of importance of 16.2% followed by compensation (14.2%); coordination (12.2%); awareness (11.2%); valuation (8.7%); land use quality (8.5%); restriction on subdivision (ease of use) (6.1%); mortgage availability (5.1%); expectation (5.0%); zoning adequacy (3.2%); lot size control (3.1%); transaction cost (3.1%); taxation (2.0%); proximity (1.4%). The market received a slightly positive impact of scale 0.28 across environmental dimension whereas quite negative impact of scale -1.92 across economic dimension followed by slightly negative scores of -0.73 and -0.31 across institutional and social dimension respectively. This framework generated by synthesizing the concepts of multi-dimensional impact factors measures the impact of the introduction of land use regulation on the Nepalese land market. The land market assessment framework brings to the fore that the economic aspects of Nepalese land market needs immediate attention relative to others so as to be able to push-up the overall success level of land use implementation in Nepal. We conclude that this assessment framework can be used to identify the impact of the introduction of land use regulation on the Nepalese land market and needs further research on its applicability across jurisdictions.
LAND EVALUATION FOR LAND USE PLANNING IN SAMBHUNATH MUNICIPALITY, NEPAL

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KEY WORDS: Land Evaluation, Suitability Analysis, Cellular Automata, Integrated Land Use Planning

ABSTRACT:

Land is the basic precious natural resources on the earth surface which is essential to human beings. Land use relates to the human activity or economic function in a specific piece of land. Land use planning facilities and services with a view to securing the physical, economic and social efficiency, health and well-being of urban and rural communities based on the physical, socio-economic, institutional and legal potentials and constraints for sustainable use of land resources. Sustainable land management is comprised with land use planning, land use design and land development for finding a balance among competing demand for multiple land uses and ecosystem services and sometimes contradictory uses. Land use schema is developed for representing the real situation of land to understand the practice of existing land use and its pattern. Land evaluation process is carried out conducting different suitability criteria’s/factors with different constraints as parameter in land suitability analysis. The land suitability of each land use category is analyzed with the consideration of different parameter associated with its weight-scoring. The weight-scoring of parameters are achieved with the ground parameters, expert opinion and people aspiration in the planning process. Local knowledge through PRA technique is used for linking qualitative and quantitative data and this information is incorporated in modeling process in ArcGIS environment. The projected land use map is prepared based on existing land use map, standardized group of suitability maps and contiguity filters using CA model. Flood modeling is conducting for determination of flood risk using HEC-RAS and HEC-GeoRAS. Similarly, landslide hazard modeling has evaluated using MCE-AHP and pairwise comparison of parameters to determine land slide susceptibility prone area. The physical development plan has analyzed from the existing infrastructure in the present land use map, strategic road network, rural and local road network for future developable area. Then, integrated land use plan is prepared from projected land use plan, guided physical development plan considering different risk layers in GIS based planning framework to support and facilitate the decision making process in land use planning process. The integrated land use plan is analyzed through SWOT analysis process to identify its strength and opportunities as well as its weakness and threat for implementing this plan at local level. The integrated land use plan is modified the weakness and threat through subjective analysis by preserving strength and opportunities to improve the public engagement by enabling the different stakeholders to fully understand the planning consideration of planners for implementation of land use at local level. PBCI system is developed through seamless cadastral data, land valuation, taxation and related land records which is linked with the integrated land use plan by spatial overlaid process.
A 40-YEAR MONITORING OF URBAN EXPANSION IN NEPAL USING TIME SERIES LANDSAT SATELLITE IMAGES: 1976 TO 2016

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KEY WORDS: Urban Expansion, Remote Sensing, Nepal

ABSTRACT:

Nepal has a short urban history of almost six decades and unprecedented urban expansion occurred during the last three decades. This study has explored the urban expansion pattern of Nepal during 1976-2016 using Landsat Satellite images. To explore the urban scenario over the study period, all available cloud free Landsat MSS, TM, ETM and OLI with 30 meter resolutions images were used. The cloud coverage during June, July and August were always just considerable and were not included. The Scan Line Corrector (SLC)-off data after May 2003 have been collected only for one month per year due to the unavailability of the TM images. All obtainable images were stacked and subset in ENVI environment applying supervised approaches with the maximum likelihood (ML) and support Vector Machine (SVM) classifier algorithms. Change analysis has been investigated for six time periods: 1976-1989, 1989-1996, 1996-2001, 2001-2006, 2006-2011 and 2011-2016. Spatially, southern plain (Tarai) region, Kathmandu valley, Pokhara valley along with the major city centers and highway peripheral areas have experienced remarkable urban sprawl over the period which is largely driven by its topography, migration-led population growth and various socioeconomic factors. Temporally, the largest urban expansion occurred during 1996-2006 particularly due to the political upheaval of the country. The vast majority of the expanded urban area is sourced from the cultivated land resulting in the sharp decline of prime farm land area posing threat to sustainable food security of the country. Similarly, it is the mountain region in the northern part of the country to experience the least urban development which is particularly due to its harsh topography and high out-migration rate. The acquired outputs of the research will function as the significant benchmark for the planners, policy makers and researchers to formulate effective land use plans ensuing the maximum and sustainable utilization of limited land resource of the country.
ESTIMATING THE VOLUME OF ICE LOSS USING LANDSAT IMAGERIES: A CASE STUDY OF RIKHASAMBHA GLACIER, NEPAL

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KEY WORDS: Glaciers, Remote Sensing, NDSI, Ice Velocity, Ice Loss

ABSTRACT:

Climate is usually defined as the “average weather” in a place. It includes patterns of temperature, precipitation (rain or snow), humidity, wind and seasons. Climate patterns play a fundamental role in shaping natural ecosystems, and the human economies and cultures that depend on them. But the climate come to expect is not what it used to be, because the past is no longer a reliable predictor of the future. Glaciers are regarded as natural elements documenting climate change most clearly to a wide public (Lemke et al., 2007). Climate is rapidly changing with disruptive impacts, and that change is progressing faster than any seen in the last 2,000 years (Gantayat.,2014). For this and further reasons glaciers are considered as one of the terrestrial essential climate variables by the Global Climate Observing System. In the last century, glaciers worldwide experienced a strong decline (retreat and mass loss) with only a few local exceptions (Bajracharya et al., 2014).

According to the report Team (2000), rising levels of carbon dioxide and other heat-trapping gases in the atmosphere have warmed the Earth and are causing wide-ranging impacts, including rising sea levels; melting snow and ice; more extreme heat events, fires and drought; and more extreme storms, rainfall and floods. Scientists project that these trends will continue and, in some cases, accelerate, posing significant risks to human health, our forests, agriculture, freshwater supplies, coastlines, and other natural resources that are vital to Washington state’s economy, environment, and our quality of life.

Earth’s average temperature is expected to rise even if the amount of greenhouse gases in the atmosphere decreases (Fujita et al., 2001). But the rise would be less if greenhouse gas amount remain the same or increase. Some impacts already are occurring. For example, sea levels are rising, and snow and ice cover is decreasing. Rainfall patterns and growing seasons are changing. Further sea-level rise and melting of snow and ice are likely as Earth warms. The warming climate likely will cause more floods, droughts and heat waves. The heat waves may get hotter, and hurricanes may get stronger.

Despite the relatively small area, Nepal has very diverse climatic conditions, ranging from tropical in the south to alpine in the north. The country’s three distinct geographies—the snow-covered mountains, the mid hills and the Terai (plains)—embodies this diversity. Its hydrology is fed largely by the South Asian monsoon system (SAM), but the relationship between the timing, volume of ice loss in glacier and the mountain landscape is poorly understood. The dramatic variation in altitude over a short distance has resulted in pronounced orographic effects, effects which severely limit our ability to explain precipitation dynamics in Nepal.

This study aims to monitor the Rikhasamba glacier for the period of 1995-2016 utilising the Landsat imageries with the objective of evaluating the volume of ice loss throughout the period.

1. INTRODUCTION

Climate change resulting devastating consequences on billions of people living downstream. This is why regular monitoring of the glaciers on that region is important not only to have insight into the glacier change but also to mitigate the effect of it. The satellite image as an alternate to ground based approach provides much more flexibility for monitoring in a regular basis. Therefore, this research aimed to map the decadal changes in glacier extent followed by estimating volume of ice loss of Rikha Samba Glacier located in Mustang district of Nepal. Multitemporal Landsat satellite images dating back from 1995 to 2015 were utilized in the study. The current research involved the calculation of snow index like NDSI on the radiometrically corrected satellite imageries. An open source GIS software package was used to automatically delineate the boundary of glacier based on the NDSI. It has been revealed that the glacier area shrunk by 2.608km² on an average over the period. The ice velocity of the glacier was estimated. Laminar flow approach (Cuffey and Paterson, 2010) was utilized to find the ice thickness of glacier based on the evaluated velocity information. The utilization of thus computed ice thickness gave the volume of ice loss during the study period (i.e. 310000 m³). In addition, 0.69km glacier retreat was observed over the period.

2. STUDY AREA

To study the ice loss and surface velocity of Glacier. Hidden valley was chosen because it is also one of those places in Nepal where the study has been done frequently and working on this site will surely help for the further research works. There are altogether ten glaciers in hidden valley i.e. G1, G2 up to G10. Rikhasamba is the largest Glacier in Hidden Valley. Figure 1 represents the study area of Rikha samba Glacier which extends from 5421 meters to 6507 meters above sea level with a total length of 5.5 kilometers.
3. METHODOLOGY

The overall workflow used in research is shown in Figure 2. The first step included the download of Landsat imageries from USGS Archive. These satellite imageries were then preprocessed. This included radiometric correction. Finally, calibrated satellite imagery was obtained. Normalized Difference Snow Index (NDSI) is the next step which deals with separating ice and non-ice area. With the help of QGIS, the change in Glacier extent was determined. Hence, COSI-Corr extension of ENVI was used in order to determine the surface velocity of glaciers which needs pre-event and post event images. The surface velocity of the studied glacier was evaluated for three different time period (i.e. 1996, 2006, 2016) in an interval of 10 years. The reason behind calculating surface in interval of 10 years is because of the fact that surface velocity within an interval of 5 years was found to be insignificant. In order to calculate surface velocity two subsequent images were used (i.e. to find surface velocity of 1996 satellite image of 1995 and 1996 were used and similar is the case with 2006 and 2016). Then, the vector field was calculated which gives the output as East/West Displacement, North/South Displacement and Signal to Noise Ratio (SNR). Since more SNR gives good result so it was used and filtered from 0.9 to 1 and removed (Gongotri.,2014) other. And Finally, the resultant of East/West displacement and North/South displacement was calculated. The output from the COSI-Corr was the displacement map of surface ice at certain time period and by using this displacement and time period, the surface velocity of glacier was calculated. The obtained result was used with slope (30m SRTM DEM) to determine the thickness of the glacier in the particular year using the concept of Laminar flow (Cuffey and Paterson, 2010). The thickness change was determined with the help of thickness and area previously calculated.

3.1 Ice Thickness Determination Using Surface Velocity and Slope:

According to (Cuffey and Paterson, 2010) Ice thickness was estimated using the equation of laminar flow (Equation 1) which represented as:

\[ U_s = U_b + \frac{2A}{n+1} \tau_b H \]

(1)

Where \( U_s \) and \( U_b \) are surface and basal velocities, respectively. To date, no accurate estimate of basal velocity for Glacier in Nepal is available, so we assumed \( U_b \) to be 25% of the surface velocity (Gongotri.,2014). Glen’s flow law exponent, \( n \), is assumed to be 3, \( H \) is ice thickness and \( A \) is a creep parameter (which depends on temperature, fabric, grain size and impurity content and has a value of 3.24 \( \times 10^{-24} \) Pa\(^{-3} \) s\(^{-1} \) for temperate glaciers; (Cuffey and Paterson, 2010). The basal stress is modelled as,

\[ \tau_b = f \rho g H \sin \alpha \]

(2)

where \( \rho \) is the ice density, assigned a constant value of 900 kg m\(^{-3} \) (Farinotti and others, 2009a), \( g \) is acceleration due to gravity (9.8 m s\(^{-2} \)) and \( f \) is a scale factor, i.e. the ratio between the driving stress and basal stress along a glacier, and has a range of [0.8, 1] for temperate glaciers (Gantayat et al.,2014). From Equation (1) and (2) we find,

\[ H = \frac{s}{\sqrt{\frac{1.5 fs}{f g \sin \alpha}}} \]

(3)

4. RESULT AND DISCUSSION

4.1 Area of Rikhasamba Glacier (G5) at different time

The multi-spectral Landsat images were used and the result showing change in glacier area of rikhasamba is shown in Table 1 below. The area of G5 is found to be 5.62 km\(^2\). The change in ice
area of glacier in every 5 years interval from 1995 to 2015 was studied and the result has shown that its area has been changing continuously. The glacier area change from 1995 to 2005 is 0.0008 km² and from 1995 to 2015 is 0.4850 km² which shows cumulative change in area of 20.07% from year 1995 to 2015 (Table 1). The most significant change has been seen in the year between 2005-2015 (Figure 3).

<table>
<thead>
<tr>
<th>Year</th>
<th>AREA (sq.km)</th>
<th>CHANGE</th>
<th>∑CHANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>5.6193</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>6.4589</td>
<td>0.8396</td>
<td>0.8396</td>
</tr>
<tr>
<td>2005</td>
<td>6.4587</td>
<td>-0.0002</td>
<td>0.8394</td>
</tr>
<tr>
<td>2010</td>
<td>6.1766</td>
<td>-0.2821</td>
<td>0.5573</td>
</tr>
<tr>
<td>2015</td>
<td>4.4911</td>
<td>-1.6855</td>
<td>-1.1282</td>
</tr>
</tbody>
</table>

Table 1. Summary of change in ice area of Glacier.

4.2 Tongue length

Tongue Length is the distance from the highest point in the glacier to the lowest point of that same glacier. The tongue length of Rikhasambha glacier was calculated from year 1995 to 2016. The maximum change in tongue length from 1995 to 2016 is 0.69km. The data showing change in tongue length is in agreement with the fact that glacier is shrinking in size due to climate change.

4.3 Surface Velocity Glacier at different time:

Temporal satellite imageries of the glacier were used to calculate the surface velocity of the glacier. To calculate the velocity, two images of one year interval were used in COSI-Corr extension. The mean and maximum surface velocity of the glacier obtained are shown on Table 2. The mean surface velocity of the studied glacier over the period was found to be increasing from 4.66 meters/year in the year 1996 to 12.67 meters/year. In addition to this, it has also been observed that the maximum surface velocity of the glacier was observed to be ranging from minimum 71.47 meters/year to the maximum of 87.75 meters/year for the year 1996 and 2016 respectively.

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean Surface velocity (meters/year)</th>
<th>Maximum Surface velocity (meters/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>4.6600</td>
<td>71.4700</td>
</tr>
<tr>
<td>2006</td>
<td>6.7445</td>
<td>80.5307</td>
</tr>
<tr>
<td>2016</td>
<td>12.6609</td>
<td>87.7593</td>
</tr>
</tbody>
</table>

Table 2. Summary of Mean Surface Velocity and maximum surface velocity of Glacier
4.4 Thickness of Glaciers at different time

The depth of glacier at different time period was evaluated using the equation of laminar flow based on surface velocity and Slope of the research glacier. The maximum and mean thickness of glacier was found to be 234.395m and 66.553m in 2006 as shown in Table 3. The mean thickness of glacier decreases by 4.257m from 1996 to 2016.

Table 3. Summary of Mean Thickness and maximum thickness of Glacier.

<table>
<thead>
<tr>
<th>Year/Glacier</th>
<th>Mean thickness (m)</th>
<th>Maximum thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>65.696</td>
<td>227.257</td>
</tr>
<tr>
<td>2006</td>
<td>66.553</td>
<td>234.395</td>
</tr>
<tr>
<td>2016</td>
<td>61.439</td>
<td>222.407</td>
</tr>
</tbody>
</table>

The ice thickness map for the three different time period (1996, 2006 and 2016) thus obtained are presented in the figure 7, 8 and 9 respectively.

4.5 Volume of Glacier at Different Years

The table 4 below shows the volume of ice in glaciers at different time from 1996 to 2016 in an interval of 10 years. The researched glacier showed volume of ice in the year 1996 was found to be 0.3939 cubic meter. Surprisingly, the volume of the ice in glacier for the year 2006 was observed to be increased. However, over the whole study period, a decreasing trend in the volume of glacier ice was observed. Rikhasamba Glacier showed change in ice volume of 0.00031 km³ from 1996 to 2016.

Table 4. Volume of Glaciers at Different Years.

<table>
<thead>
<tr>
<th>Year</th>
<th>G5 Rikhasamba (km³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>0.3939</td>
</tr>
<tr>
<td>2006</td>
<td>0.4335</td>
</tr>
<tr>
<td>2016</td>
<td>0.3908</td>
</tr>
</tbody>
</table>
5. UNCERTAINTY ANALYSIS

In order to quantify the total uncertainty (for a particular value of basal velocity, i.e. 25% of surface velocity) in volume estimation using equation used for determining the height, we fix the values between observed and modelled outputs) obtained at the two sites (Swaroop et al., 2003), and df was set to 0.1. In the literature (e.g. Hubbard et al., 1998; Gudmundsson, 1999; Farinotti and et al., 2009a) A is set to $2.4 \times 10^{-24}$ Pa$^{-3}$ s$^{-1}$ (Swaroop et al., (2003)). We set dA to be the difference between the value assigned by us and $2.4 \times 10^{-24}$Pa$^{-3}$ s$^{-1}$. To estimate the uncertainty in slope angle over a region, the vertical accuracy of the DEM must be known. The potential uncertainty in the Astor DEM for the Himalayan region is 11 m (Fujita et al., 2004). Therefore, the term d ($\sin \alpha)/(\sin \alpha$) has a value of 0.09. Variation in ice density, $\rho$, over the depth of the glacier is not known. We assume relative uncertainties of 10%, and take $d\rho$ as 90 kg m$^{-3}$ (Swaroop and others (2003)).

Given parameters to find uncertainties are:

$U_s = 12.66$ meters/year
$\Delta U_s = 3.5$ meters/year
$\Delta A = 0.84 + 10^{-24}$
$A = 2.4 \times 10^{-24}$
$df = 0.1$
$f = 0.8$
$d\rho = 90$
$\rho = 900$

The uncertainty in depth estimates is quantified by differentiating the formula taken to find the height in previous section which results in following:

$$\frac{dH}{H} = 0.25 \left( \frac{dU_s}{U_s} - \frac{dA}{A} - 3 \frac{df}{f} - 3 \frac{d\rho}{\rho} - 3 \frac{d(\sin \alpha)}{(\sin \alpha)} \right)$$

Substituting these values into Eqn of height, we find the maximum relative error in the volume measurement for Rikha Sambha Glacier is $\pm 23.22\%$ (assuming that the parameters vary independently and randomly).

6. CONCLUSION

Ice thickness for Rikhasambha from surface velocities and slope was estimated using the flow law equation of ice. The thickness was further used to find the volume of Rikhasambha glacier. The volume of ice loss of Rikhasambha Glacier was found to be 0.0031 km$^3$ from 1995 - 2016. The Maximum surface velocity of Glacier was 12.67 meters/year for the year 2016. The velocities were mostly found higher in the upper sections with higher slope and mostly in the clean ice part of the glacier whereas velocities were lower in the debris part and vice versa for the ice thickness. The volume of the ice loss was estimated with the uncertainty of $\pm 23.22\%$. All these analyses shows the effect of climate change on the glacier and hence it can be stated as the method applied could be a useful tool to fulfill data gaps related to estimate glacier ice thickness and volume of ice.

for $dU_s$, $dA$, $d(\sin \alpha)/(\sin \alpha)$ and $dA$. The ice thickness varies by a very small magnitude for a given range of basal velocities (expressed as per cent of surface velocity). The value of $dU_s$ was fixed as 3.5 meter/year, which is the average of the differences (}

REFERENCES


SPATIO-TEMPORAL EVALUATION OF LONG-TERM EARTHQUAKE EVENTS AND ITS CONTRIBUTION IN GENESIS OF TSUNAMI IN THE INDIAN OCEAN

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KEY WORDS: Earthquake, Tsunami, GIS, Remote Sensing, Hypocentre, Disaster Management

ABSTRACT:
A very high magnitude earthquake (9.1 MW) triggered a devastating Tsunami in the Indian Ocean on 26th December 2004. The epicentre was located at 3.3° N, 95.8° E with a focal depth of ∼30 km. The impacts of Tsunami were felt as far away in Somalia, Tanzania and Kenya along the east coast of Africa. Considering the role of earthquake, in the present study the spatio-temporal analysis of long term (1901 to 2019) earthquake events was performed, which recorded by USGS to understand the genesis of Tsunami (2004) in the Indian Ocean. The study exhibited that the maximum frequency of earthquake was observed between the ranges of 4 MW to 6 MW on the Richter scale during 2001 – 2010. There was only one earthquake event >8 MW on the Richter scale (26th December 2004 having depth 30 Km) in the Indian Ocean recorded during 1901 - 2019. The study exhibited that the maximum earthquake was observed in the buffer of 200 km from fault line in Bay of Bengal. The decadal variation of earthquake exhibits that the maximum number of earthquake events (8427 events) were triggered during the year 2001-2010, whereas during the year 2004, the total 902 earthquake events >4 MW was recorded. The study indicates that the earthquakes >7 MW (on Richter scale) and depth below 30 km (shallow earthquake) are primarily responsible to major Tsunami events in the Indian Ocean. The very high magnitude (>9 MW on the Richter scale) and shallow depth (∼30 km) are the major cause of 2004 Tsunami and its high level of damage. There were very low frequency (10 – 15 events) of earthquake occurred having magnitude >7 and depth < 30 km.

1. INTRODUCTION

Tsunami, often incorrectly called tidal waves, is a series of waves with a long wavelength and period (time between crests) (Mathur and Udani, 2015). Since 1750, the Indian Ocean has not experienced a natural disaster of such magnitude, with enormous consequences for the region’s environment (Sirikulchayanon et al., 2008). On 26th December 2004, an earthquake of 9.1 MW occurred at 05:58:53 GMT in Indian Ocean. The epicentre of earthquake was located at 3.3 N, 95.8 E with a focal depth of approximately 30 km (Lavigne et al., 2013), which triggered a massive Tsunami in coastal areas of Indian Ocean. Around 280,000 people were killed in South Asia, Southeast Asia, and East Africa (Lavigne et al., 2013). The vertical offset of the ocean floor by 7 to 10 meters on 26th December 2004, Sumatra earthquake displaced massive volumes of water, resulting in a destructive Tsunami. Because of the north-south direction of the fault line, the Tsunami was the strongest in the east-west direction. The wave height in deep water (open ocean) was measured through satellites to be approximately 60 cm, while traveling at a speed of 500 to 800 km/hr. The velocity decreased to only tens of kilometres per hour in shallow water near the shoreline, depending on the local bathymetry. This, however, resulted in large and destructive waves that reached run-up heights of 20 to 30 meters in Banda Aceh (Saatcioglu et al., 2005). The distribution of aftershocks (U.S. Geological Survey1) suggests that the rupture extended over a distance of 1500 km (measured parallel to the arc), but seismic inversions for this event are non-unique and cannot resolve many details of slip, especially along the northern portion of the rupture (Ammon et al. 2005). Furthermore, considering that slip north of ∼9°N appears to have generated little or no seismic radiation (Lay et al. 2005; Ammon et al. 2005), seismic inversions will only provide a minimum constraint on the extent and amount of slip, and geodetic inversions will be required to provide a maximum (and perhaps more accurate) constraint. However, inversions of the sparse geodetic data that were available prior to this study provided only limited constraints on the amount and distribution of slip (Subarya et al. 2006). Since as per current research knowledge there is no established methods to detect the tsunami being generated due to earthquake or landslide. The phenomenon of tsunami is mainly generated undersea disturbance due to earthquake or landslide or activity near the coast or in the ocean and displace few kilometres to ∼1000 km apart from epicentre, the earthquakes mainly occurs in the region having a high tectonic subduction zones along with tectonic plate boundaries and high seismicity in a regions, caused due to collision of tectonic plates. When a disturbance happens the ocean, the ocean floor rise or falls and effects on water above it and as the water moves up and down, seeking to regain its balance, a tsunami is born. (Borrero, 2005; Kanamori and Kikuchi, 1993; Pelayo and Wiens, 1990; Tsuboi, 2000).

The earthquake of 26th December 2004 occurred due to slip on the subduction interface between the Indo- Australian plate and the Burma microplate below Andaman and Nicobar Islands and Aceh province, Sumatra. The Indian plate has been moving north-east at a rate of approximately 60 mm/year, subduction under the overriding Burma microplate. The epicentre of the quake was about 155 km west of Sumatra and about 255 km south-east of Banda Aceh, Indonesia.

* *Corresponding author
(Saatcioglu et al., 2005). Along the Java Trench to the southeast of Sumatra, the Australian plate sub ducts beneath the Sunda Shelf in a direction nearly orthogonal to the trench and at a rate of about 63 mm/year. (Bock, 2003; Michel et al., 2001). Along Sumatra the direction of convergence becomes increasingly oblique towards the north-west and the relative plate slip is partitioned into nearly perpendicular thrusting at the trench and trench-parallel, right-lateral slip at the Sumatran fault (SF) (Fitch, 1972). The strength of a Tsunami depends upon the magnitude of earthquakes occur in the Ocean. There are a number of earthquakes occurring in the earth’s crust but their magnitude is very low to trigger a Tsunami.

2. STUDY AREA
In the present study, the North Indian Ocean comprising the parts of Bay of Bengal was considered as study area. The territory is about 150 km north of Aceh in Indonesia and separated from Thailand and Myanmar by the Andaman Sea. In this region, the group of Andaman and Nicobar Islands was located, which is a Union territory of India comprising 572 islands of which 37 are inhabited, are a group of islands at the juncture of the Bay of Bengal and Andaman Sea. There are 572 islands in the territory having an area of 8,249 km². Of these, about 38 are permanently inhabited. The islands extend from 6° to 14° North latitudes and from 92° to 94° East longitude. The Andaman and Nicobar Islands have a tropical rainforest canopy, made of a mixed flora with elements from Indian, Myanmar, Malaysian and endemic floral strains. So far, about 2,200 varieties of plants have been recorded, out of which 200 are endemic and 1,300 do not occur in mainland India. As of 2011 Census of India, the population of the Union Territory of Andaman and Nicobar Islands was 379,944, of which 202,330 (53.25%) were male and 177,614 (46.75%) were female.

3. METHODOLOGY
This study aims to analyse the earthquakes events, which is obtained from USGS earthquake portal. Earthquakes of different intensities were plotted in the GIS environment where the events were analysed with reference to its spatio-temporal occurrences, decadal occurrences, magnitude, depth of occurrences, proximity to major fault line near the Andaman and Nicobar Islands. Fault line has been taken from and proximity analysis at various proximity viz., >5 km, 5-10 km, 10-50 km, 50-100 km, and >100 km from major fault line. The earthquake events of occurred during 2004 was analysed with reference to the earthquake events of a century (1901 to 2019).

4. RESULTS AND DISCUSSION
The earthquakes occurred during 1901 to 2019 was analysed in GIS environment showing its magnitude and its depth. The maximum number of earthquakes was observed in the range of 4-5 MW on Richter scale (figure 1). Usually, it takes an earthquake with a Richter magnitude exceeding 7.5 MW to produce a destructive tsunami at specific depth. The earthquakes in this range is of very low intensity. Maximum frequency of earthquake magnitude occurs in the range of 5-6 MW in 2004, which releases low amounts of energy to trigger Tsunami (figure 2). Earthquake magnitude more than 8 is observed in 2004, which triggered a massive Tsunami near Sumatra Island (figure 2). The energy released during this earthquake is sufficient to trigger a devastating tsunami. Scatterplots provides better understanding of the frequency of earthquakes occurred from 1901 to 2019. The maximum earthquake belongs to less than 6 magnitudes on the Richter scale. A very few Earthquakes belong to above 8 magnitudes on the Richter scale. An increase in the trend of earthquake event was witnessed from the scatterplot (Figure 4). Since the number of events of earthquakes was increased during the post 1960s, but the magnitude trend was observed decreasing, means earthquake event occurring with less magnitude. This may be attributed to the movement of oceanic plate at various intensity leading to earthquake of varied intensity/magnitude. From 1901-2010, the depth of the maximum earthquake located between 10-

Figure 81. Spatio-temporal distribution of earthquake based on its magnitude during 1901 to 2019

Figure 2. Spatio-temporal distribution of earthquake based on its magnitude during 2004 in Indian Ocean

Figure 82. Spatio-temporal distribution of earthquake based on depth to hypocentre during 1901 – 2019

2 http://earthquake.usgs.gov/
50 km range (figure 3) and having magnitude between 4.0 and 6.0. The study exhibited that the nearer the depth of earthquake, the higher the devastation. Increase in distance of surface from the focus, decrease in the impacts of the earthquake on the surface. Earthquake magnitude >4 was analysed from 1901 to 2019 with a sum of occurrence of earthquake in decadal time scale. As per USGS, very less number of earthquakes was recorded till 1970s. The least event of earthquakes captured was one in 1901-1910 followed by 4 events in 1911-20, 12 events in 1921-30, 15 events between 1931-40 as well as in 1941-50 and 50 events in 1961-70.

The highest number (8427 events) of earthquake events occurred was during 2001-10 followed by 3581 events during 2011-18 (March), 1232 events in 1991-2000, 1164 events in 1981-90 and 509 events in 1971-80 in Indian ocean. In year 2004, 902 events of earthquake triggered, which shows a huge number of earthquakes. The less number of events captured till 1970s may be attributed to limitation of observation, recording station, methods etc. The maximum frequency of earthquake events was recorded at the depth between 10 to 50 km in the year 2004. It is difficult to conclude the magnitude of an earthquake on the basis of its depth (figure 5). The correlation analysis of magnitude and depth of the earthquake events (1901-2019) exhibits that the more occurrence of earthquake with higher magnitude (>7 MW) at the shallow depth (<50 km).

Figure 83. Trend of number of Earthquake from year 1901 - 2019

Figure 84. Correlation Map of Magnitude v/s Depth

Figure 85. Number of earthquake events in the proximity of major fault line
### Year | Events of Earthquake with Frequency (MW>4)
---|---
1901-1910 | 1
1911-1920 | 4
1921-1930 | 12
1931-1940 | 15
1941-1950 | 15
1951-1960 | 45
1961-1970 | 50
1971-1980 | 509
1981-1990 | 1164
1991-2000 | 1232
2001-2010 | 8427
2011-2019 | 3581
2004 | 902

Table 1. Number of Earthquake Events in different decade between 1901 - 2019 and year 2004

The depth of the earthquake events were analysed with reference to its depth. The study exhibits that the most events of earthquake occurred between 30 - 40 km vertical depth i.e., 7126 events, followed by 2379 events in 10 - 20 km vertical depth, 1958 events at 20 - 30 km depth and 1278 events >100 km depth. Least events of earthquake (163 events) was occurred at <10 Km vertical depth followed by 464 events at 80 - 100 km vertical depth and 659 events at 60 - 80 km vertical depth. It is to note that in 2004, the most number of events i.e., 455 events occurred at 30 - 40 km depth followed by 192 events at 20 - 30 km vertical depth and 94 events at 10 - 20 km vertical depth. Least event was recorded (10 events) at < 10 km vertical depth followed by 21 events at 80 - 100 km vertical depth, 27 events at 60 - 80 km depth, and 30 events at more than 100 km depth and 73 events at 40 - 60 km vertical depth. Here all events are the recorded occurrence events of earthquakes events.

The proximity analysis (<5 km, 5-10 km, 10-50km, 50-100 km and 100-200 km) of earthquakes events along the major fault line was performed during the period 1901-2019 to deduce the geography of earthquake events in the Indian Ocean (Figure 5, Figure 6). The study exhibited that the maximum number of earthquakes events of <4 MW was observed within the proximity of 100-200 km from the major fault line. Further, a decreasing trend in the frequency of earthquakes of 5 to 8 magnitude was observed (Figure 6). The maximum number of earthquakes were observed in the proximity of 100-200 km zone from the fault line. Only one earthquake event was observed having magnitude >8 in the proximity of 50-100 km from the major fault line.

![Figure 66. Depth to Hypocentre](image1)

![Figure 87. Earthquake events based on magnitude with in the proximity of major fault line in Indian Ocean](image2)

![Figure 88. Proximity analysis based on depth to hypocentre along the major fault line](image3)
Analyzing the USGS based earthquake events occurred in Indian Ocean based on its various characteristics, it is concluded that earthquake exceeding with magnitude >7.5 occurring near the ocean surface or ≤50 km depth triggers the devastating tsunami. The same result has been reported by various studies done on various regions around the globe (Annaka et al., 2007; Fujii et al., 2011; Satake, 1994; Satake et al., 1996; Tanioka and Satake, 1996; Tomazevic, 1999). As per Global Historical Tsunami Database (GHTD) about 85% - 89% of tsunami are generated by large earthquakes or landslide.

5. CONCLUSION

The study concludes that the maximum number of earthquake events having 4 to 6 MW on the Richter scale has been occurring along the fault line does not contribute in the genesis of Tsunami. The earthquakes (>7.5 MW) observed are mainly responsible for the formation of destructive Tsunami in the Indian Ocean. It is to note that there are very less frequency of earthquake events, which had magnitude >7.5 on the Richter scale. Generally, earthquake of higher magnitude (>7.5) primarily at shallow depth (<50 km) trigger the devastating Tsunami. The proximity analysis along the major fault line concludes that the maximum earthquakes occur in the proximity of 200 km along the fault line. It is to mark that since 2004 (> 9.1 MW), no significant earthquake event was recorded of such high magnitude. The region is tectonically activated and frequency of high magnitude earthquake events was observed post 1960 periods, primarily during 2001-10. Although, earthquake of MW >8 occurred at the depth below 200 km which does not conclude Tsunami eventually. In future work, subsidence and upliftment of earth's surface due to earthquake generated Tsunami using SAR offset tracking (Lai et al., 2018; Sun et al., 2017) or interferometry approach (Fornaro and Pascazio, 2014; Massonnet et al., 1993) may be considered for better understanding of deformation occurred during 2004 earthquake and Tsunami.

ACKNOWLEDGEMENT

We thank the anonymous reviewers for their careful reading of our manuscript and their insightful comments and suggestions. The authors would like to express their gratitude to USGS (http://earthquake.usgs.gov/), from where the earthquake data were downloaded and used in the present study.

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SURFACE VELOCITY DYNAMICS OF SAMUDRA TAPU GLACIER, INDIA FROM 2013 TO 2017 USING LANDSAT-8 DATA

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KEY WORDS: Surface Velocity, Glacier, Cross-correlation, PAN Data, Landsat-8 OLI

ABSTRACT:

In glacier dynamics, surface velocity of glacier is an important parameter to understand the behaviour of glacier in absence of mass balance and long-term glacier area change information. In present study, surface velocity of Samudra Tapu Glacier, India is estimated using freely available Landsat-8 OLI (PAN) images during 2013-2017. To estimate surface velocity, open source COSI-Corr tool is used which is based on cross-correlation algorithm. Maximum annual surface velocity estimated is 55.68 ± 4.01 m/year during 2015-2016 while the minimum surface velocity being 44.99 ± 4.67 m/year in 2016-2017. The average annual velocity during 2013-2017 was 50.51 ± 4.49 m/year which is higher than other glaciers in Chandra basin. The variation in annual surface velocity is analysed which not only depends on mass loss but also on temperature, pressure and internal drainage. Further, as one moves opposite to glacier terminus, the surface velocity increases with the increase in glacier elevation and slope. The higher surface velocity can be attributed to the fact that Samudra Tapu is a top-heavy glacier based on HI index analysis having larger accumulation area along with high glacier ice-thickness.

1. INTRODUCTION

Glaciers are highly sensitive to climate change and an increase in glaciers retreat rate is observed all over the world due to climate change since last decade (Azam et al., 2018). Different parameters i.e. glacier area, surface velocity and mass balance have been used for glacier monitoring. Glacier surface velocity is one of important parameters to understand behaviour of glacier in absence of mass balance and long-term glacier area change information. Glacier surface velocity also helps to understand glacier retreat and advance, mass balance changes, ice thickness estimation, early warning of glacier lake outburst flood and change in strain rate (Dehecq et al., 2019; Gantayat et al., 2014; Paul et al., 2017; Yan et al., 2018). Therefore, it is necessary to study surface velocity of the glaciers to increase the knowledge in glacier dynamics.

Conventionally, surface velocity of glacier is computed by drilling the stakes on the glacier and using Global Positioning System (GPS). But these methods are time consuming and costly. However, most of the glaciers in high mountain Asia are inaccessible due to rugged topography (Dehecq et al., 2015). The remote sensing data provide alternative way to monitor the glacier surface velocity on daily to yearly basis (Heid and Kääb, 2012). Optical and microwave remote sensing are generally used in surface velocity estimation. Optical remote sensing data are now-a-days commonly used for surface velocity estimation by researchers using feature tracking method due to availability of data from large number of optical sensor, from low resolution to high resolution (Bhushan et al., 2018; Paul et al., 2017; Sun et al., 2017) which is even freely available from some sensors. MODIS, ASTER, Landsat ETM+, TM, OLI and Sentinel-2 MSI sensors can be used for surface velocity estimation. The active microwave gives all weather data which can be used in SAR interferometry and feature tracking method for surface velocity estimation (Kumar et al., 2013; Yasuda and Furuya, 2013; Yellala et al., 2019).


Researchers have carried out various studies on Samudra Tapu Glacier. Mukherjee et al. (2018) estimated glacier area and length change of Samudra Tapu Glacier from 1971 to 2015 and correlated this with mass balance in the same period. Vijay and

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Braun (2016) analysed mass balance of all glaciers along with Samudra Tapu Glacier in Chandra Basin during 2000-2013. Pandey and Venkataraman (2013) analysed the glacier area and length change of Samudra Tapu Glacier during 1962-2000. Thus, all these studies related to Samudra Tapu Glacier have been carried out in reference to glacier area, length change and mass balance. This is an important glacier because it has pro-glacial lake in its terminus which is prone to outburst flood (Prakash and Nagarajan, 2018). However, studies related to the estimation of surface velocity of Samudra Tapu Glacier have not been taken up in the past even though surface velocity is also an important parameter in the study of glacier dynamics. Hence, in the present work, surface velocity of Samudra Tapu Glacier is analysed using freely available Landsat-8 OLI (PAN) images during 2013-2017 to fill the knowledge gap for Samudra Tapu Glacier in Chandra basin. For this purpose, open source COSI-Corr tool, a freely available plug-in for commercial ENVI software and based on cross-correlation algorithm, is used for estimation of surface velocity.

2. STUDY AREA

Samudra Tapu Glacier is selected for inter-annual surface velocity analysis during 2013 to 2017. Samudra Tapu Glacier is located in Chandra basin, Western Himalaya (figure 1). This glacier is a second largest glacier in terms of area in Chandra basin. The central longitude and latitude of Samudra Tapu Glacier is 77.41°E and 32.48°N respectively. Total glacier area is 80.01 km² and its minimum, maximum and median elevation is 4237, 6098, and 5254 m a.s.l. respectively (RGI inventory). Samudra Tapu Glacier falls in monsoon arid transition zone and receives precipitation due to Indian summer monsoon and mid-latitude westerlies (Bajpai, 1995).

3. DATA USED

In present study, freely available Panchromatic (PAN) data of Landsat-8 Operational Land Imager (OLI) sensor is used to estimate surface velocity of Samudra Tapu Glacier. Landsat-8 satellites were launched on February 11, 2013 and is operational. One scene of OLI image covers 185 km x 170 km area with revisit period being 16 days. Total 05 Landsat-8 OLI images were downloaded from USGS website (Table 1). All the data of Landsat-8 is acquired for the end of ablation period of the glacier. Further, the data selected is cloud free in glacier region and have minimum snow. Landsat-8 OLI images are a good source for monitoring high mountain glaciers. Therefore, in present study, Landsat-8 OLI PAN (15 m resolution) data is used to analyse surface velocity of Samudra Tapu Glacier during study period 2013-2017.

![Figure 1. Location Map of Samudra Tapu Glacier in Chandra basin](image)

<table>
<thead>
<tr>
<th>Sensor &amp; Resolution</th>
<th>Date</th>
<th>Image Id</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat-8 OLI (PAN), 15m</td>
<td>27-October-2013</td>
<td>LC08_L1TP_147038_20131027_20170429_01_T1</td>
</tr>
<tr>
<td>Landsat-8 OLI (PAN), 15m</td>
<td>28-September-2014</td>
<td>LC08_L1TP_147038_20140928_20170419_01_T1</td>
</tr>
<tr>
<td>Landsat-8 OLI (PAN), 15m</td>
<td>15-September-2015</td>
<td>LC08_L1TP_147038_20150915_20170404_01_T1</td>
</tr>
<tr>
<td>Landsat -8 OLI (PAN), 15m</td>
<td>03-October-2016</td>
<td>LC08_L1TP_147038_20161003_20170319_01_T1</td>
</tr>
<tr>
<td>Landsat-8 OLI (PAN), 15m</td>
<td>06-October-2017</td>
<td>LC08_L1TP_147038_20171006_20171014_01_T1</td>
</tr>
</tbody>
</table>

Table 1. Landsat-8 OLI (PAN) images used to estimate surface velocity
4. METHODOLOGY

In present study, surface velocity of Samudra Tapu Glacier is estimated through co-registration of optically sensed images using COSI-Corr correlation tool. This is an open source tool which work on cross-correlation algorithm and can be downloaded from http://www.tectonics.caltech.edu/slip_history/spot_coseis/download_software.html (Leprince et al., 2007). COSI-Corr tool was initially in use for monitoring tectonic displacements but later several researcher successfully applied this in glacier surface velocity estimation (Quincey et al., 2009a; Sahu and Gupta, 2019; Tiwari et al., 2014). The main principle of COSI-Corr algorithm is identification of common features in both images. For this purpose, two images of pre-event and post event are selected, and common features are identified using desirable window on pre-event and post event images. This algorithm works on the frequency domain at sub-pixel level. This also minimises the error due to DEM inaccuracy, and increase the co-registration accuracy of images (Leprince et al., 2007).

Surface velocity estimation using COSI-Corr algorithm follows three steps process, namely, orthorectification, co-registration and correlation. Landsat-8 OLI PAN images are already orthorectified. Since Landsat-8 OLI images are used, hence there is no need to perform co-registration of these images in the present study. In COSI-Corr software, the optimum value of window size, step size and number of iterations is obtained iteratively using different parameter values for estimation of surface velocity. In correlation process, pre and post event images are first selected, then initial and final window size are selected as 64 x 64 pixel and 32 x 32 pixel respectively. Along with this, step size equal to 2 is chosen while the number of iterations is taken as 5. Correlation process is executed until common features are matched or till it reaches maximum iteration. Output of correlation process provides three images, i.e., North-South (N-S), East-West (E-W) and SNR (Signal to Noise Ratio) images. After this, all pixels having SNR <0.9 are removed using SNR file. The displacement map is generated using N-S and E-W images through the application of euclidean distance concept. To generate final surface velocity map, displacement is normalised on 365 day for annual basis, and surface velocity is then estimated in m/year. The flowchart of the methodology adopted is shown in figure 2.

Surface velocity pattern can also be correlated by Hypsometric Index (HI) analysis. HI can be calculated as equation 1 and 2 (Jiskoot et al., 2009).

\[ HI = \frac{(E_{\text{max}} - E_{\text{med}})}{(E_{\text{med}} - E_{\text{min}})} \]  
\[ \text{If } HI < 1 \text{ then } HI = \frac{-1}{HI} \]

Where \( E_{\text{max}} \), \( E_{\text{med}} \) and \( E_{\text{min}} \) are maximum, median and minimum elevation of Samudra Tapu Glacier respectively.

<table>
<thead>
<tr>
<th>HI Value</th>
<th>Glacier Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI &lt; -1.5</td>
<td>Very top heavy</td>
</tr>
<tr>
<td>-1.5 &lt; HI &lt; -1.2</td>
<td>Top heavy</td>
</tr>
<tr>
<td>-1.2 &lt; HI &lt; 1.2</td>
<td>Equidimensional</td>
</tr>
<tr>
<td>1.2 &lt; HI &lt; 1.5</td>
<td>Bottom heavy</td>
</tr>
<tr>
<td>HI &gt; 1.5</td>
<td>Very bottom heavy</td>
</tr>
</tbody>
</table>

Table 2. Glacier type based on HI value

5. ERROR ESTIMATION

Surface velocity estimation using COSI-Corr algorithm mainly experience three types of error. First one is due to orthorectification. However, in the present study, orthorectified Landsat-8 OLI images are acquired, so this error is already minimal and can’t be further reduced. Second error occurs due to snow cover, cloud and melting glacier. This can be minimised by selecting satellite image having minimum snow and cloud as well as the image should be acquired at the end of ablation period. Third error can occur due to poor image contrast in images. To overcome this error, surface velocity is estimated only in ablation zone instead of accumulation zone (Bhushan et al., 2017; Garg et al., 2017; Paul et al., 2015).

To estimate the error in surface velocity estimation using COSI-Corr algorithm, non-glaciated area near to the terminus of the glacier is selected. It is assumed that surface velocity in non-glaciated stable area should be zero in ideal condition. Thus, mean surface velocity obtained in this non-glaciated stable area will be treated as an error in surface velocity estimation. In present study, total ~750 points are selected near the terminus and then mean surface velocity is estimated. This is the most common method to estimate the error in surface velocity, which has previously been used by various authors (Garg et al., 2017; Saraswat et al., 2013).

6. RESULT AND DISCUSSION

Surface velocity of Samudra Tapu Glacier is estimated during 2013 to 2017 using freely available 15m PAN images of Landsat-8 OLI sensor. Samudra Tapu Glacier boundary is taken from RGI 6.0 inventory. For better visualisation, SRTM-DEM based hillshade image is used as background image for surface velocity map. Surface velocity is estimated only in ablation area of the glaciers because more trackable features and good image contrast is available in this zone as compared to accumulation zone. This also increases the accuracy of velocity estimation (Sun et al., 2017). Mean annual surface velocity along the centre flow line during 2013 to 2017 are compiled in Table 3.
## Table 3. Annual surface velocity

<table>
<thead>
<tr>
<th>Study duration</th>
<th>Surface velocity (m/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-2014</td>
<td>53.79 ± 4.71</td>
</tr>
<tr>
<td>2014-2015</td>
<td>47.58 ± 4.55</td>
</tr>
<tr>
<td>2015-2016</td>
<td>55.68 ± 4.01</td>
</tr>
<tr>
<td>2016-2017</td>
<td>44.99 ± 4.67</td>
</tr>
<tr>
<td>Average (2013-2017)</td>
<td>50.51 ± 4.49</td>
</tr>
</tbody>
</table>

In 2013-2014, annual surface velocity of Samudra Tapu Glacier was 53.79 ± 4.71 m/year which decreased to 44.99 ± 4.67 m/year in 2016-2017. However, annual surface velocity was 47.58 ± 4.55 m/year and 55.68 ± 4.01 m/year in 2014-2015 and 2015-2016 respectively. The average annual velocity computed during 2013-2017 was 50.51 ± 4.49 m/year. This variation in surface velocity is largely affected by mass loss coupled with some other parameters i.e. temperature, pressure and basal drainage system (Usman and Furuya, 2018). For this purpose, seasonal surface velocity is also required along with long term (annual) surface velocity (Satyabala, 2016).

The surface velocity map of Samudra Tapu Glacier for the year 2013-2014, 2014-2015, 2015-2016 and 2016-2017, with hillshade image of SRTM DEM as background image is shown in figure 3. In figure 3(a), AA’ is the centre flow line and annual surface velocities are extracted along this centre flow line for further analysis. Maximum surface velocity is identified in upper ablation zone due to the mass transformation from its tributaries. It can be identified that from the terminus to till 1 km, surface velocity was < 10 m/year which indicate the stagnancy in surface velocity (figure 4). The main reason behind stagnancy in surface velocity is presence of debris covered ice, which is common characteristic of debris covered glaciers (Quincey et al., 2009b; Yan et al., 2018). In debris covered glacier, in lower ablation zone and near the terminus, maximum ice thickness reduction and surface lowering occur; and as a result stagnant low sloping downstream lower ablation zone appears (Benn et al., 2012). As shown in figure 5, as one moves opposite to glacier terminus, increasing trend is observed in the surface velocity and glacier elevation. Slope is showing a zig-zag pattern. Still, it is increasing slightly till 4 km from terminus then decreased from 4 km to 4.5 km, and then again showing slightly increasing pattern. However, the surface velocity is showing an increasing pattern. Garg et al (2017) have also observed increasing pattern. The error in surface velocity is estimated in non-glaciated stable area. The error varied from ± 4.01 to ± 4.71 m/year during 2013-2017 with mean error being ± 4.49 m/year.

![Figure 3. Surface velocity map of Samudra Tapu Glacier for the year (a) 2013-2014; (b) 2014-2015; (c) 2015-2016; (d) 2016-2017, with background image being a hillshade image of SRTM DEM](image-url)
Surface velocity of Samudra Tapu Glacier is much larger than other glaciers in Chandra basin (Garg et al., 2017; Sahu and Gupta, 2019; Tiwari et al., 2014; Yellala et al., 2019). The surface velocity estimation for Samudra Tapu Glacier using remote sensing data or through field methods is also not available in the literature. To understand this behaviour, HI index analysis for Samudra Tapu Glacier is also carried out. The HI index of glacier is -1.204 which signifies that Samudra Tapu is top heavy glacier. It shows that bottom 50% of Samudra Tapu Glacier area distribution span 1.204 times as much elevation as the top 50% of the area distribution. On this basis, Samudra Tapu Glacier is top heavy glacier in the sense that the area distribution is skewed toward top of elevation range (McGrath et al., 2017). Due to larger accumulation area, more mass is present in accumulation zone and larger amount of mass is available for movement (Quincey et al., 2009b). However, this one parameter alone is not responsible for higher surface velocity. The ice thickness also plays an important role for higher surface velocity which controls the basal movement of glacier (Paul et al., 2017). Thus, seasonal surface velocity and ice thickness information are also required to understand complete behaviour of Samudra Tapu Glacier in term of surface velocity.

6.1 Comparison of surface velocity with other studies in Himalayan region

Several studies have been carried out in different part of Himalaya. Bhattacharya et al. (2016) used Landsat TM, ETM+, OLI and ASTER data during 1993-2014 to estimate surface velocity of Gangotri Glacier. They estimated annual surface velocity ~46 ± 7.5 m/year (1993-1994), ~50 ± 7.2 m/year (1998-1999), ~48 ± 4.8 m/year (2008-2009) and ~43 ± 5.1 m/year (2013-2014). Bhushan et al. (2017) also estimated surface velocity of Gangotri Glacier using Landsat ETM+, and OLI data as 42.42 ± 6.28 m/year (1999 – 2000), and 26 % velocity reduction in 2013-2014 along the main trunk. Saraswat et al. (2013) also estimated surface velocity of Gangotri Glacier during
2004 - 2010 using ASTER images, and found minimum and maximum velocity as 13.9 ± 2.3 and 70.2 ± 2.3 m/year. All studies on Gangotri Glacier show marginally less surface velocity as compared to Samudra Tapu Glacier. But studies carried out for other glaciers in Chandra basin have much lesser surface velocity, even up to half of Samudra Tapu Glacier (Garg et al., 2017; Sahu and Gupta, 2019; Tiwari et al., 2014; Yellala et al., 2019). Sahu and Gupta (2019) analysed four glaciers in Chandra basin, namely Chhota Shigri, Bara Shigri, Pempag Gath and Hamtah; and their average velocity during 2013-2017 was 20, 20.79, 10.53 and 7.52 m/yr respectively. In previous studies, it is observed that surface velocity of glacier is directly proportional to glacier thickness, and hence higher glacier ice thickness leads to higher surface velocity to (Cuffy and Paterson, 2010; Gantayat et al. 2014). In previous studies maximum ice thickness of Chhota Shigri, Hamtah and Samudra Tapu glaciers were found as 300m, 95m and 350m respectively (Manya et al., 2016; Ramashankaran et al., 2018; Swain et al., 2018), thereby, validating our results.

7. CONCLUSION

In present study, annual surface velocity of Samudra Tapu Glacier is estimated using Ladsat-8 OLI PAN (15 m spatial resolution) images during 2013-2017. The surface velocity is estimated using open source COSI-Corr tool based on cross-correlation algorithm. The average annual surface velocity of Samudra Tapu Glacier during 2013-2017 was 50.51 ± 4.49 m/year. The annual surface velocity was maximum (55.68 ± 4.01 m/year) in 2015-2016 while it was minimum (44.99 ± 4.67 m/year) in 2016-2017. The annual surface velocity was 53.79 ± 4.71 m/yr and 47.58 ± 4.55 m/yr in 2013-2014 and 2014-2015 respectively. The annual variation in surface velocity not only depends on mass loss but also on temperature, pressure and basal drainage system. As one moves opposite to glacier terminus, the surface velocity increases with the increase in glacier elevation and slope. The present study will add value to the already existing research in the field of glacier dynamics for Chandra basin.

It is observed that surface velocity of Samudra Tapu Glacier is higher than other glaciers in Chandra basin. To understand this pattern, HI index analysis of Samudra Tapu Glacier was also carried out. The HI index of glacier is -1.204 which signifies that Samudra Tapu Glacier is top heavy glacier. Due to larger accumulation area, more mass is present in accumulation zone and larger amount of mass is available for movement. The ice thickness can also contribute to higher surface velocity which controls the basal movement of glacier, which can be taken up in future studies for better understanding glacier dynamics of Samudra Tapu glacier.

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TEMPORAL SHIFT OF BAGMATI RIVER OVER 25 YEARS USING LANDSAT

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KEY WORDS: River, RS, GIS, Landsat 8, NDWI, Temporal Shift

ABSTRACT:

Bagmati River has been a terrific boon in different aspects like natural, cultural, ecological, etc. However, the river has been in a critical situation with the shift in its quality and quantity during these years. Since the changes are slow-growing, actual shifts are barely noticed. While the in-situ analysis and experimentation become costly, the analysis of Landsat images acquired with the application of Remote Sensing (RS) and Geographic Information System (GIS) provides an inexpensive technique in estimating and mapping such temporal shift in the river. Concerning the case, this study modelled the temporal changes of the Bagmati River within 25 years (1991–2016) using the multi-temporal Landsat images. We adopted the Normalized Difference Water Index (NDWI) for the unsupervised extraction of the water feature and monitoring the changes. A model was developed in Arc-GIS by discerning the river, and the difference was determined for 25 years. The result indicated a major temporal shift in the river channel with a decreasing trend from 1991 to 2016. Over 25 years, the river loss almost one-third of its original water-flow channel with a severe sweep in the south-western portion of the study area. With this precise information, a field-based study can be undertaken either to analyse the damage caused by the river in those particular portions or to assess the factors affecting the river shift. Hence, we strongly recommend employing the cost-effective methods, RS and GIS, for detecting, analysing and monitoring the shifts and changes in the rivers and lakes over a while.

1. INTRODUCTION

Nepal, a country rich in its water resource, encompasses more than 6000 rivers originated from the lap of majestic Himalayas. These major sources of water not only provide fresh water to fulfill the basic needs of people, but also plays equally important role in other major aspects like drinking water, agriculture, electricity production, transportation etc. Water habitats to a raft of flora and fauna and helps in the preservation of biodiversity in the riparian or wetland ecosystem (Vörösmarty et al., 2010). Thus, they are recognized as critical as breathing-air for sustaining all life forms. Rivers have been important assets in the regulation of natural water cycle, climatic regulation as well as other ecological cycles. The same services are provided by the Bagmati River.

Bagmati is not only regarded as the holy river but also considered the source of Nepalese civilization and urbanization. Besides having variable utilities in different aspects like aesthetic, scenic, drinking water, etc. the river, since passes through the most populated city: Kathmandu, quality has been disastrously impaired in the recent years. Because of varied factors like climate change, natural disasters, environmental hazards, undesirable anthropogenic influences, etc., both quality and quantity have been substantially decreased. These challenges the river has been facing since long has been overlooked by the concerned authorities, due to which it has been restrained towards the adversity. The river shape, size, and water volume are changing. Such variation consequently hampers, in one way or another, to other natural resources, environment as well as humans and their assets too. These shifts, however, are slow and takes a long time, thus posed great difficulty in taking rapid measures. Hence, long historic data available provides a clear insight of how these changes are taking place, the trends and even future predictions to prevent changes.

These changes can be studied and examined through the field-based experimentation and analysis but are inordinately costly. Thus, relying on information acquired through the use of remote sensing and geographic information system, this dynamism could easily be identified, at a very low cost, precisely. Therefore, to efficiently detect the existence of water in a river, to extract its actual extent, quantify volume, to predict the embankment shifts, and to constantly monitor its spatio-temporal dynamics has been very crucial. Remote sensing satellites like LANDSAT, SPOT, IKONOS, QUICK BIRD, etc. have been continuously observing the earth. They provide very reliable, accurate and cost-effective information for various changes happening in the earth. Landsat series data are the most widely used optical sensors for measuring and mapping water bodies because of the free and continuous accessibility of high-resolution remote sensing images. Optical sensors have been widely used due to the availability and the suitability of spatial and temporal resolutions (Huang et al., 2015).

The surface waters are mercurous and undergo shrink, expansion or shifts in its appearance during the time owing to various natural and human-induced factors (Karpate et al., 2016).
Remote sensing has been prevalent in detecting the changes of surface water like a river, lakes, flood detection and prediction, large scale Spatio-temporal change detection of other water reservoirs (Acharya et al., 2019a). Multi-temporal remote sensing images provide the basis for monitoring surface water (Mueller et al., 2016; Schaffer-Smith et al., 2017). A plethora of methods has been developed for extracting water areas from optical remote sensing imagery. Either supervised or unsupervised method of classification can be adapted for deriving and generating land cover maps, through which water areas could be delineated easily (Manavalan et al., 1993; Ozesmi, Bauer, 2002; Acharya et al., 2018; Acharya et al., 2019b). Among such, unsupervised classification methods, including the spectral water extraction methods, are commonly used for water body extraction procedures as these produce impressive results with the Landsat images (Tulbure, Broich, 2013). The water index method, an easy and effective way to extract water body, identifies the difference between water and non-water area.

NDWI is one of the widely adopted indexes for water features extraction and as well as monitoring the changes in the water bodies which precisely highlights the subtle differences between water and non-water areas. It provides information both on the spatial distribution of the water stress and its temporal evolution over longer time periods and assists in improving the accuracy in retrieving the vegetation water content (Ceccato et al. 2001). Similarly, it is a good indicator for liquid water content identification and is less sensitive to atmospheric scattering effects (Gao, 1996; Delbart et al. 2005, Jackson et al. 2004). NDWI employs green band and NIR band (McFeeters, 1996). The value of NDWI ranges from −1 to 1; water features are likely to have positive values, but terrestrial vegetation and bare soil generally have negative values. Therefore, 0 is often considered a default threshold for the NDWI results.

In this study, we analyse the image-data from satellite image (Landsat-series images) and geographical information system (GIS) to find the temporal shift in the Bagmati river. Between supervised and unsupervised methods of image classification and the analysis, we used the NDWI method to detect and monitor the temporal shift of the Bagmati River for a period of 25 years using the Landsat series data of 1991, 2002 and 2016. A model was developed in the ArcGIS after detecting the differences using the index method and the change was identified.

2. EXPERIMENTS

2.1 Test site: A geographical area between 26.7385° N to 27.1824° N latitude and 85.2755° E to 85.5359° E longitude was selected as the study area. The area incorporates the Bagmati River: the site where we analysed the temporal shift. The river separates the two major districts: Rautahat and Sarlahi. The study area with the Bagmati River is shown in Figure 1.

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In this study, we analyse the image-data from satellite image (Landsat-series images) and geographical information system (GIS) to find the temporal shift in the Bagmati river. Between supervised and unsupervised methods of image classification and the analysis, we used the NDWI method to detect and monitor the temporal shift of the Bagmati River for a period of 25 years using the Landsat series data of 1991, 2002 and 2016. A model was developed in the ArcGIS after detecting the differences using the index method and the change was identified.

2.2 Data

The data acquired by Landsat series available from the USGS GLOVIS portal were used as the data in the study. Three images from 1991 to 2016, a 25 years gap data, were used for the study of a temporal shift of the Bagmati River within the study area. Those images were acquired by the same satellite and were, thus, chosen such that they were from the same season of the year. This procedure kept the images well-matched spatially and temporally so that the accuracy increases (Dai, Khorram, 1998).

2.3 Methods

The accessed image file was subjected towards eliminating radiometric as well as a geometric aberration, if any. Subsequently, the area of interest (Bagmati River) was delineated in the software. The images, pre-georeferenced to the Universal Transverse Mercator zone 45 north, were exported into the GeoTIFF format for further analysis.

After the pre-processing step, all three images of the corresponding year were used in the Arc Map for calculating the NDWI. A model was developed in ArcGIS for the unsupervised change detection, recognized as the prioritized option for achieving the Spatio-temporal monitoring of the river dynamics,
thus, the McFeeters’s formula for NDWI, employing the green band and NIR band, was used for the calculation as follows:

\[
\text{NDWI} = \frac{\rho_{\text{Band2}} - \rho_{\text{Band4}}}{\rho_{\text{Band2}} - \rho_{\text{Band4}}}
\]

where \( \rho_{\text{Band2}} \) = Reflectance value of the green band
\( \rho_{\text{Band4}} \) = Reflectance value of the NIR band

3. RESULTS AND DISCUSSION

The ordinary naked-eye view of the pansharpened Landsat images showed the tentative changes in the body of the whole river channel; this depicted the river is certainly shifting being narrower from the base year to the present. Harmoniously, the temporal analysis of the river within the period between 1991 and 2016 also suggested the shrinkage of the water surface during the period in the Bagmati River which can be seen from the figure 2.

A comparative study of the river, through the unsupervised classification, indicated a major shift in the Bagmati River channel with a decreasing trend from 1991 to 2016 as can be seen in Figure 3. The surface of the Bagmati River was seen – and found through the NDWI index analysis- quite wide in its extension in 1991 in comparison to other two year. The overall surface area coverage of the river was found to be 32.80 sq. km, which was the highest among the compared with other two years. In 2002, on the another hand, the area of the surface water of the Bagmati River shrank to become 28.34 sq. km which dramatically reduced to 11.99 sq. km in 2016 along with drastic fluctuations in the water-current flow channel. In the first decade, i.e. from 1991 to 2002, Bagmati River is confirmed to have shrank 0.45 sq. m/year; where as in the another 15 years of period (2002-2016), the river is shrinking with the more higher rate : 1.09 sq. m/year. The river is, thus, having the constant displacement and shrinkage in the bank and the water availability. Not only the river is shrinking in terms of the area, but the river channel is erratically fluctuating from the base year to present.

While the meanderings of the river in the other sections of the river showed low dynamism, a very distinct change of the Bagmati river channel is found in the mid- south-western portion during each of the years. Even though the surface area of the river has shrank to intolerable range, the channel displacement of the subsequent year are overlapping the previous. However, river channel of the year 1991, in the south-western section, has disparate channel for approximately 7 kilometers. The subsequent year, i.e. 2002 has the river channel distinctly deviating from the channel of the former period.

Figure 2. Detected river surface for the years a) 1991 b) 2002 c) 2016

Figure 3. A map showing the changes during the 25-year period, comparatively

This result, overall, connotes the loss of about one-third of original water-flow channel by the river, just within the 25 years
of period, with a severe sweep in the south-western portion of the study area. This suggests, on the one hand, that there must be several factors which have heightened such displacement and shifts in the river. These factors may range from the series of natural hazards to the range of anthropogenic agents. The changing climate in the global scale resulting severe drought and aridity throughout the long period of time may be the most compelling natural cause, whereas unmanaged human-water-utilization practices, artificial river channelization, excavation, etc. could be the artificial reasons. On the other hand, such shifting might have resulted dire ramifications in the particular area where the river is seen shifting at a greater extent. It may have marred the natural integrity of the site as well as the life of many different creatures including the humans. This paves way for the further analysis through the general field based study and analysis.

Concerning the performance of the unsupervised classification, the NDWI performed well in the detection, delineation, and shift identification of the surface water. This index could be used in the similar approaches of detecting and monitoring the changes in the rivers, lakes, and other water sources.

4. CONCLUSION

In our study, we used the unsupervised index method of classification which showed good change effects in the overall surface coverage of the Bagmati River. “The Bagmati River is shrinking at the greatest rate”, is what our result showed. These sweeping and shrinking trend of the Bagmati River during just 25 year period is the indication of the vulnerability of the river. The river may ultimately, if the situation persists and the river goes losing the coverage in the same rate, will be bereft of water. Thus, appropriate policies, laws, planning and other research and analysis must be carried out for the constant monitoring of the river and preserving our greatest natural assets. The risk zone delineation and identification for the people

Such results can be a useful in monitoring the river system as well as planning for the future actions, most importantly in the countries like Nepal where field-based-sophisticated research and analysis are rarely prone to happen. Constant River monitoring, risk zone mapping, disaster risk area identification and prediction, etc. could be effective way to minimize the uncertain risk to living creatures and to keep the water conserved. The series of Landsat images are, therefore, totally useful in discerning the shifts in the river, lakes, and other water bodies. Hence, we strongly recommend employing the cost-effective methods: RS and GIS, for detecting, analysing and monitoring the shift and changes in the rivers and lakes over a while.

ACKNOWLEDGEMENTS

We are thankful to USGS for providing free access to Landsat images. We express our sincere gratitude to Ashok Subedi and Arjun Subedi for their support and improvisation from data mining to the data analysis.

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LAND SURFACE TEMPERATURE PROFILING AND ITS RELATIONSHIPS WITH LAND INDICES: A CASE STUDY ON LUCKNOW CITY

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KEY WORDS: LST, Land Indices, NDVI, NDBI, EBBI, Correlation Coefficients, LST profiling

ABSTRACT:
Globally, 54.5% of the total population was living in urban settings in 2016 and a projection indicates that if the same trend goes, then this population will be 60% in 2030. Natural land has been converted to impervious space rapidly which is altering the climate change. The main focus of the present paper is the study of Land Surface Temperature (LST) dynamics and its relationship with Land Indices, viz., Normal Difference Vegetation Index (NDVI) which is found negative, Normal Difference Built-up Index (NDBI) which is found positive, Enhanced Built-up and Bareness Index (EBBI) which is found positive in Lucknow city on both time points of 1993 and 2019. This study also includes the effects of land indices on LST profiling in nine different parts and eight different directions to explore the spatial dynamics of city landscape. The NDVI is found higher in the southern side than any other parts of the city in 2019 because of high vegetation growth which resulted in reduction of LST by 4.42 °C to 5.76 °C as compared to parts of the city. The results of NDBI and EBBI exhibit high built-up growth in the landscape of the Lucknow city especially from city center to 13 km (least growth in south-eastern side) from 1993 to 2019. The results indicate intensification of LST in the range of 0.26 °C to 2.24 °C between city centre and city periphery from 1993 to 2019. The findings of the present study will help urban planners and policy makers to adopt suitable measures for sustainable planning for Lucknow city landscape to reduce the adverse effects of LST.

1. INTRODUCTION

Worldwide, 54.5% of total population lived in urban space in 2016 and projection said if the trend is same then it will be 60% in 2030 (UN, 2016). Between the pre-industrial period (1850-1900) and the recent post-industrial period (2006-2015), the global Land Surface Temperature (LST) has increased by 1.53 °C and global (ocean and land) mean surface air temperature increased by 0.87 °C (IPCC, 2019). The explosive nature of urbanisation rise has severe environmental consequences due to the effects of increased LST which has degrading impact on human health as well as climate change that is one of the most concerned topics of the globe (Santos et al., 2017).

The surface features of city landscape constitute the diverse electromagnetic behaviour in respect to wide radiation, absorbance and evaporation thatprevailing winds and long wave radiation result into augmented heat discharge (Bokaie et al., 2016). These surface properties constitute gravels, pebbles, asphalts and stones which hike the sensitivity and lower the evapotranspiration in the city space with significant effects on city environment (Babaradeh and Kumar, 2015; Son et al., 2017). This results into dramatic change in LST over city space where core city witness higher temperature than the rural/ sub-urban space. This difference pattern of LST, called Surface Urban Heat Island (SUHI), happens due to conversion of natural land surface into impervious surface and shrinking/depletion of water bodies (Rousta et al., 2018). At present, LST rise is one of crucial influencing factor for changing climate as well as quality of life

The policy makers, urban planners, health authorities, urban investors and environmentalists are paying lot of attention to overcome its severe effects on various aspects of environment (Li et al., 2017). In recent past, researchers have carried out studies for the LST evaluation and its relationship with different land indices like Normal Difference Vegetation Index (NDVI), Normal Difference Built-up Index (NDBI) in different Indian cities including Delhi and Mumbai (Grover and Singh, 2015), Kolkata (Ghosh et al., 2018), Noida (Kikon et al., 2016), major cities of Punjab (Mukherjee et al., 2017), ten metropolitan cities of India (Sultana and Satyanarayana, 2018).

Singh et al. (2017) carried out analysis of spatial dynamics of Land Use/Land Cover (LU/LC), land indices and LST in Lucknow City where they explored the UHI for the years of 2000 and 2014. However, the quantitative analysis for the whole landscape was not carried out. (Singh et al., 2017). For Lucknow city, comparative analysis of thermal state and its effects due to land indices in different parts of the city and direction is lacking. There is a need to carry out study for quantitate analysis of intensity of land indices and LST in different direction of the city for depiction of the detailed status of the spatial pattern in city landscape.

The present study analyses the dynamics of spatial pattern of LST over the city landscape through direction wise spatial quantification. The role of land indices is also studied to find out the influence of NDVI, NDBI, and Enhanced Built-up and Bareness Index (EBBI) on the pattern of LST spatial dynamics on the city landscape.

Lucknow City is chosen as study area as it is capital of Uttar Pradesh State and is one of the fastest growing metropolitan economy and industrial development in North India. In this work, the correlation study of LST and land indices (NDVI, NDBI and EBBI) is carried out. For evaluating the effect of land indices on LST, dynamics profiling in eight different directions,
namely, West, East, North, South, North-West, South-East, South-West, North-East, and one overall analysis from city center to city periphery is also carried out.

2. MATERIAL AND METHODS

2.1 Study Area: Lucknow City, India

Lucknow City, the capital of Uttar Pradesh, spread over 315.63 km² and extending between longitude 80°49'50"E to 81°03'14"E and latitude 26°44'08"N to 26°05'57"N is selected as the study area (Figure 1). The Gomti River is flowing on central part of the city from North-West to South-East (Figure 1c). The city is located about 123.000 m above mean sea level (msl) and has sub-humid climate where minimum and maximum temperature range are 40-45°C and 5-15°C respectively with average rainfall of 904 mm (Singh et al., 2017).

Figure 89. Study area, Lucknow City; (a) Location of Uttar Pradesh in India; (b) Location of Lucknow City in Uttar Pradesh; (c) Landsat 8 Standard False Colour Composite (FCC) of Lucknow City of 01/06/2019 with buffer zones and directions

2.2 Satellite Images

In this study, satellite images of Landsat Thematic Mapper (TM) of 09/06/1993, and Landsat Operational Land Imager (OLI)/Thermal Infrared Scanner (TIRS) of 01/06/2019 (Table 1) are used which have spatial resolution of 30 meters (except Band 8 of Landsat OLI/TIRS). For the computation of land Indices (NDVI, NDBI and EBBI), bands 3-5 of Landsat TM, and bands 4-6 of Landsat OLI/TIRS are used. For computation of LST, band 6 of Landsat TM and Band 10 of Landsat OLI/TIRS are used. The satellite data is obtained from United States Geological Survey’s portal (https://earthexplorer.usgs.gov/).

<table>
<thead>
<tr>
<th>Satellite (Sensor)</th>
<th>Path/ Row</th>
<th>Date &amp; Time (GMT)</th>
<th>LST Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>K1</td>
</tr>
<tr>
<td>Landsat 5 (TM)</td>
<td>144/4 1</td>
<td>09/06/1993 04:29:25</td>
<td>607.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Band 6)</td>
</tr>
<tr>
<td>Landsat 8 (OLI/TIRS)</td>
<td>144/4 1</td>
<td>01/06/2019 05:06:37</td>
<td>774.8853</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Band 10)</td>
</tr>
</tbody>
</table>

Table 34. Description of data used

2.3 Retrieval of LST

For extraction of LST, thermal band (band 6) of Landsat 5 and thermal band (band 10) of Landsat 8 are used to get spectral radiance using Equation (1) (Landsat 8 (L8) Data Users Handbook, 2016): \[ L_\alpha = M_L \cdot Q_{cal} + A_L \] (1)

where, \( L_\alpha = \) Top of Atmosphere (TOA) spectral radiance \((\text{watts} / (\text{sr} \cdot \text{m} \cdot \mu \text{m}))\), \( M_L = \) specific band’s multiplicative rescaling factor from the metadata, \( Q_{cal} = \) quantized and calibrated Digital Number (DN) values of standard product, \( A_L = \) specific band’s additive rescaling factor from metadata.

Now, brightness temperature (at sensor) is calculated using Equation (2) (Rousta et al., 2018; Sultana and Satyanarayana, 2018): \[ \Omega = \left[ \frac{K_2}{\ln \left( \frac{K_1}{L_\alpha} + 1 \right)} \right] \] (2)

where, \( \Omega = \) brightness temperature (at sensor), \( K_1 \) and \( K_2 = \) constants for thermal conversion from metadata (Table 1).

Then, LST (in K) is derived by brightness temperature and correction of emissivity using Equation (3): \[ \Phi = \frac{\Omega}{1 + \left( \frac{\Omega}{p} \right) \ln(e)} \] (3)

Where, \( \Phi = \) temperature (at sensor), \( W = \) emitted radiance wavelength (11.5 \( \mu \text{m} \) for Band 6 of Landsat 5 TM, and 10.8 \( \mu \text{m} \) for Band 10 of Landsat 8 OLI/TIRS), \( p = h \cdot c / s \ (1.438 \times 10^{-2} \text{mK}) \), \( h = \) plank’s constant (6.626\times10^{-34} \text{Js} ), \( S = \) Boltzmann Constant \((1.38 \times 10^{-23} \text{J/K})\), \( C = \) velocity of light \((2.988 \times 10^{8} \text{m/s})\).

Land surface emissivity (\( e' \)) is obtained using Equation (4): \[ e = nP_v + m \] (4)

where, \( n = 0.004 \) (Estoque and Murayama, 2017), \( m = 0.986 \) (Estoque and Murayama, 2017).

Proportion of vegetation (\( P_v \)) is measured using Equation (5): \[ P_v = \frac{\text{NDVI} - \text{NDVI}_{\text{minimum}}}{\text{NDVI}_{\text{maximum}} - \text{NDVI}_{\text{minimum}}} \] (5)

Where, \( \text{NDVI} \) is computed using Equation (6) in section 2.4.
2.4 NDVI Computation

NDVI is one of the important indicators of urban climate. It is calculated using Equation (6):

\[
NDVI = \frac{\text{Band}_{\text{NIR}} - \text{Band}_{\text{Red}}}{\text{Band}_{\text{NIR}} + \text{Band}_{\text{Red}}}
\]  

(6)

Where, in Landsat 5 TM, \(\text{Band}_{\text{NIR}}\) is band 4 and \(\text{Band}_{\text{Red}}\) is band 3; and in Landsat 8 OLI/TIRS, \(\text{Band}_{\text{NIR}}\) is band 5 and \(\text{Band}_{\text{Red}}\) is band 4.

It ranges between -1 to +1. Its large positive values is vegetation, lower positive values built-up area or bare soils, the negative values is water bodies (Rousta et al., 2018). It exhibits the amount vegetation, phenology, and health information (Pal and Ziaul, 2017).

2.5 NDBI Computation

NDBI is another important indicator of urban climate. It is calculated using Equation (7):

\[
NDBI = \frac{\text{Band}_{\text{MIR}} - \text{Band}_{\text{NIR}}}{\text{Band}_{\text{MIR}} + \text{Band}_{\text{NIR}}}
\]  

(7)

Where, in Landsat 5 TM, \(\text{Band}_{\text{MIR}}\) is band 5 and \(\text{Band}_{\text{NIR}}\) is band 4; and in Landsat 8 OLI/TIRS, \(\text{Band}_{\text{MIR}}\) is band 6 and \(\text{Band}_{\text{NIR}}\) is band 5.

It ranges between -1 to +1. Its higher positive values is bare soils, lower positive values and lower negative (adjacent to 0) is built-up area, its large negative values is indicating water, vegetation, phenology, and health information (Pal and Ziaul, 2017).

2.6 EBBI Computation

EBBI is another one of the important indicators of urban climate. It is calculated using Equation (8):

\[
EBBI = \frac{\text{Band}_{\text{MIR}} - \text{Band}_{\text{NIR}}}{10 \sqrt{\text{Band}_{\text{MIR}} + \text{Band}_{\text{TIR}}}}
\]  

(8)

Where, in Landsat 5 TM, \(\text{Band}_{\text{MIR}}\) is band 5, \(\text{Band}_{\text{NIR}}\) is band 4 and \(\text{Band}_{\text{TIR}}\) is band 6; and in Landsat 8 OLI/TIRS, \(\text{Band}_{\text{MIR}}\) is band 6, \(\text{Band}_{\text{NIR}}\) is band 5 and \(\text{Band}_{\text{TIR}}\) is band 10.

It ranges between 0 to +1. Its higher values (> 0.35) indicate bare land and lower values indicate built-up area (0.1-0.35) (As-syakur et al., 2012).

2.7 Statistical Analysis

To extract the effect of land indices (NDVI, NDBI and EBBI) distinctly on LST intensification, scatter plots are made for both time points of 1993 and 2019 using linear regression. Pearson’s correlation coefficients (r) is used to evaluate the relationship among LST vs NDVI, LST vs NDBI, and LST vs EBBI, where LST is dependent variable and NDVI/ NDBI/ EBBI are independent variables. Pearson’s ‘r’ is derived using Equation (9):

\[
r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2} \sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}
\]  

(9)

Where, \(x_i\) defines NDVI/ NDBI/ EBBI values, \(y_i\) defines LST values.

2.8 Urban-Rural Gradient

The urban-rural gradient approach is used to evaluate the difference of spatial pattern of land indices (NDVI, NDBI and EBBI) on LST. This approach is used to extract dynamics of LST, NDVI, NDBI and EBBI at 1 km of intervals from city center to city periphery up to 16 km in eight different directions, viz, West (up to 16 km), East (up to 13 km), North (up to 14 km), South (up to 16 km), North-West (up to 16 km), South-East (up to 13 km), South-West (up to 16 km), and North-East (up to 12 km), and an overall analysis from city center to city periphery (Figure 1c).

3. RESULTS AND DISCUSSION

3.1 Relationship of Land Indices (NDVI/ NDBI/ EBBI) and LST

The spatio-temporal distribution of LST, NDVI, NDBI and EBBI of 1993 and 2019 for Lucknow City is shown in Figure 2. The statistics of LST and land indices (NDVI, NDBI and EBBI) with their correlation coefficients are compiled in Table 2. It can be observed that the computed mean LST was 31.572 °C in 1993 which increased to 31.915 °C in 2019. The computed mean NDVI was 0.165 in 1993 which increased to 0.215 in 2019. The computed mean NDBI in 1993 was 0.031 which decreased to -0.024 in 2019. The mean EBBI found in 1993 was 0.234 which decreased to -0.222 in 2019.

The pattern of NDVI (Figure 1c and 1g) and EBBI (Figure 1d and 1h) clearly shows that built-up land has explosively increased at the cost of other natural land like vegetation, water, and bare soils from 1993 to 2019. NDVI includes forest lands, grass lands and crops lands. The pattern of NDVI shows increasing trend from 1993 (Figure 1b) to 2019 (Figure 1f). It can be observed that LST (Figure 1a and Figure 1e) has increased from 1993 to 2019.

The relationship of Land Indices (NDVI/ NDBI/ EBBI) and LST for Lucknow City for 1993 and 2019 is shown in Figure 3. The relationship between NDVI and LST is negative both the time points, and correlation coefficient was -0.396 (p < 0.001) in 1993 (Figure 3a) which increased to -0.363 (p < 0.001) in 2019 (Figure 3d) (Table 2). This means vegetation played important role to reduce the intensity of LST over the landscape of the city. The relationship between NDBI and LST is positive both at time points with correlation coefficients being 0.648 (p < 0.001) in 1993 (Figure 3b) which increased to 0.681 (p < 0.001) in 2019 (Figure 3e). This means vegetation played important role to escalate the intensity of LST over the landscape of the city.
Figure 90. Spatial dynamics of LST and Land Indices (NDVI, NDBI and EBBI) on the Landscape of Lucknow City: (a - d) spatial distribution of LST, NDVI, NDBI, and EBBI respectively of 09/06/1993; (e - f) spatial distribution of LST, NDVI, NDBI and EBBI respectively.

Statistics of LST and Land Indices (NDVI, NDBI, and EBBI)

<table>
<thead>
<tr>
<th>Date</th>
<th>Variables</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Correlation with LST (r)</th>
<th>Significance (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>09/06/1993</td>
<td>LST</td>
<td>25.823</td>
<td>35.647</td>
<td>31.572</td>
<td>1.114</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>NDVI</td>
<td>-0.113</td>
<td>0.617</td>
<td>0.165</td>
<td>0.078</td>
<td>-0.396</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>NDBI</td>
<td>-0.464</td>
<td>0.187</td>
<td>0.031</td>
<td>0.07</td>
<td>0.648</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>EBBI</td>
<td>0.029</td>
<td>0.384</td>
<td>0.234</td>
<td>0.05</td>
<td>0.643</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>01/06/2019</td>
<td>LST</td>
<td>26.75</td>
<td>35.638</td>
<td>31.915</td>
<td>0.929</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>NDVI</td>
<td>-0.051</td>
<td>0.585</td>
<td>0.215</td>
<td>0.078</td>
<td>-0.363</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>NDBI</td>
<td>-0.374</td>
<td>0.252</td>
<td>-0.024</td>
<td>0.063</td>
<td>0.681</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>EBBI</td>
<td>0.06</td>
<td>0.749</td>
<td>0.222</td>
<td>0.04</td>
<td>0.628</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Table 35. Statistics of LST and Land Indices (NDVI, NDBI, and EBBI) with their correlation coefficients.

Figure 91. Scatter plots of LST and Land Indices for 09/06/1993: (a) LST vs NDVI, (b) LST vs NDBI, (c) LST vs EBBI; for 01/06/2019: (d) LST vs NDVI, (e) LST vs NDBI, (f) LST vs EBBI.
3.2 Effects of Land Indices (NDVI/ NDBI/ EBBI) on LST Profiling

The dynamics of spatio-temporal pattern of LST, NDVI, NDBI and EBBI of 1993 and 2019 in eight directions, viz, West, East, North, South, North-West, South-East, South-West, North-East, and an overall analysis from city center to city periphery for Lucknow city is shown in Figure 4.

West to East direction:

In west (from city center towards city periphery), the LST has observed 30.51 °C to 32.37 °C in 1993 and which has been increased to 31.52 °C to 32.60 °C in 2019; whereas NDVI has observed 0.038 to 0.271 in 1993 and which has been increased to 0.093 to 0.255 in 2019 (except at 16 km); where NDBI has observed -0.074 to 0.054 in 1993 and which has been increased to -0.067 to 0.005 in 2019; and EBBI has observed 0.124 to 0.261 in 1993 and which has been decreased to 0.138 to 0.264 in 2019 (Figure 4a).

In East (from city center towards city periphery), the LST has observed 30.17 °C to 32.05 °C in 1993 and which has been increased to 30.87 °C to 32.54 °C in 2019; whereas NDVI has observed 0.038 to 0.219 in 1993 and which has been increased to 0.093 to 0.275 in 1993 (except at 16 km); where NDBI has observed -0.046 to -0.059 in 1993 and which has been increased to -0.081 to 0.0002 in 2019; and EBBI has observed 0.124 to 0.263 in 1993 and which has been decreased to 0.139 to 0.250 in 2019 (Figure 4a).

Between West and East direction (Figure 4a-d), mean LST was higher in West than East in the variation of 0.32 °C to 2.20 °C in 1993 and again it was higher in West than East in 2019 by the variation of 0.06 °C to 1.73 °C (Figure 4a); whereas, NDVI mean has found lower in West than East by the variation of 0.01 to 0.181 in 1993 and it was in 2019 where West again lower than East in the variation of 0.052 to 0.182 (except higher peak in west near 15-16 km towards west) (Figure 4b); where, NDBI mean has found higher in West than East by the variation of -0.010 to 0.113 in 1993 and it was in 2019 where West again higher than East in the variation of 0.005 to 0.086 (Figure 4c); and EBBI mean has found also higher in West than East by the variation of 0.003 to 0.137 in 1993 (except higher peak in west at 8 km towards west from City center) and it was in 2019 where West again higher than East in the variation of 0.014 to 0.125 (Figure 4d). Here, it has clear that western part of city has more urbanisation than eastern part.

The above two direction (West and East) has been used to extract the difference of change dynamics between West and East in 1993 and 2019. This similar approach has been employed to get the difference of change dynamics between rest of the directions, like as, North and South, North-West and South-East, South-West and North-East.

North to South direction:

Between North and South direction (Figure 4e-f), LST mean was higher in North than South in the variation of 0.34 °C to 1.88 °C in 1993 and again it was higher in North than South in 2019 by the drastic variation of 4.42 °C to 5.76 °C (Figure 4e). Where, NDVI mean has found lower in North than South by the variation of 0.02 to 0.05 in 1993 and it was in 2019 where North again lower than South in the variation of 0.02 to 0.15 (Figure 4f). Where, NDBI was higher in North than South in the variation of -0.001 to 0.02 in 1993 and it was in 2019 where North again higher than South in the variation of 0.003 to -0.04 (Figure 4g). EBBI mean has found also higher in North than South by the variation of 0.02 to 0.04 in 1993 (except higher peak in west near 7-10 km towards South from City center) and it was in 2019 where North again higher than South in the variation of 0.02 to 0.09 (Figure 4h). Here, it has found drastic effects of urban development in northern side of the city whereas in southern side has found rapid higher vegetation growth in 2019. This growth of vegetation in south direction (Figure 4e and 4f) and its effects on LST in same direction (Figure 5a and 5b) has been validated by Landsat OLI/TIRS of 01/06/2019 (FCC image) (Figure 5d) and Google Earth image of 09/05/2019 (Figure 5f).

North-West to South-East direction:

Between North-West and South-East direction (Figure 4i-j), LST mean was higher in North-West than South-East in the variation of 0.36 °C to 2.1 °C in 1993 and again it was higher in North-West than South-East in 2019 by the drastic variation of 1 °C to 2.17 °C (Figure 4i). Where, NDVI mean has found lower in North-West than South-East by the variation of 0.05 to 0.21 in 1993 and it was in 2019 where North-West again lower than South-East in the variation of 0.09 to 0.24 (Figure 4j). Where, NDBI was higher in North-West than South-East in the variation of -0.02 to 0.12 in 1993 (except higher peak in near 8-10 km towards South-East from City center) and it was in 2019 where North-West again higher than South-East in the variation of 0.02 to 0.14 (Figure 4k). EBBI mean has found also higher in North-West than South-East by the variation of 0.02 to 0.17 in 1993 (except higher peak in west near 8-10 km towards South-East from City center) and it was in 2019 where North-West again higher than South-East in the variation of 0.02 to 0.17 (Figure 4l). Here, it has also found drastic effects of urban development in north-western side of the city whereas in southern side has found most vegetation growth (especially from 1 kms to 7 kms) in 2019.

South-West to North-East direction:

Between South-West and North-East direction (Figure 4m-p), LST mean was higher in South-West than North-East in the variation of 0.72 °C to 2.37 °C in 1993 and again it was higher in South-West than North-East in 2019 by the variation of 0.52 °C to 2.03 °C (Figure 4m). Where, NDVI mean has found higher in South-West than North-East by the variation of 0.04 to 0.23 in 1993 and it was in 2019 where South-West again higher than North-East in the variation of 0.003 to 0.18 (Figure 4n). Where, NDBI was higher in South-West than North-East in the variation of 0.01 to 0.09 in 1993 and it was in 2019 where South-West again higher than North-East in the variation of -0.001 to 0.06 (except higher peak in near 10-12 km towards North-East from City center) (Figure 4o). EBBI mean has found also higher in South-West than North-East by the variation of 0.01 to 0.07 in 1993 (except higher peak in west near 10-12 km towards North-East from City center) and it was in 2019 where South-West again higher than North-East in the variation of 0.01 to 0.06 (Figure 4p). Here, it has also found drastic effects of urban development in both south-western side as well as north-eastern side of the city but south-western side was having more intense urban development with bare land effects in 2019.

City Center to City Periphery:
Between city center and city periphery (Figure 4q-t), LST has found 0.26 °C to 2.24 °C of higher variation from 1993 to 2019 (Figure 4q). Where, NDVI has found higher variation between city center and city periphery from 1993 to 2019 by 0.05 to 0.22 (except higher peak in near 16 km towards City periphery from City center) (Figure 4r). NDBI has found lower variation between city center and city periphery from 1993 to 2019 by in the range of -0.05 to 0.08 (except slight higher in near 16 km towards City periphery from City center) (Figure 4s). EBBI has found higher variation in city center to city periphery from 1993 to 2019 by in the range of 0.01 to 0.13 (except higher peak in near 7-11 km towards City periphery from City center) (Figure 4t). Here, it has found the drastic effects of urban development from 4 kms from city center to 14 kms of city center in 2019.

Figure 92. Spatial dynamics of LST and Land Indices: (a - d) Pattern of LST, NDVI, NDBI and EBBI in 1993 and 2019 in West to East direction respectively; (e - h) Pattern of LST, NDVI, NDBI and EBBI in 1993 and 2019 in North to South direction respectively; (i - l) Pattern of LST, NDVI, NDBI and EBBI in 1993 and 2019 in North-West to South-East direction respectively; (m - p) Pattern of LST, NDVI, NDBI and EBBI in 1993 and 2019 in South-West to North-East direction respectively; (q - t) Pattern of LST, NDVI, NDBI and EBBI in 1993 and 2019 on over all analysis from City centre to City periphery respectively.

Figure 93. Validation of vegetation growth in south-east direction and its effect on LST in same direction using Landsat Image and Google Earth Image: (a) LST in time-point of 01/06/2019; (b) LST distributional profile on south-east direction in time-point of 01/06/2019; (c) NDVI in time-point of 01/06/2019; (d) NDVI distributional profile on south-east direction in time-point of 01/06/2019; (e) NDVI distributional profile on south-east direction in time-point of 01/06/2019; (f) Selected circle portion on Landsat OLI/TIRS image in time-point of 01/06/2019; (f) Selected circle portion on Google Earth image in time-point of 09/05/2019 respectively.

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3.3 Study of Thermal State and Land Indices in Urban Planning

The study of LST and land indices (NDVI, NDBI and EBBI) for Lucknow city has significant importance to get the spatial dynamics of the city landscape in terms of natural space diversities and thermal state along different directions of the city.

The results of NDBI and EBBI exhibits overall huge built-up growth in the landscape of Lucknow City from city center to 13 kms (least growth in south-eastern side) from 1993 to 2019. The high NDVI is found in the southern side due to the huge vegetation growth which resulted in the reduction of LST by 4.42 °C to 5.76 °C as compared to northern parts of the city in 2019 (Figure 4e). This clearly explains that vegetation has prominent role to reduce the LST. This also explains that northern part has been explosively developed into urban settings that southern part during 1993-2019.

Our results found that LST has intensified throughout from city center to city periphery from 1993 to 2019 in the range of 0.26°C to 2.24°C (Figure 4). This finding has crucial implication on the city climate. The information derived from the present study regarding LST dynamics of the city will provide a useful insight to urban planners and policy makers in adopting sustainable planning for city landscape by reducing the severe effects of LST.

Presently, people from different part of world are using numerous mitigation strategies, such as growing plants on roofs (green roofs), tree plantation on streets, cool roof creation, use of light materials and paints (Mohajerani et al., 2017). Other strategies include improved wind flow system by designing the size, shape and orientation of the structure of the building (Sen et al., 2019). Other than this, novel mitigation approaches like creation of numerous small to large scale water bodies, plantation of trees and grasses on barren space, use of water harvesting can be noteworthy to enhance the local ecosystem of city landscape (Estoque et al., 2012; Ranagalage et al., 2018; Santos et al., 2017). In this above mitigation strategies making, the monitoring of spatiotemporal remote sensing datasets has been playing significant role to understand the real scenario of the landscape (Sarif et al., 2017). Along with this, public awareness regarding contribution towards reducing LST intensification is essential to create a systematic approach for implementation of plans and policies to improve the city environment.

4. CONCLUSION

The result of relationship between LST vs. NDVI is found negative, LST vs. NDBI is found positive, and LST vs. EBBI is found positive in both time points of 1993 and 2019. This relationship pattern describes that built-up area plays a significant role in enhancing the LST at greater extent by 2°C to 4°C. On the other hand, vegetation also has important role in reducing the LST distribution at large extent by 2°C to 6°C.

The cooler most parts of the city were South and South-East as these parts of Lucknow City have high vegetation growth in 2019. On the other hand, the hotter most parts of the city were South-West and North-West in 2019. The major built-up developed parts were North-West, South-West and North-East.

The overall change of LST observed is in the range of 0.26°C to 2.24°C from city center to city periphery where specifically within 1 km to 13 km, a huge built-up development has taken place from 1993 to 2019. The lesser built-up development is in South-East.

On the basis of our findings, it can be said that aforesaid mitigation plans and policies (section 3.3) need to be incorporated in Lucknow City to reduce the severe effects of LST intensification and for the sustainability of the city climate as well as for making the living standard of human life better. This can help in reducing the LST intensification in climate change.

ACKNOWLEDGEMENTS

Authors are thankful to USGS for making Landsat TM and Landsat OLI/TIRS data available on their portal free. Author, Md. Omar Sarif, is also grateful to University Grants Commission (UGC) for provided him financial support through Maulana Azad National Fellowship (MANF) scheme (2017-18).

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ANALYSIS OF POSSIBILITIES OF LOW-COST PHOTOGRAMMETRY FOR INTERIOR MAPPING

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KEY WORDS: Photogrammetry, Interior mapping, Exposure, SfM, BIM, fisheye lens

ABSTRACT:

This paper shows the possibilities of using low-cost photogrammetry for interior mapping as a tool to gather fast and accurate data for 3D modelling and BIM. To create a 3D model of a building interior with a high level of detail requires techniques such as laser scanning and photogrammetry. In the case of photogrammetry, it is possible to use standard cameras and SfM software to create an accurate point cloud which can be used for 3D modelling and then for BIM. The images captured indoor are often captured under lower light conditions. Using different exposure during capturing of images of building interior was tested. Frequent plain walls of a building interior cause that the images are usually lack of any features and their photogrammetric processing is getting much more difficult. In some cases, results of photogrammetric processing are poor and inaccurate. In this paper, an experiment of creating a 3D model of a building interior using photogrammetric processing of images was carried out. For this experiment digital camera with two different lenses (16 mm lens and fisheye lens) was used. For photogrammetric processing were chosen different software. All the results were compared to each other and to the laser scanning data of the interior. At the end of the paper, the discussion of the advantages and disadvantages of the shown method has been made.

1. INTRODUCTION

3D modelling of already constructed objects is getting to be more and more important due to the increasing number of inquiries for Building Information Modelling (BIM). Laser scanning is a sufficient and reliable tool for obtaining point cloud for following 3D modelling. In this paper. Leica BLK 360 laser scanner was used, because it is a device which offers suitable and reliable results (Luhman, 2019). Photogrammetry, mainly SfM (Structure from Motion), is an alternative to laser scanning in point cloud generation. In the case of interior mapping, the problem with low or non-textured parts of object e.g. plain walls and possibly low light conditions makes photogrammetric processing much more difficult. In this paper, an experiment of interior mapping has been carried out. As a test object a room of a family house has been chosen. The room with plain white walls and few glossy objects which are considered as a negative factor for SfM processing was chosen on purpose. The room was surveyed with a total station and with the laser scanner Leica BLK 360. For photogrammetric processing, images were captured by mirrorless camera SONY alpha a6000. It is possible to consider a room as a narrow object, where fisheye lens for imaging is suitable to use (Perfetti, 2017) (Marcšič, 2016). The captured images were processed in SfM software. Agisoft Photoscan has been chosen as a commercial alternative based on SfM and photogrammetric software MicMac has been chosen as an opensource low-cost alternative, also based on SfM. The ability of 3D modelling from point cloud created with photogrammetric processing based on SfM was tested. Parameters of the final 3D model were compared to the measurement with the total station and to the point cloud obtained by the laser scanner. At the end of the paper, discussion about the advantages and disadvantages of tested methods including factors as accuracy, user-friendliness, the time cost is part of the paper.

1.1 Test object

As a test object, a room of a family house has been chosen. The room was chosen on purpose to simulate difficult conditions. The walls of the room are white and plain without any texture. There is a glossy wardrobe, glossy table, a large mirror in the room, glass door and lots of high flowers set in the room corners. All these factors potentially make photogrammetric processing based on SfM much more difficult. The room has also three windows, one door, a wooden floor and a plain ceiling with chandeliers made from metal.

Figure 1. Test room
2. SURVEYING OF THE TEST OBJECT

2.1 Camera, lenses and laser scanner

For capturing images has been chosen digital mirrorless camera SONY alpha a6000 with original lens (16 mm focal length) and Samyang fisheye lens (8 mm focal length) suitable for imaging of narrow places as this room could be considered. For laser scanning Leica BLK 360 was used. Leica BLK 360 is a relatively small and easy-to-use laser scanner that is operated by a tablet connected via Wi-Fi to the laser scanner.

2.2 Surveying

First of all, coded targets and black-and-white targets were equally distributed around the room. There were used 10 12-bit coded targets, 5 used as control points and 5 used as check points. 8 black-and-white targets were placed for laser scanning. Those targets were measured with total station Topcon DS Series from a single station. After measuring the targets, corners of the room, the height of the floor, the height of the ceiling and windows were measured as well. Then the room has been surveyed with laser scanner Leica BLK 360. Capturing of images with 16 mm lens has been carried out during midday daylight without artificial lighting. The capturing scenario was set to follow the official recommendation of Agisoft Photoscan manual but because of all the furniture and other objects, it was not ideally possible. For each window, extra images were captured. In total, 90 images have been captured. Capturing of images with fisheye lens were carried out immediately after. Due to the wide field of view was not necessary to capture too many images. 35 images have been captured with fisheye lens. The idea was to not capture too many images to make imaging as fast as possible and to cut the time cost down. For both groups of images (16 mm lens and fisheye lens) quite dense point cloud. For group of images captured with fisheye lens the lower number of tie points computed from fisheye lens images could be caused by lower number of images. Most of the tie points were on furniture in the room, on flowers and on the floor. Some of them were even on metal chandeliers.

<table>
<thead>
<tr>
<th>Co-registered images</th>
<th>Num. of tie Points</th>
<th>Num. of points in point cloud</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 mm lens</td>
<td>90/90</td>
<td>61 855</td>
</tr>
<tr>
<td>Fisheye lens</td>
<td>35/35</td>
<td>12 263</td>
</tr>
</tbody>
</table>

Table 1. Results of processing in Agisoft Photoscan.

After computing relative orientation, photogrammetric targets were automatically detected on images and 5 of them were used for absolute orientation and bundle adjustment of the model. 5 of them were left for an accuracy check. Total RMSE of control points was 0,002 m for group of images captured with 16 mm lens and 0,001 m for group of images captured with fisheye lens. Total RMSE of check points was 0,006 m for group of images captured with 16 mm lens and 0,002 m for group of images captured with fisheye lens.

<table>
<thead>
<tr>
<th>X Error [m]</th>
<th>Y Error [m]</th>
<th>Z Error [m]</th>
<th>Total [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 mm lens</td>
<td>0,002</td>
<td>0,001</td>
<td>0,001</td>
</tr>
<tr>
<td>Fisheye lens</td>
<td>0,001</td>
<td>0,001</td>
<td>0,001</td>
</tr>
</tbody>
</table>

Table 2. Control points – RMSE values.

Then, Build Dense Cloud tool computed for both groups (16 mm lens and fisheye lens) quite dense point cloud. For group of images captured with 16 mm focal length, point cloud with 7369776 points was created. 90/90 images were automatically detected on images and 5 of them were used for absolute orientation and bundle adjustment of the model. 5 of them were left for an accuracy check. Total RMSE of control points was 0,002 m for group of images captured with 16 mm lens and 0,001 m for group of images captured with fisheye lens. Total RMSE of check points was 0,006 m for group of images captured with 16 mm lens and 0,002 m for group of images captured with fisheye lens.

<table>
<thead>
<tr>
<th>X Error [m]</th>
<th>Y Error [m]</th>
<th>Z Error [m]</th>
<th>Total [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 mm lens</td>
<td>0,002</td>
<td>0,003</td>
<td>0,004</td>
</tr>
<tr>
<td>Fisheye lens</td>
<td>0,002</td>
<td>0,001</td>
<td>0,001</td>
</tr>
</tbody>
</table>

Table 3. Check points – RMSE values.

For photogrammetric processing was used software based on SfM. There were chosen two alternatives – commercial software and opensource. In each software two groups of images (16mm original lens and fisheye) have been processed separately. The goal of the processing was to create a dense accurate point cloud that could be then used for proper and easy 3D modelling of the room.

3. PHOTOGammaMetry PROCessing

For photogrammetric processing was used softwere based on SfM. There were chosen two alternatives – commercial software and opensource. In each software two groups of images (16mm original lens and fisheye) have been processed separately. The goal of the processing was to create a dense accurate point cloud that could be then used for proper and easy 3D modelling of the room.

3.1 Processing in Agisoft Photoscan

As a commercial alternative of photogrammetric software based on SfM, Agisoft Photoscan (in version 1.4.3.6488) has been used. Following workflow of processing images was used.

1. Align Photos
2. Detecting Markers
3. Optimize Camera
4. Build Dense Cloud

Using Align Photos, the relative orientation of all the images was computed. All the images of both groups were co-registered. In total, 61855 tie points were computed for a group of photos captured with 16 mm lens and 12263 tie points were computed for group of images captured with fisheye lens. The lower
3.2 Processing in MicMac

MicMac is a free and opensource photogrammetric tool based on SfM and developed at the National Institute of Geographic and Forestry Information (IGN) and ENSG (French national school for geographic sciences). MicMac is controlled through the command line and is suitable for different kinds of application. For the processing in this paper, MicMac v1.0.beta13 was used. Photogrammetric workflow for creating point cloud is:

1. Tapioca
2. Tapas
3. GCPBascule
4. Campari
5. C3DC

By using commands Tapioca and Tapas, the relative orientation of images was computed. All the images of both groups were co-registered. Number of tie points was much higher compared to the tie points from processing in Agisoft Photoscan. Most of the tie points represented objects like flowers and wooden furniture. Fewer tie points were on room floor.

<table>
<thead>
<tr>
<th>Coregistered images</th>
<th>Num. of tie Points</th>
<th>Num. of points in point cloud (by C3DC QuickMac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 mm lens</td>
<td>90/90</td>
<td>230 073</td>
</tr>
<tr>
<td>Fisheye lens</td>
<td>35/35</td>
<td>59 289</td>
</tr>
</tbody>
</table>

Table 4. Results of processing in MicMac.

Absolute orientation was computed after manual marking of targets by GCPBascule and Campari commands. 5 of the points were used as control points and total RMSE of control points after absolute orientation was 0.002 m for group of images captured with 16 mm lens and 0.001 m for group of images captured with fisheye lens. After commands GCPBascule and Campari, 5 checked points were measured, and the coordinates were compared to the coordinates measured with the total station. For group of images captured with 16 mm lens total RMSE of the check points was 0.003 m and 0.002 m for the group of images captured with fisheye lens.

<table>
<thead>
<tr>
<th>X Error [m]</th>
<th>Y Error [m]</th>
<th>Z Error [m]</th>
<th>Total [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 mm lens</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Fisheye lens</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Table 5. Control points – RMSE values.

<table>
<thead>
<tr>
<th>X Error [m]</th>
<th>Y Error [m]</th>
<th>Z Error [m]</th>
<th>Total [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 mm lens</td>
<td>0.002</td>
<td>0.002</td>
<td>0.001</td>
</tr>
<tr>
<td>Fisheye lens</td>
<td>0.002</td>
<td>0.002</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Table 6. Check points – RMSE values.

Point cloud was created using command C3DC. The resulted point clouds for both sets of images were very thin and for 3D modelling obviously unusable. C3DC command was used with different types of arguments. Argument Statue which uses strictly epipolar mode provided the highest number of points (more than 1 million) in the point cloud but compared to the point cloud from Agisoft Photoscan it is a very low number. At parts of the room such as white walls and ceiling, almost none of the points were created. At parts as window frames, the point cloud was very thin and even with almost no points on the floor. C3DC command with QuickMac argument provided fewer points but better distributed around the test room. Even these point clouds were obviously unusable for further modelling. Compared to point cloud made in Agisoft Photoscan, where the floor represented enough number of points the result of C3DC command was very poor. Even though accuracy check by 5 check points showed accurate relative orientation which could be usable for discrete points measuring.

Figure 3. Point cloud created by C3DC QuickMac in MicMac.

4. RESULTS

The results of photogrammetric processing in Agisoft Photoscan were point clouds that were analysed if it is possible to use the point clouds for following 3D modelling and if the method is comparable to laser scanning with Leica BLK 360. The resulted point clouds from photogrammetric processing in MicMac were not sufficient to use for modelling of the room and were not in the following experiment used.

4.1 Comparison to ideal planes

3D model of the room was created from points measured by the total station. The walls, floor and ceiling were considered as ideal planes and the point clouds from photogrammetric processing were compared to the 3D model in Cloud Compare software. First of all, point clouds were manually filtered into three parts. To the first part belonged points which obviously represented walls of the room. The second part belonged to the points which represented the floor and points of the third part represented the ceiling of the room.

Figure 4. Example of comparison between point cloud and 3D model of the floor.

The following graphs show that the average value of the set of distances in the parts of the floor and walls is under 0.01 m from the model of ideal planes for both group of images. In the case of point cloud which represents wall, standard deviation of set of distances is much higher compared to the standard deviation of distances computed from point cloud which represents floor. The
point cloud of the ceiling is much noisier and in this case, point cloud created from images captured with fisheye lens in comparison to the model of ceiling has lower mean and lower standard deviation then point cloud created from images captured with 16 mm lens in comparison to the model of the ceiling.

Table 7. Statistical values of set of distances for walls.

<table>
<thead>
<tr>
<th></th>
<th>Mean [m]</th>
<th>Standard deviation [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 mm lens</td>
<td>-0.001</td>
<td>0.056</td>
</tr>
<tr>
<td>Fisheye lens</td>
<td>-0.007</td>
<td>0.057</td>
</tr>
</tbody>
</table>

Figure 5. Histogram of set of distances for walls.

Figure 6. Histogram of set of distances for floor.

<table>
<thead>
<tr>
<th></th>
<th>Mean [m]</th>
<th>Standard deviation [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 mm lens</td>
<td>0.002</td>
<td>0.007</td>
</tr>
<tr>
<td>Fisheye lens</td>
<td>0.001</td>
<td>0.006</td>
</tr>
</tbody>
</table>

Table 8. Statistical values of set of distances for floor.

4.2 Test of modelling

Resulted point clouds from photogrammetric processing from Agisoft Photoscan were tested in a matter of possibility of using these point clouds for 3D modelling. Point cloud created by laser scanner Leica BLK 360 was taken into account as well. A slice of the point clouds was created. The slice was 0.20 m thick and cut the point clouds horizontally. If the slice was thinner it was not possible to detect the position of the wall properly on point cloud created photogrammetrically. Point cloud created with BLK 360 could be investigated with a thinner slice. For both cases (16 mm lens and fisheye lens) was not a problem to determine the course of the wall. Using both point clouds created in Agisoft Photoscan and point cloud created with laser scanner Leica BLK 360 were created 3D models. Comparison of parameters of the model has been made. Among the tested parameters were lengths of chosen walls, width of all three windows and height of the ceiling. As reference values were taken values from measurement with the total station which were used also for modelling the ideal planes.

Table 9. Statistical values of set of distances for ceiling.

<table>
<thead>
<tr>
<th></th>
<th>Mean [m]</th>
<th>Standard deviation [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 mm lens</td>
<td>0.084</td>
<td>0.119</td>
</tr>
<tr>
<td>Fisheye lens</td>
<td>0.059</td>
<td>0.075</td>
</tr>
</tbody>
</table>

Figure 7. Histogram of set of distances for ceiling.
The average difference was computed as a mean value of set of absolute values of differences. The comparison showed that parameters of created model from point cloud by Leica BLK 360 are in average difference 0.005 m. The highest difference 0.009 m is in length number 4. The comparison showed a difference between modelling from point cloud created by photogrammetric processing of images captured with 16 mm lens and fisheye lens. Lower differences were shown in parameters at model created from point cloud created from 16 mm lens images. Average difference was 0.010 m. The highest difference was 0.023 m. Parameters of model created from fisheye lens images differ more. The average difference was 0.033 m and even in width of one window the difference was 0.084 m which shows unreliability.

5. CONCLUSION

Interior mapping for 3D modelling and BIM could be carried out by laser scanner. Photogrammetry and SFM could be an alternative for laser scanning in terms of interior mapping. In interiors of buildings there are many factors that can negatively affect photogrammetric processing. One of those factors can be lack of texture on plain walls of interior or lots of glossy and shiny objects. Also, lighting condition is usually darker than outside of the building and proper exposure must be set for every room of building interior which takes time. Capturing of images on tripod with long exposure also increases the time of surveying the interior. This paper showed if photogrammetry is a comparable alternative to laser scanning for interior mapping under unpleasant mentioned conditions. For testing, the room of a family house has been chosen. The room was measured by the total station and was surveyed also with laser scanner Leica 360 BLK. Images were captured by the mirrorless camera with two different lenses (16 mm original lens and fisheye lens). The images were processed in two different software. Agisoft Photoscan was chosen as a commercial alternative and MicMac was chosen as an opensource alternative. Relative orientation of two groups of images (16mm and fisheye) was successful and accuracy check on checkpoints showed that the orientation is relatively accurate. Total RMSE of check points were not higher than 0.006 m. This shows that it is possible to expect good results during discrete measuring of points. For faster 3D modelling of the room it is necessary to compute point cloud. Point clouds created with MicMac were very thin and it was obvious at first sight that it is not possible to create 3D model from those point clouds. On the other hand, commercial software Agisoft Photoscan created relatively dense point cloud from both sets of images (16 mm and fisheye). Different parts of the point clouds (walls, floor, ceiling) were compared to the 3D model composed of ideal planes. At the part of floor, both point clouds had the lowest standard deviation. The part of ceiling was the most inaccurate and contained a lot of noise. At the part of walls, means of all distances were under 0.01 m but the standard deviations were under 0.06 m. Both point clouds (16 mm and fisheye) were tested with point cloud created by Leica BLK 360 if it is possible to create accurately 3D model based on them. The test was carried out by testing on chosen parameters of the resulted 3D model. Different lengths, widths and high were tested and compared to the measurement by total station. Parameters from model created from point cloud by Leica BLK scanner were most accurate to the model from measurement by total station. The average value of absolute values of differences was 0.005 m and the highest difference was 0.01 m. 3D model created from images captured by 16 mm lens was more accurate to the 3D model created from measurement by total station then 3D model from point cloud created by fisheye images. The average value of absolute values of differences was 0.010 m and the highest difference was 0.023 but the parameters of 3D model from point cloud created from fisheye images differed in average 0.033 m and the highest difference was 0.084 m. This could be also caused by the lower number of images captured with fisheye lens. Even though differences of parameters of 3D model created from point cloud from images by 16 mm lens were under certain tolerance, the testing showed the unreliability of the method. Also, the time cost should be considered. Time for capturing of the images is comparable to the time of the scanning with Leica BLK 360. The scanning itself with Leica BLK 360 is user-friendly, the scanner is light and operated just with one button. The resulted point cloud of laser scanner is denser and more reliable for 3D modelling. Time for photogrammetric processing is much higher than for processing of laser scanning data. The point clouds from photogrammetric processing were noisy in parts with lack of texture and creating 3D model was more difficult which increased time cost as well.

ACKNOWLEDGEMENTS

This project was supported by grant of the Grant Agency of the Czech Technical University in Prague, grant No. SGS19/048/0HK1/1T/11. This project is a part of internal research of EuroGV s.r.o. company.

REFERENCES


APPLICATION OF THREE-DIMENSIONAL SCENE TECHNOLOGY IN LAND MANAGEMENT

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KEY WORDS: Three-Dimensional Scene, Land Management, Fly View, Oblique Photography, Sunshine Analysis, Visual Analysis, Flood Analysis

ABSTRACT:
The traditional two-dimensional technology is mainly used to describe and analyze the plane position and mutual relationship of geographical entities, and the land use is developing towards the three-dimensional trend; facing the new trend, the traditional two-dimensional technology cannot meet the requirements of the three-dimensional land management. In this paper, the characteristics of three-dimensional technology are described in detail, and the applicability of three-dimensional technology to land management is analyzed. Finally, the application effect of three-dimensional technology in land management is verified through the actual project.

1. INTRODUCTION

With the development of land use to three-dimensional and complex, land management urgently needs to change from plane management to three-dimensional management mode. However, due to the unprecedented development of sensor, platform and processing software technology of three-dimensional data collection, the acquisition of real three-dimensional land model is easier than ever (Guo r.z, 2018). three-dimensional technology has attracted much attention because of its ability to fully perceive large-scale, high-precision, high-definition complex scenes, acquire high-resolution digital ground model, realistic Orthophoto Image, fine 3D city model and other measurement products. The current two-dimensional land management technology aims to describe, analyze and manage the information of the plane position, relationship and state of the surface, such as the investigation and statistics of the plane land parcel and its use, the evaluation and planning of the surface resources of the land, etc., which is difficult to support the quantitative positioning and analysis management of the three-dimensional extension parts outside the surface (Qin R, 2016); the three-dimensional real-world technology not only provides different forms of data for land management As a new method of geometric analysis of land elements based on three-dimensional and high detail, it goes beyond the analysis boundary of traditional two-dimensional Technology (Zhang y.l., 1997).

This paper first reviews the background of 3D land management, and discusses the feasibility of land management based on 3D real scene technology from three aspects: the demand of architectural planning for 3D real scene technology, tilt photography technology and the support of the corresponding processing software development for 3D real scene technology. Finally, through a specific project application in Xi’an, the author puts forward the method Verification.

2. FEASIBILITY ANALYSIS of 3D LAND MANAGEMENT

2.1 The Urgent Need of Three-dimensional City

Several urban planning trends, as well as some political and historic considerations, are presently generating the need for legal recognition of three-dimensional property units. The traditional legal doctrine in all legal systems assumes vertical merger of ownership of all land strata. Several urban planning trends are presently generating, and will continue to generate in the future, the need for legal recognition of three-dimensional property units. The condominium phenomenon creates independent land units (Encyclopedia). The formation of multi-level mega-structures in the urban space and the development of three-dimensional and multi-level traffic and transport patterns, both above and below ground level (Birat), leads to the creation of functional and three-dimensional property units in an unconventional geometric forms. It could be seen in the large cities of the United States since the first decades of the twentieth century. Both worldwide and in the State of Israel a planning trend towards greater utilization of underground space is taking shape, accompanied by the minimizing of damage to the environment, to the landscape and to the rights of owners of above-ground land, while utilizing the advantages of the underground in terms of protection or isolation against weather conditions (HAIM SANDBERG, 2001).

2.2 Current Situation of 3D Modeling

In the process of data acquisition of building digital 3D model, tilt photography has the advantages of low cost, easy operation, full color, high fidelity and so on (L.V. X.w., 2017). Tilt photogrammetry technology can fully perceive and collect the ground feature information of complex scenes in a fast, large-scale and high-resolution way, and the data results generated by efficient data collection equipment and professional data processing process can directly reflect the appearance, position, height and other attributes of the ground features, providing
guarantee for the real effect and geometric accuracy (Deng. Y., 2016).

3. PROJECT APPLICATION

3.1 Project Background

Compared with the traditional two-dimensional orthophoto image, the real-world three-dimensional image can observe the objects from many angles, and reflect the actual situation of the objects more truly. The three-dimensional scene system integrates abundant land information and basic geographic information, provides intuitive three-dimensional scene, and can realize the functions of three-dimensional calculation, location planning, editing and analysis. Compared with the traditional two-dimensional images, the real scene three-dimensional construction of the geographical scene is simple and intuitive, even non-professionals are easy to interpret and recognize (Deng. Y., 2016).

According to the needs of this project, we use the 3D real scene technology to obtain and process the 3D data of this area through the method of tilt photography. Then we use the flight control software independently developed by coal airlines to build the model of the planned building, and carry out sunshine analysis, visual field analysis, flood analysis. The analysis results fully meet the requirements of government land management and residents' living Room lighting, ventilation, visual understanding of the needs of the situation.

3.2 Overall Flow Chart of the Project

Customer Demand Analisis

Data Collection

Technical Design

Oblique Aerial Photography

Establishment of 3D Model

3D Analysis

Output Results

Submission Results

Figure 1. Work flow chart

3.3 Implementation of the Project

The data acquisition of this project adopts helicopter as the aerial camera carrying platform, and the aerial camera has used swdc-5 tilt aerial camera.

<table>
<thead>
<tr>
<th>Device Name</th>
<th>Device Type</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little squirrel h125</td>
<td>Helicopter</td>
<td>Airbus</td>
</tr>
<tr>
<td>SWDC-5 (Bring IMU)</td>
<td>Tilt digital camera</td>
<td>Four dimensional vision dimensional vision</td>
</tr>
</tbody>
</table>

Table 1. Parameter table of tilt photography instrument

Tilt photography is as follows:

Figure 2. Implementation of aerial photography flight

After obtaining the 3D image, we processed the data and established the 3D model as follows:

Figure 3. Three-dimensional model

After detailed investigation, the location of the proposed new building is as follows:
3.3.1 Sunshine Analysis: Day lighting right refers to the right of the house owner to obtain appropriate light source from the outside. In this project, the light of the building to be built may be affected by the adjacent buildings, and after the completion of the building construction, it may also affect the daylighting of the surrounding buildings. In order to make the daylighting of the new building and the surrounding buildings reach a relative balance as far as possible, we are in favor of the sunshine analysis. Four seasons are selected, namely spring, summer, autumn and winter. The sunshine analysis is carried out at 8:00 a.m., 12:00 p.m. and 6:00 p.m. in each season. The simulation results are as Figure 6.

After analysis, in the design scheme of the building, the lighting in the morning, noon and afternoon of summer and autumn is better than the relevant standards, and the lighting in the morning and afternoon of spring and winter is poor, which can barely reach the relevant standards. After analysis, the lighting situation after the building is completed is described quantitatively, which provides image data support for land planning and management.

3.3.2 Visual Analysis: Visual field refers to the specific location of a point as a viewpoint to analyze the coverage of the point's visual field; visual field is an important indicator of the quality of the house. We use the fly by wire software to analyze the visual field of the building and vividly show the scope of the building's visual field. The analysis results are as follows:

In the analysis results, the green part represents visible, and the red part represents invisible. After analysis, it can vividly express the situation of the visible vision of the building and meet the requirements of customers for the vision analysis.

3.3.3 Flood Analysis: In urban land management, it is very important to analyze the impact of heavy rain and flood on the...
city. We simulate the impact of different situations of heavy rain and flood on buildings with the help of the flying crane software. The results are as follows:

Figure 8. Rainstorm inundation scenario (simulate the scenario of heavy rain, the blue part is the flooded area)

Figure 9. Flood inundation scenario (flood simulation scenario, the blue part is the flooded area)

By using this function, we simulate the surrounding situation of the building in rainstorm and flood, which can provide reference for flood disaster prevention and land management.

3.3.5 Space measurement: In the traditional two-dimensional map, only the projection area of the building can be measured. In the land management, the space area of the planned building needs to be measured in addition to the projection area. Using the space area and space distance measurement function of the flyover software, the space area of the planned building and the space distance between the planned building and the surrounding buildings can be calculated, which can be used for land management and planning. The analysis results are as follows:

Figure 11. Space area and distance measurement

3.3.6 Snow simulation: In land management, a very important work is to simulate the impact of various rain and snow weather. With the support of three-dimensional real-world technology, we developed the rain and snow weather simulation function. The purpose is to provide effective help for land management and residents' lives through the simulation of rain and snow weather. The simulated snow weather scenario is as follows:

Figure 12. Snow scenario simulation

4. CONCLUSION

This paper introduces the new situation of three-dimensional land management, and introduces the concept of real three-dimensional. In order to express the third dimension information of geographic information elements, this study adopts the method of three-dimensional real scene. Based on the comparison of two-dimensional images, the advantages of real three-dimensional technology in land management are obtained. As shown in this paper, the three-dimensional reality platform can be used for sunshine analysis, visual analysis, submergence analysis, etc. In order to support the application of land management in the complex background, the researchers of “Fly View” added the functions of model video projection, underground pipe network display, two or three-dimensional two screen comparison, fire scene simulation demonstration, etc. Through the analysis of sunshine, visual field and inundation of a new planning building in Xi'an, it shows that the software can better express three-dimensional reality.
dimensional geographic information and promote the land management to a more intuitive and efficient direction.

There are several limitations in this study, such as difficulties in the follow-up development and application of 3D models, incomplete use of data, too many faces of 3D models, reduced effect after platform transplantation, large amount of data, lack of update and platform integration capabilities. In the future, with the solution of these problems one by one, we believe that real 3D can be applied to more fields to solve more practical production problems.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support by data providers and software developers.

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APPLICATION OF 3DGIS IN SMART CITIES – TAKING APPLICATION OF GIS+BIM IN URBAN ROAD ENGINEERING FOR EXAMPLE

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KEY WORDS: 3DGIS, BIM, Integration, Urban road design, People oriented

ABSTRACT:

With the development of technology and society, surveying and mapping, and geographic information technology as basic and popular technologies have been widely used in China. With BIM technology helping expand the basic geodatabase. The integration of GIS and BIM promote further development of 3DGIS technology, which will play an effective role in the construction of smart cities. As the backbone of urban functions and landscapes, urban road is a comprehensive engineering involving many factors. But the GIS+BIM application in the realm were inadequate. In the study, based on the summaries of the BIM and GIS characteristics, the gaps and connections between BIM and GIS were analyzed. Gaining experiences from previous researches of GIS + BIM, the study applied GIS + BIM to urban road design. With the combination of GIS and BIM, the urban road model designed on BIM platform was successfully placed into the real 3D scenes, which was achieved by UAV tilt photogrammetry. Then the line shape and location of the urban road can be better fit into surroundings, with the assistance of the scope from the driver. The study will offer one more practice of GIS + BIM in urban road engineering, and lead following designers to consider more about people-oriented models.

1. INTRODUCTION

In January 2013, China's Ministry of Housing and Urban-Rural announced the first pilot list of 90 smart cities; in 2019, more than 500 cities were built to smart cities. The fast-growing population will make the size of urban areas double, calling for developing smart cities utilizing information tools such as Geographic Information System (GIS) and Building Information System (BIM) (Karen, 2018). In 2017, Autodesk and Esri, the leading provider of GIS mapping software, announced a partnership to integrate BIM and GIS workflows between the company’s products, showing that the integrated application of GIS and BIM are heading forth.

Truly, there were many researches involving many realms on the integration of GIS and BIM. But as for its application on the urban road design, it is not mature and few outcomes were achieved. Actually, urban roads are the backbone of urban functions and landscapes, and their planning and design influence the landscape and spatial form of the city. Urban transport infrastructure can promote the rapid development of the city, especially in China’s urbanization. With the urban population expanding, which caused the continuous expansion of the surrounding border in the city, it is urgent for the city road planning and design. So it is essential to take trials to apply GIS + BIM to the application of urban road design by gaining experiences from other successful cases.

2. OVERVIEW OF GIS AND BIM

GIS and BIM are both powerful tools in their own realms. As an effective information tool, GIS has been characterized by its capacity of spatial data management and spatial analysis (Chen G. et al, 2019), which guarantees its ability of deeper insights into data and assistance in the analysis and management of smart cities. 3DGIS appeared based on the rapid development of 3D visualization and virtual reality technology in the 1990s. Relied on computer software and hardware, taking spatial database technology as a basis, the 3DGIS provides realistic information for decision-making, planning, research and management by scientifically analyzing and managing the spatial data. 3DGIS is a multi-directional and interdisciplinary emerging field of research in space technology, geosciences and management science (Zhao, 2012). Specifically in urban planning, GIS is mainly applied to realize seven functions, namely: (1) Fast reproduction of real urban 3D landscape; (2) Real-time operation on 3D scene; (3) Rapid query of attribute information; (4) Roaming operation by operating keyboard; (5) 3D flight according to any given line; (6) Graphics and animation output; (7) Data update and maintenance.

As for BIM, regarded as a technological revolution following CAD, the technique has revolutionized the building projects since its appearance in 2003. Based on the relevant information data of the construction project, BIM can establish a three-dimensional building model to simulate the real information of the building through digital information simulation (Zhu, 2015). It is featured by its good information integrity, information relevance, information consistency, visualization, coordination, simulation, optimization and graphical features. Also, since the first time the term BIM was mentioned in China in 2003, the government has been promoting and specifying the application of BIM, with massive policies issued from 2011 to 2019 (See APPENDIX).

2.1 Gaps and Connections between GIS and BIM

Considering that BIM is not capable of storing, analyzing and displaying large-scale geographic information data, GIS was introduced. Here, 3DGIS has become more universal for the combining of three-dimensional characteristics of BIM and GIS characteristics.

According to the massive researches, the difficulties on the integration of GIS and BIM mainly referred to the conversion of BIM data and GIS data. Since the two are oriented to different application fields at the first beginning, they adopt different model standards and technologies, which are also obvious in
geometric expression and semantics. Differently, BIM is based on IFC (Industry Foundation Classes). The 3DGIS urban model information is based on CityGML (City Geography Markup Language). The integration process requires the transformation and mapping of the model semantics of the two (Wang, 2017).

Nevertheless, the integration of GIS and BIM is potential. On the one hand, data from BIM technique can be regarded as an important data source for the GIS application, making 3DGIS go from macro to micro. On the other hand, the integration of the GIS data with BIM data makes it possible to combine indoor and outdoor management, by means of going deep into the interior of the buildings according to geographical environment elements. Further, the structure, representation and objects of GIS data cover those aspects of BIM data. Specifically, the BIM data structure consists of spatial data and attribute data, wherein the spatial data includes spatial position, shape, etc. and attribute data includes design parameters, construction parameters, and operation and maintenance parameters, etc. The presentation refers to 3D modeling. BIM is mainly applying in architectural field, while GIS objects covers a wider range including architecture. Besides, there are overlaps even on their functions, such as information management and spatial analysis.

2.2 Typical Applications of GIS + BIM

There were already many researches on the integration of GIS and BIM. Typically, four applications were introduced here.

Firstly, urban rail transit engineering is a systematic project involving a range of aspects and factors. In the process of design, the line often conflicts at the locations with various structures such as underground pipelines, building pile foundations and existing transportation facilities, or conflicts on the landscape with ground buildings. 3D technique offers a visualized way to observe and judge whether these conflicts appear (Bi K., 2015).

Secondly, according to existing researches about simulation of ancient architecture scenes based on GIS, the researchers mainly put emphasis on architectural visualization, omnidirectional roaming, weather effects simulation, etc. But the representation of architectural structures and fabrication techniques (such as construction space division, combination, composition and dynamic construction process) were ignored. With regard to those based on BIM, parameter modeling and component management were better achieved, but they showed that the bad aspects on 3D rendering and physical simulation capabilities. As a typical case of Cambodia Angkor monument, which was listed in the World Heritage in 1992, the Ta Keo Temple was to be simulated on the scenes and construction processes (Chen, 2017). Based on SolidWorks software, the author realized the reconstruction of the model of Ta Keo Temple building group, and made a preliminary research and experiment using parametric modeling method. And the preliminary design of the three-dimensional ancient architectural scene simulation system was completed with Unreal Engine.

Thirdly, long-distance water diversion project was introduced to address the imbalance both on time and space between water and soil resources in China. At the same time, the project can also benefit on water power, flood control, shipping and aquaculture. For its characteristics of long line span, large investment, many participants and long construction period, traditional engineering management mode cannot meet the various needs through the whole construction process of the project. On the point, GIS and BIM were introduced to build a 3D visualization scene of long-distance water diversion project, and to realize the fusion and deep analysis application (Qiu, 2015).

Lastly, as for the application of underground pipeline information management, a complete 3D space including above ground space and underground space will be showed. For the underground space, BIM can be used to realize 3D modeling, an omnidirectional expression of pipeline network, collision check after modeling and optimized design. And work of space above ground mainly completes using GIS technique. Based on the visible 3D data above ground, which is often acquired by aerial photography, digital elevation model (DEM) or elevation points are produced to build the 3D terrain skeleton. Then the integration of urban 3D scenes can be achieved by superimposing digital orthophoto maps, textures of buildings and vegetation, and sketch models on the terrain skeleton. Besides, GIS also is used to correlate pipeline attribute information with spatial information (Yang, 2017).

For most researches, here, the integration of GIS and BIM was achieved based on 3ds Max. Take Qiu’s work for example, in order to display efficiently and explicitly in the Skyline TerraExplorer environment, BIM model files created based on the Revit requires a series of operations such as conversion and post-processing editing. According to Qiu’s work, the Revit model integration flow is as follows (see Figure 1). As we can see, massive 3D BIM models can be introduced rapidly with the use of the DirectX model as an intermediate transformation model.

![Figure 1. Integration operational flow on Revit platform with 3ds Max as an intermediate aid](image)

3. A CASE ON URBAN ROAD DESIGN

The traditional urban road design is “car-oriented”, ignoring the thinking of the main body of traffic-persons, causing some unreasonable problems in road design and construction, and leading to problems such as urban traffic safety. That goes against the aim of sustainable development of the city. In addition to diverting traffic and reducing traffic pressure, urban road planning should also take more people's factors into account to ensure people's travel safety and living convenience. More attention should also be paid to urban roads and cities.

In order to better coordinate the urban roads and the surrounding environment, and consider the rationality and operability of urban ground and underground road facilities, it requires the designer to obtain the details of the project scope at the beginning
of the design. Municipal road planning, design and construction must fully consider a wide range of factors, such as the topography, geology, landscape, transportation facilities and the ancillary facilities, status of built-up areas, calling for multi-level, multi-angle analysis of urban road.

3.1 Overview of Urban Road Construction Zone

In this case, the terrain of a city road construction area is flat, and the distribution of residents is relatively discrete, mainly distributed in the north-south direction, as shown in Figure 2. The road project is completed urban expressway roads, needs throughout the east-west direction, converge on the highway.

![Figure 2. A regional road projects](image)

3.2 Urban Road Planning Design Based on GIS + BIM

In the road planning and design, due to the long thread of the road, the environment of different road sections changes greatly, which makes the road engineering design more difficult and the volume increases. The traditional two-dimensional design drawings are difficult for designers to overall considerations, it is more difficult to take into account the "human" factors, designed in the real-life three-dimensional environment based on BIM + GIS technology integration, can overcome this difficulty.

![Figure 3. Road planning and design technology roadmap](image)

In this case, on the GIS platform, the natural geography environment data is comprehensively analyzed to meet the requirements of “human” requirements. Cost, project requirements and other factors were also comprehensively considered. The technical roadmap of the design was finally determined as which was showed in figure 3.

In the urban road planning and design process, in addition to considering the terrain, landform, resident distribution, cost, commercial function, traffic flow and other design factors to determine the direction and line type of the route, we should also consider the effects of the main body of the road - "people", such as: the need to pay careful consideration of safety facilities design, so that the "people" feel more convenient, safe and comfortable. This collection of existing building area of geological, surveying and mapping data, the real three-dimensional data and DEM, geology map of the construction area, etc. were loaded into the GIS platform. A comprehensive analysis of the distribution of the residents of the area, topography, the use of spatial analysis functions using GIS technology, with geographical and humane environmental factors such as residents distribution, traffic flow, and business functions being assigned weights as needed. On this basis, the road direction and the road surface line were designed according to the needs of the construction project (see Figure 4). Then the cross-sectional design of the road was determined according to urban expressway construction standards.

![Figure 4. Road graphic design](image)

With AutoCAD Civil 3D as the BIM design platform, the design of the “human” care as the starting point, the design of materials and quantity of barrier-free facilities, slope protection, etc. was in accordance with the requirements of stable traffic design. According to the design drawings, the road modeling results were inspected to realize the 3D road planning design integrating the road function and the geographical environment (see Figure 5). After the BIM modeling was completed, it was necessary to estimate the amount of concrete, the amount of steel, the amount of earthwork, and the amount of material involved in the design.

![Figure 5. BIM Design of urban roads](image)

According to IFC, the real 3D model and the BIM model are merged, and the 3D road planning and design results are finally obtained. In the final stages of design, It was checked that whether the road design coordinated with the surrounding environment from the driver’s perspective (see Figure 6), such as traffic safety check in accordance, and consideration of the human psychology in traffic on the way. Corrections were made for unreasonable factors after the macro and micro rationality check.
3.3 Conclusions

This case used BIM+GIS technology to realize the planning and design of urban roads under the guidance of “people-oriented” concept. The GIS technology is used to comprehensively analyze the surrounding environment to determine the line shape and location of the urban roads, and to check the rationality of road design from macro and micro perspectives. There are many factors to be considered in the planning and design of urban roads. It is necessary to consider not only the natural environmental factors such as topography and landform, but also the factors such as economy and quality. It is worth noting that in the process of wider and deeper application of GIS+BIM mode, standards for data fusion still need to be further explored and standardized.

4. DISCUSSION

For BIM, it is gaining more and more favor. But in China, there is still not detailed data standard, causing it difficult to develop deeper-level application of BIM. More researches and energy need to put on BIM to make it a more mature technique to utilize.

As for the information techniques, it is not the point that which is better to choose. We should promote more researches on the integration of data from different sources for their complementary advantages. Specifically, it is meaningful to integrate photogrammetry with laser scanning, so as GIS with BIM. To integrate the microscopic advantages of BIM technology and the macroscopic advantages of GIS technology, it can not only satisfy the structure information management and geospatial information management to BIM, but also link BIM models to the real and physical world profile with the support of GIS.

What should be noticed about researches of the integration of GIS and BIM is that in China, most of the “GIS + BIM” researches are about applications in various fields, while theoretical investigations are relatively absent. This imbalance may block further development of applications with GIS + BIM mode.

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APPENDIX

<table>
<thead>
<tr>
<th>Time</th>
<th>National policies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov., 2003</td>
<td>BIM was first mentioned in the government document in which We demonstrated the application of BIM in engineering.</td>
</tr>
<tr>
<td>May., 2011</td>
<td>During the 12th Five-Year Plan period, we would accelerate the application of new technologies such as BIM in</td>
</tr>
</tbody>
</table>
engineering to achieve the universal application of the constructive enterprise information system.

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul., 2014</td>
<td>We would put emphasis on the application of information technology such as BIM in the whole process of engineering design, construction, operation and maintenance.</td>
</tr>
<tr>
<td>Jun., 2015</td>
<td>The specific objectives were clarified: by the end of 2020, the Grade A survey and design units of the construction industry, the construction enterprises of special grade and first-class housing construction projects should master and implement the integration of BIM and enterprise management systems and other information technologies; by the end of 2020, the ratio of the project with integration involving BIM would reach 90%.</td>
</tr>
<tr>
<td>Aug., 2016</td>
<td>We would focused on strengthening the integration capacity of multiple information technologies including BIM, big data, intelligence, mobile communications, cloud computing and Internet of Things, etc. Specially, BIM was the first mentioned among five information technologies.</td>
</tr>
<tr>
<td>Feb., 2017</td>
<td>We would accelerate the integrated application of BIM technology through the entire proceeding from planning, surveying, design, construction, operation and maintenance.</td>
</tr>
<tr>
<td>May, 2017</td>
<td>We drew up and completed the first BIM application standard in China’s construction engineering construction field, and implemented it on January 1st, 2018.</td>
</tr>
<tr>
<td>Mar., 2018</td>
<td>We would carry out the application demonstration of BIM in the prefabricated building, and actively applied BIM technology to urban governance and municipal infrastructure construction.</td>
</tr>
<tr>
<td>Mar., 2018</td>
<td>We needed to strengthen technological innovation in the construction industry with further applying the information technology in construction industry such as BIM.</td>
</tr>
<tr>
<td>Mar., 2018</td>
<td>It was put forward that the application of BIM in highway waterway engineering would be orderly promoted.</td>
</tr>
<tr>
<td>Jan., 2019</td>
<td>It was pointed out that we needed to promote steadily the application guide of BIM in urban rail transit engineering.</td>
</tr>
<tr>
<td>Mar., 2019</td>
<td>BIM engineer as a new occupation was defined explicitly by Human Resources and Social Security.</td>
</tr>
<tr>
<td>Apr., 2019</td>
<td>BIM was listed as one of the first batch of pilot technical indicators by Bureau of Education.</td>
</tr>
</tbody>
</table>

Table 1. The government policies involving BIM
INTEGRATION OF SAFETY ASSESSMENT IN BIM FOR TRANSPORTATION INFRASTRUCTURE

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KEY WORDS: Building information model, Road infrastructure, Road safety, Road safety inspection, Operation and Maintenance

ABSTRACT:

Effective and safe transportation infrastructure presents one of the crucial conditions for functional society. Its ceaseless development and construction can be taken as a proof of its importance even despite the corresponding financial and time demands. The complexity and scale of the projects related to transportation infrastructure presents an ideal field for implementation of the BIM approaches. However, it is necessary to implement the BIM to the whole life cycle of the transport structure, especially not only to the pre-investment and investment phases but also to the operation and maintenance. For every road infrastructure, it is important to observe the performance of the road, behaviour of road users and evaluate the resulting safety risks, to be able to correspond with adequate and effective measures and to secure sufficient level of safety. The paper aims to present an implementation of the road safety aspects and statistics into the processes of BIM applications and strategies, which are prepared on the base of Government Resolution No 958, on the importance of the Building Information Modelling (BIM) in the Czech Republic. The accident statistics, safety audits and inspections presents a valuable source of information that should be adequately implemented with the BIM processes.

1. INTRODUCTION

Transportation infrastructure presents a key role in social and economic development of all countries and applying new methods for improving their design and operation should be desired. While the implementation of building information modelling (BIM) has become a central topic to the improvement of the AECOO (Architecture, Engineering, Construction, Owner and Operator) industry around the world, the usage of BIM broaden and is nowadays applied to the civil infrastructure. However, the concept of BIM was initially designed for application in building sector. The transition has to overcome several limitations and adapt to slightly different environment and processes.

It is believed that the use of BIM in infrastructure is several years behind from its use for buildings, but evidence show that recently the use of BIM in civil infrastructure is steadily rising (Al-Mashta, Alkass, 2010). An increasing number of European governments and public sector agencies are setting up programmes to promote wider use of BIM at national and regional levels. Government policies and public procurement provide significant support to motivate positive changes in the sector. There is a significant growth in adoption of BIM for infrastructure since 2012 in Europe, and the rate of BIM implementation for infrastructure projects is steadily increasing (Gökçe et al., 2006). This article focuses mainly on the implementation of BIM in the Czech Republic. The Czech government is trying to follow the lead of other European countries and it is developing BIM strategies, which are prepared on the base of Government Resolution No 958, on the importance of the BIM in the Czech Republic (IEG BIM, 2017).

The development of standards and procedures is in its initial period and focuses mainly on the pre-investment and investment phases of the projects. However, based on the Government Resolution, after the year 2022 the BIM will be applied to whole life cycle of the assets. Therefore, it is necessary to focus on the remaining aspects of the building life cycle. The necessity is stressed by the fact, that in cases of road infrastructure, where are newly designed long-lived or even perpetual pavements, the operation phase is carried over long periods of time and is usually connected with significant costs and gradual development of the road itself (Ferne B., 2006). Furthermore, for road infrastructure it is important to observe the performance of the road, behaviour of road users and evaluate the resulting road safety risks, to be able to correspond with adequate and effective measures. The maintenance and operation phase of road life cycle involves not only slight changes in road equipment or gradual replacement of worn-out parts but also changes of the road spatial layout due to additional influences, e.g. identification of more suitable layout of intersections, introduction of new lanes to improve the resulting level of road safety, etc. Thus, the aim of this paper is to present an implementation of the road safety aspects and statistics into the processes of BIM applications and strategies to enable efficient and effective measures and to secure sufficient level of safety.

2. BIM FOR ROAD INFRASTRUCTURE

The implementation of BIM concept for civil infrastructure, especially road network, presents an expansion into domain where it was not originally conceived to address. The advantage
of use of BIM for road infrastructure, where the graphical designs are already widely used, lies mainly in coordination and visual integration of non-graphical data into the models. BIM models can store considerable amount of information through the life cycle of the infrastructure (See et al., 2012). As with any BIM approach, the effectiveness and usefulness of the data is dependent on the ability to specify what data should be collected, who will be responsible for their collection and how it will be utilised, along with the provision of technologies to capture and transfer the data between participating parties (Bradley et al., 2016).

Many common features are shared between buildings and transportation infrastructure from the perspective of BIM implementation. However, there are several differences in a way, how they are designed and subsequently managed.

In transport construction, interconnected line construction works are used, unlike in the case of building construction that are dominated by point structures located on a concentrated area with a more complex internal arrangement. An important specific aspect of transport structures is their spatial location and the need to manage information models as a complex geographic data. Spatially organized information is necessary in all phases – for planning, designing, constructing, operating, and maintaining of transportation facilities. It is important to understand how the components of a transportation facility are located in the real world or the proposed real world. The data, information, and knowledge have to be linked to specific locations and it is necessary to enable their efficient retrieval. While it is important that the model is sufficiently accurate and tied to a robust datum, it is also necessary to operate with adequate level of detail in correspondence to the phase of the project or level of project documentation. Furthermore, the structure and components of buildings differ from those used for road infrastructure facilities. Thus, there is a need for development of new representative terminology and its standardisation. However, the defining principles of BIM data management and exchange are still the same.

There is an increasing trend in publication of academic and non-academic papers or case studies that are focused on BIM for road infrastructure. (Bradley et al., 2016), (Cheng et. al., 2016) and (Costin et. al., 2018) made a comprehensive literature review of the use of BIM in transportation infrastructure. The reviews showed that most of the studies or researches dealing with road infrastructure are focused on use of BIM in the pre-investment and investment phases of the road life cycle.

It is generally accepted that the transportation infrastructure needs constant monitoring to remain at the acceptable operational and safety level and to enable informed decisions of the authorities or decision makers. BIM principles can be used for these purposes due to the collection of data throughout the life cycle of a structure. Robust data frame and database, prediction of future behaviour and needs of infrastructure used in BIM can be therefore a decisive factor in maintenance and management process. Yet, only a few of reviewed articles, e.g. (Pevret et. al., 2000), (Chen, Shirole, 2006), (Platt, 2007), (Vonderohe, Hinz, 2010), (Kubota, Mikami, 2013), (Reeder, Nelson 2015), (Elmabwry et al., 2016), (Shindo et al., 2016), deals with use of BIM during the maintenance and operational phase of road life cycle. Furthermore, none of these contributions proposes to gather and implement new type of information into the BIM model during these phases.

Similarly, as is accepted that the deviations and changes have to be incorporated into the resulting BIM model, otherwise its content is pointless for subsequent management and maintenance, the important information gathered throughout the operational phase, such as accidents statistics or safety measures, should be also incorporated into the model. If this demand is not feasible, the data should be at least highly compatible with the structure of BIM model to improve the efficiency of decision-making and further investments. Out of the reviewed publications and study cases, none of the contributions considered implementation of road safety data or accident information within the BIM model. This fact is rather surprising in comparison with current policies and increasing demands on the road safety worldwide.

### 2.1. BIM in the Czech Republic

In the Czech Republic, the Ministry of Transport of the Czech Republic (MOT) and its subordinate organizations, such as the Road and Motorway Directorate (RMD), are responsible for the construction, modernization and maintenance of the major transport infrastructures. The MOT is also responsible for introduction and revision of existing regulations in the field of transport infrastructure. These materials and their revisions, thus the revisions of the BIM requirements and the actual information models of buildings, are key to further implementation of necessary BIM methodology.

The BIM models started to be discussed more extensively in the Czech Republic in 2011 due to the activities of major design companies. In 2014, the European Union issued a reactive 2014/24/EU on public procurement, which allowed contracting authorities across Europe to request the use of BIM when awarding public contracts. In the Czech Republic, this idea was implemented through Act No 134/2016, on public procurement. This opened a door for the implementation of BIM for civil infrastructure in the Czech Republic.

The BIM implementation strategy is currently being elaborated on the basis of Government Resolution No 958, on the importance of the Building Information Modelling (BIM) method for building practice in the Czech Republic and the subsequent proposals for its implementation. The government also set year 2022 as a milestone. After 1.1.2022, it will be mandatory to use BIM for over-limit public contracts financed from public budget. The obligation will be not only for the documentation and construction phases but also during the initiation and definition of the projects. Furthermore, it is planned to require all newly acquired road passports after this date in accordance to current BIM practices (IEG BIM, 2017).

The strategy is proposed with an aim to mitigate current difficulties preventing the effective use of the BIM methods in the Czech Republic and is gradually being established.

### 2.2. Data transition in BIM processes

The technical heart of the BIM method is the Common Data Environment (CDE), which includes all the information. That is not only the 3D model and its non-geometric data, but also all other documents, communication between the project participants and their processes in the various phases of the building’s life cycle. However, based on the proposed methodology for selection of CDE, the RMD does not currently operate a sufficient solution and is only in initial phases of definition of requirements and expectations. Based on the
available information, the concentrated data on a low level of detail will be available for not only managerial information system, but also for the needs of data integration and data sources of affected applications, such as BIM, CDE, or third-party applications (SFTI Expert Executive Team for BIM, 2019).

As the Czech Republic is still in initial phases of implementation of BIM for road infrastructure, discussions on standardization format are also ongoing. In order to achieve interoperability based on public procurement a neutral and stable open data formats has to be used. It is planned to adopt the open Industry Foundation Classes (IFC) format as nationwide for the transmission of BIM models between individual actors in the transport infrastructure life cycle (IEG BIM, 2017). The IFC format is adopted in Czech Republic through the standard CSN EN ISO 16739: 2017. The standard is based on the international standard ISO 16739.

The new IFC 5.0 format version should incorporate definitions for road infrastructure. The 5.0 version is however still being discussed and exists only in form of draft. The current version IFC 4.2 version, have only limited or missing semantics for transportation infrastructure facilities. The semantics and definitions are in both versions mostly focused on the pre-investment and investment phase. Thus, similarly as it is the literature focus, it is entirely omitting the maintenance phase and potential inputs for road infrastructure acquired during its operation phase. This factor is crucial for further development of BIM models for transportation infrastructure. If the definition of BIM should be fulfilled, then the structure of the used CDE and data format should be able to incorporate additional information and data, which are acquired through reaming phases of the road life cycle. Important factor is however, the structure of these data and the possibility of their difference to the information used through planning and construction phases. (Eastmen, 2011)

### 3. ROAD SAFETY ASSESSMENT

Road safety is currently recognized by the WHO as a major global epidemic, and a large amount of research on road safety and safety data analysis is focused to mitigate its consequences, e.g. (Road Safety Manual, 2004), (Elvik et al., 2009), (Commandeur et al., 2013), (Dupont et al., 2014), (UNECE, 2018). However, the effectivity of proposed measures is ultimately decided by the underlying data. The main base for evaluation of the road safety presents the traffic accident data and statistics. Nevertheless, analysis of these data must be accompanied by examination of the characteristics of the road infrastructure to obtain reliable and effective measures. The resulting outcomes afterwards directly affect the road itself, either in change of the traffic organisation, road equipment or in overall reconstruction of specific parts of the road.

Currently, there are two main approaches aiming to increase the safety on roads. Reactive approach which relies on analyses of available accident data and proactive approach which relies on the analysis of physical and operational characteristics of existing roads or road projects to identify actual and future safety deficiencies (Road Safety Manual, 2004).

For the reactive approach, relevant and sufficient data are crucial. The data consists from actual traffic accidents statistics and traffic volumes on particular roads. In the Czech Republic, a web based GIS application Statistical Overview of the Road Traffic Accidents in the Selected Administrative Territorial Unit is commonly used for assessment. The application is operated on the GIS portal of MOT. It enables statistical analysis of the traffic accident rate in frame of the specified administrative unit by the selected criteria (period, type of the road traffic accident). The data are directly imported from the database of Police of the Czech Republic (PCR). Furthermore, every year statistical yearbook of accident rate on roads is published for presenting statistics from previous year by the PCR. The traffic volumes can be obtained through a national traffic census that is periodically updated every 5 years or automatic counters that are installed on highways. The resulting traffic volume data are accessible through web based GIS application and are administered by the RMD.

As the knowledge evolves, safety actions are becoming more proactive in their nature. Various types of proactive measures have been long included in the practices of road authorities. The main tools are Road Safety Audit (RSA), Road Safety Inspection (RSI) and Road Safety Impact Assessment (RSIA). Wider spread of proactive approach within European countries was introduced by EU Directive 2008/96/EC, which defines their mandatory use on the TEN-T network and recommends their application for the whole road network.

The RSA deals with the design characteristics of new or reconstructed road infrastructure projects and RSI and RSIA deals with existing roads. The purpose is to make new, reconstructed and existing roads as safe as possible before construction starts and/or accidents occur. Both road safety audit and inspection focus solely on road safety without regard for other possibly conflicting objectives (Elvik et. al, 2009). The main aim is to ensure adequate level of road safety and provide additional source of information for the road authorities and decision makers.

From the perspective of BIM model for road infrastructure, The RSA is performed during all design and construction stages – from planning to early operation of the project. The necessary information for the evaluation are the same as information and data that are used for planning and design. The results and findings can be distributed to required participants with use of existing CDE.

The RSI and the RSIA are performed during the maintenance and operational phase of the road life cycle. In case of functional and precise BIM model, the supplementary information necessary for the RSI and RSIA can be obtained from its current form. However, the findings and identified safety deficits, especially for longer sections of the road network, cannot be in current frame implemented in a suitable form and in correspondence to their spatial location. Traditional approach of paper form is in this case highly inefficient and decrease the potential usage of the acquired information. Faculty of Transportation Sciences at the Czech Technical University in Prague (FTS, CTU in Prague) in close cooperation with RMD had therefore developed an effective and easy to use application for these purposes in 2015.

### 3.1. CEBASS – RSI generated data

Department of Forensic Experts in transportation at the FTS, CTU in Prague developed in cooperation with RMD application that was subsequently named Central Register of Road Network Safety Analysis (CEBASS). It is a GIS application with web interface. The main aim was to develop a tool not only for the processing of data obtained during drive-through RSI,
but also for effective management of the information, e.g. for presentation of registered risks, their statistical evaluation or subsequent indication of elimination. Overall, the web application contains information about more than 10,000 traffic-safety defects on the Czech road network. The database covers almost 4,000 km and it is being used by the RMD for all performed RSI within the TEN-T network.

Figure 94. An illustrative example of identified safety deficit

Each record within the database represents an identified safety deficit and includes a standardized description, specification of the defect and its location, together with indication of the degree of severity and determination of the difficulty of implementing the proposed remediation measure. Specifications includes 14 main categories of the deficits that are further divided into more than 250 subcategories. Each record is accompanied by an illustrative photograph. Proposals for remediation measures conceptually outline for the road administrators how to achieve an adequate level of road safety in the area.

The application enables an effective control management due to intuitive and clear statistical evaluation. The road authority can use the graphical interface and possibilities to filter the identified deficits by their severity, type, proposed remedial measures or expected financial costs. Thus, it is enabled to perform an informed and effective prioritising and decision-making. The application also distinguishes several user roles that have different rights. For example, a selected professional public can only look at individual deficits sets. However, only responsible administrators can comment on the state of work.

4. IMPLEMENTATION OF ROAD SAFETY ASPECTS IN ROAD BIM MODELS

One of the differences between the road infrastructure and typical building is the requirement of adequate road safety for the road users. Even with application of complex technical standards, expert knowledge and modern approaches, the blackspots or locations with inadequate level of road safety may occur after the road is put into operation. Main reasons can be seen in the complexity and interconnection of various aspects during the road design and certain randomness in the behaviour of the road users (Elvik et. al, 2009). Thus, the current road safety practise is based on utilisation of the above-mentioned road safety approaches. Their aim is to identify the problematic or risky locations or design flaws, ideally proactively, and then implement proper countermeasures. It is one of the innate characteristic of roads and for successful and effective implementation of BIM on road infrastructure; the BIM model should be able to incorporate the necessary data and information. Due to the complexity of the safety assessment and wide range of information needed for accurate and precise analysis of traffic accidents or their causes, it is not possible or suitable to try to implement all the necessary data into the BIM of road infrastructures. However, one of the properties of BIM is that it can also be used as a repository for additional data, information, and knowledge that is generated during operation and maintenance. There are already examples of such principles in pavement management systems, bridge management systems, and similar knowledge bases (Jahren, 2015).

Desirable approach is to implement information that are closely connected to the road and its operation and ensure their compatibility with remaining information that are stored outside the BIM model. Traffic volumes identified on the road, identified deficiencies from RSI or RSIA or basic information about recorded accidents are examples of such data. Important factor is the necessity of geospatial reference of these data and their connection to already existing information within the database. The macroscopic tools, such as GIS applications managed by the MOT or RMD, should then aggregate this information from various projects or sources, similarly as the Statistical Overview of the Road Traffic Accidents in the Selected Administrative Territorial Unit or CEBASS application. The planned aggregation of several information sources in the CDE by RMD is in concord with the proposed solution.

(Bradley, 2016) identify the basic definitions that are necessary to properly and efficiently govern the information of a project as a need to define: data responsibility, data generator and data consumer. The proposed safety data, which should be incorporated into the BIM models of road infrastructure in Czech Republic, are mainly traffic volumes identified on the road, identified deficiencies from RSI or RSIA and basic information about recorded accidents. The overall responsibility of their acquisition and incorporation into the model is dependent on the data itself. The overall CDE and the projects of road infrastructures will be managed by RMD in future. Traffic volumes are detected with use of automatic counters that are administered by the road authority (RMD) or through a national traffic census. The contracting authority for the periodical census is also RMD. The RSI or RSIA are contracted through RMD and performed by certified safety auditors. Thus, the only data without direct connection to the RMD is information about traffic accidents. These data are currently acquired by the PCR and are already shared with the MOT, superior organisation of the RMD. The implementation of such data into the BIM model would lead to a higher value of non-graphical data, easier assessment of safety needs and improve the governance strategy of the road authorities.

5. CONCLUSIONS

Transportation infrastructure is an integral part of economic growth and social improvement of every country. Road infrastructures are connected with significant costs that
are related to its full life cycle. Thus, a significant effort is required to preserve and maintain the facility as an asset. The road infrastructure requires an efficient and tailored management for the whole system. Maintenance of adequate road safety level and elimination of potential risks for all road user presents a major problem of a nation’s transportation network. Traditional inspection and management systems are now inefficient due to extensive expansion of this network, fractured and mutually disparate information. Thus, there is an immediate need for shifting toward modern and automated management systems. Using BIM in correlation with emerging technologies for the management of infrastructure can help in more reliable, sustainable, and safer performance of the network while decreasing maintenance costs and risks.

While there are significant efforts for implementation of BIM models for road infrastructure, the implementation is mainly focused on the pre-investment and investment phase of the road life cycle. However, for every road infrastructure, it is important to observe the performance of the road, behaviour of road users and evaluate the resulting safety risk, to be able to correspond with adequate and effective measures and to secure sufficient level of safety. The paper discussed and proposed an implementation of the road safety aspects and statistics into the processes of BIM applications and strategies in the Czech Republic.

6. REFERENCES


Road Safety Manual, 2004; Recommendations from the World Road Association (PIARC), PIARC Technical Committee on Road Safety (C13).


Summary of LMTC Closed Session

During the International Workshop on 'Capacity building and Education Outreach in Advanced Geospatial Technologies and Land Management' held at Land Management Training Center (LMTC), Dhulikhel, Nepal on 10-11 Dec 2019, keynote speakers and professors had discussion with senior management team of LMTC in a closed session to explore the possibility of collaboration. Ganesh Prasad Bhatta, Executive Director of LMTC, moderated the closed session and presented introduction of LMTC, courses offered at LMTC, challenges and future plans of LMTC. The major points raised during the closed meeting conducted on 11 Dec 2019 are mentioned here:

1. **Prof. Dr. J.A. Zevenbergen, Faculty ITC, University of Twente, The Netherlands**
   - Collaboration with private sector as well as national and international forum.
   - Build strong International Network as well as regional network like in Africa.
   - Training of Trainers (TOT) needed for effective training.
   - Explore the possibility of Tailor Made Training (TMT) support from abroad.
   - Scholarship at Faculty ITC (Joint agreement).
   - Explore the opportunities of training in German.
   - Internship at national and international organizations such as UN-HABITAT.
   - Get exposed with international activities.
   - You need to be trained with new tools and translate the tools in the context of your country.
   - Should introduce e-learning.
   - Idea of impact assessment of government policies is good and should be continued.

2. **Prof. Dr. Ruizhi CHEN, Wuhan University, China**
   - Appreciated the identification of challenges.
   - High level academicians are required at LMTC to conduct policy research.
   - Need of PhD people in this sector of Geoinformation.
   - Conduction of workshop is very good to gather knowledge on what others are doing worldwide and should continue conducting conferences in future.
   - Use of Local resources for training.
   - Changing technology day to day so it is required to update Curriculum incorporating the technological change.
   - Provision for Survey License is necessary. Course for upgrade at least in 3 years.
   - Use Exchange opportunity to go abroad for acquiring knowledge.
   - Acquire knowledge of new technology.
   - Collaboration with National and International Society.
   - Can collaborate in Citizen Science.
   - Use China scholarship program at Wuhan University and other University.
   - Participate in 2 weeks long international summer school held in July at Wuhan University related to positioning, GIS and remote sensing and tourist courses may be useful as refreshment courses.
3. Dr. Sultan Kocaman, Department of Geomatics Engineering, Hacettepe University, Ankara, Turkey
   • Challenges that you are facing are not only for you. Its similar cases elsewhere as well.
   • Need of research in Geospatial domain.
   • Every country has own issues. Should concentrate on own issues for research.
   • Education free in Turkey. May grab this opportunities for further undergraduate, graduate and PhD studies.
   • Possible to collaborate in land management sector with Turkish University.
   • Co-supervision of thesis from Hacettepe University.
   • Possibility of getting funds for research Turkish National Science Foundation.
   • Focus on remote sensing, photogrammetry, GIS and geodesy.
   • Hacettepe University has project and research collaboration with several government agencies for Land Management and Urban Development.
   • Students from Government employees bring in domain knowledge and University adds technological knowledge
   • ISPRS provides travel support to attend conference.
   • Curriculum development and revision continuously by analyzing with regards to country specific needs.
   • Contact Land Registry and Cadastral Organization of Turkey for mapping, cadastral services and land management research like the one they have running project in Afghanistan and Uzbekistan.
   • Looking at the topography of Nepal, focus should be on remote sensing and UAV photogrammetry.

4. Prof. Candan Gokceoglu, Dean Hacettepe University, Ankara, Turkey
   • Very good summary of LMTC.
   • Focus on Research and Development especially developing countries.
   • Technology transfer is very important as the technologies are changing very fast.
   • Use e-learning and remote education as they are cheap to learn and great means for technology transfer by development of competent human resources.
   • Hacettepe University is open to collaboration with LMTC.

5. Prof. Dr. Kevin McDougall, University of Southern Queensland, Australia
   • LMTC, together with the government and partnership with universities, should look at its new vision on where does want to be in future and its priorities. Then, refocus and review roles of each of them.
   • Professional practice year after degree for obtaining real world professional experiences.
   • Prioritize research area in line with government’s vision that can be collaborated.
   • Revision of Land Management training and academic courses.
   • Income generation by conducting private sector training for strengthening LMTC.
   • PhD support is necessary from national and international universities.
   • University of Southern Queensland can collaborate in research with LMTC in areas that benefit Nepal.
• Integrated course of University and Training Center may be useful for capacity development.
• Staffs and students from Australia can work with staffs and students of LMTC in projects such that they can gain skills from each other and develop better understanding if issues and challenges.

6. **Dr. Devraj Pyaudel, University of Southern Queensland, Australia**
   • Congratulations for organizing this event.
   • LMTC already has strong collaboration with Kathmandu university
   • University of Southern Queensland is number Online Education provider in Australia. May be LMTC staffs and students can explore and enroll in those courses.
   • Possibility of PhD in Queensland University
   • Develop curriculum that matches the international standards like of Australian universities such that the courses provided here is easily accredited, graduates get recruited and obtain graduate studies opportunities in Australia.
   • Work together
   • Colombo plan may be useful for further studies.
   • Joint supervision of PhD research with LMTC/KU.
   • LMTC can provide energizing and urgent topics on issues that are to be solved in Nepal to develop projects that can be worked on together at University of Southern Queensland.

7. **Dr. Subash Ghimire, Department of Geomatics Engineering, Kathmandu University, Nepal**
   • Students and Faculty exchange is major tool for knowledge sharing.
   • Common area for collaboration with national and international organization.
   • Ready to support in research

8. **Janak Raj Joshi, Joint Secretary, Ministry of Land Management, Cooperatives and Poverty Alleviation**
   • Thanked the eagerness of renowned and reputed International Universities to support LMTC for its capacity building and collaboration.
   • Government of Nepal (GoN) is in verse of transfer of technology. New initiatives adopted by Government of Nepal to harness modern Geoinformation Technologies. This demands quite large number of trainings.
   • Two departments namely Survey Department and Department of Land Management and Archive (DoLMA), under the Ministry Land Management, Cooperatives and Poverty Alleviation are working in the field of Surveying and Mapping, Geoinformation, Land Administration and Management.
   • Survey Department has over 6000+ surveying and mapping professionals graduated and trained in some sort of training courses, still they require some sort of inservice and skill upgrade trainings on modern geoinformation technologies and adopt them for service delivery.
   • Employees and professionals working at DoLMA come from various academic fields, not only Geoinformation, Land Administration and Management, but also from general administration background. To make them capable to deliver effective and efficient land
administration and management services various inservice training, skill updating training, refresher courses and tailor made trainings are required.

- Nepal has three levels of government—1 federal, 7 provincial governments and 753 local governments. They all deal with land related activities in one or the other way. All levels of government require qualified human resources based on the nature of work i.e. federal government might require highly skilled academic work force whereas local governments may need just tailor made trainings with skills like go to field and collect data using handheld GPS, delineate area using satellite images. This call for development and capacity building of human resources through large number of trainings per year. LMTC, being at receiving end, seeks support and collaboration for short term trainings, skill updating training, refresher courses, tailor made trainings and research from prestigious International Universities.

**Conclusion:**

Based on the aforementioned summary, LMTC will carry out the further processing for possible collaboration with National and International Universities. Hopefully there is possibility of bilateral MoU for faculty and Student exchange. LMTC will start research work in collaboration with Universities on Issues of Land Administration and Management.