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Visit http://www.lmtc.gov.np for online manuscript preparation and submission guidelines. Contribution of original unpublished research, review articles, scholarly essays are welcome. The articles will be published only after peer review.

Cover Page

Virtual classroom of two week basic GIS training conducted by Land Management Training Center. Despite the global pandemic situation of COVID 19, the photograph reflects the dedication of the center in sturdy continuity of long term and short term training, conducted as per approved fiscal plan of the organization.

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EDITORIAL

It gives me and my team immense pleasure to present you the third issue of 'Journal of Land Management and Geomatics Education'. For an academic institution like Land Management Training Center which is continuously focusing on imparting the knowledge of geoinformation in Nepal through various educational activities, this journal plays a significant role. It's a big part of our institution that, we believe, will help the readers to gain some perspectives about geomatics field and enhance their knowledge on the domain to a great extent. For this purpose, we have been very conscious about improving the content and quality of this volume. We have requested and included articles from wide range of theme such as environment, glacier, disaster management, land administration and diverse topics such as Remote Sensing, Geographic Information System, Surveying and Mapping, etc. In addition, special effort has been given by our team of guest editors for maintaining the standard of those articles.

The major highlights of this journal are the uses of remote sensing, GIS or machine learning techniques for studying and analyzing, forest encroachment, landslides, route planing and precipitation. Also, an analysis assessing the status of land tenure system of Nepal is also included.

Getting the journal published was not an easy journey. Therefore, I would like to express my sincere gratitude to all those direct and indirect helping hands that made this attempt possible. On behalf of editorial committee, I would kindly like to thank the authors for their contribution on this issue. Similarly, I am very grateful to the advisory committee for their kind suggestions, our guest editors for their valuable edits and the editorial team for their constant dedication and effort. Lastly, I express my warm regards to all our readers for being big source of motivation for us to publish this great piece of knowledge.

We will be back again with the next issue of this journal in the upcoming year!

A big congratulations to our institution in its 53rd academic year!

Thank you!

Ramesh Gyawali

Editor in Chief

July, 2021

Executive Director's Message

It gives me immense pleasure to present the third issue of the "Journal of Land Management and Geomatic Education" on the auspicious occasion of the 53rd Anniversary of the Land Management Training Center (LMTC). Let me take this opportunity to congratulate entire LMTC family, who are associated with this glorious institution in a way or another, and extend heartiest thankfulness to those who have contributed to bring LMTC to the present height.

Personally, this is my second term in this capacity in between the two consecutive issues of this journal, and I feel proud to have this opportunity. In the second issues of the journal, I presented our outstanding achievements made through innovative works, and it is worth to mention that we walked through the same spirit over the year to witness the achievements of even higher level, despite the impact of global pandemic of COVID-19.

I feel it is quite relevant to mention, how we are coping with the pandemic to run the training courses at LMTC. It is well known fact that the COVID-19 pandemic has brought unprecedented challenges to the entire system of human activities globally. No sector left unaffected and similar is the case for LMTC. It was the fourth week of March, 2020, when the Government of Nepal announced nationwide lockdown. About 200 participants of the different training courses, who were about to complete their courses were affected with the lockdown. In the meantime, the management team of LMTC put forwarded the idea of adopting virtual classroom option for the completing the courses, and launched the its first virtual class on the 2nd April 2020, just in 10 days of lockdown, with the approval from the Ministry of Land Management, Cooperatives and Poverty Alleviation. Unfortunately, the COVID-19 situation kept on degrading and no one could predict the date for the country to come back in normal situation. Therefore, the LMTC continued adopting the virtual classroom method even to run new batches of different training courses and the situation is still going with the same approach. We proudly claim that LMTC is the first academic institution of its kind to adopt the virtual classroom, and we are determined and trying our best to maintain the quality of our trainings. We could not complete our commitment of celebrating the year 2020 as "Visit LMTC 2020". At the same time, we have realized that it is quite difficult to run the field based practical courses in the virtual environment.

There have been remarkable additions to the infrastructure at LMTC over the past two years. The process of acquiring additional land of area around 3,500 sq. meter (7 ropanies) has been completed after a struggle of more than 4 years. The boys' hostel, with a capacity of 48 twin beds, has got renovated after a wait of long 5 years. The digital infrastructure is developed more than ever. Survey Museum has been established in the training building in order to keep the history of surveying and mapping education in Nepal alive.

The LMTC is determined to keep improving the quality of education. Our courses are delivered by passionate and dedicated faculties/trainers, who possess wealth of national and international expertise, and high qualification obtained from renowned national and international universities. It is so encouraging that young and energetic officers are highly motivated and attracted to join this institution. One of the strongest part of LMTC is that current workforce is strong enough to conduct any kind of training courses in the field of Geomatics and land administration and management.

Let me reiterate our commitment to cultivate this Journal in such a way that it creates its own space as a standard scientific Journal published in Nepal. Despite various shortcomings, we are committed to keep our dedication and hard work to make this journal as a 'journal of interest' for the professionals and academicians of land management and geomatics domain. The glory of this journal is that all the papers are double blinded peer reviewed by the leading Geomatics academicians and professionals from Nepal including Mr. Janak Raj Joshi, Dr. Jagannath Aryal, Dr. Dev Raj Paudyal, Dr. Arun Kumar Pratihast, Dr. Subash Ghimire, Dr. Reshma Shrestha and Mr. Uma Shankar Panday, as the Guest Editors of the Journal. The Guest Editors have contributed immensely not only by reviewing the papers but also by providing precious in inputs to improve its quality.

I would like to express my sincere appreciation to the fellow colleagues, the members of Advisory Committee, and the Editorial Committee for their invaluable contribution in bringing out this issue. More importantly, I extend my sincere gratitude to all the Guest Editors for their invaluable efforts on reviewing the papers and guiding us to improve the quality of the Journal. I would like to thank all the authors for their resourceful professional contribution. I am confident that such a support and professional contribution will be continued in the upcoming issues too.

Finally, let me extend special thanks to Mr. Ramesh Gyawali for facilitating the overall process of this publication, Er. Sharad Chandra Mainali for his tireless efforts to bring the Journal in stipulated time. I must say, we are still starving of quality papers. I, once again, encourage my fellow colleagues from the Centre as well as the professionals of Land Management and Geomatics to contribute to the journal by providing quality articles in the future.

We expect your critical feedback on our endeavor.

Wishing you

Ganesh Prasad Bhatta
Executive Director
Land Management Training Center
July, 2021

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Original Articles

ENCROACHMENT OF FOREST COVER IN CHITWAN AND PARSHA DISTRICTS OF NEPAL: A SPATIOTEMPORAL QUANTIFICATION OVER 25 YEARS

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ABSTRACT

Forest mapping is necessary for its protection, conservation, resource analysis, policymaking, decision making, and climate change research. This study covers the application of Google Earth Engine (GEE), analysis of Landsat data, and use of machine learning algorithm (Random forest classifier) for forest mapping of Chitwan and Parsha district of Nepal. The forest of Nepal has encountered various changes due to natural and anthropogenic activities such as deforestation, forest fire, drought, landslide, urbanization, etc. So, it is necessary to track that kind of change to help to improve the policy and decision-making. First, GEE was used to download atmospherically corrected, cloud-free satellite images composite from 1995-2020. ArcGIS was used to collect reference data using the images downloaded via GEE. Normalized Difference Vegetation Index and slope and elevation data from shuttle radar topography mission (SRTM) were combined and supervised classification was performed using a random forest classifier. The model performed well with an overall accuracy of 0.99 for 1995 and 2020, 0.98 for 2000, 2005 and 2010 and 1 for 2015. After classification, change detection and accuracy assessment were done using the maps and quantitative data obtained from classification. The result showed that most of the forest in the northern part of our study area was converted into a settlement. There was less change in the forest due to strict rules and regulations in the southern part which consists of Chitwan National Park and a part of Parsha Wildlife Reserve. This study will help to implement a strong policy for management and decision making for the welfare of the forest.

KEY WORDS

Forest, Google Earth Engine, Random Forest Classifier, Machine Learning, Encroachment, Landsat

INTRODUCTION

Forest contributes a lot to the species on earth. We use forests directly to survive from the air we breathe to the wood we use. Moreover, the forest provides shelter for human and wild species, also watersheds are protected, soil erosion is prevented and climate change is mitigated by forest (WWF, 2021). So, the conservation of forests is mandatory for our survival.

Nepal is rich in natural resources and they are changing with human impact over time (Wagle and Acharya, 2020). Forest being one major resource there is a saying called “Hario Ban Nepal Ko Dhan” i.e., Nepal’s wealth is a green forest. But, nowadays the quantity of forest is decreasing day by day due to an increase in population, forest fire, using fuelwood as the main source of energy, unmanaged urbanization, illegal timber harvesting, development activities, tourism and trekking, political and non-political use and misuse of forest etc. (Adhikari, 2018).

This loss in the quantity of forest has a direct impact on humans, wild species as well as the environment and causes climate change, landslide, soil-erosion, flood etc. Characterizing and mapping forest cover is essential for planning and managing natural forest resources (e.g., conservation, and/or development). Detecting changes in the forest via satellite observations has a long tradition, beginning with Landsat satellites in the 1980s and 1990s. Satellite remote sensing provides a viable means for identifying, mapping, assessing, and monitoring forest cover at a range of spatial and temporal scales. Remote sensors offer a quick and low-cost way to map thousands of acres per day to monitor deforestation, logging, and other disturbances, as well as the recovery of forests (Acharya et al., 2019; Acharya and Lee, 2019).

Meanwhile, repeated and consistent observations from satellites allow us to investigate the local effects of forests from a global perspective at high resolution, which can improve our understanding of forestry policy outcomes (Adhikari, 2018).

The recent effort of updating the topographic map in Nepal is a bit show and consumes quite a time (Dhungana et al., 2021).

Due to advancements in Remote Sensing (RS) technology, techniques and platforms, this technology has been used for mapping the diversity of land cover variables for a long time (Acharya and Lee, 2019; Acharya et al., 2018; Lee et al., 2018). Remote sensing technology is a valuable technique to map forests as it provides high spatial resolution, more frequent coverage and increased spectral information required for analysis. It is a low-cost mechanism for forest mapping (Calders et al., 2020). Landsat study is the project initiated by the United States Geological Survey (USGS) with the motive of conducting a study to investigate the users, uses and benefits of Landsat imagery. Landsat offers high enough spatial resolution and a large enough footprint for cost-efficient large-scale forest cover change monitoring. The Landsat satellite imagery is made freely available by the USGS to download via the internet(USGS, 2020a). In this paper, we use Landsat imagery having a spatial resolution of 30m. So, we can easily detect forest changes using this data.

In previous studies, forest mapping was done using traditional approaches (Bolyn et al., 2018). Downloading the satellite imagery and classification and analysis was a very tedious task and in such a case, Google Earth Engine (GEE) makes it easy to use pre-processed Landsat imagery from 1995-2020, classify and analyse them (Wagle et al., 2020a). GEE is cloud-based geospatial processing and analysing platform for executing large scale data analysis. It reduces the need for large space to store data, high processing power and has interactive development platforms (Wagle et al., 2020a). This study answers the question that how we can analyse and manage data in less time, limited processing resources and storage available.

Machine learning type classifier like artificial neural networks (NN), support vector machine (SVM), random forest classifiers uses a large set of training data, we can achieve higher mapping accuracy in comparison to conventional classifiers (Rodriguez-Galiano et al., 2012; Wagle et al., 2020b, 2020a). The main objective of this study is to find the area with maximum forest loss and the reason behind the loss. And the secondary objective is to use a machine learning algorithm (random forest classifier) in the google earth engine to classify and analyse multi-temporal Landsat satellite imagery.

1.1 METHODOLOGY

Study Area

The study area is focused on the Chitwan and Parsha Districts of Nepal. These two districts are selected because those districts consist of Chitwan national park, a part of Parsha wildlife reserve and part of the densest forest of Nepal i.e., Char Kose Jhadi and depletion of such type of forest is increasing day by day. The study area has an estimated area of 36600 ha and is geographically between 26°97⍰-26°97⍰ latitude and 83°91⍰-84°98⍰ longitude. Climate is tropical monsoon with high humidity throughout the year. The vegetation is Sal (*Shorea robusta*) forest, riverine forest Sal with Chir Pine (*Pinus roxburghii*). These parks are especially renowned for the protection of One Horned Rhinoceros, Royal Bengal Tiger and Gharial Crocodile. The topography of the study area is an undulating upland consisting of a Chure Range connected to lowland areas called Terai.

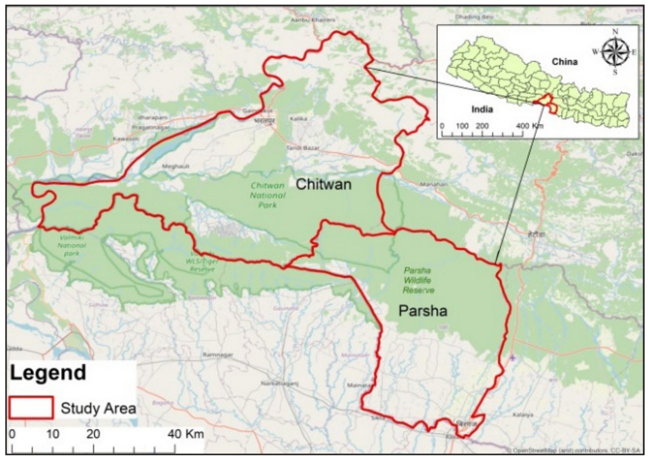
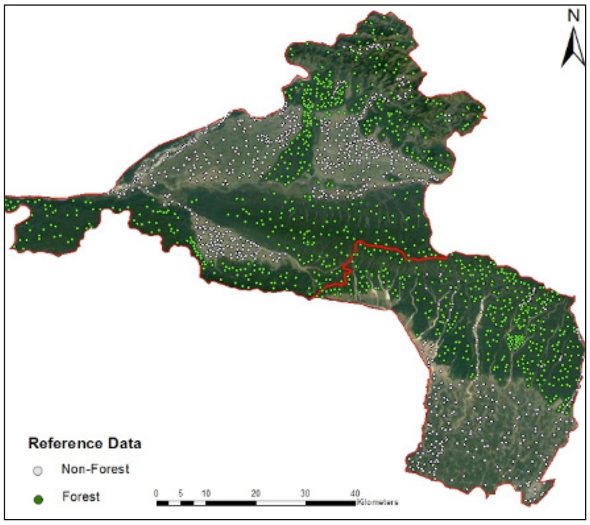


Fig 1. The geographic location of the study area (Chitwan and Parsha district, Nepal).

1.2 DATA COLLECTION

The Landsat satellite images were downloaded using Google Earth Engine. Landsat, which is a mutual program of USGS and NASA, is the satellite observing the earth continuously from 1972 till today. It takes satellite images of 30- meter resolution once every 15 days. USGS produces data in three tiers for each satellite (Acharya and Yang, 2015; USGS, 2020b). Tier 1 is the data that fulfils geometric and radiometric quality requirements. Tier 2 is the data that does not fulfil Tier 1 requirements. And, Real-Time data has not been evaluated yet. In this paper, we used satellite images of USGS Landsat 5 Surface Reflectance Tier 1 which is atmospherically corrected surface reflectance using an ETM sensor. Images from this dataset contain four visible and near-infrared (VNIR) bands and two short-wave (SWIR) bands which are processed to orthorectified surface reflectance and one thermal infrared (TIR) band processed to orthorectified brightness temperature. Cloud, shadow and snow were masked using CFMASK and atmospherically corrected using LEAPS (USGS, 2020c). Also, we are using atmospherically corrected surface reflectance from Landsat 8 OLI/TIRS sensors which contain five VNIR bands and two SWIR bands that are processed to orthorectified surface reflectance, and two TIR bands to ortho-rectified brightness temperature (USGS, 2020d). Moreover, the slope from the shuttle radar topography mission (SRTM) is used to support the classification process. Also, Normalized Vegetation Index (NDVI) which is the difference between the NIR band and the red band, was used to produce classified maps. As it is sensitive to vegetation it helped us to classify images accurately.

(a)



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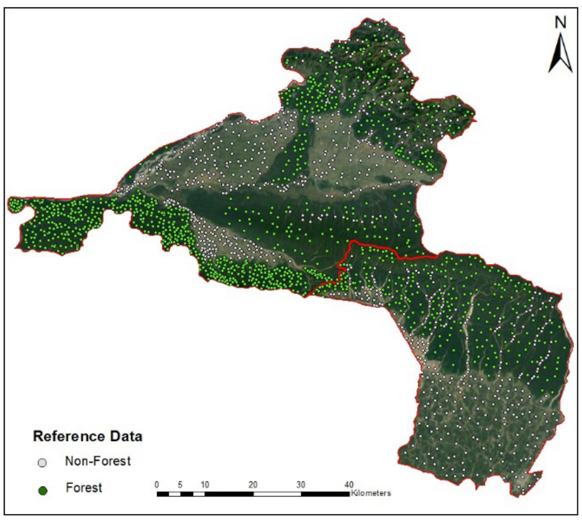

Fig 2: Distribution of training samples a) for the year 1995; b) for the year 2015.

1.3 REFERENCE DATA

After selecting the study area reference data of pure pixels were taken to minimize classification error and maximize the classification accuracy. For this study, we used a total of 1617 and 1907 sample points (forest and non-forest) for the years 1995 and 2020 respectively. Those given reference data were roughly divided into 70% training set and 30% testing set. We reserved testing data to avoid overfitting the model.

1.4 IMAGE CLASSIFICATION

A random forest (RF) is a supervised machine learning algorithm mainly used for classification and regression problems. RF classifier contains various decision trees and takes the average of multiple subsets of a given dataset to improve the prediction accuracy of that dataset. RF does not depend on one decision tree; it takes the prediction from each tree and predicts the final output according to the majority of no given dataset. RF classifiers can handle high data dimensionality and multi-co-linearity without affecting the processing speed and sensitivity due to overfitting (Breiman, 2001). We used a random forest classifier in this study because among all classification algorithms random forest provides the highest accuracy. The image classification was done in the GEE platform. The code can be found in https://code.earthengine.google.com /7271f5ed5269cec60f6f45dc70d0ad01

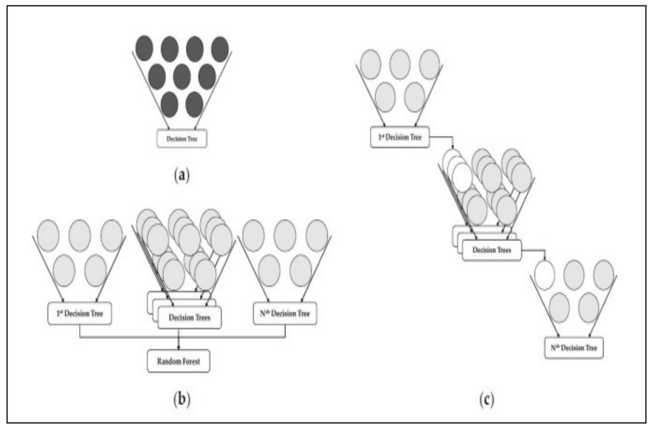

Fig 3: Representation of models adopted from (Wagle et al., 2020a).
(a) The single tree out of all samples; (b) Bagging grows tree parallel with subsamples.

RESULT AND DISCUSSION

Google earth engine was used to download and classify satellite imagery. The reference data were taken using the images of 1995 and 2015. Two different reference data were used because we used the images from Landsat 5 till 2010 and Landsat 8 afterwards. We used SRTM DEM to increase the accuracy of classification because the working site contains plain area as well as Chure Hills. We used a cloud mask to remove the cloud cover from the images. We used the Normalized Difference Vegetation Index (NDVI) as it represents forest cover in the best way. Binary classification of forest and non-forest was done using a random forest classifier. Figure 5 shows the results of image classification. We used mode as a morphological operation and obtained the cloud and salt and pepper effect the free image for the year 1995-2020.

In this study, accuracy assessment was done by calculating overall accuracy, Kappa coefficient and F1 score from the reports of a confusion matrix for all the points which were used for validation of data. Overall accuracy is one of the parameters to rate the efficiency of classification models and is calculated by dividing the total number of correctly predicted samples by the total no of testing samples (Machine Learning Crash Course, 2020). The kappa coefficient quantifies the agreement between the classification and truth values. Kappa values of 0 and 1 represent no agreement and perfect agreement respectively (L3HARRIS, 2019). F1 score is the way of combining the precision and recall of classification models. It is commonly used for evaluating various machine learning models (Sasaki, 2015; Sasaki and Fellow, 2007). Table 1 shows the overall accuracy, kappa coefficient and F1 score of the classification model from the year 1995-2020.

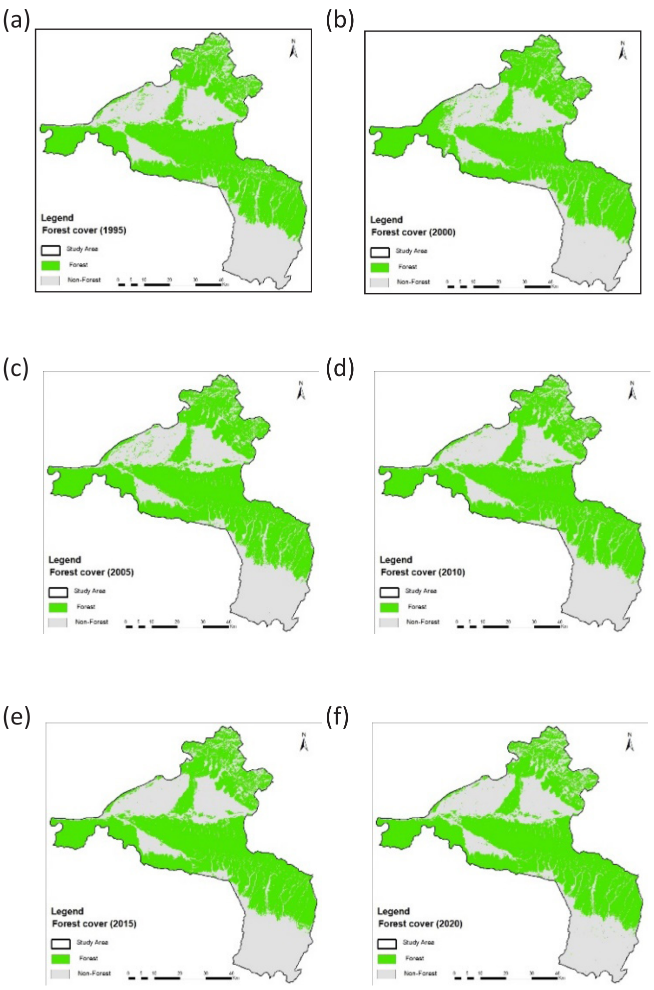

Fig 4: a) Classified image of 1995; b) Classified image of 2000; c) Classified image of 2005; d) Classified image of 2010; e) Classified image of 2015; f) Classified image of 2020.

Year	Overall Accuracy	Kappa Coefficient	F1 Score
1995	0.99	0.98	0.98
2000	0.98	0.97	0.98
2005	0.98	0.97	0.98
2010	0.98	0.96	0.98
2015	1	0.99	1
2020	0.99	0.99	0.99

Table 1. Values of overall accuracy, kappa coefficient and F1 score of all years.

After accuracy assessment, change in forest cover was measured by comparing the classified image of 1995 and 2020. We used ArcGIS software to map the change and it is represented in Figure 5. From Figure 6 we can see that overall deforestation is higher than afforestation. The main reason for deforestation in terai is forest fire. Forest fire frequently occurs due to human and natural causes.

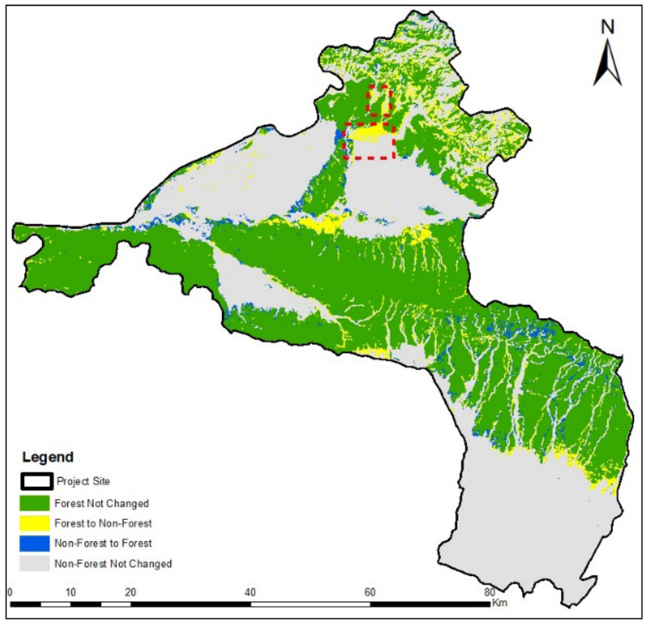

Fig 5. Forest cover change map in the years 1995 and 2020.

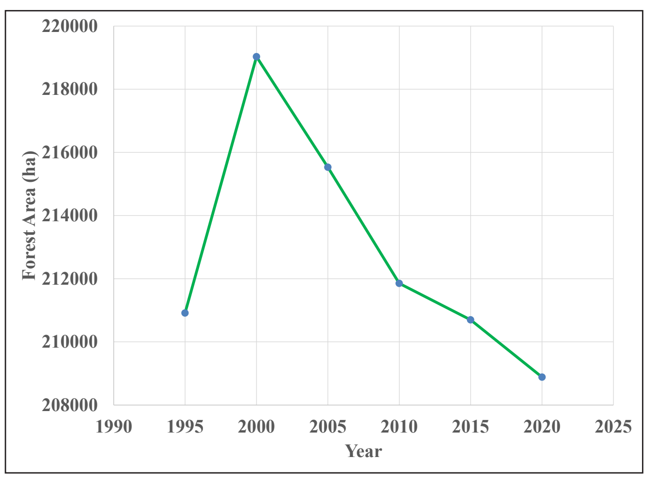

Fig 6: Graph showing the change in Forest area over time.

Land Cover Change	Producer's Accuracy	User's Accuracy
Non-Forest to Forest	0.55	0.50
Forest not Changed	1.00	0.97
Forest to Non Forest	0.82	0.88
Non Forest not Changed	0.99	1.00

Table 2. Producers and Users accuracy of four classes of a change map.

The overall accuracy of the change map was 0.93 and Kappa Coefficient was 0.89. Producer's and user's accuracy for all classes of change maps were calculated. The producer's accuracy represents the probability that a reference sample is correctly identified in the classification map and users accuracy represents the probability that a pixel classified into a given category represents that category on the ground. Table 2 shows the producers accuracy and consumers accuracy of the change map.

Availability of ready to use datasets in the GEE repository made it very easy to download the satellite imageries and compute the result in resources with low processing power and less space available. Due to this feature, traditional map-making methods are decreasing in use day by day. In this study, forest cover mapping, change detection in the forest, the use of effective tools and the reason for forest cover change are presented effectively. During this study, good accuracy for forest and non-forest classification and a reasonable outcome was obtained. Overall accuracy for all the classification results was obtained over a 95% confidence interval using a random forest classifier. We used the data from 1995 to 2020. So, we can conclude that GEE can be the best platform for land cover mapping in a large area in terms of accuracy, data availability and processing cost.

The change in the land cover map from 1995 and 2020 shows that 19711.88 ha of forest was converted into non-forest. Most of the forest loss is in the northern part which consists of Chure Range. It may be due to the lack of strict rules and regulations by the government. The following figure 7 shows the areas which are converted from forest to settlements. As the population is increasing people are destroying the forest for settlement, cultivation, livestock grazing, etc. The forest in the southern part of the study area is not much changed. As the southern part consists of a national park and wildlife reserve. So, the forest is constant may be due to strict rules and regulations and penalties for the poachers by the government. As the restriction starts from the buffer zone of the national park, there is no way to reach inside the reserved areas. In contrast to this, in some places, the forest cover has increased over time. This is due to the concept of community forest(Joshi, 2003). People are migrating from villages into city areas due to this, cultivable land is converting into barren land and gradually into forests (Nath Gartaula and Niehof, 2013). Apart from this, the main reason for forest gain is the implementation of forest protection programmes, state initiatives to protect the forest, forestation programs by the public and recovery from a forest fire (Rashtriya Samachar Samiti, 2016).

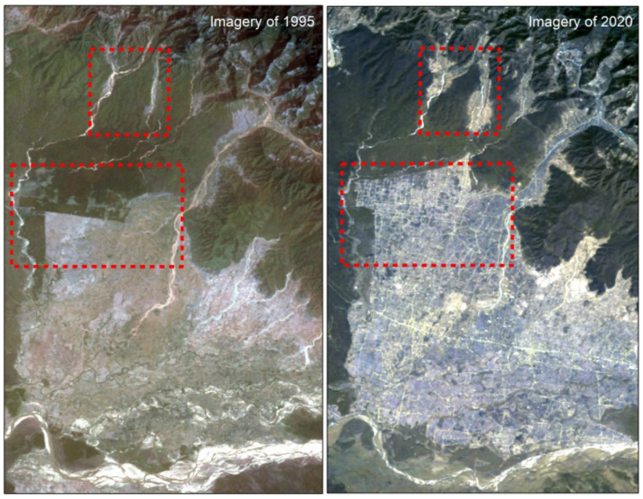

Fig 7: Map showing the land cover of the same place in 1995 and 2020.

From the map in Figure 7, we can conclude that if strict rules and regulations are not implemented by concerned authorities regarding the conservation of forest, in a few years most of the forest will be converted into non-forest land cover. Due to these natural causes like a heavy flood, degradation of the watershed, lowering groundwater etc. are occurring continuously (Pokhrel, 2013). We can compare the forest cover change in the southern part as negligible due to strict rules and regulations in the forest, whereas in the northern Chure Range the forest is decreasing rapidly. So, if any strict policy and awareness are not implemented as soon as possible, there may be a time soon that the whole forest will be converted into non-forest(Stapp et al., 2015). Overall, due to forest loss air pollution has increased because the forest takes CO2 and due to reasons such as forest fire CO2 emission has increased but the amount of forest to take this emission has decreased rapidly (Hengaju and Manandhar, 2015).

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ASSESSING THE STATUS OF LAND TENURE SYSTEM OF NEPAL USING SWOT MATRIX METHOD

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ABSTRACT

Land tenure as a dynamic institution is defined differently way by diverse community; either by written or unwritten law. Land tenure as a function of its elements needs to be analyzed. Since land tenure has direct impact on poverty eradication and enhancement of agricultural production, the tenure needs to be secured. In this paper, the current land tenure security of Nepal based on the legal framework is analyzed. The main objective of this paper is to critically evaluate the current land tenure system of Nepal and suggest strategies towards strengthening the tenure security. In this paper, the current scenario is analyzed using SWOT analysis. Existing legal frameworks and available articles related to tenure security are taken into account for analysis. Major components that have direct impact on tenure are discussed. SWOT matrix is developed to explore the possible strategic implications. In Nepal, Land tenure for (rural) poor is less secured in comparison with urban and overall tenure security is satisfactory with respect to other developing countries. The situation can be enhanced by introducing inclusive land administration tools and increasing transparency and accountability of land administration organizations. This paper analyzes the current land tenure security and suggests with the potentials strategies for securing the land tenure of Nepal.

KEY WORDS

land tenure, security, land registry, cadastre, land transaction, land administration

1. INTRODUCTION

Land tenure defines how a land owner is freely practicing his/her land. Land tenure security, in some manner, existed without land registration and cadastral survey in old age (Acharya, 2008). Around the 1250s, during the Lichchhabi regime, the land was recorded using local area measurement units called *Panchali*. Progressively, the measurement units were modified with change in rural or the king. In 1900s AD, prime minister Bir Samser introduced a mathematical unit of area measurement as a *Ropani* system (1 *Ropani* = 508.74 m^2.) which is still adopted. Later, First World War returned Nepali army personnel introduced compass and chains for land survey and cadastral mapping (Survey Department 2015).

Survey Department under the Ministry of Finance was established in 1975 (Survey Department, 2015). The main activities assigned to this department was to prepare a cadastral map of the whole country for the purpose of taxation. Legal framework for this cadastral survey and mapping was *Land (Survey and Measurement) Act 1963*. Till 2001, out of 75 districts - 38 districts were mapped and recorded using local control networks *i.e.* free-sheets and 37 with national geodetic control points (trig-sheets). The government also started its activities for registering the land in the name of peasants or land owner (Survey Department, 2015). This cadastral surveying along with its objective to record land for taxation was also able to register bundles of rights to land and distributed land ownership certificate to respective land owners or/and peasants. Along with, individuals were provided with land ownership certificate which is perceived as "land guarantee paper" granted by the state.

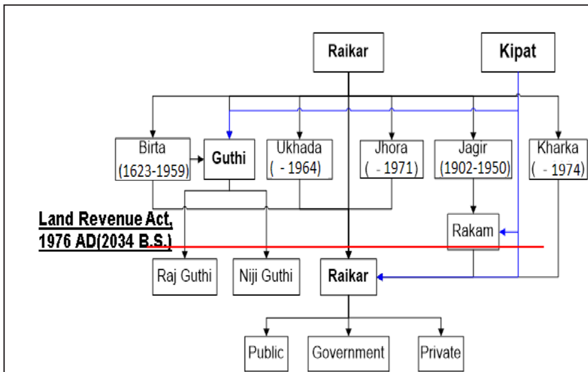

Fig 1: Different forms of land ownership in AD

Under Land (survey and measurement) Act 1963, land is categorized into three types – private land, public land and government land.

Private land refers to freehold in which individuals can exercise optimal rights to their land as defined by the existing law. Land of any form and use, used for personal propose before mapping were mapped and recorded as private land. Before execution of Land Revenue Act 1976, there exist various forms of customary tenure such as *birta, ukhada, kharka*, etc. These customary lands are now legally registered as described by this Act.

As shown in the Figure 1, land is either registered as Raikar (freehold) or Guthi (trust lands: as a part of religious tenure with certain restrictions). The provision of trust land is to support the continuity of religious Activities through taxes in these lands. The existence of trust lands is legally redefined by the constitution of Nepal 2015 under section 26(2) as, "every religious denomination shall have the right to operate and protect its religious sites and religious Guthi (trusts)".

2. LITERATURE REVIEW

Public land by law is defined as land used by the community for paths, sources of water, pastures, and the like, which are not owned by any individual or family. According to Land (survey and measurement) Act 1963, government land means land occupied by road, railway and government building/office. In addition to this the land under Nepal government as forest, river, lakes, channels, common share, high rocks are also the lands defined as "government land" in Nepal Gazette published in a different timeframe (Dhakal, 2011). Also there exists trust land, which can be defined in-between customary and statutory freehold as ownership is registered in deeds, however, they cannot exercise all rights as freehold land ownership.

Thirty-seven districts among seventy-seven districts in Nepal were mapped without national control point network. The hardcopy maps and the field-book are digitized but the Survey Department of Nepal lacks central database. There is not a fixed record of total number of parcels, area mapped, and registered. Different literatures reveal different data. Experts in this field figureout approximate 98% of private parcel (nearly 23% of total land) are mapped and recorded. Although major portion of private land is mapped, recorded with the parcels registered, thousands of appeals per year regarding land disputes are registered in the judicial bodies. This situation can be because of either the data of cadastral and registry is not reliable or the service delivery of land professionals biased and corrupt (Dhakal, 2011). Corruption in Land administration due the organizational culture, is positioned as the most corrupted sector in the country (Agyen-Brefo, 2012). The government time and again has made amendments to existing Act and regulations and even has formulated new Acts and policies to strengthen the land governance. Commission to solve problems of landless and squatted settlements were formed several times but due to unstable political condition, the task was limited up to data collection. However, these data are somehow acknowledged by the Land Issue Resolving Commission formed in 2020 with the time bound of three years. These data prevails that indigenous and lower cast population are the most to be landless. Illetracy, basically in these community, still exists which is one reason to loss their property during the process of adjudication and registration. Various sectors involved in land administration with different vested interests, Acts and policies conflicting with each other, inefficient and unprofessional land agencies, corruption, unaccountability, etc. are major challenges of land management in Nepal.

Today, land use and land tenure have become the global common issue because of declining trend of capability and productivity of land. There is universal agreement in the fact that stable economic transformation depends on "fair" land-man relations (De Soto, 2000). The implication of proper Land Management system with collaborative and responsible governance in land could be the only way out to come up with this global problem of land tenure insecurity.

3. RESEARCH METHODOLOGY

Various organizations involved directly or indirectly in analyzing and evaluating land administration and land tenure security like the World Bank Doing Business reports, the World Bank Development Indicators, United State Agency for International Development (USAID), etc. have developed their own indicators of evaluation. There also exists land tenure security indicators that are developed by individual researchers or scholars (Simbizi, 2016). Since, sectoral experts define land and tenure in different direction based on their profession, indicators and methods developed for analysis are the often subjected to criticism.

In this study, we define land tenure as the function of different variables such as land registry, cadastral, rights on land, transaction procedure, transaction cost, gender equality, etc. Since this study lacks field data collection and interviews, it is difficult to have a quantitative analysis. Assessment of different aspects of land tenure and analyze them on the basis of their strength, weakness, opportunity and threat, acronym as SWOT analysis is suitable method for assessment of land tenure security in Nepal. This method of analysis is generally for analyzing the current performance, evaluating current mission, objectives and strategies and revise these on the basis of internal and external capacity and influences. SWOT analysis is one of the worldwide accepted method for analyzing the current status of any system. Figure 2 shows the framework of SWOT for evaluating current performance and developing strategic alternatives.

By carefully listing S's, W's, O's and T's it is possible to compare the internal organization is supporting and servicing the external environment, and how the external environment is acting upon and influencing the single organization (De Vries 2015). The next step after analysis is to develop a set of strategy implication in a SWOT matrix were strength. In this section, Strengths, weakness, opportunities and threats together are included in a matrix to sort out the possible efficient policies.

4. FINDINGS AND DISCUSSIONS

Tenure security can be defined as an equation that links legal situation to the physical and sentimental relation between land and people and hence cannot be defined with reference to few and fixed elements (GLTN, UNHABITAT, 2014). Registration of lands and redefining rights related to land is not enough to improve tenure security. The land tenure is perceived secure if the relation between right, restriction, and responsibility on land is balanced. Enhancing tenure security directly subjects towards increase in investment on land. "Because the rights to these possessions [house, industries, ...] are not adequately documented, these assets cannot readily be turned into capital, cannot be traded outside of narrow local circles where people know and trust each other, cannot be used as collateral for a loan and cannot be used as a share against an investment" (De Soto, 2000).

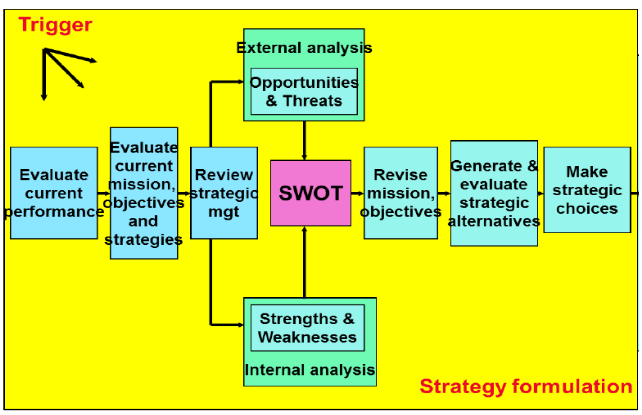

Fig 2: SWOT strategy formulation (De Vries 2015)

As shown in fig 3, Land tenure is driven by its components which we define above as variables. Social, legal, economic and natural impacts to this function or variables individually moves the tenure status either towards secured direction or towards unsecured one. The bond of variables, dark blue for instance in the fig 3: if strengthened, will drive the system towards more security. This can be achieved by improving policy and making the governance responsive.

As in global consequence, Land Tenure security is important in Nepal because of its interventions in multiple sectors. Some of them are:

- Greater investment incentives
- Transferability of land
- Improved credit market access
- Independence form discretionary interference by bureaucrats
- Reduction on private investment on securing of property rights
- Increase land value (low risk of eviction)

4.1 Current state of land tenure

GLTN, UN-HABITAT in the year 2014 have accessed the state of land tenure of different countries using different parameters. The use of similar parameters used by GLTN, UN HABITAT, 2014 shows that the state of tenure security in Nepal graphs up because of various factors in legal framework, increase and influence of international interest on tenure security. Even though land tenure security and agricultural land reform are main political agenda of every political party, the government is not able to implement any successful programs towards improving land tenure. However, inclusion of some land issues in the new constitution such as compensation in expropriation, relocation in case of disaster, land distribution for landless, etc. are admirable.

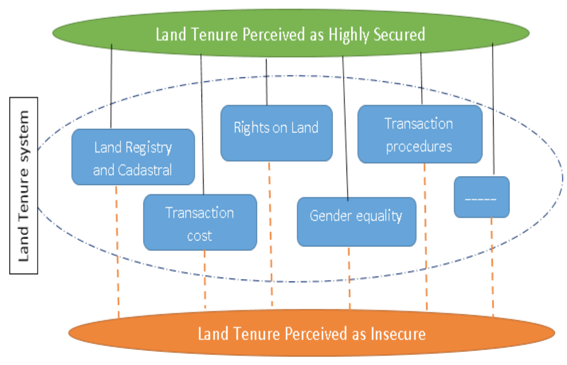

Fig 3: Land Tenure as function of various tools (Source: Author)

The picture of land tenure and its security is very often perceived different by state and public. For instance, state does not consider expropriation as a major issue which is in fact one of the main causes to landlessness. In Current situation, settlements and land along the major highway are perceived highly insecure because of government's intention of expropriation without compensation even though those parcels are registered as private land. Besides this, urban encroachment in public land, especially in river bank and open public lands has been a headache for government. The current government's decision to provide electricity in slum and informal settlements is a positive move to recognize these settlements. This action is taken as positive way as government recognizes the so called informal settlers. Some variables of current land tenure and their impacts on tenure security are critically analyzed under following headings.

4.1.1 Land registry and cadastral

Introduction of land (surveying and mapping) Act 1963 was a milestone in land sector in Nepal. As defined by this legal framework, organizational framework under the leadership of Ministry of Land Reform and Management (MoLRM) is responsible for surveying, recording and registering land in a form of parcel. MoLRM's major two departments, Department of Survey (DoS) and Department of Land Reform and Management (DoLRM) are responsible for mapping and land registration respectively.

Department of Survey and its units, survey offices, are recording, updating and archiving the spatial information of particular parcel. The data recordation is systemic. Survey office has technical task such as parcel split, land consolidation, boundary dispute resolution, cadastral surveying and mapping, map printing, etc. As land market is booming day to day, the accuracy of map, drawing in clothe piece and scribed in plastic sheet with fixed scales of 1:500, 1:1250 and 1:2500 are often criticized because of low precision (reading error).

On the other side, DoLRM and its units, Land revenue Office, as guided by land revenue Act 2034 under same ministry registers those recorded parcels and provides ownership certificates. Land reform office basically deal with land registration, transfer of property, update the record, revenue collection, etc.

Land registration in Nepal is improved deed registration system. Even though ownership certificate is issued to respective owner, state does not guarantee the land as in title registration system but responses to any type of disputes. Survey offices (SOs) and Land revenue offices (LROs) are two different district level organizations who are responsible of preparing, safeguarding and updating cadastral maps and land records respectively. These offices are delivering land administrative services through 128 district level offices countrywide. These organizations still hold traditional filing system for hardcopy data and often have dispute among each other because of legal pluralism and bureaucratic culture. Both land administration organizations have legal authority to act as semi-judiciary body.

Regarding disputes of land boundary, the victim have to register his application in survey office and surveyors have to resolve within 15 days of application. If the dispute is of overlapping or overriding interest, the victim with proof have to register the application in land revenue office and the process of resolution begins. If the victim or victimizing group is not satisfied with the decision of these offices, he/she have right to approach judiciary against these decision.

4.1.2 Rights, restrictions and responsibilities

Bundle of rights along with responsibilities and restrictions to land and property are institutionalized by different land related Acts introduced in different time frame. Very often, right to land provisioned by one Act are restricted by another one. For instance, an owner holds the right to fruit in his/her land but at the same time they restricted to cut the trees down in his/her private property without undergoing several procedures of forest Act 1992. Some of rights and restrictions relating land and land tenure, defined by law and exercised are briefly discussed below.

- **Right to use:** Since land use policy is still under discussion, there are not planned land use pattern followed in Nepal. Land owner can use their land for any purpose but he/she shall insure that the use will not affect the environment and topology. In case of building construction, various codes defined by law shall be taken under consideration.
- **Right to transfer:** Any land owner has right to transfer or sell his property to any Nepali citizen with their mutual understandings. Meanwhile, for any transaction, he/she shall have agreement of family members who are defined as heirs by existing law.
- **Right to income:** Land owner, tenant or leaseholder can use land as income source through agricultural or any economic Activities. However, they are restricted to farm any type of illegal crops and conduct illegal Activities/trade as defined by existing law.
- **Right to exclude:** Land owner can exclude anyone to enter and conduct any Activities in his/her private land without approval. But they shall not disturb the continuity of easements like irrigation channel, foot trails, etc. that are used for public purpose since generations.
- **Right to compensation**: According to clause 25(3) of the Constitution of Nepal 2015, the basis of compensation to be provided and procedures to be followed in the requisition by the State of property of any person for public interest in accordance with clause (3) shall be as provided for in the Act. Even though compensation has been made compulsory by the constitution, the value of property is evaluated as per government rate which is often very less as compared to market value.

4.1.3 Transaction procedure

According to the World Bank doing business 2016, registration of property in Nepal takes five days with three procedures. Three procedures in the transaction phase are:

1. Notary: Finding a registered layer and preparing the transaction document.
2. Land Revenue Office: Check, verify and update the transaction document.
3. Survey Office: Update the cadastral data/map as per request of LRO

"Land registration process in Nepal is classified into four main phases as marketing and pre-contracting, parcel sub-division and contrActing, verification and revenue collection and registration and conclusion. The whole process can be completed in sixteen steps" (Subedi, 2009). Most of the steps in these sixteen steps process is related to registration and conclusion. Since 2014, land revenue offices and survey offices in 20 districts have started implementing Citizen Charter with Compensation. The purpose of this initiative is to complete the transaction within a day, if required documents are attached. According this policy, the service provider (government employer) has to pay compensation to service holder, if the process could not be completed without any genuine reason.

2.1.4 Transaction cost

Land Reform Office in the time of land transaction is responsible to tax the property registration. This taxation in transaction is calculated as defined by Finance Act 2016, revised yearly. Land revenue office publishes "minimum valuation book" where along with the rate of tax, the minimum value of parcel in the whole district is defined. Tax amount increases almost every year because Land revenue office each year increases the valuation amount. Most of the time the tax amount raises beyond the capacity of owner, especially for rural population. Transaction tax for different type of transaction in Metropolitan, Sub-Metropolitan, Municipality and Village Development Committee (VDC) is shown in table 1 below.

raise voice against this legal provision.

Ministry of land reform and management along with different international organizations working for women rights are working together to increase female ownership to the land. The provision of 25 percent registration fee waiver if the land is registered in name of a female member of the family is an example that the government is willing to increase women rights in land. Also, the government in collaboration with different NGO/INGOs is advocating for dual ownership of land (husband and wife).

4.2 INDIGENOUS AND CUSTOMARY RIGHTS

No precise statistics are available regarding indigenous and customary land holding in Nepal. "Most of the customary land tenure(s) have been abolished since 1951. Some of the remaining ones were abolished during systematic and compulsory cadastral surveying and preparation of basic land records or land register called *Moth*" (Acharya 2008). All transfers of real property must be registered in the land register. According to Land Revenue Act (1978), the land revenue office should register all categories of lands as (ibid):

1. Government lands: in the name of Nepal Government.
2. Public lands: in the name of Nepal Government including its use.

SN	Transaction Type	Metropolitan	Sub-Metropolitan	Municipality	VDC	Remarks
1	Private-private sale	5%	4.5%	4%	2%	% Of total property value
2	Divorce transaction	2.5%	2%	2%	1%	
3	Within family trans.	1.5%	1%	1%	0.5%	
4	Inheritance	0.2-0.5%	0.2-0.5%	0.2-0.5%	0.2-0.5%	
5	Kitchen division (HH)	12000-15000	11000-12000	10000	5000	Highest value for property valued over 20 million
6	Inheritance after death	7000-12000	6000-11000	5000-10000	2000-4000	
7	Inheritance to adopted child	1000-7000	1000-6000	1000-5000	1000-4000	

Table 1: Transaction tax for land in 2016 (source: Nepal Government, Ministry of Finance)

4.1.5 Gender equality

According to General Code 1963, in the course of partition of a property after death of the father and husband, all the remaining properties after performing his last rites including the earnings and loans of the father and the grandfather and husband living jointly or separately shall be partitioned equally between the wives and the sons and unmarried daughters in accordance with law.

Chapter 14 titled "Women's Share and Property" under the same code states, an unmarried woman, a woman having a husband or a widow may use and dispose of the movable or immovable property which they have earned on their discretion. The married daughter of the family shall leave her inherited property to her brother/s if she is married after having ancestral property. Since unmarried daughter only can claim for ancestral property, women Activist often

3. *Raikar* lands: in the name of the owners as freehold.
4. *Guthi* lands: in the name of concerned religious/ cultural organization (*Guthi)*
5. *Guthi Raitan Nambari:* in the name the owner (*Guthi* lands converted to private freehold as *Raikar* or *Raitan Nambari*)
6. Land and building on possession: in the name of the user (even though land is unregistered, constructions on land are registered)
7. *Birta* Lands: in the name of tenants (land transferred as gift by the state)
8. *Haal Aabadi lands* (virgin or unregistered lands): in the name of the tiller (for two decades implementation has been restricted by the government)

Apart from these registered tenures, there exist some indigenous groups like *Raute, Chepang, musahar,* etc. who live in forest. These communities run their own hierarchy and system. Since these indigenous community migrates from place to place according to season change, they do not expect any exclusion to their traditional flow. The government often tried to convince the chiefs of these group to give up the tenure and even offered alternative as freehold land but they denied. Main threats for these people are regarding restriction policies in the name of conservation. After different international agreements including United Nations Declaration on the Rights of Indigenous Peoples, the constitution of Nepal 2015 explains the conservation of indigenous people under article 18 (3) as, "Nothing shall be deemed to prevent the making of special provisions by law for the protection, empowerment or development of the citizens including the socially or culturally backward women, *Dalit,* indigenous people, indigenous nationalities, *Madhesi, Tharu, Muslim*, ...". The government's action always seems to be focused on transforming customary tenure towards registered statutory one.

4.3 STRATEGY IMPLICATIONS

Hereby, using some of the major strengths, weaknesses, opportunities and threats of land tenure as discussed above, we develop a SWOT matrix for strategy implication.

SWOT ANALYSIS / **LAND TENURE SECURITY IN NEPAL**	Internal Strength Country wide cadastral and land record Legally defined land holding limit Effective organizational structure Towards ICT adaptation Free land market	Internal Weakness Corruption Hard copy and multistep transaction Traditional archive of documents Lengthy judicial process Rural poverty
External Opportunities Development of central and integrated LIS Global commitment to improve tenure security Improving land governance Formulate and implement collaborative land use policy Collaborative/participatory land governance Decentralization and integration of land authorities	(SO, strategy) Adaptation of multipurpose cadastral system Equitable redistribution of land Integrate land agencies towards collaborative governance Decentralize land administration using ICT Enhance public participation for land use implementation	(WO Strategy) Development of database of land records for online access Updated achieve of land related data Enhance transparency and accountability Programs to support rural Activities from subsistence to sustainable
External Threats Population growth Climate change affecting agriculture Frequent natural disasters Rapid urban migration Political, social and economic instability	(ST Strategy) Develop new settlements and protect agricultural land Change production pattern of crops Improve infrastructure in rural area to develop land market Develop agriculture and productivity as social and economic agenda	(WT Strategy) Introduce anti-corruption Activities in social level Develop database of possible effects due to disasters and introduce mitigation Improve agricultural infrastructure

CONCLUSION

Land for generations in Nepal are being recognized and recorded in various form. Before 1964, when land records were not based on cadastral maps, lands were recorded by local heads like *Jimindars, Talukdars, Mukhyas* and *Patawaris* (Acharya 2008). Since the introduction of the Land Act 1964, "there have been a number of amendments and revisions but ultimately there was a lack of political will to enforce them" (CSRC 2009). The government of Nepal has created legislation for land management and reform time and again but with the little actual result. Fixing land ceiling, protection of tenancy rights, farmer oriented land reform, land right to landless slum dwellers, preparation of land use policies, strengthening LIS and many other activities to improve land administration in order to improve tenure status are legally introduced. Existing bureaucratic system and less participation of public in policy formulation is driving the situation away from the desired destination.

However the registration of parcel has made positive impact all over the country but many ethnic groups have lost their access to their customary land. The district profile of Kanchanpur district reveals that the *Tharu Chaudhari* occupied 82% of the land some 50 years ago; they now have only 16% (ibid). These situations are reflection of biased local governance, illiteracy, free access to land grabbers and mostly corrupted institutional policy and framework. Even though legal frameworks for conservation of indigenous rights are being developed, the implementation shall be strategic. The policies need to be developed in such a way that reduces the social conflicts.

Countrywide coverage of cadaster and compulsory provision of land transaction registration is good base for formulating strategies. In order to safeguard the archive, integrated LIS can be developed in database form. Solving the dilemma created by bureaucrats on the basis of legal pluralism can be a better way to reduce corruption and increase accountability and responsibility of land administration organizations. Along with, enhancing public participation in policy formulation and implementation definitely reduces the current land disputes.

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ROUTE PLANNING USING LEAST COST PATH ANALYSIS (A CASE STUDY OF JANAKPUR – BIRGUNJ SECTION)

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ABSTRACT

Transportation is one of the major parameters of socioeconomic development. Monitoring road feasibility study and understanding the dynamic of socioeconomic factors is increasingly important in sustainable development and management of roadway transportation. This paper uses Geographic Information System (GIS) to explore the various route alternatives from Janakpur to Birgunj that will touch all the major settlement area in between. A least cost model was created in ArcGIS and weighted overlay was performed to find the weighted cost raster. Different influencing parameters like land use pattern, slope, settlement, existing linear features and ecology of the study area were assigned proper weights and accordingly their class types to work on with overlay algorithm. Cost distance was computed from cost raster and the least cost path between source and destination was found using cost path function in ArcGIS. The Least Cost Path (LCP) model applied for the mentioned route paths were quite successful in avoiding forest, faults, high slopes and zones of ecological or cultural values, and thus satisfying the objective of this study within the given criteria and data. This paper concludes that if Geographic Information System and shortest path algorithm is embedded in the early planning system, it proves to be well suited, economic and time-saving for a sustainable corridor location design.

KEY WORDS

Route Planning, Least Cost Path Analysis, GIS, Land Use, Weighted Overlay

1. INTRODUCTION

The design of the cheapest route between any two locations within a cost surface accounting for different environmental issues can be computed using least cost path analysis based on multiple criteria evaluation. For finding a minimum cost path over a surface that is partitioned into regions of different resistances to movement, there are a number of basic steps involved (Collischonn and Pilar, 2000). Usually, one or more alternative alignments that represent the interest of the stakeholders are proposed in route planning. For planning and designing of linear infrastructures such as roads, railways, transmission lines, pipelines, etc., Geographic Information System (GIS) techniques are widely implemented. A rational, transparent stakeholder based process is required to generate the alternative alignments in order to improve Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) and for better decision making (Keshkamat, 2007). For determining the optimal path between any two or more destinations, least cost path is considered as a highly significant tool (Lee and Stucky, 1998). The commercial GIS packages provide various methods for the calculation of accumulated cost surface (Collischonn and Pilar, 2000). Physical, environment, political, socio-economic, and regulatory factors often act as limiting conditions for the route planning of linear features such as roads, railways, pipelines, etc., for which a wide range of alternatives can be generated with a system that can relate these factors and identify trade-offs (Motemurro et al., 1998). Selecting all weather road has been one of the recent applications of the least cost path methodology (Atkinson et al., 2005). For solving several routing problems of different utility infrastructures such as pipeline routing (Bagli et al. 2011), transmission line routing and telecommunication network design (Paulus et al., 2006), Spatial Multi-Criteria Evaluation (SMCE) has been used as a powerful technique. SMCE model can be employed to integrate environmental and economic factors with analytical hierarchy process, thereby creating cost surface for each cost factor standardized, weighed and aggregated (Effat and Hassan, 2013).

2. PROBLEM STATEMENT

Transportation is one of the major parameters of socioeconomic development. In context of country like Nepal, where airways are inaccessible to majority of rural people, dependency on roadway is indispensable. The population density of project study area is very high. The average economic status of the study area is not so good, mostly agriculture dependent.

All these factors create a force for high traffic on road ways. But the existing status of roadways in the study area is very poor. The width of road is not compatible with traffic flow and the existing road is mostly earthen and gravel type that become full of mud in rainy season. There is no proper drainage system along the road. Frequently many road accidents occur in this area despite of plain topography of the area. Janakpur and Birgunj are also connected by the east west highway, but the highway does not connect to the rest of the area with major population density in between these places. Also all the designed routes are mainly prepared by top-down approach. There is no proper study on land use pattern, ecological data, settlement pattern, slope pattern, etc. which has been done before proposing any road alignments. No involvement of the local beneficiary people has been made in decision making process. In these circumstances, the output of this study would provide useful information for the preparation, implementation and monitoring of the road construction plan in the study area.

3. METHODOLOGY

This is a quantitative research based on multi criteria evaluation. A GIS model is built that uses least cost path algorithm to determine the optimal route between Janakpur and Birgunj. In addition to the least cost path given by ArcGIS, three alternative alignments are also proposed based on field data collection using GPS.

3.1 Study Area

The project study area is from Janakpur to Birgunj. The area covers six districts of Nepal. Janakpur is located at 26.722° north latitude, 85.916° east longitude and Birgunj is located at 27.027° north latitude, 84.895° east longitude. This route is chosen for the study because Janakpur is well known globally for its religious view while Birgunj is one of the major industrial areas of Nepal.

The terrain of study area is plain with very less variation in altitude. The area is mainly covered with agricultural land with very high population density and dense settlement pattern. The population of all these six district is about 250000. Other major places in of study area are the headquarters of the districts, i.e. Jaleshwar, Malangawa, Gaur and Kalaiya.

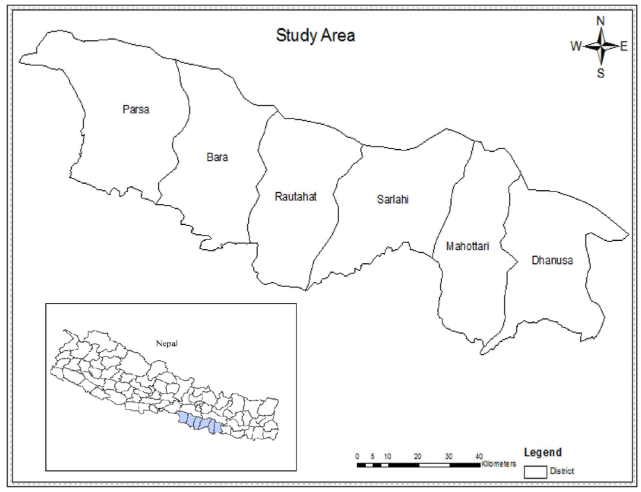

Figure 1. Study Area

3.2 Data sets and pre-processing

Different influencing parameters like land use pattern, slope, settlement, existing linear features and ecology of the study area were assigned proper weights and accordingly their class types to work on with overlay algorithm.

3.2.1 Land use pattern:

The map of land use pattern of Nepal in raster format was downloaded from the site Open Data Nepal. The land use pattern of Nepal was categorized in 8 classes. We had also downloaded the shapefile of district administrative boundary of Nepal. By editing the shapefile of district level administrative boundary, a new level of selected six district was created. Using the extraction by mask in extraction tools of ArcMap toolbox, the land use pattern of the six district of study area was selected on the basis of previously leveled six districts. The color of different classes of raster of land use pattern of study area was arranged as to appear more distinct from each other. Using the attribute of the map, the percentage area covered by each type of land was determined. The study area was mostly covered with agricultural land about 61%.

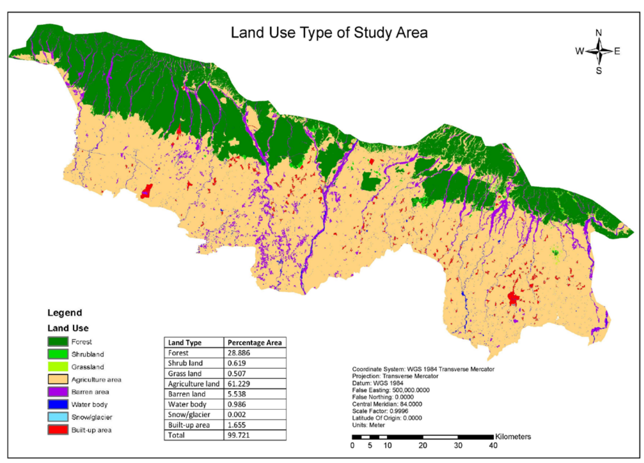

Figure 2. Land Use Type of Study Area

3.2.2 Slope:

The DEM of Nepal in TIFF format was downloaded from Open Data Nepal site. It was in gray color band with minimum value -97 and maximum value 8623. Using the slope toolset in the surface parameter of spatial analysis toolbox of ArcMap the slope pattern of study area was created. The slope was in measured in degree using the Z values of DEM. Using reclassify tool of ArcMap toolbox the obtained slope raster was reclassified in 10 classes based on quantile classification.

3.2.3 Settlement pattern:

The shapefile of settlement pattern of Nepal was downloaded from Open Data Nepal site. The settlement pattern was in point data. The attribute of settlement pattern map was total population and total household in a local unit. From the settlement pattern of Nepal, it was clear to see how really dense the settlement in the study area was. After Kathmandu and Pokhara, the settlement of six district of the study area of project was most high. Since the settlement pattern map was in vector format, the settlement map of project study area was found by using selection by location based on the selected administrative boundary map of the study area. The settlement pattern of project area helped to select the current alternative alignment from Janakpur to Birgunj so that the route will be selected to cover major settlement area.

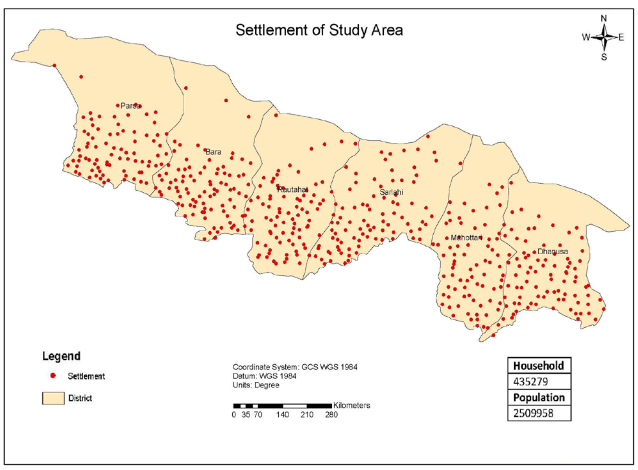

Figure 3. Settlement of Study Area

3.2.4 Existing roads:

The open street map data of existing linear features in the study area was downloaded using QGIS. The open street map linear feature was then exported in shapefile format using QGIS. Using selection by location and then selection by attribute, the shapefile data of existing roads in study area was layered in GIS. Based on open street base map in GIS, initially three linear feature classes on a new geodatabase were created to draw the alternative alignments based on secondary data analysis and desk work. Taking the mapped alternative alignment as reference, the field validation was done with GPS to analyze how actually the three alignments are on ground reality. Analyzing their feasibility and also taking the decentralized planning system in account, the field data was collected using GPS. At some places the alignments were modified based on the ideas by local people on participatory approach.

3.2.5 Ecology:

The shapefile of ecological map of Nepal was downloaded from Open Data Nepal. As the construction of new road alignment has influence on the ecology of the area, we should also consider the ecology of the area during selection of alignments. The shapefile data was in polygon format. Again using the selection by area based on selected administrative boundary shapefile of the study area, the ecological map of the study area was found. The vector shapefile of ecology of the study area was converted into raster using raster conversion tool of ArcMap toolbox for weighted overlay analysis. Also the obtained raster file of ecology of the project area was reclassified in 10 classes based on quantile classification.

3.3 Designing alternative routes and least cost path analysis

The alternative routes are now designed based on the data collected by GPS route. The GPS data is converted

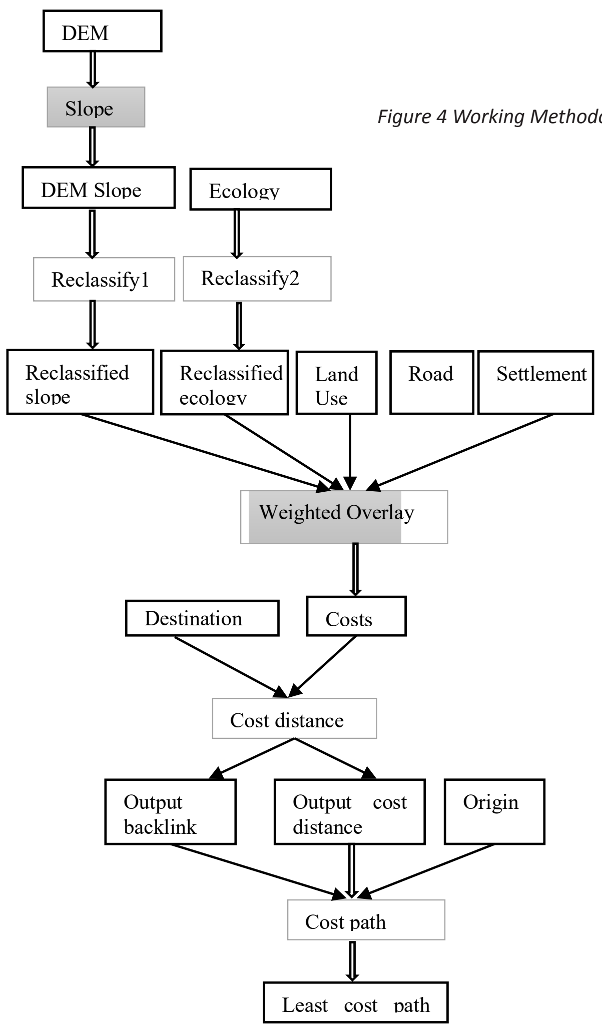

Figure 4 Working Methodology

to shapefile with the help of a software Expert GPS. Also to tackle with error in GPS data, the open street map is used as base map in ArcMap during the drawing of three alignments. To find the least cost path using GIS, first of all a new toolbox was created in ArcMap. The toolbox was named leastcost. Then the leastcost toolbox was modeled. The model was named least_cost_path. The environment of the model was selected as working space, raster analysis and processing extent. Their values were checked and set as default. Then the model parameters were saved.

First, the slope tool was used to create the slope pattern from the DEM data. Then the reclassify tool was used to reclassify both the DEM Slope and ecology of the area in 10 classes based on quantile classification. Now there were all together five data source for weighted overlay.

3.3.1 Weighted overlay:

Each type of criteria was given certain weight value as per their expected influence on the construction of least cost path. The below table shows their percentage weight and their classes values varying from 1-10 as per their expected influence on the path.

Class_name	Value
Population	7
Household	5

Table 1. Settlement - 30%

Class	Value
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10

Table 2. Ecology - 20%

Class	Value
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10

Table 3. Slope - 15%

Class_name	Value
Construction	4
Footpath	2
Primary	7
Secondary	6
Tertiary	5
Residential	6
Service	4
Track	3
Trunk	2
Unclassified	2

Table 4. Road – 15%

Class_name	Value
Forest	3
Shrub land	4
Grass land	5
Agricultural land	6
Barren land	7
Water body	3
Snow/glacier	4
Built-up area	6

Table 5. Land use type- 20%

Performing the weighted overlay on least_cost_path model, the cost raster will be obtained. An overlay function aggregates the cost grids in a theme into one cost grid.

3.3.2 Cost distance:

Cost distance analysis relies on a ‘‘cost surface’’, which is a raster dataset. The value of each cell represents the cost per unit distance of crossing that cell. Generally, and according to the study area characteristics, the cost is based on one or several variables such as slope (the route through plain land cost lesser than steeper land), land cover class, ecology, settlement, etc. For each single cost a raster is created. Cost distance function operates on the cost raster and the feature class destination point of the route to give output cost distance and output backlink.

3.3.3 Cost path:

The combined cost surfaces were then used in least cost path algorithm. The cost path function operates on the output of cost distance and a feature class origin of the route to give output raster least cost path. Actual construction costs are not included in this model as those values were not available, and the assignment of monetary costs to environmental factors is beyond the scope of this paper. This one is last step of least path generation using ArcMap and takes a long time to execute the output based on the size of input parameters. Then the output is named least cost path and was levelled to the layer on ArcMap. Also the output least cost path was in pixel based raster format, using georeferencing it was converted to linear vector feature.

3.3.4 Buffer:

Using the buffer type georeferencing, the settlement pattern in 1.5 km width along each alignment was determined. It was to analyze the influence area due to alignments. The buffer of each of the three alternative alignments and the least cost path generated by ArcMap was created. The buffer determined the total sum of beneficial population and household along each route.

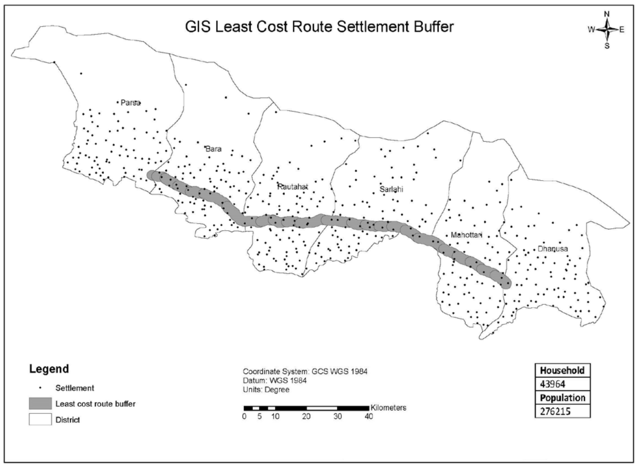

Figure 5. GIS Least Cost Route Settlement Buffer

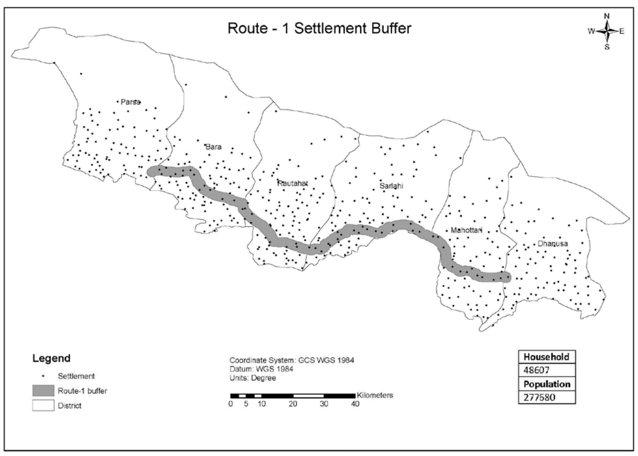

Figure 6. Route - 1 Settlement Buffer

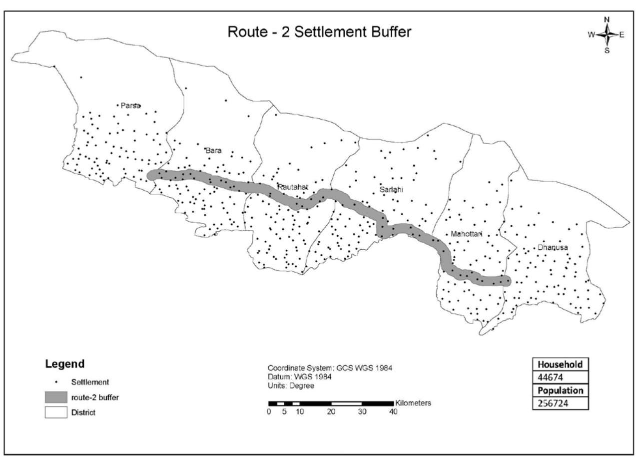

Figure 7. Route - 2 Settlement Buffer

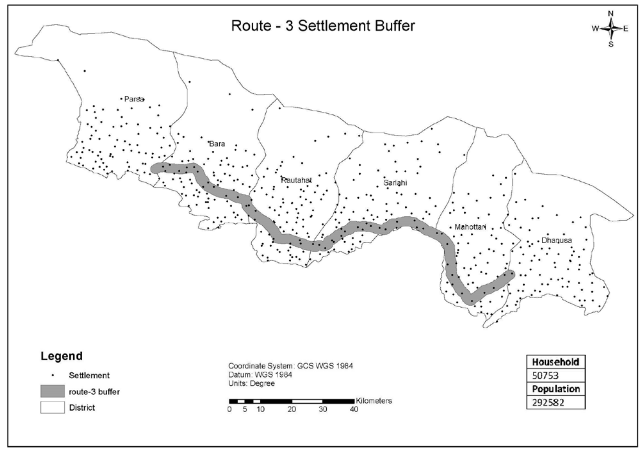

Figure 8. Route - 3 Settlement Buffer

4. RESULT AND DISCUSSION

The major output of the project is the generated least cost path using ArcMap 10.2. The three alternative alignments were mapped along with the least cost path. The generated least cost path is around the expected region. The buffer of settlement was created to find and analyse the total population and household along the alignments in their 1.5 km width. The generated least cost path was found to be beneficial for 276215 peoples and 43964 households in its 1.5 km width, which is very good. Along the selected alignments, the third alignment was found to beneficial for maximum peoples i.e. 292582. In land use pattern map of the study area, the maximum area was found to be covered by agricultural land.

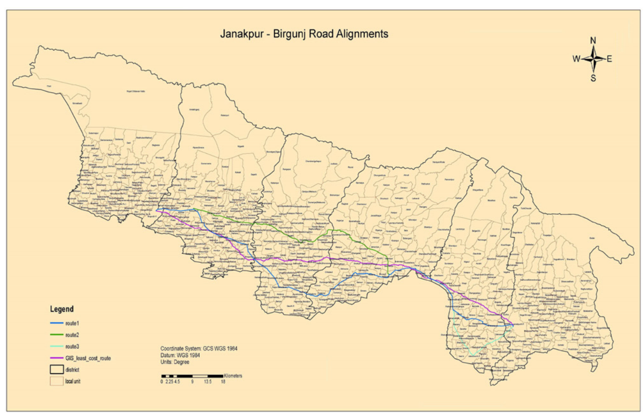

Figure 9. Janakpur - Birgunj Road Alignments

5. CONCLUSION AND RECOMMENDATION

In this study, Geographic Information System (GIS) was used to explore the various route alternatives from Janakpur to Birgunj that will touch all the major settlement area in between. The Least Cost Path (LCP) model applied for the mentioned route paths were quite successful in avoiding forest, faults, high slopes and zones of ecological or cultural values, and thus satisfying the objective of this study within the given criteria and data.

Further detailed studies are recommended for using the Least Cost Path (LCP) in route planning and field investigations are a necessity prior to the final decision making. Some improvements in the route design are required to satisfy more detailed construction criteria.

It is concluded that if Geographic Information System and shortest path algorithm is embedded in the early planning system, it proves to be well suited, economic and time-saving for a sustainable corridor location design. It can avoid many location problems, in addition, the ability of the technique to provide several alternatives and to compare such alternatives is a benefit for designers.

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LAND SLIDE SUSCEPTIBILITY MAPPING OF BUDHIGANDAKI RIVER SUB-BASIN USING ANALYTIC HEIRARCHY PROCESS AND MACHINE LEARNING METHODS

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ABSTRACT

Landslide is one of natural hazard causing loss of lives and properties every year. Landslides are inevitable but losses could be minimized by predicting susceptible areas. Different factors causing landslides and using them to identify the landslide susceptible areas. This paper presents a landslide susceptibility mapping in Budhigandaki river sub-basin, Gandaki Province Nepal using AHP (Analytic Hierarchy Process), Artificial Neural Network (ANN) methods like Multi-Layer Perceptron and Random Forest algorithms. For the assessment of the landslide susceptibility, 6 factors that affect the happening of landslides were selected, which are slope, fault, distance from road, land use, aspect and stream. Landslides and non-landslide data were digitized form ArcGIS base map server was used to train and validate the model for machine learning methods. Result obtained from testing the model was used to compare the models. Probability of classification to the landslide class was used to prepare the landslide susceptibility map of the study area.

KEY WORDS

Landslide, Susceptibility mapping, AHP (Analytic Hierarchy Process, Random Forest (RF), Multi-Layer Perceptron (MLP)

1. INTRODUCTION

“Landslide” is a common term describing an event covering a wide variety of mass movement and processes involved in downward movement of masses of rock, earth or debris under the gravitational influence(Hemasinghe et al., 2018). Landslides occur in hilly and mountainous terrain in Nepal due to steep slopes, highly fractured rock masses, high intensity of rainfall. The study of Landslide, their causes and effects are vital to control its risks and hazard caused by it. The landslide susceptibility mapping offers crucial information for city planning, infrastructure development and agricultural planning in the future or in other area with similar geological and meteorological conditions(Varnes, 1984). Land slide causes damage of houses, properties and infrastructures along with human casualties in Nepal. The Jure landslide of the year 2014 is one of the representative catastrophic event(Geest & Schindler, 2016).

To study the phenomenon of this catastrophe various qualitative and quantitative methods have been proposed. The qualitative approach incorporates field analysis techniques and/or overlaying of various index maps and applying conventional weight rating systems to arrive at the hazard and/or susceptibility map of the study area. The quantitative approach incorporates AI techniques like ANN and fuzzy systems, statistical techniques and deterministic or probabilistic geotechnical approaches. It may be argued that a highly random phenomenon like landslides may not be amenable to rigorous quantification as in AI or other deterministic techniques. On the other hand, subjective techniques depend on the experience level of the investigator (Bhardwaj & Venkatachalam, 2014).The study is concerned with preparing landslide susceptibility map of Budhi Gandaki Sub-Basin by using AHP, Multilayer perceptron, Logistic Regression and Random forest algorithms. The study has been carried out by considering various extrinsic factors causing landslides.

2. DATASET USED

The data required for this project are from secondary sources, which are listed below:

Table 1: List of dataset and details

S.N	Data	Source	Remarks
1	ALOS PALSAR DEM 12.5m	NASA Earth DATA	Slope and Aspect Raster
2	Geological Map	Department of Mines and Geology	Fault line raster
3	Topographic Map	Department of Survey	LULC, Stream, Road
4	Satellite imagery	ArcGIS Basemap Server	Landslide Inventory

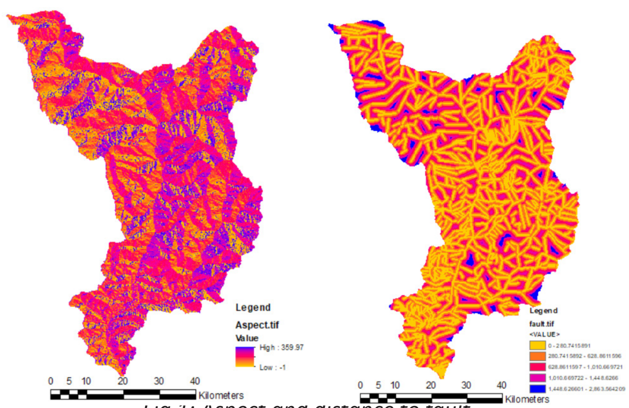
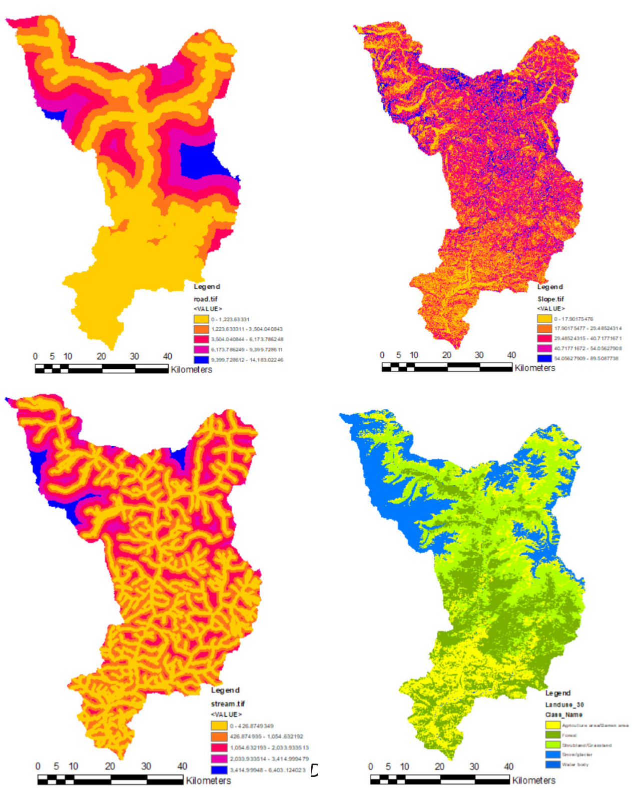


Fig 1: Aspect and distance to fault



3. METHODOLOGY

3.1 Study Area

Budhi Gandaki river sub-basin is typically a river belt comprising three districts Gorkha, Dhading and Nuwakot within an approximate area of 3522.52 square kilometers. The area is trans-boundary lying north-south in the central Himalayan region. It extends from China in the north, through mid-hills to the plains of terai region in the south and bounded by the Gandaki basin to the west and the Koshi basin to the east.

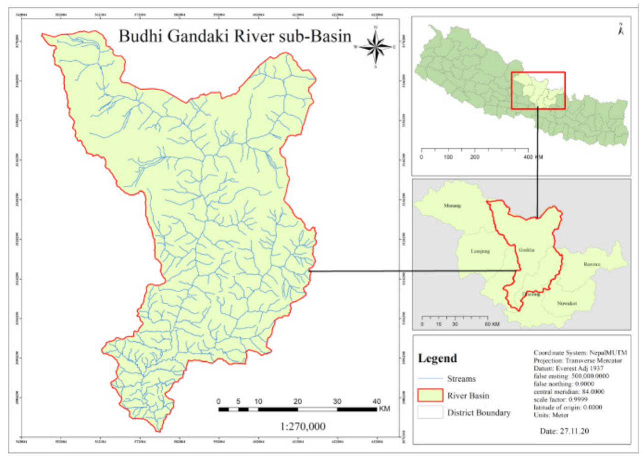


Fig 3: Study Area

3.2 Workflow

3.2.1 Analytic Hierarchy Process

Analytic hierarchy process is an adaptable tool created by Saaty, 1980, which is used for various decision makings such as suitability analysis and susceptibility analysis. It is considered as a rational decision-making process for multi-criteria as well as for multi-target approach(Taherdoost, 2017). In this method the most suitable site or choice for question of interest is solved by identifying a number of criteria, alternatives within each criterion and determining the contribution of each of them in the phenomena under consideration(Saaty, 2008).

Following the standard procedure for AHP as devised by Saaty 1980, the criteria were arranged on pairwise comparison matrix. Prioritized Factor Rating Value (PFRV) technique was used to assign a numerical value to the factors in the AHP on the basis of their importance as compared with other factors. The numerical value assigned to the factors was based on expert knowledge, literature, observations, and experiences. The maximum eigen value is 6.464 and consistency ratio is 7.4% for calculation of normalized principal vector ie weight in percentage each influencing factor. Figure 2 shows the calculated weight for each causative factor.

3.2.2 Random Forest Algorithm

Random forest is an ensemble machine learning technique which can construct a large number of decision trees to

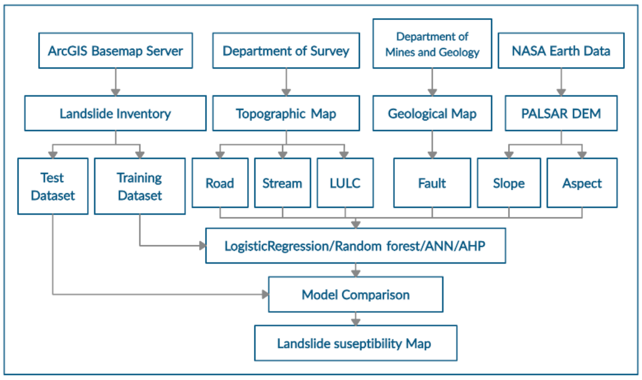


Fig 4: Methodological Workflow

explain the spatial relationship between the landslide occurrences(Kim et al., 2018). It works by creating a number of decision trees at the time of training and provides output classes that are the mode of classification or regression of individual trees(Breiman, 2001).

3.2.3 Logistic Regression Algorithm

Logistic Regression(LR) is a mathematical modelling approach that can be used for predicting the presence or absence of outcome based on the values of a set of predictor variables (Ayalew and Yamagishi, 2005, Lee, 2005). The advantage of LR over multiple linear regressions is that logistic regression does not assume a linear relationship between the dependent and the independent variables. It assumes a linear relationship between the logit of the independent variables and the response. In addition, the dependent variable does not need to be normally distributed. No assumptions are needed for the homogeneity of variance and normally distributed error terms.

used neural network for machine learning. The MLP uses backpropagation to classify and consists of three layers: an input layer, any number of hidden layers, and an output layer. The ability of MLP is to interconnect between different nodes through the hidden layer allows it to evaluate data with non-linear functions. The MLP uses algorithms to calculate weights for input values at each node as the data is introduced to the network in a "feed forward" manner (Pijanowski et al., 2005). The output values from each node are calculated as functions of inputs, called activation functions. The most common algorithm used for building a neural network is the back-propagation algorithm (Skapura, 1996). In a network utilizing this algorithm, a BPN (Back-Propagation Network), weights are randomly assigned to the initial input connectors, propagated forward through the network, and calculated for comparison against some known output value.

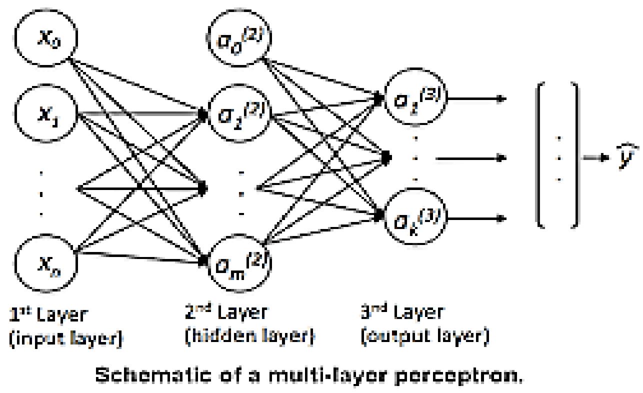


Fig 6: Schematic Multi-layer perceptron

Table 2: Calculated weight for each causative factor

	SLOPE	FAULT	ROAD	LAND USE	ASPECT	STREAM	NORMALIZED PRINCIPAL EIGEN VECTOR
Slope	1	3	4	6	7	6	44.054
Fault	0.333	1	3	4	5	6	25.206
Road	0.25	0.333	1	2	3	3	11.949
Landuse	0.167	0.25	0.5	1	5	4	10.496
Aspect	0.143	0.2	0.333	2	1	2	4.556
Stream	0.167	0.167	0.333	0.25	0.5	1	3.739

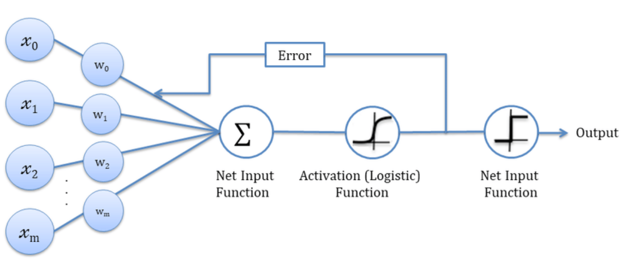


Fig 5: Schematics of logistic regression classifier

Multilayer Perceptron

The MLP (Multi-Layer Perceptron), is one of the commonly

4. RESULT

Landslide susceptibility map of Budhigandaki Basin is prepared using AHP, Multi-Layer Perceptron, Random Forest and Logistic regression and compared. Thematic raster of cell size 30mX30m for each factor was created and stacked. Training dataset was also prepared of similar cell size consisting of landslide and non-landslide data. The precision, recall and f1-score was found similar for MLP and random forest hence the susceptible values are also seem to be similar. In the figure:7, result from logistic regression is not consistent with the other methods.

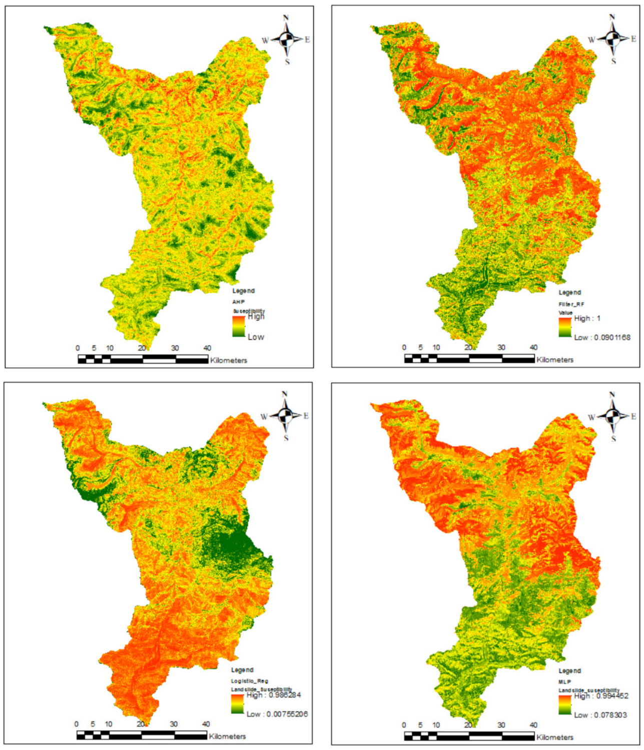


Fig 7: Landslide susceptibility values from AHP, Multi-Layer Perceptron, Logistic Regression, and Random Forest

Table 3 :Classification report for model predictions

ML Method	Precision	Recall	F1-score
Random Forest	0.84	0.84	0.84
Logistic Regression	0.80	0.80	0.80
Multi-Layer Perceptron	0.84	0.84	0.84

5. CONCLUSION AND RECOMMENDATION

Natural disasters including landslide are very complex phenomena and cannot be controlled. Either, we can minimize the loss by predicting the possible zones considering the factors that may influence the landslide. Landslide susceptibility map would aware the people and minimize the loss due to landslides. Landslide susceptibility map was prepared using AHP and different machine learning methods: random forest, multilayer perceptron and logistic regression. Accuracy score for model was 0.84 for Multilayer Perceptron and Random Forest and 0.80 for logistic regression.

Other factors such as soil types, elevation, parent material, rainfall, curvatures, earthquake related data could be incorporated for the reliable results and future prospects. The size of training dataset could be increased for better result. The accuracy of machine learning method could be increased by validating the model with wide range of hyperparameters to obtain the optimal hyperparameter which requires high computation power. Ground truth form the field observation would better validate the model

6. ACKNOWLEDGEMENT

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LANDSLIDES IN NEPAL: A CASE STUDY OF POST-EARTHQUAKE LANDSLIDES IN UPPER BHOTEKOSHI

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ABSTRACT

Nepal is listed among the top twenty most disaster-prone countries in the world. Among thirteen types of major disasters recorded in Nepal, landslide holds significant position in terms of casualties and destroying the landforms, infrastructures and other assets associated with the land. It is a geographical phenomenon which includes a broad range of ground movements including rockfalls, debris flows, deep failure of slope under the influence of gravity. Active and untimely monsoon has been noticed as one of the major factors for triggering landslides. After Nepal earthquake 2015, the cases of landslides in the areas most hit by the earthquake has increased. Multiple national and international agencies are actively using their efforts in monitoring landslide situations. Different interventions to minimize the impact of landslides in the weakened mountains are studied and the cases of post-earthquake landslides are analysed. This research suggests that intensified monsoon rainfall as result of global climate change is more likely to trigger landslides in post-earthquake situations.

KEY WORDS

Earthquake, Landslide, Hazard, Disaster

1. INTRODUCTION

Nepal is a Mountainous country located in South Asia. This land locked country has a total area of 147,516 sq. km., among which 68% are high hills and 15% are snow covered mountains (Himalayas). The capital city, Kathmandu, is located in central part of the country. With total population of 28,037,904, the country expands with an average length of 193 KM north-south and 885 KM east-west (Central Bureau of Statistics & Secret, 2015). Within this small range, the altitude of terrain varies from 58m to 8848m (top of the world- Mount Everest) from MSL. Considering this altitude difference along with climatic parameters, the country is geographically divided into three regions- Terai (plane), Hilly and Mountainous regions.

Natural disasters have always been a terror to human lives. Nepal is ranked 11th in the world in terms of vulnerability to earthquakes and 30th in terms of flood risks (Kafle, 2017). Since Nepal is located in the collision point of Indian Plate and Eurasian plate, earthquake is frequent due to active tectonic movement. These shakes and subsequent aftershocks often aid to increase in landslide risks. Along with, Monsoon in Nepal is active from June to September. Annual rainfall is measured minimum of 160 mm and maximum of 5500 mm resulting an average of 1600mm. Since earthquakes and aftershocks weakens the geography and destabilizes the slopes, heavy rain on these cracks makes landslides more risky (Faris & Wang, 2014). Hence, these two factors, earthquake and cloud burst, are considered as crucial roll triggering factors for landslides in this mountainous country (Dahal, Hasegawa 2008).

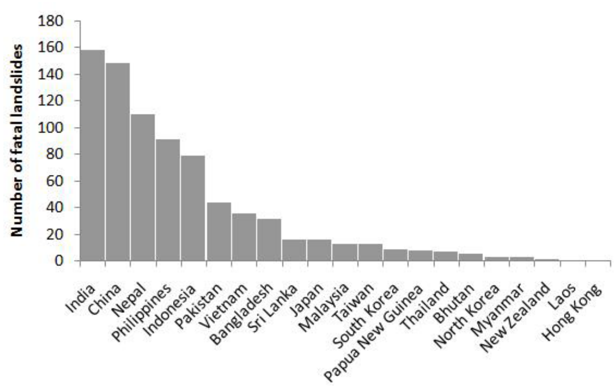

Fig 1:The number of recorded fatal landslides organized by countries from 2006 to 2008 (Source: Rey-Drapeau, 2010)

Analysis by Rey-Drapeau, 2010 ranked Nepal as the third country in Asia Pacific to have fatal landslide as shown in Figure 1. Even though landslide is a major disaster occurring in Nepal, it ranks the third after epidemics and earthquake as in figure 2. DRR Report of Nepal published by the Ministry of Home Affairs, would be important to consider, as per which landslide is the second most fatal disaster (MOHA, 2019). In between 1971-2016 report, landslide is reported as 5th key hazardous and in 2015& 2016, it is ranked 4th. This situation is influenced by the Gorkha Earthquake 2015.

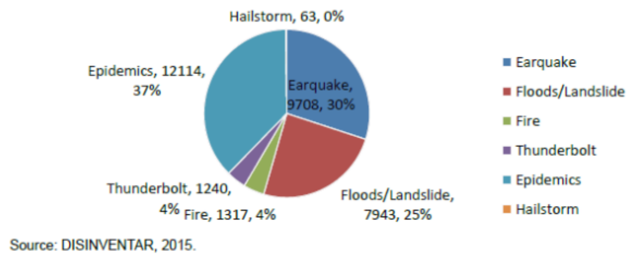

Fig 2:Number and % of death due to disaster in Nepal (1972-2014)
(Source: Kafle, S. K, 2017.)

2. ENVIRONMENTAL HAZARDS IN NEPAL

Natural hazards have made the lifestyle challenging in all geographic distribution. The common and frequent occurring hazards are flood, landslides, Glacial Lake outburst flood (GLOF), drought, earthquakes and wildfires (Kafle, 2017). As mentioned above, major portion of the country is hilly, slopes are prone to landslide. On the other side, due to lack of proper land use plan including the city planning, the population is distributed heterogeneously throughout the country. Mostly, people live near the riverbank because of their livelihood are always prone to flood and landslide. So, disasters, occurring wherever, often causes loss of lives and huge number of properties.

Land along with other natural resources in Nepal are not properly distributed to the population. This uneven distribution of land is considered as one of the main causes of informal settlements. These settlements are generally found along the river line or other vulnerable area (Kafle, 2017). In this situation, early warning system (EWS) has been developed as a topic of discussion, due to political unwillingness, these concepts are limited in papers (ibid). Status of EWS in different disaster situations are presented in table below:

Table 1:Status of EWS in different disaster situations

Natural Hazards	Occurrence[1]	Status of EWS[2]			
		Risk Knowledge	Monitoring and Warning Services	Dissemination and Communication	Response Capability
Earthquakes	All of Nepal	M	L	L	M
Floods	Terai, middle hills	H	H	M	M
Landslides	Hills and mountain	H	M	M	L
Debris flow	Hills and mountain; severe in areas of elevations greater than 1700m that are covered by glacial deposits of previous ice age	M	M	L	L
GLOF	Origin at the tongue of glaciers in Higher Himalayas, Higher Mountains, flow reach down to middle hills regions.	M	L	L	L
Avalanche	Higher Himalayas	M	L	L	L
Forest Fire	Hills and Terai(forest belt at foot of southern-most hills)	H	H	M	M
Drought	All over the country	L	L	L	L
Windstorm	All over the country	L	L	L	L
Hailstorm	Hills	M	M	L	L
Lightening	All over the country	L	L	L	L

[1]Source: (MOHA, 2009)

[2]Current Study.H:High ,Government agencies and NGOs involved ; M:Medium, Sporadic interventions; L:Low , NGOs in some areas ,project specific

3. LANDSLIDES: CAUSES AND TRIGGERS

Rotational slides and flows are the common type of landslides in Nepal. Besides these slides, topple and spread also occur in different situations. Nepal is prone to landslides because of very high peaks, active monsoon, rugged and fragile geophysical structure, high angles of slopes, complex geology, variable climate, active tectonic process, unplanned constructions, mass-movement and so on.

As human settlements are spread haphazardly without risk analysis, these settlements are most vulnerable to landslides. Besides human population, livestock, agriculture, forest, road, service centres, etc. are too vulnerable to disaster. Data regarding losses and damages varies from private source with government data because of legal/ administrative bound. Gaire et al., 2015 after analysing landslides for 30 years conclude that in an average, 278 people loss their life due to landslides. Similarly, 2892 families are affected directly or indirectly and total property loss is estimated to be an average of USD 7,855,670 per year.

Year	1983 – 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Nepal	5,829	196	441	232	131	141	114	216	134	135	240	252	120	219
EM-DAT	3,553	144	472	239	185	51	157	214	115	127	150	133	72	195
DesInventar	4,030	319	613	287	124	31	208	216	290	233	264	139	0	0

Fig 3: Deaths due to landslides (Source: Gaire)

Major causes and triggers of landslide in Nepal are listed in the table below.

Table 2:Cause and triggers of landslide in Nepal

Causes of Landslide	Trigger
• Very high peaks • Active Monsoon • Rugged and fragile geophysical structure • Undercutting of cliffs by river • High angle of slopes • Complex geology • Variable Climate • Active tectonic processes • Unplanned Constructions & mining • Mass movement (dry and wet)	• Cloud burst (200-1000mmm/day) • Uncontrolled flow of water on slope surface from over flooded steep gullies. • Toe cutting may activate failure by overtopping of rock blocks or slides in colluvium. • Earthquake • Blasting of rocks • Flash flood due to glacial lake outbursts

4. AUTHORITIES INVOLVED

Central Disaster Relief committee (CDRC) under the Office of Prime minister is the responsible body for any types of disasters. CDRC activities are conducted in coordination with Ministry of Home Affairs (MOHA). This central committee is active in policy formulation for rescue, recovery and relief (RRR). As per hierarchy of institutions, District Disaster Relief Committee (DDRC) is the district level local body to conduct RRR activities on the ground. DDRC is chaired by Chief District Administrator (CDO). Different NGOs and INGOs conduct post-disaster and pre-disaster programs in coordination to DDRC. Figure 4 describes the connection and functions of different authorities involved in disaster situation including landslides.

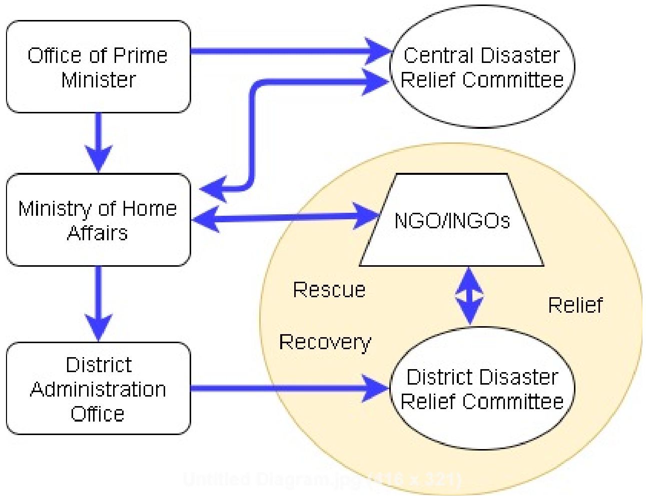

Fig 4 : Function and connection of different Authorities involved

5. EARTHQUAKE AND LANDSLIDES

Since Nepal is geographically located in collision line of two active plates, theories predict the mountains are newly formed by tectonics movement. Studies reveal that Nepal faces earthquakes of high magnitudes (above 6 rector) every 80-100 years. On April 25, 2015, an Earthquake of magnitude 7.6 rector scale hit Nepal. The epicentre of this devastating earthquake was Barpak of Gorkha district, North-west part of the country. According to government record, 8,020 people died, 16,033 were injured, 375 people missing, 202,157 buildings completely damaged, 214,202 buildings partially damaged and about 100,000 people were displaced due to earthquake (MOHA, 2015). International Centre for Integrated Mountain Development (ICIMOD) in collaboration with different national and international partners figured out 4,312 numbers of landslides due to this quake (The Himalayan Times, 2016). Even though the number is quite big, it was less than anticipated (ibid).

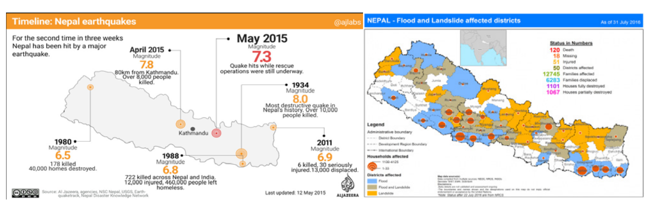

Fig 5: Earthquakes and Landslides in Nepal (Source:IMU/RCO, Aljagera

Thematic maps in figure 5 (Earthquake epi-center & Flood and Landslides) elaborates the relation between earthquake and landslides. Earthquakes of April and May 2015 of 7.8 & 7.3 rector respectively hit central part of the country. Landslides, marked as yellow in Flood and Landslide map is also concentrated in central part of the country. This visualization of landslides in post-earthquake situation explains that landslides are more likely to occur in the area where earthquakes occur frequently.

6. CASE OF STUDY: POST EARTHQUAKE LANDSLIDES IN UPPER BHOTEKOSHI

Upper Bhotekoshi region of Sindhupalchwok district is located in the central part of the country. Sindhupalchwok district is the worst-affected district from Nepal Earthquake 2015 where 3,065 people died and thousands of people were homeless (MOHA, 2015). The study area is close to Nepal-China boarder, a sensitive area with economic importance. After Earthquake on April, transportation networks were completely disturbed by numbers of landslides. In this paper we analysed series of landslides triggered by earthquake.

Fig 6: Phulping Bridge before Earthquake

Fig 7:Phulping Bridge after Earthquake

Fig 8: Phulping River without Bridge (23rd July, 2017)

6.1 Case 1: General Overview

Araniko Highway, one of the important connections between Nepal with China was blocked due to landslides caused by Nepal earthquake 2015. The geography is weakened by the shakes such that, even a moderate rainfall sometimes is enough to trigger landslides. For example- in these three pictures, we can visualize Larcha Bridge area before earthquake and after earthquake. The post-earthquake slides still continues but triggering factors are different, heavy rainfall being the most. A big mass of rock fall onto the bridge this monsoon (23rd July 2017) and completely collapsed the bridge.

Case 2: Landslide Monitoring

Nepalese Society for Earthquake Technology (NSET), British Geological Survey (BGS) and Durham University UK together started to monitor landslides after the earthquake. This team focused on landslides that are (can be) caused or triggered by earthquake. The figure 9 demonstrates how the landslide can be mapped before and after the earthquake using satellite images of different time. This team is working on central part of the country- Upper Bhote Koshi region being one study area. Satellite images of different timeframe were used to generate landslide inventory.

Geostationary Satellites are being specially tasked to collect images throughout the monsoon. Temporal analysis of satellite images is used to track previous and new slides. Ongoing monsoon landslides monitoring via satellite image analysis and ground receivers are challenging task for the team. Use of web and social media (facebook, twitter, youtube, etc.) for landslide monitoring in this project is new intervention to reduce deaths and properties through public participation in early warning system in landslide monitoring.

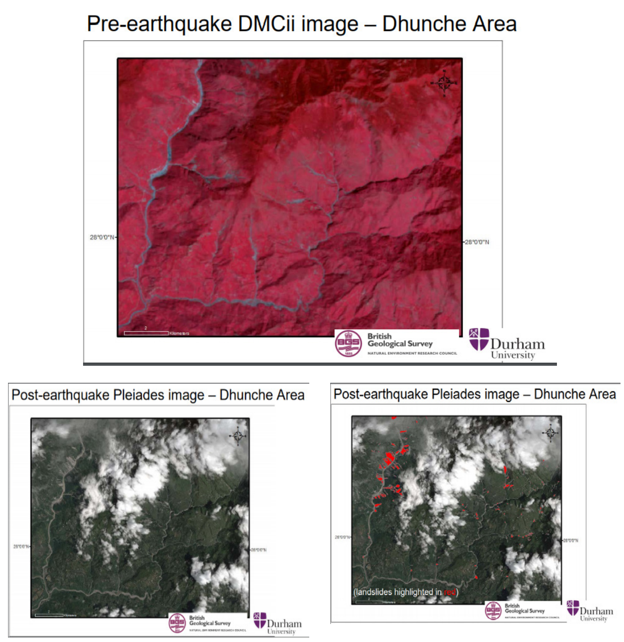

Fig 9:Satellite images for landslide monitoring

Along with satellite image analysis, ground receiver stations are used with real time web-based data logging system, remote access to data via cellular, WIFI or Ethernet. These stations along with continuous mass movement measures rainfall and climatic conditions. Ten such stations are being continuously observed along Upper Bhotekoshi region. The major task of these station is to investigate the mechanics of post-earthquake slope failure with recording the ground crack opening with precision of ±2mm. The installation of these devices are as in figure 10.

Fig 10:Ground receivers for landslide monitoring

Fig 11: Examples of post-earthquake landslides

Landslide and flood have been a serious problem in Nepal. Due to varying topography, landslides in the are common. After 55 years of studies in High Himalayas, researchers reveal that landslides in Nepal occur due to wide range of rainfall duration (5 hours a day and maximum 90 days in a season) (Dahal, Hasegawa, 2008). Even though active monsoon has been triggering factor for most of the slides, high slopes and earthquakes are major causes. Involvement of multi sectoral agencies but lack of coordination among them is one of the major challenges in understanding, analysing and preparing for landslides. Limitation of relevant data, budget, technology, infrastructure, human resources, policies, early warning systems, etc. are additional challenges (Kafle, 2017).

7. CONCLUSION

Different case studies discussed in previous sections conclude that landslides are more to occur in case of post-earthquake situations. Coordination among agencies working for disaster risk reduction needs to be enhanced in order to achieve combined goal for reducing risks from disasters. Along with, legal frameworks also shall ensure the establishment and mobilization of government, non-government and private sectors . Regular monitoring of landslides along with geological and geomorphological properties of soil can come up with relevant preparedness. Continuous monitoring of fatal landslides and implementation of early warning system in participatory approach can prevent hazards from being disasters. As mentioned in Sendai Framework for Disaster Risk Reduction (2015-2030), use of geospatial data for generating landslide hazard maps can be a best way to increase disaster risk information in local level.

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QUANTIFICATION OF SURFACE VELOCITY AND ICE THICKNESS OF GLACIER: A CASE STUDY OF G9 GLACIER, HIDDEN VALLEY NEPAL

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ABSTRACT

Nepal being a portion of Hindu Kush Himalayan region is one of the greatest concentration of frosty masses. The loss of ice on that region reflects the climate change coming almost pulverizing billions of people living downstream. This is why regular monitoring of the glaciers on every region is important not only to have insight into the glacier change but also to mitigate the effect of it. The satellite image act as substitute to ground based approach that gives much more flexibility for monitoring glaciers on a regular basis. Therefore, this research aimed to map the decadal changes in area of the glacier and the ice thickness using surface velocity derived from satellite imageries of Glacier G9 located in Hidden valley of Mustang district Nepal. Multitemporal Landsat satellite images dating back from 1995 to 2015 were utilized. The current research involved the calculation of snow index like Normalized Difference Snow Index (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 0.417□□^{2}on an average over the period. The ice velocity of the glacier was estimated. Laminar flow approach was utilized to find the ice thickness of glacier based on the evaluated velocity information.

KEY WORDS

glaciers, remote sensing, NDSI, surface velocity, ice thickness

1. INTRODUCTION

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. As of now, 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) in Nepal, itself facing severe effects in several glaciers.

This study aims to monitor the G9 Glacier of Hidden valley, Mustang district of Nepal for the period of 1995-2016 utilizing the Landsat imageries with the objective of evaluating the ice thickness change over the period. The advantages that can be observed by this technique are numerous, but the most substantial one being the ice thickness estimation over the whole glacier (i.e. larger glacier extent) without requiring the time consuming and expensive ground-based survey.

Mountainous regions are more likely vulnerable to climate change and Nepal being mountainous area lacks comprehensive study of glaciers. Lack of temporal glacier data in Nepal has prevented a comprehensive assessment of glacier surface velocity change, thickness change which may result to many severe natural calamities and may take life of many creatures. In recent years, however, people in the high mountain region of Nepal have noticed that the snow line is receding and that glacial lakes are growing at an abnormal rate which may result to burst of those glacier lakes in near future. (Fushimi et al. 1985). The third assessment report of the Intergovernmental Panel for Climate Change (IPCC 2001b) indicated a projected warming in the Asian region of 3.0°C by 2100. These changes cannot be generalized across the region, and the implications for glaciological hazard events and changes in water resources are difficult to predict (ICIMOD 2011). In order to understand these changes and project future scenarios, it is necessary to know the present status of glaciers and have an indication of the extent and rate of ongoing change. So, this paper describes an assessment of the surface velocity and thickness of G9 glacier in temporal period of 20 years which may be the preliminary data source to study further regarding these glaciers.

Having said that, there is a lot more studies to be done as 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 remains 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. All these study can provide more lights to study the pattern of surface velocity and even thickness of ice. The quantification of changing surface velocity and ice thickness on such extremely difficult topographic terrain through ground-based surveying methods is usually not economic, time consuming and is unable to provide amount of glacier ice loss in terms of real time spatial and temporal extent. To combat the problem, satellite based remote sensing is a powerful approach for routine assessment of spatial and temporal variations in the velocity and thickness of ice loss over the study region.

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. Figure 1 represents the study area of G9 Glacier which extends from 5625 meters to 6223 meters above sea level with an approximate area of 1 sq.km.

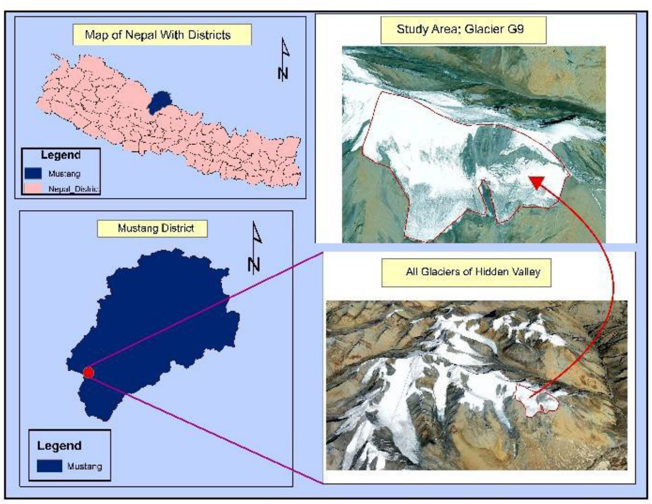

Figure 1: Study Area (G9 Glacier, Nepal)

3. METHODOLOGY

The overall workflow used in research is shown in Figure 2.

3.1 Image Preprocessing

The first step included the download of Landsat imageries from USGS Archive. These satellite imageries were then preprocessed. All image processing tasks were implemented on ENVI platform. The purpose of image pre-processing was to make sure all of the images similar so that they can be considered to be taken at uniform environmental conditions, and by the same sensors. The process of conversion of digital numbers (DNs) into radiance or surface reflectance is a requirement for qualitative analysis of multiple images acquired on different dates. This process included radiometric correction. Finally, calibrated satellite imagery was obtained.

3.2 NDSI & Glacier Area Calculation

Normalized Difference Snow Index (NDSI) highlights snow cover areas by using a combination of visible (green band typically) and shortwave infrared (SWIR) wavelengths. Mathematically, NDSI is represented by the following (Equation 1) with green band ranging between (0.5 - 0.6) µm and (1.55 -1.75) µm respectively:

$$NDSI = \frac{(Green-SWIR)}{(Green+SWIR)} \qquad (1)$$

This is the step which deals with separating ice and non-ice area. With the help of QGIS, the change in Glacier extent was determined.

3.3 Surface Velocity Determination

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 an interval of 10 years is because of the fact that surface velocity with in an interval of 5 years was found to be insignificant. In order to calculate the surface velocity, two subsequent images were used (i.e., to find the 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 provided the output as East/West, North/South Displacement and Signal to Noise Ratio (SNR). 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 Aster DEM) to determine the thickness of the glacier in the particular year using the concept of Laminar flow (Cuffey and Paterson, 2010).

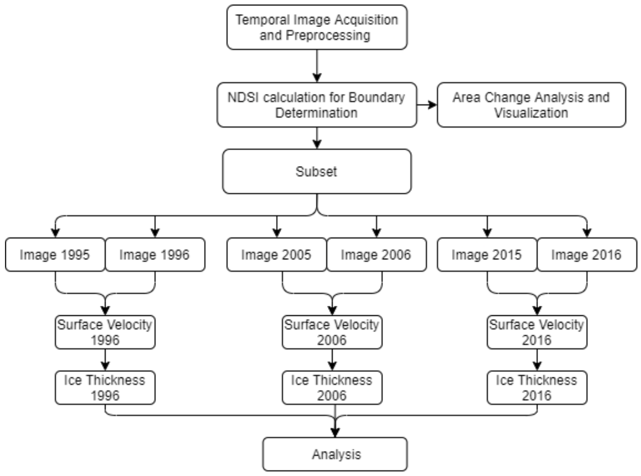

Figure 2: Overall workflow to estimate surface velocity and ice thickness of glacier.

3.4 Ice Thickness Determination

According to (Cuffey and Paterson, 2010) Ice thickness was estimated using the equation of laminar flow 2 which is represented as:

$$U_s = U_b + \frac{2A}{n+1}\tau_b^n H \qquad (2)$$

Where U_s and U_b are surface and basal velocities, respectively. To the 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 $*10^{-24}\ Pa^{-3}\, s^{-1}$ for temperate glaciers; (Cuffey and Paterson, 2010). The basal stress 'τ_b' is modelled by using equation (3);

$$\tau_b = f\rho g H \sin\alpha \qquad (3)$$

where r is the ice density, assigned a constant value of 900 kg/m^3(Farinotti and others, 2009a), g is acceleration due to gravity (9.8ms–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 (2) and (3) we computed the ice thickness (H) by using the equation (4) represented as shown below:

$$H = \sqrt[4]{\frac{1.5Us}{Af^3(\rho g \sin\alpha)^3}} \qquad (4)$$

4. RESULT AND DISCUSSION

4.1 Area of Glacier G9 at different time

The area of Glacier 9 is 1.39 km^2. We have studied the change in ice area of glacier in every 5 years' interval from 1995 to 2015 and the result has shown that its area has been changing continuous. The glacier area changes from 1995 to 2005 is 0.3668 km^2 and from 1995 to 2015 is 0.4174 km^2 where positive sign mean the increase in area and negative sign means the decrease in area. The cumulative change in area of 29.98 % from year 1995 to 2015(Table1).

Table 1: Summary of change in ice area of Glacier.

Year	AREA(sq.km)	CHANGE	∑CHANGE
1995	1.3924	0	0
2000	1.4052	0.0128	0.0128
2005	1.0256	-0.3796	-0.3668
2010	1.1135	0.0879	-0.2789
2015	0.975	-0.1385	-0.4174

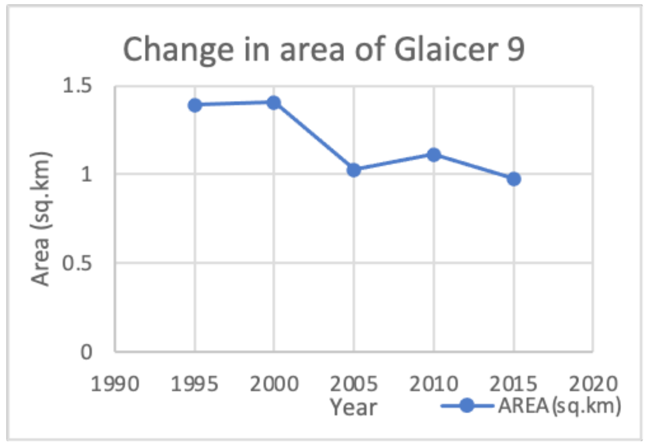

Figure 3: Change in area of Glacier from NDSI.

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 5.12 meters/year in the year 1996 to 5.32 meters/year in year 2006 and then decrease to 2.73 meters/year in the year 2016. In addition to this, it has also been observed that the maximum surface velocity of the glacier was observed to be ranging from minimum 22.55 meters/year to the maximum of 40.05 meters/year for the year 2016 and 1996 respectively.

Year	Mean Surface velocity (meters/year)	Maximum Surface velocity(meters/year)
1996	5.120266	40.05423
2006	5.323428	35.55197
2016	2.730879	22.5484

Table 2: Summary of Mean Surface Velocity and maximum surface velocity.

The surface velocity map for the three different time period (1996, 2006 and 2016) thus obtained are presented in the figure 4, 5 and 6 respectively.

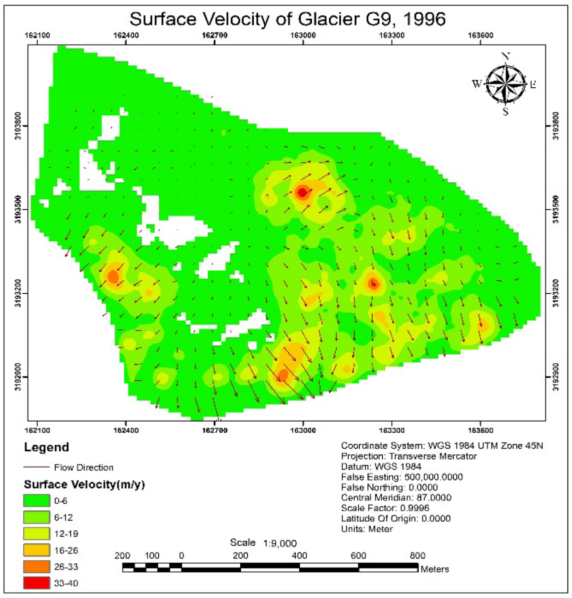

Figure 4: Surface Velocity of G9 Glacier at 1996.

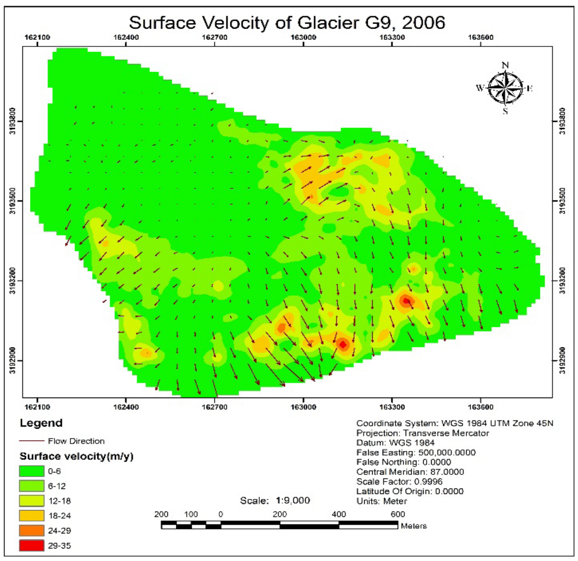

Figure 5: Surface Velocity of G9 Glacier at 2006.

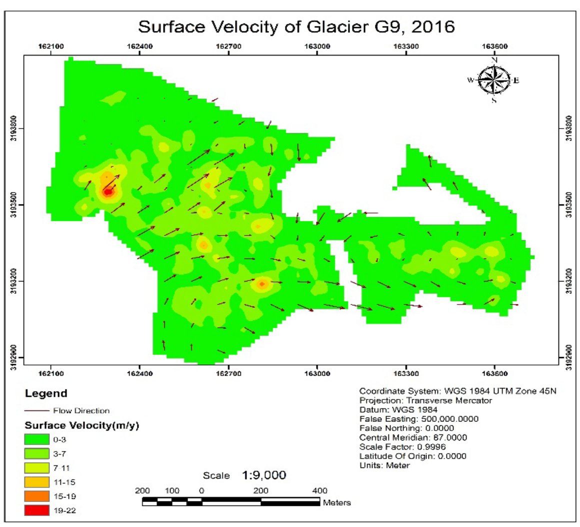

Figure 6: Surface Velocity G9 Glacier at 2016.

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 86.626 m and 33.76 m in 2006 as shown in Table 3. The mean thickness of glacier decreases by 0.2215m from 1996 to 2016.

Table 3: Summary of Mean Thickness and maximum thickness of Glacier.

Year/Glacier	Mean thickness (m)	Maximum thickness (m)
1996	31.1275	82.42691
2006	33.76461	86.62569
2016	30.90598	77.44405

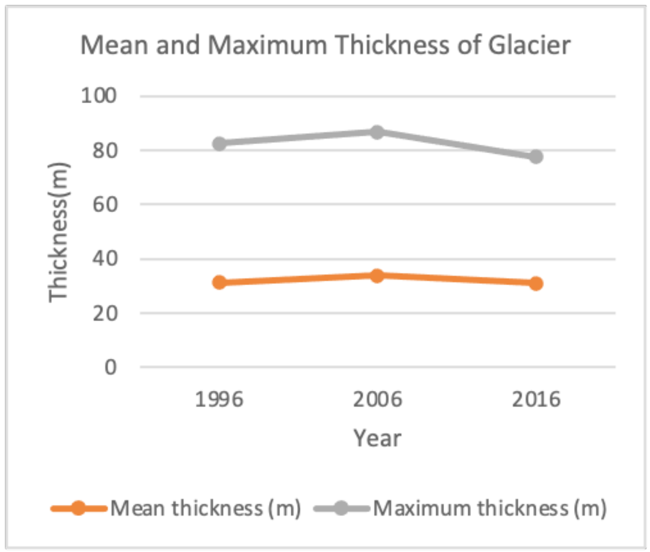

Figure 7: Change in Thickness of Glacier

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.

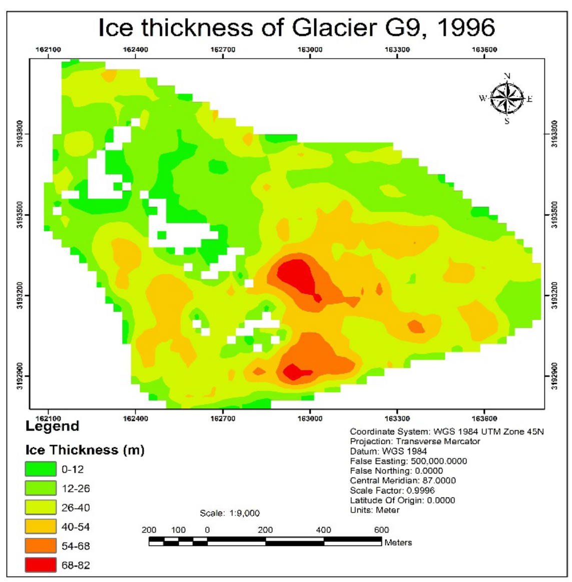

Figure 8: Thickness of G9 Glacier at 1996.

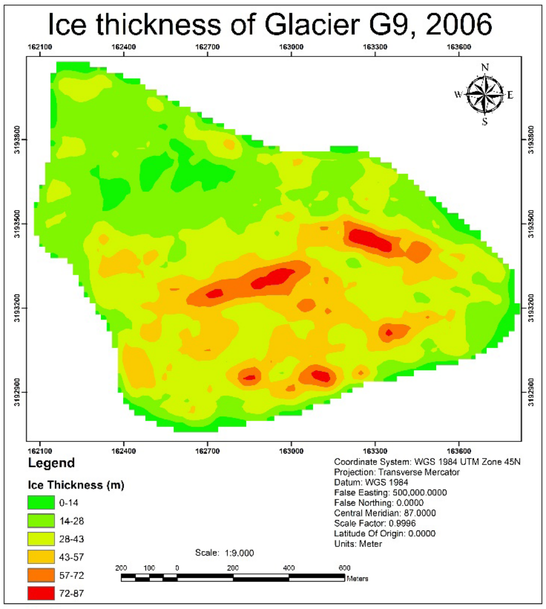

Figure 9: Thickness of Glacier G9 in 2006.

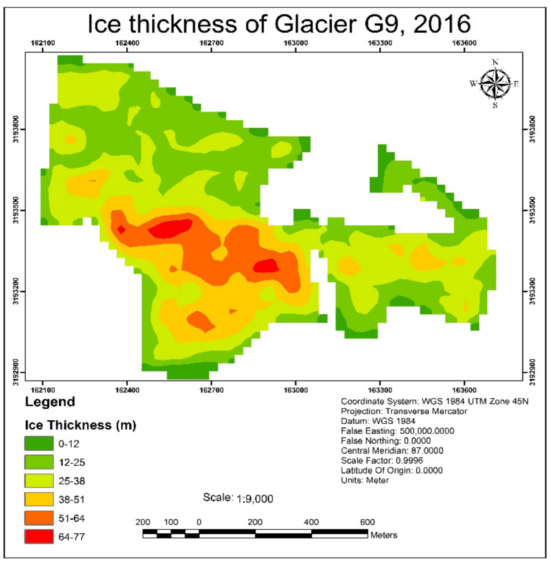

Figure 10: Thickness of Glacier G9 in 2016.

4.5 Uncertainty Analysis

In order to quantify the total uncertainty (for a particular value of basal velocity, i.e. 25% of surface velocity), we fix the values for dUs(change in surface velocity per year), df(infinitesimally small change in scale factor), d*p*(variation in ice density over the depth), d(sin)/(sin)(derivative of sine of slope angle per unit sine of slope angle) and dA(creep parameter). 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 dUs was fixed as 3.5 meter/year, which is the average of the differences (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 $2.4 * 10^{-24}$ Pa^{-3} s^{-1}(Swaroop et al., (2003)). We set dA to be the difference between the value assigned by us and $2.4 * 10^{-24}$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 Aster DEM for the Himalayan region is 11 m (Fujita et al., 2004). Therefore, the term d (sin $\boldsymbol{\alpha}$)/(sin $\boldsymbol{\alpha}$) has a value of 0.09. Variation in ice density, over the depth of the glacier is not known. We assume relative uncertainties of 10%, and take d*p* as 90 kg m–3 (Swaroop and others (2003). Given parameters to find uncertainties are:

U_s= 2.731 meters/year

dU_s= 3.5 meters/year

dA= $0.84 * 10^{-24}$

A= $24 * 10^{-24}$

df = 0.1

f= 0.8

d*p*= 90

p= 900

The uncertainty in depth estimates is quantified by differentiating the formula taken to find the height in previous section which results in following:

$$\frac{dH}{H} = 0.25\left[\frac{dUs}{Us} - \frac{dA}{A} - 3\frac{df}{f} - 3\frac{d\rho}{\rho} - 3\frac{d(\sin\alpha)}{(\sin\alpha\ )}\right.$$

Substituting these values into Equation of height, we find the maximum relative error for G9 Glacier is ± 8.45% (assuming that the parameters vary independently and randomly).

5. CONCLUSION

Ice thickness for glacier G9 from surface velocities and slope was estimated using the flow law equation of ice. This study provides insight into the temporal variation of glacier over a period of 20 years which vividly shows that the future shrinkage of the glacier area needs a more detailed investigation to understand its intrinsic relationship with its surrounding climate.

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 depth of the ice loss was estimated with an uncertainty of ±8.45 %.

In fact, all these works done may not resemble the real ground scenario. Use of high resolution temporal DEM can ensure more accurate and precise result as this research is based on 20 years of time. Similarly, the work would have been more reliable with field verification. The use of SAR datasets could provide next dimension to validate the result beside uncertainty analysis. We conclude that these above mentioned aspects would bring new depth to study ice thickness.

To conclude, environment enthusiast may use this result as this provides great aid to study the impact of climate pattern on glaciers. Environment monitoring organizations, disaster relief organizations are the highly benefited stakeholders as this research can be benchmark to study in-depth consequences of ice loss.

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COMPARATIVE ANALYSIS OF DIFFERENT METHODS OF SPATIAL INTERPOLATION: INTERPOLATING ANNUAL PRECIPITATION ON THE KOSHI BASIN

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ABSTRACT

Two spatial interpolation methods (Inverse Distance Weighting (IDW) and Ordinary Kriging (OK)) which are often used in the Geographical Information System (GIS) have been applied on the mapping of annual average amount of precipitation in Koshi Basin, Nepal. Annual average precipitation (mm) from 55 meteorological stations over the time period from 1981 to 2010 were used for the study. The time period of 30 years was split into three decades like 1981-1990, 1991-2000 and 2001-2010. Using the annual average precipitation (mm) of three different time periods, spatial interpolation was done for the study area. The IDW and Ordinary Kriging (OK) were compared with each other by cross validation technique and analyzed. Three different parameters; coefficient of determination (R^2), mean absolute error (MAE) and root mean square error (RMSE) were calculated for IDW and OK methods. R^2 of OK are better than IDW in three different time periods. RMSE error was less in 1981-1990 time period for both methods (611.23 mm for IDW and 553.31 mm for OK). However, MAE was least in 2001-2010 for both the methods.

KEY WORDS

Precipitation, Interpolation, IDW, Ordinary Kriging

1. INTRODUCTION

For hydro-meteorological studies, precipitation data are vital input. In this regard, if the representation of spatial precipitation is accurate, then the study of it can be perceived as success (Shahbeik et al., 2014). In addition, rainfall information plays a vital role in hydrological modelling, predicting precipitation events like draught and floods, optimizing water resource management and enhancing capability to cope with natural disasters (Michaelides et al., 2009). South Asian region is generally considered as vulnerable zones to climate change (Hoque et al., 2016). Mountainous area is highly susceptible to climate change and it is also the source of drinking water supply, irrigation etc (McDowell et al., 2013). Extreme rainfall has direct impact to mountainous region. Therefore, it is necessary to understand spatial and temporal distribution of extreme rainfall to identify vulnerable areas (Shrestha & Baidar, 2018). However, meteorological stations for measuring precipitation are generally sparse and the available data are not sufficient to characterize the highly variable precipitation and its spatial distribution (Keblouti et al., 2012). Thus, it is necessary to find out the methods to estimate rainfall precipitations where measuring stations and rain gauge are not installed using the data from surrounding weather stations. Spatial interpolation can be used for estimation of precipitation at unsampled locations using surrounding sample points. It is used to estimate values of unknown locations using the values of measured locations (Borges et al., 2016). Though there are many spatial interpolation methods, it can be difficult to choose the best method that produces actual distribution and pattern of the data. Based on the characteristics of data, the advantage and disadvantages of each interpolation can be analyzed (G. Pellicone et al., 2018). The selection of interpolation methods depends on the aim of the study area, and the terrestrial context of that area (surface, network density etc.) (Keblouti et al., 2012).

Many interpolation techniques and methods have been adapted for spatial interpolation for hydrological modeling. Pellicone et al. (2018) used different spatial interpolation methods such as inverse distance weighting (IDW), ordinary kriging (OK), kriging with external drift (KED), ordinary cokriging (COK) and empirical Bayesian kriging (EBK) in a region of southern Italy (Calabria) to choose best approach for producing actual precipitation field surface. After performing cross validation and visual analysis, they found kriging performed better than IDW. Moreover, among them, the kriging with an external drift gave the smallest error of prediction. Chen & Liu (2012) has examined IDW method to estimate spatial rainfall distribution in the middle of Taiwan. Using rainfall data from 46 rainfall stations, the author concluded that IDW to be a suitable method of spatial interpolation to predict rainfall data. Xu et al. (2015) compared three different interpolation techniques IDW, Ordinary Kriging (OK) and Cokriging (CK) for daily rainfall data in Sichuan Province of China. Cross validation technique was applied for prediction performance of three methods and the paper concluded that both OK and CK methods recorded smaller mean absolute error and root mean square error than IDW method. Similarly, Nusret & Dug, (2012) applied IDW and Kriging methods for spatial interpolation of annual precipitation data in Bosnia and Herzegovina. They found kriging method was better than IDW. Shahbeik et al. (2014) estimated minerals using IDW and ordinary kriging (OK) based on error estimation in the Dardevey iron ore deposit, NE Iran. Result obtained by the study indicates that OK method is reliable than IDW for interpolation. Gilmanshina et al., (2016) used eight different interpolation methods for modeling the monthly rainfall for Iran from 1975 to 2014. In the study 140 stations were considered for the study and different interpolation methods were compared using RMSE value for each interpolation methods.

On reviewing various literature, it can be seen that for the estimation of spatial distribution IDW and Kriging are popular techniques worldwide. The aim of this research is to develop interpolated precipitation surface of Koshi river basin area by IDW and Ordinary Kriging method and to compare the resulting surface generated by them.

2. METHODOLOGY AND METHODS

2.1 Study Area

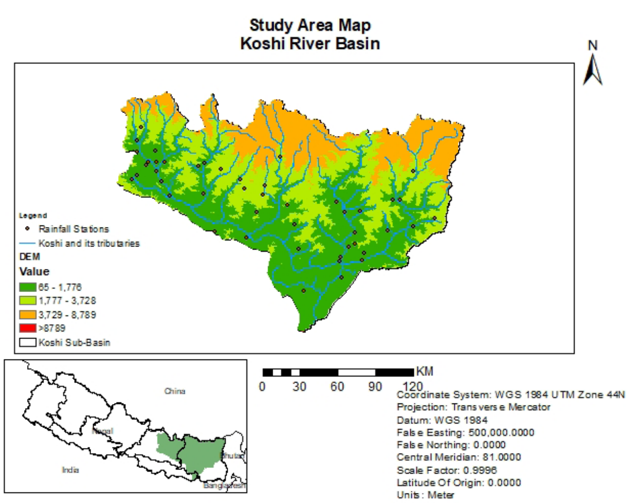


Fig 1. Study area with elevation range, precipitation stations along with Koshi tributaries (Data source: Survey Department, DHM)

The study was conducted in Koshi river basin in Nepal. It covers around 30,000 km^2 with elevation ranging from 65 m meters above sea level (amsl) in low valley (terai region) to more than 8000 m in the great Himalayan range. The basin area lies within 26˚51' N and 29˚ 79' N latitudes and 85˚24' E and 88˚ 57' E longitudes. It is the largest river basin in Nepal, covering 18 districts. It consists of seven major sub-basins, namely Sun Koshi, Indrawati, Dudh Koshi, Tama Koshi, Likhu, Arun and Tamor (Shrestha & Baidar, 2018). Koshi basin consists of trans mountain region, central and eastern mountain region, central and eastern hill regions (Agarwal et al., 2014).

2.2 Data Sources

Department of Hydrology and Meteorology (DHM) is one of the major sources of data for this research study. Precipitation data are acquired from stations maintained by DHM. There are 60 operating meteorological stations in the Koshi basin. All the past data from these stations were analyzed and it was found that there are 55 stations are with long term data (at least 30 years) in the Koshi basin for precipitation.

Department of survey is another source for the GIS data of administrative boundary, river network, landcover and digital elevation model (derived from contours of topographical map) whereas basin boundary and sub-basin boundary were delineated from digital elevation model. All the GIS data layers provided by Department of Survey was in Nepal Nagarkot projected co-ordinate system.

2.3 Exploratory Data Analysis

The daily rainfall data contained outliers and null values. First, outliers and null values were detected and removed from the dataset. Ten years of time period was chosen to get insights and visualize the pattern and distribution of the annual average rainfall of 55 different stations. As the station 1123 (Manthali) was in operation since 1991 and there was no precipitation data recorded before. One of the techniques to handle unavailable data is to ignore it but while ignoring, it significantly reduced the available data. Thus, we replaced missing data by taking average of two decades i.e. 1991 to 2000 and 2001 to 2010.

The characterization of data can be analyzed by using different parameters like minimum, maximum, median, standard deviation, skewness, standard deviation, kurtosis etc. Descriptive statistics of first five meteorological stations for time period 1981-1990, 1991-2000 and 2001-2010 is shown in Table 1.

2.4 Interpolation Methods

In this study, often used interpolation methods IDW, Ordinary Kriging (OK) are used for modeling the distribution of rainfall data in GIS environment. ArcGIS, a GIS software developed by

Table 1:Descriptive statistics of first five meteorological stations

Time period: 1981- 1990								
Station ID	**Station Name**	**Min**	**Average 1981-1990**	**Median**	**Max**	**Kurtosis**	**Standard Deviation**	**Skewness**
1006	Gumthung	2974.90	3931.05	4157.25	4620.60	-1.56	656.21	-0.50
1008	Nawalpur	2213.30	2471.15	2366.50	3182.30	3.04	300.32	1.78
1009	Chautara	1899.40	2141.02	2030.15	2794.10	2.64	279.67	1.65
1016	Sarmathang	2952.00	4047.59	4091.50	4508.30	3.80	526.43	-1.82
1017	Dubachaur	2193.20	2475.73	2444.95	2834.30	-0.75	208.55	0.47
Time period: 1991- 2000								
Station ID	**Station Name**	**Min**	**Average 1991-2000**	**Median**	**Max**	**Kurtosis**	**Standard Deviation**	**Skewness**
1006	Gumthung	4080.90	2548.70	4110.90	5526.70	-0.35	925.31	0.09
1008	Nawalpur	2557.40	2050.50	2641.35	3044.00	-0.02	310.22	-0.50
1009	Chautara	1848.70	1355.80	1859.00	2265.50	-0.13	279.68	-0.27
1016	Sarmathang	3132.00	1556.20	3374.90	3967.20	2.86	785.40	-1.56
1017	Dubachaur	2448.10	1958.60	2517.30	2801.70	-1.11	293.46	-0.62
Time period: 2001-2010								
Station ID	**Station Name**	**Min**	**Average 2001-2010**	**Median**	**Max**	**Kurtosis**	**Standard Deviation**	**Skewness**
1006	Gumthung	3937.50	1715.20	4108.40	1715.20	1.12	1001.67	-1.06
1008	Nawalpur	2421.70	1355.70	2506.00	1355.70	2.50	455.52	-1.37
1009	Chautara	2073.30	884.80	2237.20	985.50	0.48	640.66	-0.72
1016	Sarmathang	2887.10	1059.90	2964.90	1059.90	4.94	718.33	-1.76
1017	Dubachaur	2117.80	1185.60	2373.10	1185.60	-0.42	574.37	-0.96

ESRI (Environmental Systems Research Institute, California, USA) is used for the study. Deterministic methods and geostatistical methods are mathematical functions where typical parameters sets are used for model calibration and developing a continuous surface from sample points (Shahmohammadi-Kalalagh & Taran, 2020). The surface created by deterministic methods are based on the degree of similarity of measured values. In contrast, geostatistical techniques use the statistical properties of measured points to measure spatial correlation between neighboring observations and assess the uncertainty of estimations (Amini et al., 2019). IDW, a deterministic method considers only distance from station for interpolations using mathematical formula whilst Kriging, a geostatistical method interpolates with the spatial distribution of the stations besides the distance (Pellicone et al., 2020). The general mathematical expression of interpolation methods is (Johnston et al., 2001):

$$P = \sum_{i=1}^{n} \lambda_i \, P_i \qquad (1)$$

P: Predicted value at the interpolation point

P_i: Observed value at point i

n: Number of sample points

λ: Weight of the observed value at point i

2.4.1 Inverse Distance Weighting (IDW)

IDW technique is a type of deterministic method which computes an average value for unsampled locations using weighted average of values at nearby measured points. Data points are weighted during interpolation. Let P be estimated value at interpolation point, Pi be the observed value at point i, n be sample points, Di be distance between interpolation and observation points and k be the weight parameter for IDW, then value at interpolation point can be estimated as follows: (TANJUNG et al., 2020).

$$P = \frac{\sum_{i=1}^{n} \frac{1}{d_i{}^k} P_i}{\sum_{i=1}^{n} \frac{1}{d_i{}^k}} \qquad (2)$$

The greater value of k gives higher weights to the closer samples than the farther ones for estimating surface values at unsampled location. For the small value of k, it gives equal weights to all the points within the search radius (Xu et al., 2015).

2.4.2 Kriging

Kriging is a geostatistical method for spatial interpolation that can assess the quality of prediction with estimated prediction errors. It is based on semi variogram theory and structure analysis. Spatial variation are selected based on the available semi variogram that are calculated from number of input points (Varatharajan et al., 2018). Several methods of Kriging interpolation like simple kriging (SK), ordinary kriging (OK), CoKriging(CK) are available.

Ordinary Kriging (OK)

Ordinary kriging (OK) focuses on the spatially correlated component and it uses the fitted semi variogram directly for interpolation. The principle of this method is that instead of using simple smooth mathematical model, it uses a random surface that can describe continuous spatial change appropriately because the spatial change is irregular (Stein, 2012,Xu et al., 2015).

Generally, this method includes:(Shahmohammadi-Kalalagh & Taran, 2020).

- Derivation of experimental semi variogram for spatial autocorrelation.
- Defining best experimental semi variogram model which characterizes better spatial autocorrelation in the data.
- Interpolation using experimental variogram.
- Use of kriging interpolated surface to produce final output.

For unsampled location u, using linear combination of sampled observation, OK estimates value at unsampled location u by (Zhang & Srinivasan, 2009)

$$Z(u) = \sum_{i=1}^{n} \lambda_{ui} Z(x_i) \qquad (3)$$

Optimum weights can be calculated as follows:

$$h_{ij} \sum_{j=1}^{n} \lambda_{uj\gamma}(h_{ij}) + \mu(u) = \gamma(h_{ui}) \qquad i = 1, \dots, n \quad (1)$$

$$\sum_{j=1}^{n} \lambda_{uj} = 1 \qquad (2)$$

Where $u(u)$ is weight constraint, h_{ij} be the separation between sampled location x_i and x_j. The semi variance can be calculated as $\gamma(h)$

$$\gamma(h) = \frac{1}{2N}\sum^{N(h)}(z(x_i) - z(x_i + h))^2 \quad (3)$$

h: difference between two-point location
$N(h)$: number of pairs of points separated by h

$z(x_i) - z(x_i + h)$: difference in value between x_i and $x_i + h$

Semi variogram

Semi variogram calculates the level of spatial dependency and the spatial auto correlation between pairs of points separated by various distance (lags). Following parameters are in semi-variogram analysis (İçağa & Taş, 2018).

Range: The lag distance at which the semi variogram reaches the sill value

Sill: The value at which the model first flattens out

Nugget: The value at which the semi-variogram (almost) intercepts the y-value.

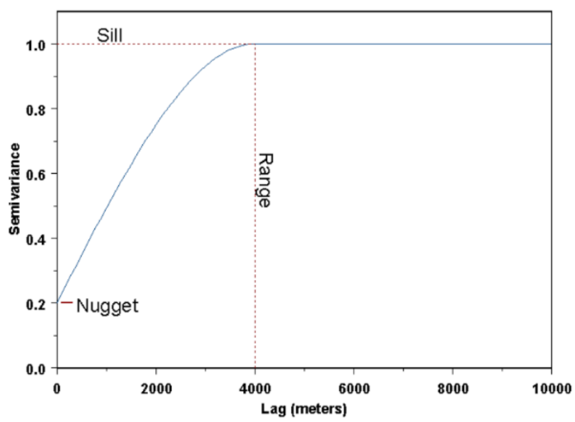


Fig 2: Semi variogram (Sekhon et al., 2019)

2.5 Cross Validation

Cross validation method can be used for validation of the model. The performance of IDW and OK methods are compared in terms of root mean square error (RMSE), mean absolute error (MAE) and coefficient of determination (R^2).

Cross validation is a technique to evaluate the performance of interpolation model. Using observed values and predicted values, it compares different performance matrices. Thus, it is used to suggest the suitable method of interpolation. Leave one out cross validation method eliminates one station every time from the observation data and considers other stations only for interpolation and the value of that eliminated station is estimated using remaining observation sample of the model (İçağa & Taş, 2018).

Different performance matrices are used for the model evaluation in our study which are R^2(coefficient of determination), RMSE (root mean square error), MAE (mean absolute error).

2.5.1 R^2 (Coefficient of determination)

It represents how well the predicted value fits the original value. The range of R^2 is 0 to 1. Closer to value to 1, the better a model is. It is calculated as below (İçağa & Taş, 2018).

$$R^2 = \left\{\frac{\sum_{i=1}^{n}[(P_{o,i} - \bar{P}_o)(P_{m,i} - \bar{P}_{m,i})]}{nS_oS_m}\right\} \quad (4)$$

where,

$P_{m,i}$	Modeled value at point i
$\bar{P}_m$	Mean of modeled
$P_{o,i}$	Observed value at point i
$\bar{P}_o$	Mean of observed time series
S_m	Standard deviation of modeled time series
S_o	Standard deviation of observed time series
n	Number of observations

MAE (Mean Absolute Error)

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|P_{m,i} - P_{o,i} \quad (8)$$

where

$P_{m,i}$	Modeled value at point i
$P_{o,i}$	Observed value at point i
n	Number of observations

RMSE (Root Mean Square Error

It is the square root of mean square error (RMSE). RMSE is calculated by squaring the average difference between original and predicted values over data set. RMSE measures standard deviation of residuals.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_{m,i} - P_{o,i})^2} \quad (9)$$

where,

$P_{m,i}$	Modeled value at point i
$P_{o,i}$	Observed value at point i
n	Number of observations

The raw data was first preprocessed in MS Excel. 30 years of time period was split into 3 spans of decades and daily basis precipitation data was converted into annual average precipitation for 10 years' time periods i.e. from 1981-1990, 1991-2000 and 2001-2010 respectively. The exploratory data analysis was performed for the data. Two often used interpolation methods called IDW and Ordinary Kriging (OK) were used. For IDW method, inverse power parameter was adjusted and semi variogram analysis was done in case of OK. Both of the interpolation methods were evaluated using leave one out cross validation method. Finally, the performance of models was compared using R^2, MAE and RMSE.

2.6 Methodological Framework

The raw data was first preprocessed in MS Excel. 30 years of time period was split into 3 spans of decades and daily basis precipitation data was converted into annual average precipitation for 10 years' time periods i.e. from 1981-1990, 1991-2000 and 2001-2010 respectively. The exploratory data analysis was performed for the data. Two often used interpolation methods called IDW and Ordinary Kriging (OK) were used. For IDW method, inverse power parameter was adjusted and semi variogram analysis was done in case of OK. Both of the interpolation methods were evaluated using leave one out cross validation method. Finally, the performance of models was compared using R^2, MAE and RMSE.

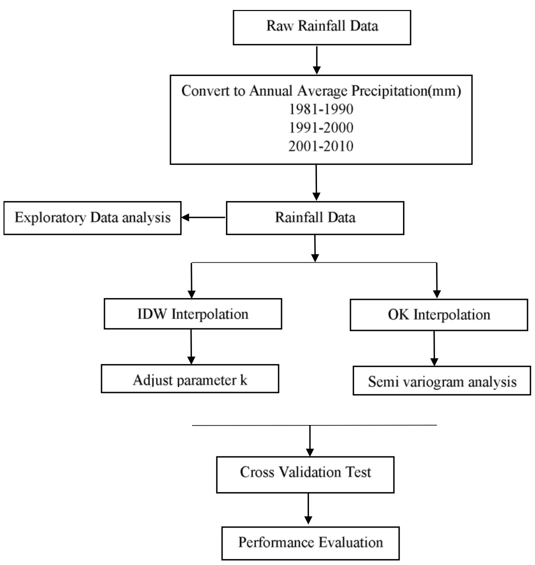


Fig 3: Adopted methodology

3. RESULT AND ANALYSIS

Average annual rainfall form 55 rain gauges of Koshi Basin of Nepal for period 1981-1990, 1991-2000 and 2001 to 2010 was interpolated using IDW and ordinary kriging. Geostatistical analyst tool in ArcGIS 10.6 was used for interpolation and analysis. The optimize option in the Geostatistical analyst was used to optimize the parameters required for the interpolation to obtain the optimum result for the particular model. Optimal model obtained from both interpolation methods were compared. The measured and predicted value for both IDW and Ordinary Kriging for three decades considered are shown in Annex-1. R^2, RMSE and MAE for each interpolation method were calculated and analysed in table 2.

Table 2: Descriptive statistics of first five meteorological stations

Time Period	Interpolation Methods					
	IDW			OK		
	R^2	RMSE	MAE	R^2	RMSE	MAE
1981-1990	0.395	611.2332	483.905	0.494	553.3102	442.881
1991-2000	0.352	662.366	446.468	0.403	625.9503	425.147
2001-2010	0.333	627.8138	442.881	0.409	580.0539	396.311

Figure 5 shows the scatter plot of measured values and predicted values obtained from two interpolation methods. Blue line representing the best fit line for measured and Gray line representing theoretical reference line. Between two methods, Ordinary kriging is predicted better than the IDW line than IDW predicted line by ordinary kriging is more near to the theoretical reference line for all time period.

3.1 Semi variogram Analysis

Experimental and theoretical semi variogram of OK methods for three different time period is shown in Figure 5. The plus (+) sign is experimental semi variogram and the line shown in the figure is the theoretical semi variogram. The nugget effect is little for all the time periods. Analysing semi variogram (Figure 5), the influence of stations are around 4000m for 1981-1990 and 4500m to 5000m for both 1991-2000 and 2001-2010.

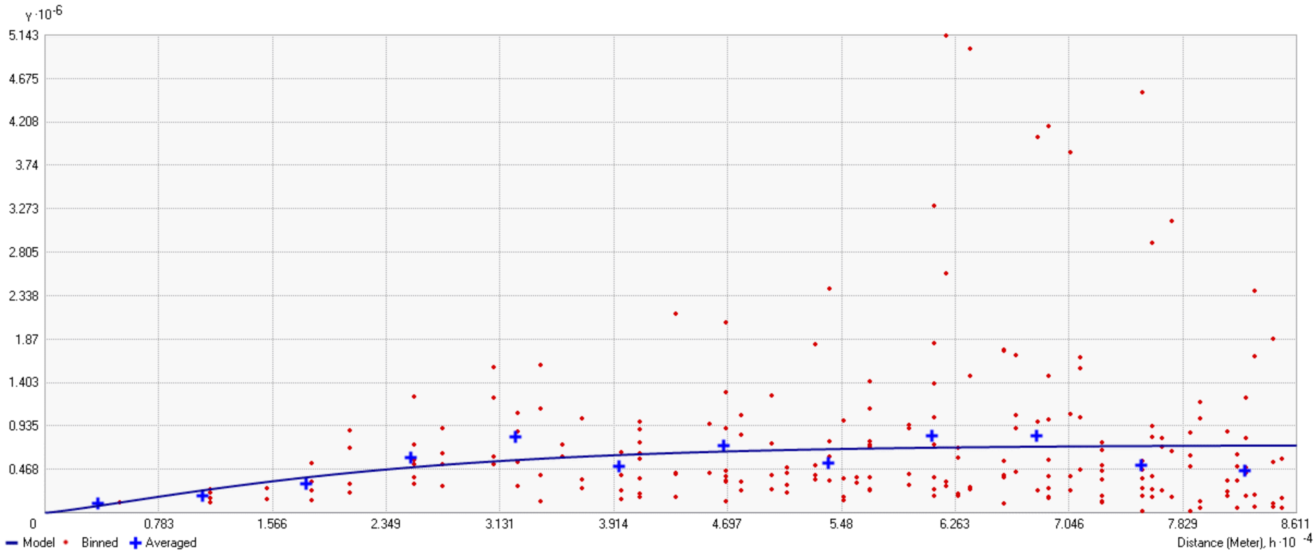
Measured values and predicted values obtained from two interpolation methods are depicted in scatter plot in Figure 5. Blue line represents the best fit line for our data (measured vs predicted). The gray line represents the reference line for perfect estimation of data. Comparing two interpolation methods, blue line in OK methods has greater slope than that of IDW. As we know, closer the blue line to gray line, better the model is. We found OK method is closer to reference line than IDW. Among three different time intervals, both IDW and Kriging method predicted relatively better in the time period of 2001 to 2010.

Both the methods were evaluated using R^2, MAE and RMSE error (Table 2). The coefficient of determination (R^2) along with RMSE and MAE seem to be better in OK method than IDW. In IDW method, it is observed that R^2 value is maximum (0.395)

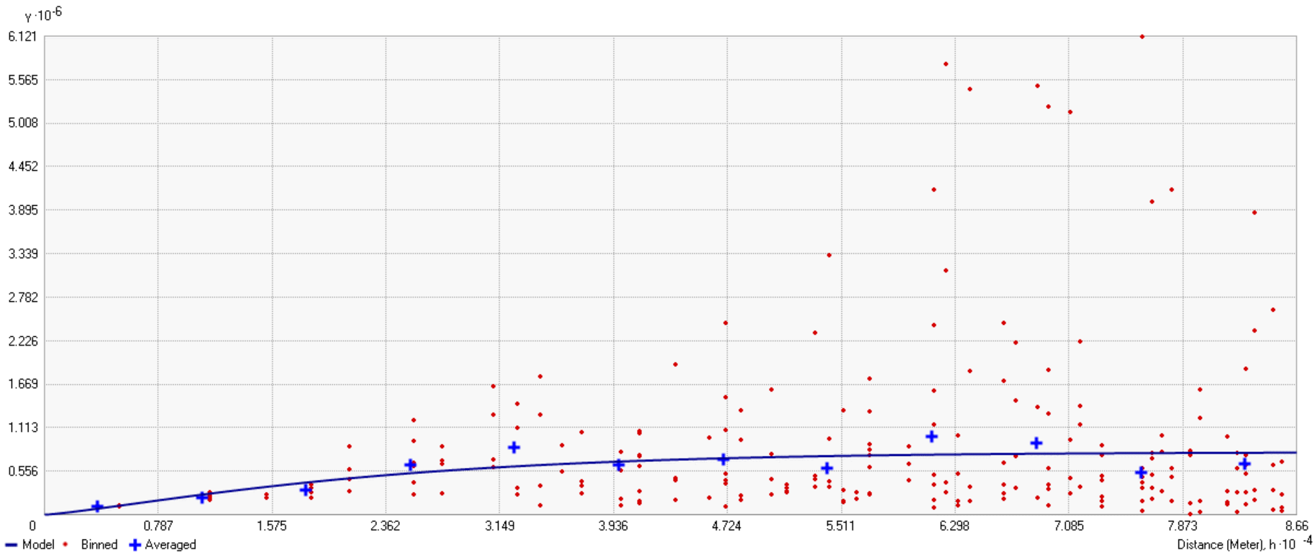
in 1981-1990, whereas in 2001-2010, the R2 is far from 1 having the value of 0.333. However, MAE in first interval is

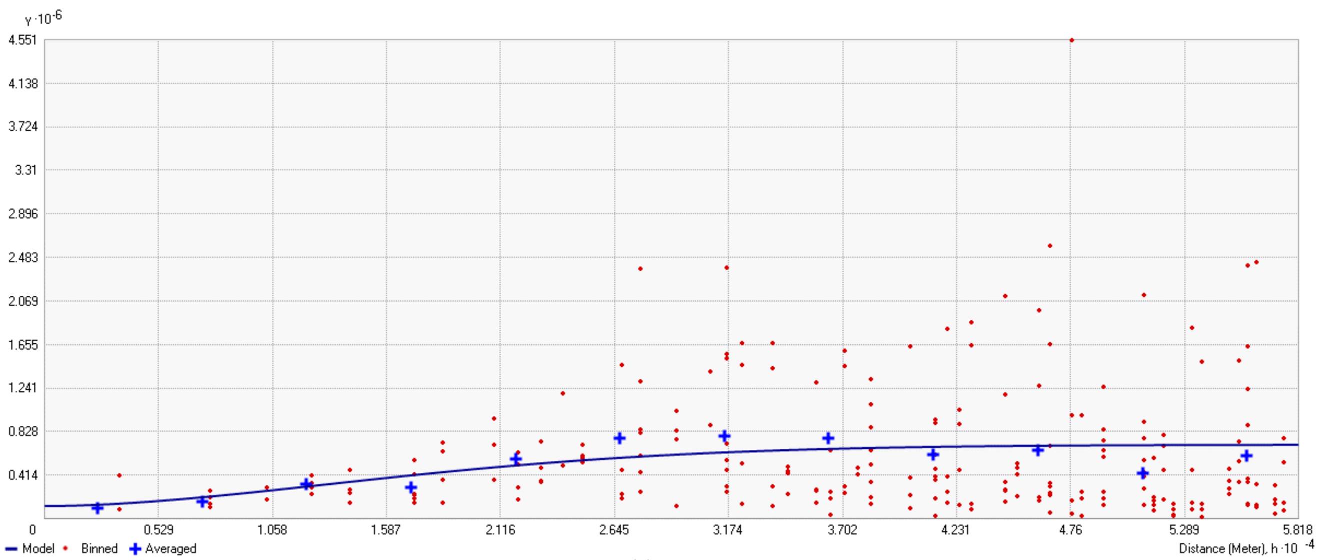
maximum 483.905 than other two decades and minimum of 442.881 in 2001-2010. RMSE value was maximum (662.366) in 1991-2000. The RMSE error then decreased relatively in 2001-2010 and reached to 627.8138.

If we observe OK method for the time periods, R^2 was better in 1981-1990 having the value of 0. 494. The least observed value of R^2 for OK was 0.403 for 1991-2000. The RMSE value was thelowest (553.31) in 1981-1990 and highest in 1991-2000. In contrast, MAE decreased from 442.881 to 425.147 and finally reached to 396.311.



(a) 1981-1990





(c) 2001-2010

Fig 4: Experimental Semivariogram of OK method for different time frame

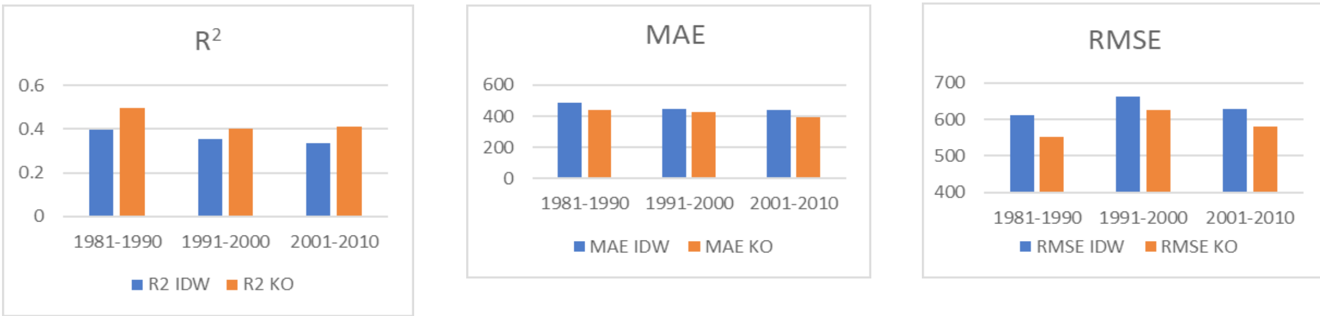
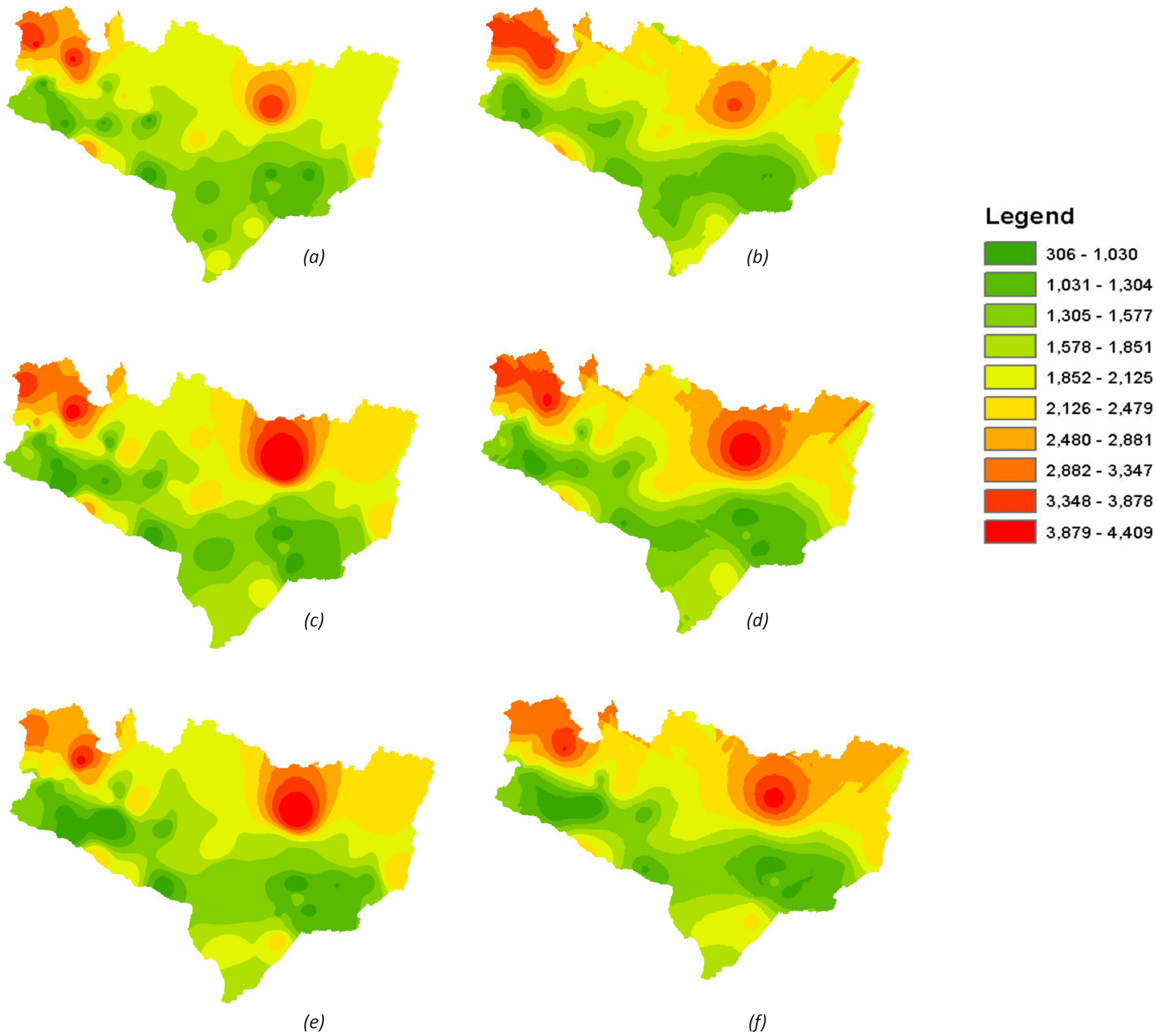


Fig 6: Comparison of Errors



(a)IDW for 1981-1990 (b)OK for 1981-1990 (c)IDW for 1991-2000 (d)OK for 1991-2000 (e)IDW for 2001-2010 (f)OK for 2001-2010

4. DISCUSSION

IDW and OK methods of interpolation was implemented for estimation of annual average precipitation (mm) of Koshi River Basin. Referring to Figure 2, the distribution of precipitation(mm) of a rainfall station is spatially correlated in three different span of time period. The coefficient of determination (R^2) is better in 1981-1990 time period in both the methods. We can observe gradual decrement in R^2 both in IDW and OK. In contrast, MAE is gradually decreased in both methods IDW and OK in three time periods 1981-1990, 1991-2000 and 2001-2010 respectively. This is not the case in RMSE. In two time periods 1981-1990 and 2001-2010, RMSE error is relatively less than that of year 1991-2000.

From the theoretical perspective, the value of R^2 should be near to 1 and the error values should be near to 0 for predicted values being closer to measured values which implies better predictor. Comparing IDW and OK in our study area, OK has better values for R^2, MAE and RMSE, though these values are farther from theoretical aspects. The reason behind this may be only 55 number of precipitation stations within 30,000 sq.km areas are being considered to generate prediction raster.

5. CONCLUSION

Deterministic and geostatistical methods of interpolations are compared for estimation of annual average precipitation climatology (1981-2010) in Koshi River Basin. 55 meteorological stations precipitation's data were investigated in three different time slots: 1981-1990, 1991-2000 and 2001-2010. In order to evaluate the performance of IDW and OK, a leave one out cross validation approach was performed, and rainfall maps were obtained for visualization. The spatial distribution from precipitation maps for both methods indicates that the precipitation is higher in mountainous region and lower in terai region. Higher rainfall indices can be seen in north-west area of Koshi Basin for all the three different time periods. The R^2, MAE and RMSE criteria confirmed the reliability of OK over IDW for our study area but it is not satisfactory.

Among various methods of interpolation we have used OK and IDW for this study. Multiple interpolation methods can be applied for estimating the annual average rainfall in future, which may give better result.

6. ACKNOWLEDGEMENTS

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GUIDELINES FOR AUTHORS PREPARING MANUSCRIPTS FOR PUBLICATION IN THE JOURNAL OF LAND MANAGEMENT AND GEOMATICS EDUCATION

Author Name,[1] Author Name[2]

[1]Author Affilation & Email Address
[2]Author Affilation & Email Address

ABSTRACT

These guidelines are provided for preparation of papers for publications in the journal going to be prepared by Land Management Training Center. These guidelines are issued to ensure a uniform style throughout the journal. All papers that are accepted by the editorial board of this journal will be published provided they arrive by the due date and they correspond to these guidelines. Reproduction is made directly from author-prepared manuscripts, in electronic or hardcopy form, in A4 paper size 297 mm x 210 mm (11.69 x 8.27 inches). To assure timely and efficient production of the journal with a consistent and easy to read format, authors must submit their manuscripts in strict conformance with these guidelines. The editorial board may omit any paper that does not conform to the specified requirements.

KEY WORDS

Manuscripts, Journals, LMTC, Guidelines for Authors, StyleGuide

1. MANUSCRIPT

1.1 General Instructions

The maximum paper length is restricted to 8 pages. The paper should have the following structure:

1. Title of the paper
2. Authors and affiliation
3. Keywords (6-8 words)
4. Abstract (100 – 250 words)
5. Introduction
6. Main body
7. Conclusions
8. Acknowledgements (if applicable)
9. References
10. Appendix (if applicable)

1.2 Page Layout, Spacing and Margins

The paper must be compiled in one column for the Title and Abstract and in two columns for all subsequent text. All text should be single-spaced, unless otherwise stated. Left and right justified typing is preferred.

1.3 Length and Font

All manuscripts are limited to a size of no more than eight (8) single-spaced pages (A4 size), including abstracts, figures, tables and references. ISPRS Invited Papers are limited to 12 pages. The font type Times New Roman with a size of nine (9) points is to be used.

Table 1. Margin settings for A4 size paper

Setting	A4 size paper	
	mm	inches
Top	25	1.0
Bottom	25	1.0
Left	20	0.8
Right	20	0.8
Column Width	82	3.2
Column Spacing	6	0.25

line. Start now with a concise Abstract (100 - 250 words) which presents briefly the content and very importantly, the news and results of the paper in words understandable also to non-specialists.

3. MAIN BODY OF TEXT

Type text single-spaced, with one blank line between paragraphs and following headings. Start paragraphs flush with left margin.

3.1 Headings

Major headings are to be centered, in bold capitals without underlining, after two blank lines and followed by a one blank line.

Type subheadings flush with the left margin in bold upper case and lowercase letters. Subheadings are on a separate line between two single blank lines.

Subsubheadings are to be typed in bold upper case and lower case letters after one blank line flush with the left margin of the page, with text following on the same line. Subsubheadings may be followed by a period or colon, they may also be the first word of the paragraph's sentence.

Use decimal numbering for headings and subheadings

3.2 Footnotes

Mark footnotes in the text with a number (1); use the same number for a second footnote of the paper and so on. Place footnotes at the bottom of the page, separated from the text above it by a horizontal line.

3.3 Illustrations and Tables

3.3.1 Placement Figures must be placed in the appropriate location in the document, as close as practicable to the reference of the figure in the text. While figures and tables are usually aligned horizontally on the page, large figures and tables some-

times need to be turned on their sides. If you must turn a figure or table sideways, please be sure that the top is always on the left-hand side of the page.

3.3.2 Captions All captions should be typed in upper and lower case letters, centered directly beneath the illustration. Use single spacing if they use more than one line. All captions are to be numbered consecutively, e.g. Figure 1, Table 2, Figure 3.

3.4 Equations, Symbols and Units

3.4.1 Equations Equations should be numbered consecutively throughout the paper. The equation number is enclosed in parentheses and placed flush right. Leave one blank lines before and after equations:

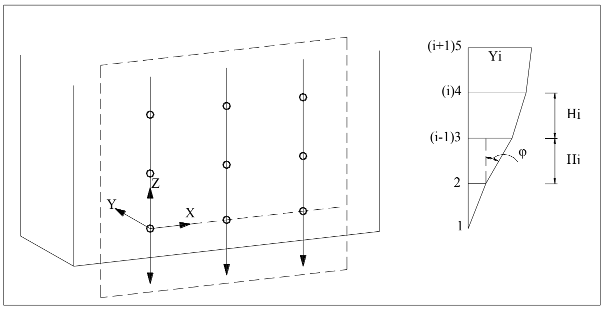

Figure 3. Figure placement and numbering

$$x=x_0 -c(X-X_0)/(Z-Z_0);\ y=y_0 -c(X-X_0)/(Z-Z_0) \quad (1)$$

where c = focal length

x, y = image coordinates

X_0, Y_0, Z_0 = coordinates of projection center

X, Y, Z = object coordinates

3.4.2 Symbols and Units Use the SI (Système Internationale) Units and Symbols. Unusual characters or symbols should be explained in a list of nomenclature.

3.5 References

References should be cited in the text, thus (Smith, 1987a), and listed in alphabetical order in the reference section. The following arrangements should be used:

3.5.1 References from Journals Journals should be cited like (Smith, 1987a). Names of journals can be abbreviated according to the "International List of Periodical Title Word Abbreviations". In case of doubt, write names in full.

3.5.2 References from Books Books should be cited like (Smith, 1989).

3.5.3 References from Other Literature Other literature should be cited like (Smith, 1987b) and (Smith, 2000).

3.5.4 References from websites References from the internet should be cited like (Maas et al. 2017). Use of persistent identifiers such as the Digital Object Identifier or (DOI) rather than a URLs is strongly advised. In this case last date of visiting the web site can be omitted, as the identifier will not change.

3.5.5 References from Research Data References from internet resources should be cited like (Dubaya et al., 2017).

3.5.6 References from Software Projects References to a software project as a high level container including multiple versions of the software should be cited like (GRASS Development Team, 2017).

3.5.7 References from Software Versions References to a specific software version should be cited like (GRASS Development Team, 2015).

3.5.8 References from Software Project Add-ons References to a specific software add-on to a software project should be cited like (Lennert and GRASS Development Team, 2017).

3.5.9 References from Software Repository References from internet resources should be cited like (Gago-Silva, 2016).

4. ACKNOWLEDGEMENTS (OPTIONAL)

Acknowledgements of support for the project/paper/ author are welcome.

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APPENDIX (OPTIONAL)

Any additional supporting data may be appended, provided the paper does not exceed the limits given above.

Note: The format for the journal is taken and modified from the format of ISPRS archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences

GOVERNMENT OF NEPAL

MINISTRY OF LAND MANAGEMENT, COOPERATIVES AND POVERTY ALLEVIATION

LAND MANAGEMENT TRAINING CENTER

Dhulikhel, Kavrepalanchok

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 8000 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.

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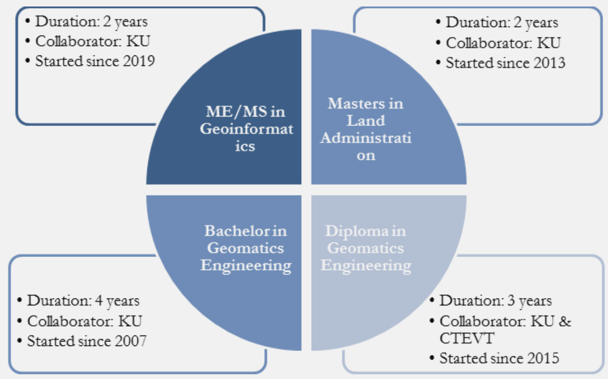
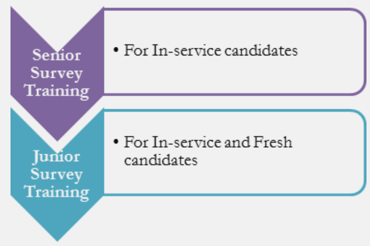


TRAINING COURSES

LONG TERM TRAININGS



SHORT TERM TRAININGS

FUTURE PLANS

- To contribute in Policy Research in the sector of Geomatics and Land Management
- To contribute to capacity Building of Local Governments in the sector of Geomatics and Land Management
- To extend collaboration with academia and regional training institutions

Government of Nepal
Ministry of Land Management, Cooperatives and Poverty Alleviation

LAND MANAGEMENT TRAINING CENTER

Dhulikhel, Kavre

ACHIEVEMENTS OF FY 2076/77

NOVEL SUCCESSES

- International workshop on 'Capacity Building & Education Outreach in advanced Geospatial Technologies & Land Management' on 10-11 Dec 2019
- Launched Journal of Land Management & Geomatics Education
- Residential Training of Trainers (TOT) for capacity building of LMTC staff
- Refresher Course for High Level Officials in land related issues
- Begun conducting trainings for local level

COPING WITH COVID-19

Adopted Online method for teaching of Senior Survey Training and Junior Survey Training courses such that trainees graduate in scheduled dates

Successful Conduction of 2 weeks Training on GIS adopting 100% online mode and open source software; Orientation Training of newly appointed Survey Officers

TRAININGS LAUNCHED THIS FISCAL YEAR

Training	Trainees
Open Source (QGIS)	15
Local Level Land Management	47
Instrument Handling & Orientation	23
Astronomical Observation	12
GNSS + UAV	11

ADDITIONAL CAPACITY BUILDING SHORT TRAININGS

- Digital Cadastre Baglung (14), Palpa (14), Chitawan (22)
- Basic GIS Training Sankhuwasabha (11)
- Remote Sensing (15)
- Land Administration & Management Gazette Class III (15)
- Land Administration & Management Non Gazette (14)

LONG TERM TRAININGS

- Senior Survey Training Inservice (24)
- Junior Survey Training Fresh (48)
- Junior Survey Training Inservice (24)
- Diploma in Geomatics Engineering (3rd year:46 2nd year 45)

INSERVICE TRAINING GRANTING 2 POINTS

Training	Trainees
Professional Course on Geomatics & Land Administration (Gazette Class III)	15
Digital Cadastre & Office Management Training (Non Gazette Class I)	11
Digital Cadastre & Office Management Training (Non Gazette Class II)	21

SALIENT FEATURES

Extended MoU with Kathmandu University in 2019 and launched ME/MS in Geoinformatics in addition to previously running MS in Land Administration and Bachelors in Geomatics Engineering courses

The figures in the parenthesis are the numbers of trainees

Staff of Land Management Training Center

LMTC visit by Vice Chancellor of School of Engineering, Kathmandu University

Virtual unveiling of Journal on Land Managment and Geomatics Education, Vol II

LMTC visit by Hon. Minister of MOLMCPA Dr. Shiva Maya Tumbahamphe

LMTC visit by Hon. Minister of MOLMCPA Mr. Laxman Lal Karn

Tree plantation inside LMTC premises in collaboration with Divisional Forest Office, Kavre

LMTC Museum

Instrument handling during Informal Land Tenure Training

Field work during Digital Cadastre Training, 2078

Closing ceremony of Junior Inservice Survey Training, 2020

Yoga during Training of Trainers program

Astronomical observation during field

Cultivating paddy in LMTC premises

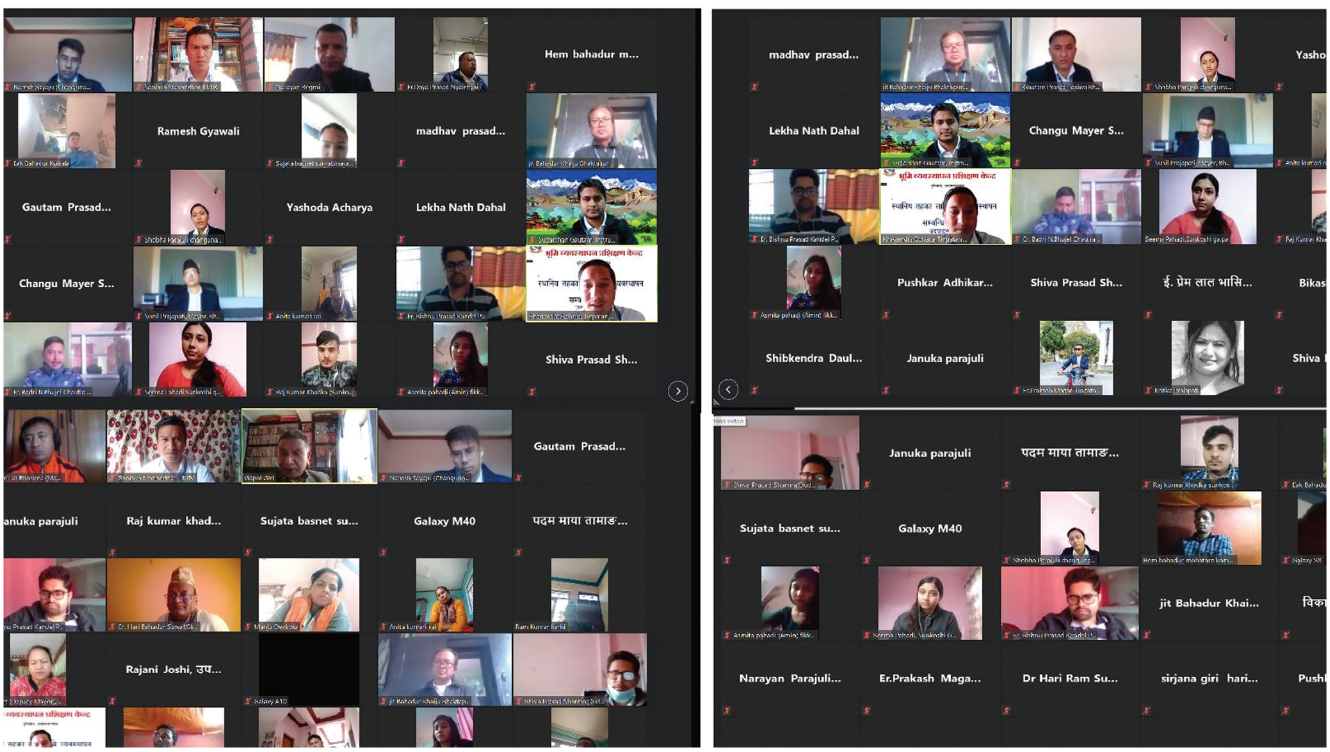
Digital Cadastre Training, 2078

LMTC staffs in hiking

LMTC visit by Secretary of MOLMCPA, Mr. Tek Narayan Pandey

LMTC Premises

Refresher program for high level officials from Land Management Sector



Virtual training on Land Management for local levels