ESTABLISHING THE INNOVATIVE METHOD FOR SEISMIC HAZARD AND RISK ASSESSMENT THROUGH SEISMIC MICROZONATION STUDY AND THEIR INTEGRATION IN MULTI-HAZARD ASSESSMENT

PROJECT COMPLETION REPORT

Submitted to USAID's Tayar Nepal - Improved Disaster Risk Management Project

Submitted by Geoengineering Consult Private Limited

ABBREVIATIONS

1C	1 Component
3C	3 Components
AD	Anno Domini
BMC	Birendranagar Municipality
CCT	Central Churiya Thrust
CF	Causative factor
Cu. Ft	Cubic Feet
Cu. M	Cubic Metre
DRRM	Disaster Risk Reduction and Management
DUDBC	Department of Urban Development and Building Construction
F/Y	Fiscal Year
FS	Factor of safety
GIS	Geographic Information System
GMPE	Ground Motion Prediction Equations
GP	Poorly Graded Gravel
GPS	Global Positioning System
HVSR	Horizontal to vertical Spectral Ratio
ISC	International Seismological Centre
ITSZ	Indus Tsangpo Suture Zone
M	Magnitude
MAM	Microtremor Array Measurement
MaxEnt	Maximum entropy
MBT	Main Boundary Thrust
MCT	Main Central Thrust
MFT	Main Frontal Thrust
MHT	Main Himalayan Thrust
ML	Low Plastic Silt
Ms	Surface Wave Magnitude
NBC	National Building Code of Nepal
NEHRP	National Earthquake Hazards Reduction Program
NE	North East

NPC	National Planning Commission
NPR	Nepalese Rupees
OPC	Ordinary Portland Cement
PGA	Peak Ground Acceleration
POE	Probability of Exceedance
PSHA	Probabilistic Seismic Hazard Assessment
RC	Reinforced Concrete
RMR	Rock Mass Rating
ROC	Receiver operating characteristic curve
RQD	Rock quality designation
RT	Ranimatta Thrust
SA	Spectral Acceleration
SESAME	Site effects assessment using ambient Excitations
SM	Silty Sand
SMC	Stone Masonry Construction
SMCE	Spatial multi-criteria evaluation
SPAC	Spatial Autocorrelation
SPI	Stream power index
STI	Sediment transport index
SW	South West
TOL	Tolerance
TWI	Topographic wetness index
USAID	United States Agency for International Development
USD	United States Dollar
USGS	United States Geological Survey
VIF	Variance inflation
Vs30	Average velocity of shear waves in top 30 m

EXECUTIVE SUMMARY

Birendranagar municipality is characterized by Siwalik Hills in the south and Lesser Himalaya in the north and Dun valley in the central part. It is situated about 7 km above the seismogenic fault in the Himalayan central seismic gap, which generated several devastating earthquakes including the great earthquake of 1505 AD and has potential to generate devastating earthquake in anytime. Therefore, it is aimed to carry out seismic risk assessment through innovative seismic hazard assessment incorporating seismic microzonation technique for the first time for western region in Nepal along with the multi hazard assessment by integrating earthquake, landslide and flood hazard assessments.

Geologically, the municipality is characterized by sedimentary rocks in the southern part and low grade metamorphic rocks of lesser Himalaya in the northern part and valley fill soft Quaternary deposits in the central part. The seismic microzonation study has revealed that the average shear wave velocity at 30 m depth (Vs30) ranges from 160.0 m/s to 508.0 m/s. The highest Vs30 is obtained in the region dominated by gravel deposit, and the lowest at region dominant by soft sediments. Similarly, fundamental frequency varies between 0.6Hz to 6Hz and amplification factor is in the range of 2 to 8. As per the NEHRP seismic site class, majority of areas in Surkhet valley of Birendranagar Municipality is classified into class C, D and E. The probabilistic seismic hazard assessment (PSHA) has shown bedrock Peak Ground Acceleration (PGA) in between 0.37g and 0.4g for 475 years return period. The study also reveals an economic loss of NPR 4,983,780,304.80 and NPR 7,898,798,054.40 for the seismic events of 475 years and 2475 years return period respectively for all buildings located in ward-6 of Birendranagar Municipality.

A flood hazard assessment of Birendranagar Municipality has shown that the wards 2 and 11 are at high risk for all three depth classes, i.e. <1m, 1 to 4m, and >4m. As these wards lie at the lower elevation of the watershed and major confluence of rivers occur in those wards whereas Wards 3, 9, 10, 13, and 15 are at moderate risk, as major tributaries of the Bheri river flow along 13 and 15 wards and remaining wards lie at major river confluence at the lower elevation of the watershed. The statistical results show that the flood events of 2014 might be of 10 years return period, meaning that they can recur at any moment throughout the ten-year period.

A probabilistic approach of landslide susceptibility modeling was used to find the probable occurrences of landslide distribution that incorporates several causative factors (CF). The results have shown that the southern and northern hills are susceptible to landslide hazard. The distribution of FS in the Birendranagar Municipality for 100 return period has shown that the unstable area (FS<1) is highly distributed in the wards containing hilly areas. Ward No. 15 is occupied by a 14.18% unstable area where, ward numbers 14 and 16 contain 12.43% and 11.20% unstable areas, respectively. Similarly, the ward-wise frequency ratio analysis shows ward no 9 is the highest vulnerable in terms of runout followed by ward no 15 and ward no 3, 6 and 8 are free from run outs.

A multi hazard assessment was carried out integrating earthquake, flood and landslide hazard assessments. The assessment shows that the ward numbers 15, 1, 4, 16 and 12 are relatively vulnerable to landslides. The ward no. 3 is an extreme hazard condition because of flooding and followed by wards no 3, 9 and 10. Birendranagar municipality is characterized by the active condition of erosion, transportation, and deposition. It is highly recommended to develop a hazard specific disaster management plan. A physical and social vulnerability and risk analysis should be assessed for the further study.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOGRAPHS

1. INTRODUCTION

PROJECT DESCRIPTION

Birendranagar Municipality is located in Dun valley and the ridges and slopes of the hills in Surkhet district. The area of the municipality is about 245 sq. Km with around 29,000 households. It is situated about 7 km above the seismogenic fault in the Himalayan central seismic gap, which generated several devastating earthquakes including the great earthquake of 1505 AD. The earthquake caused loss of lives and massive damages to buildings in the western Nepal. Several research, carried out after the 2015 Gorkha earthquake, have indicated that, an overdue event is likely to occur in western Nepal at any time. The probability of occurrence of such event has indicated that the region is in high seismic hazard and risk. Beside these, the municipality frequently witnesses flooding of the Itram, Neware and Khokre Khola and inundation due to urban and riverine flood, e.g., flood of July and August 2014. The northern part of the city suffers by recurring landslides every year. The landslide events of 2014 caused significant loss of lives and properties in the northern part of the municipality. Considering such scenario of the existing hazard and risk, under the financial assistance of the USAID/Nepal Tayar Nepal – Improved Disaster Risk Management (DRM) Project, Geo Engineering Consult implemented the project entitled as Establishing the Innovative Method for Seismic Hazard and Risk Assessment through Seismic Microzonation Study and their integration in Multi Hazard Assessment in Birendranagar Municipality of Karnali Province. Through this project, an innovative hazard assessment method and a multi hazards map were developed integrating seismic, landslide and flood hazards. The seismic risk estimation (of Ward No. 6 as a pilot project) through seismic hazard assessment was done incorporating seismic microzonation technique for the first time for western region in Nepal. Since the concept is innovative to assess multi hazards, the development of realistic methods during the implementation of the project in Birendranagar Municipality has provided an ample opportunity to replicate it in other urban areas of Nepal.

PROJECT AREA

The project area, Birendranagar Municipality, a capital city of Karnali Province, lies in Surkhet district. Geographically, it lies mostly in the Surkhet Dun Valley, and partly covers the Lesser Himalayan region. The municipality was established in 2033 BS. It is bounded by Guranse Rural Municipality of Dailekh district in the north, Bheriganga Municipality in the south, Barahtaal Rural Municipality in the west and Lekbesi Municipality and the Jhupra River in the east. The total area of municipality is 245.06 sq. km and is divided into 16 wards (Figure 1:1) (Municipal profile, 2018). In terms of area, Ward 14 is the largest with area of 28.96 sq. km and Ward 6 is the smallest with area of 0.6 sq. km (Table 1:1).

The local census conducted in 2075 BS shows a total of 29,216 households in Birendranagar Municipality (Municipal profile of 2018). The highest number (i. e. 3426) of households is in Ward 3 and the lowest (i.e., 356) is in Ward 15. A total of 1, 15,451 people live in the municipality among which 56,392 are male and 58,994 are female whilst 65 people's sex was not mentioned. Among the 16 Wards, Ward 3 is the most populated with 12.11% (i.e., 14,003) of total population and Ward 15 is the least populated with 1.47% (i.e., 1700) of total population. The population density in Birendranagar Municipality varies greatly. The highest population density (i.e., 12,408) is in Ward 6 which is the core city area while the lowest is in Ward 15 (i.e., 69). The wards with low population density cover the rural areas in the northern part of the municipality (Table 1:1).

Table 0:1 Ward wise demography and area of Birendranagar Municipality

WARD NO.	NO. HOUSEHOLDS	POPULATION	SEX RATIO	AREA (SQ. KM)	POPULATION (PEOPLE/SQ.KM) DENSITY
1	2124	8667	91.62	6.1	1421
2	2126	8949	92.37	29.2	306
3	3426	14003	106.81	6.62	2115
4	2027	8130	102.19	7.1	1145
5	1165	4911	94.42	5.8	847
6	2731	7445	99.38	0.6	12408
7	1344	5638	93.91	5.2	1084
8	1760	5982	102.03	1.4	4273
9	2099	8675	95.87	28.82	301
10	2724	11225	89.51	17	660
11	2217	8185	89.73	26.7	307
12	2804	11375	87.77	8.82	1290
13	1215	5595	99.04	25.9	216
14	660	2901	94.7	28.96	100
15	356	1700	102.38	24.61	69
16	438	2070	94	22.23	93
Total	29216	115451	95.59	245.06	

PROJECT OBJECTIVES

The goal of the study is to assess the multi hazards by establishing the innovative methods on seismic, flood and landslide hazard assessment.

The general objective of the proposed study is to develop innovative and effective methodology on multi hazard assessment to enhance the capacity of the municipality in disaster management. The specific objectives are to:

1. Develop innovative and effective method for urban seismic microzonation study, seismic hazard, and risk assessment against the overdue earthquake event in western Nepal
2. Assess the multi hazards incorporating most prevailing hazards in Birendranagar Municipality, i.e., landslide (both rainfall and earthquake induced), flood and seismic hazards
3. Orient local government and community people to understand existing hazard and risk through training

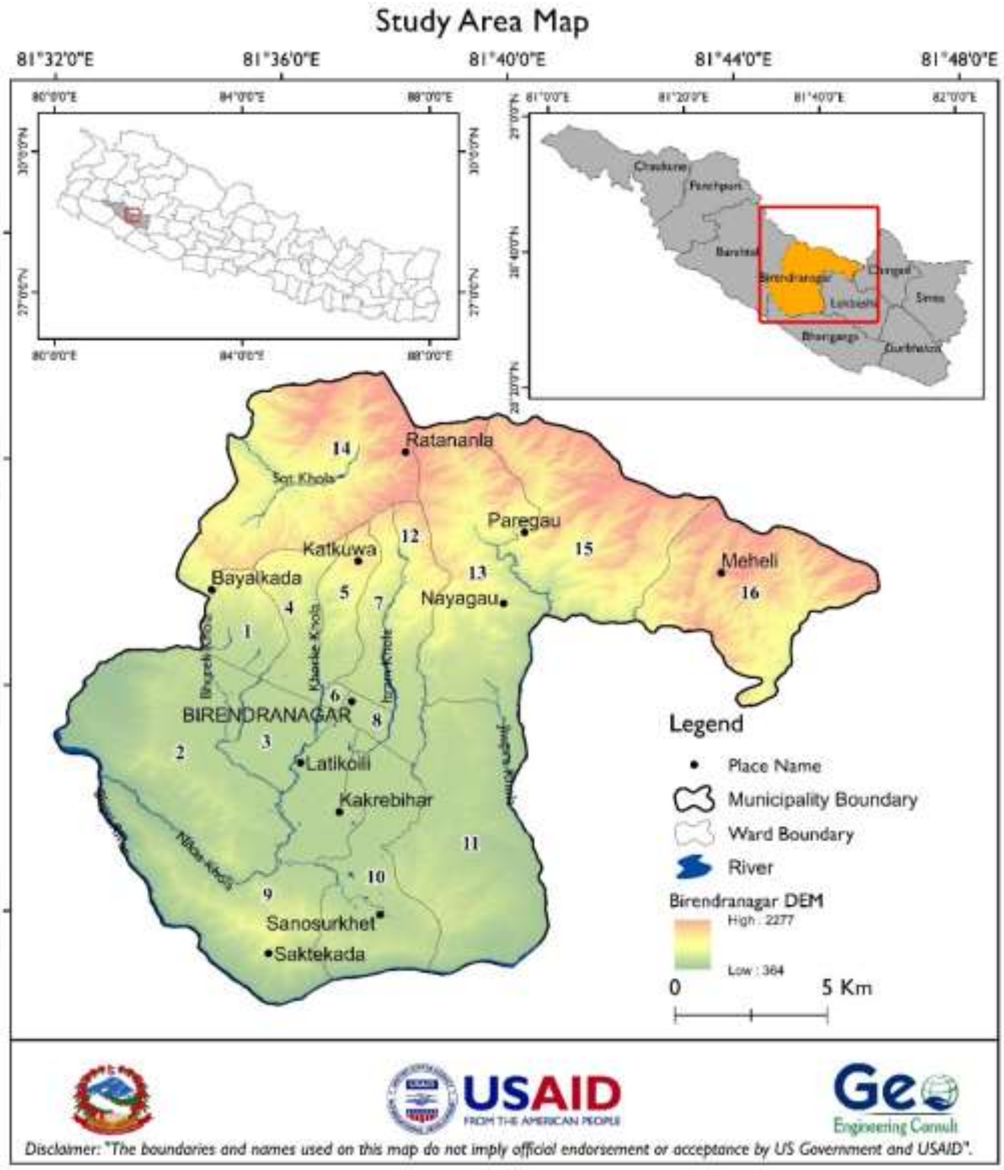


Figure 0:1 Location and administrative division of Birendranagar Municipality.

METHODOLOGY

The project aims to develop an innovative technique on seismic hazard and risk assessment. The major components of the innovative project are geological, engineering geological and geotechnical investigation, seismic microzonation through ambient noise measurement, probabilistic seismic hazard and risk assessment (PSHA). In addition to these, project aims to carry out multihazard assessment through integration of landslide and flood hazard assessments in seismic hazard assessment. The basic methodology of the execution of the project is shown in Figure 1:2. The geological and geotechnical investigations are conducted to understand the geological and geotechnical characteristics of the municipalities. The results of the investigations are fundamental bases for seismic microzonation and landslide hazard assessment. The seismic microznation study is carried out using the fundamental frequency of the sites, average shear wave velocity for upper 30 m depth (Vs30), and amplification factor of seismic wave. The measurements of ambient noise are accomplished by deploying the seismometers of one and three channels. The Vs30 is, then, integrated to conduct PSHA for 475- and 2475-year return period. The seismic risk assessment is carried out for seismic hazard scenario for

Ward No. 6 of the municipality. Using the geological data base, outputs of seismic hazard, rainfall data, a dynamic landslide susceptibility is prepared. The flood hazard assessment is conducted using the data base on river morphology, topography, rainfall, discharge and land use data. The outputs of seismic, landslide and flood hazard assessments are integrated to conduct the multihazard assessment of Birendranagar Municipality.

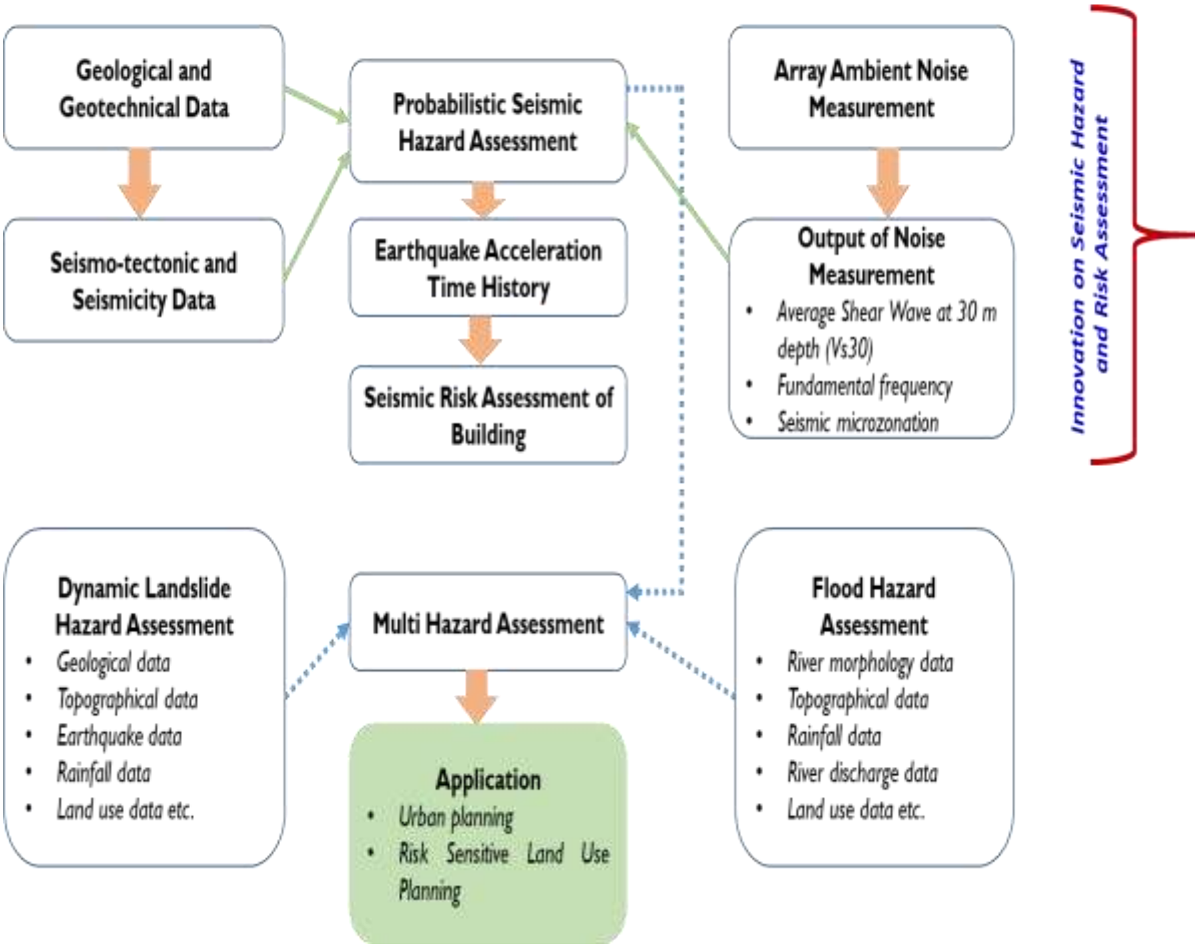


Figure 0:1 General flow chart of overall methodology adopted for the study.

2. INCEPTION PHASE ACTIVITIES

The general objective of the proposed study is to develop innovative and effective methodology on multi hazard assessment to enhance the capacity of the municipality in disaster management. Within this objective, the following major activities were conducted. The achieved results are also presented below in brief.

COORDINATION MEETING

A coordination meeting was organized on 4th January 2021 with the officials of Birendranagar Municipality, Surkhet. Mrs. Mohan Maya Dhakal, Deputy Mayor, Mr. Teeka Ram Dhakal, Chief Administrative Officer, Mr. Prakash Poudel, DRRM Focal Person, Er. Bishal Adhikari, Engineer and other officers of the municipality were present in the meeting. Similarly, Rajesh Shoni and Er. Dilli Prasad Upadhyaya were present in the meeting from TAYAR Nepal field team. Dr. Deepak Chamlagain, project Team Leader and Dr. Upendra Baral, geologist were also present from Geo Engineering Consult Pvt. Ltd. Beside these other municipal officers and representative were also present. The meeting discussed the project components, possible outcomes, coordination mechanism and finalized date for consultation workshop, i.e. 23rd January, 2021.

CONSULTATION WORKSHOP

A consultation workshop was organized on 23rd January 2021 at Hotel Namaste Nepal, Birendranagar, Surkhet. The objectives of the workshop were to discuss the project detail, existing hazard and risk and collect feedback on overall activities of the project.

There were forty-five participants including Mr. Dev Kumar Subedi, Mayor, Mrs. Mohan Maya Dhakal, Deputy Mayor and Ward Chairmans of Birendranagar Municipality. Similarly, Mr. Teeka Ram Dhakal, Similarly, Chief Administrative Officer (C.A.O.), Mr. Prakash Poudel, Disaster Risk Reduction (DRR) Focal Person and other municipal officials were also present at the workshop. Representatives from Nepal Red Cross Society, I/NGOs also joined the workshop. Community people including representatives from marginalized community, women, Dalit and people with disabilities also took part in the event. Mr. Rajesh Shoni, Field Officer, TAYAR Nepal also joined the workshop. Dr. Deepak Chamlagain, Project Team Leader and Er. Helen Upadhyay were present from Geo Engineering Consult Pvt. Ltd.

The workshop was chaired by Mr. Dev Kumar Subedi, Mayor, Birendranagar Municipality. Mr. Teeka Ram Dhakal, C.A.O., delivered welcome speech. In his welcome speech, Mr Dhakal stated that this innovative project would lead the municipality towards realistic seismic hazard and risk assessment including multi hazards assessment. Mr. Dev Kumar Subedi, Chairman of the workshop and Mayor, Birendranagar Municiaplity, in his remark, mentioned the outcomes of the project will be communicable to the local community, easily implementable and show the best example of seismic hazard and risk assessment methods for urban areas located in the valleys like Surkhet in Nepal. After the brief inauguration ceremony, in the technical session Dr. Deepak Chamlagain delivered a technical presentation highlighting the objectives of the workshop and projects, causes of natural hazards in Nepal, various effects of earthquakes, seismic site effects, project description in detail, expected outcomes of the project and their importance and uses. The program was concluded with the valedictory remark of Mrs. Mohan Maya Dhakal, Deputy Mayor, Birendranagar Municipality. She stated that Birendranagar being capital of Karnali Province is being suffered by rapid but haphazard urbanization while inhabitants of the municipality are still unaware of proper land use plan and preparedness for future disasters. She anticipated that the outcomes of the project will help to implement the municipal policies through proper understanding of the existing hazard and risks.

Photograph 0-1 Participants of the workshop.

Photograph 0-2 Mr Dev Kumar Subedi delivering his remark during the workshop.

3. ENGINEERING GEOLOGICAL AND GEOTECHNICAL INVESTIGATIONS

BACKGROUND

Geology is the study of the structure, evolution and dynamics of the Earth and its natural mineral and energy resources. Where engineering geology is a branch of it, also called Geological Engineering, deals with the application of geological knowledge to engineering problems, e.g., to reservoir design and location, determination of slope stability for construction purposes, and determination of earthquake, flood, or subsidence danger in areas considered for roads, pipelines, or other engineering works. The geotechnical results will enhance the findings from the surficial as well as sub-surficial information that acquired from the geological and geophysical investigation. The study area lies in the Churia and Mahabharat ranges and the elevation ranges from 364 m to 2277 m, numbers of rivers valleys are present, and the topography ranges from a flat land to the hilly areas.

OBJECTIVES AND METHODOLOGY

The present study has been carried out within Birendranagar Municipality to fulfill the following objectives:

- Geological and engineering geological investigations to understand the engineering geological conditions for seismic and landslide hazard assessments
- Preparation of landslide inventory using remote sensing and field-based study
- Geotechnical investigations of soil and rock to determine the engineering properties for landslide hazard assessment

The adopted basic methodology for geological and engineering geological investigation comprises both desk study, field study and laboratory study (Figure 3:1**Error! Reference source not found.**), which are described briefly below.

The desk study includes remote sensing, study of aerial photo, topography maps and other published and unpublished geological and engineering geological maps. The field study was carried out to scrutinize the detailed geology and the engineering geological condition of the municipal area. Along each traverse routes, geological data (e.g. rock/soil type, composition, weathering grade, geological structure etc.) have been recorded. The attitudes of bed and foliation planes have been measured using the Brunton compass. These data along with the detail lithological information, a geological map has been prepared in 1:25000 scale. The engineering geological study has been carried out both in soil and bedrock. Detail engineering properties of soil were documented following the field procedure and samples have been tested at laboratory for moisture content, grain size analysis, specific gravity and Atterberg limits. Rock mass rating (RMR) system given by Bieniawski (1996) was adopted for rock mass study. The following information collected from the field are presented in tabular form and map that are discussed in detail in the engineering geological section.

- Hydrological conditions
- Geomorphological conditions
    - Structures
    - Discontinuities (Joints/fault/unconformity)
- Geodynamic conditions
    - Karst
    - Landslides
    - Subsidence
    - Erosion
    - Weathering condition
- Soil classification
- Rock mass classification

Both laboratory and field data have been analyzed using various techniques and obtained results have been presented in the form of maps, diagrams and tables. All those data sets have been integrated for the interpretation of the findings.

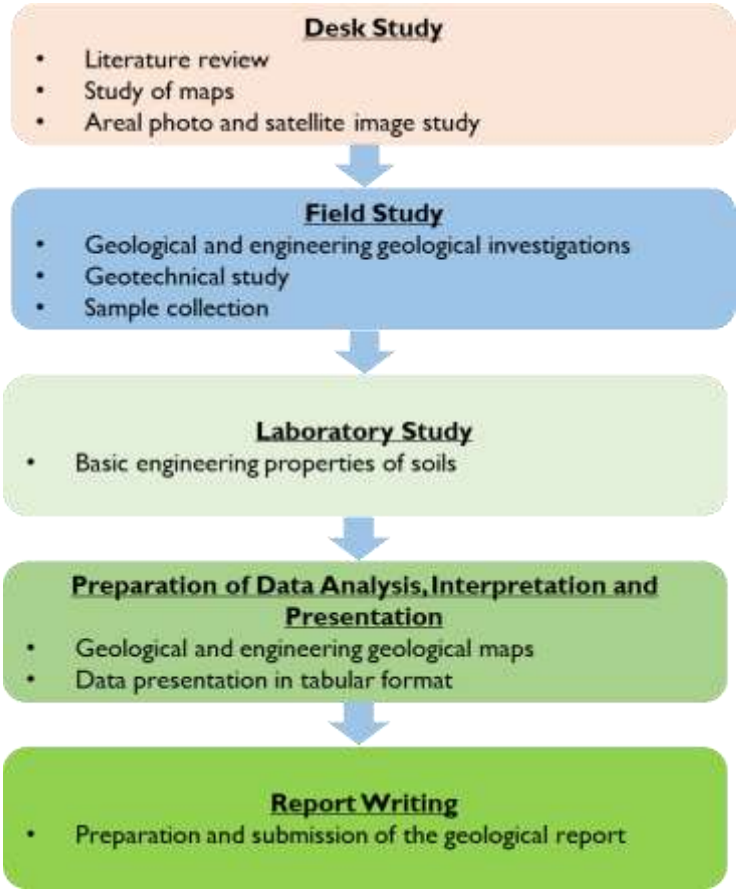


Figure 0:2 Flow chart of methodologies followed during entire phase of this report.

Lithostratigraphy

Birendranagar Municipality falls both in Siwalik Group in the southern half and the Lesser Himalayan sequence in the northern half. The geological traverses were carried out along the three major routes covering all the litho-units of within the municipal area. The area comprises sedimentary rock of Siwalik and the meta-sedimentary rocks of the Lesser Himalayan sequence.

Lesser Himalaya

A large succession of the Lesser Himalayan meta-sedimentary rocks has been exposed around the municipal area. These are exclusively low-grade metamorphic Midland Group and the Surkhet Group, which are described in the following sections.

Ranimatta Formation

The Ranimatta Thrust has placed the Ranimatta Formation over the Surkhet Group. It mainly comprises of milky white quartz arenite, lithic arenite and greenish grey schist and widely distributed in Gurase, Ranimatta, Siddhapaila, Paregaun village. Some meta-conglomerate lenses have also been observed within this unit. Two major basic igneous bodies have been found to be intruded as sill. The attitude of the foliation plane, near the Siddhapaila, is measured as N60°W/46°NE.

A small portion of Ulleri gneiss (light grey colored orthogneiss) intruding the Ranimatta Formation has been found on the northern boundary of the municipal area. The rock mass is slightly weathered and thickly foliated. The attitude of the foliation near the Bubairakhe village is N80°W/28° NE.

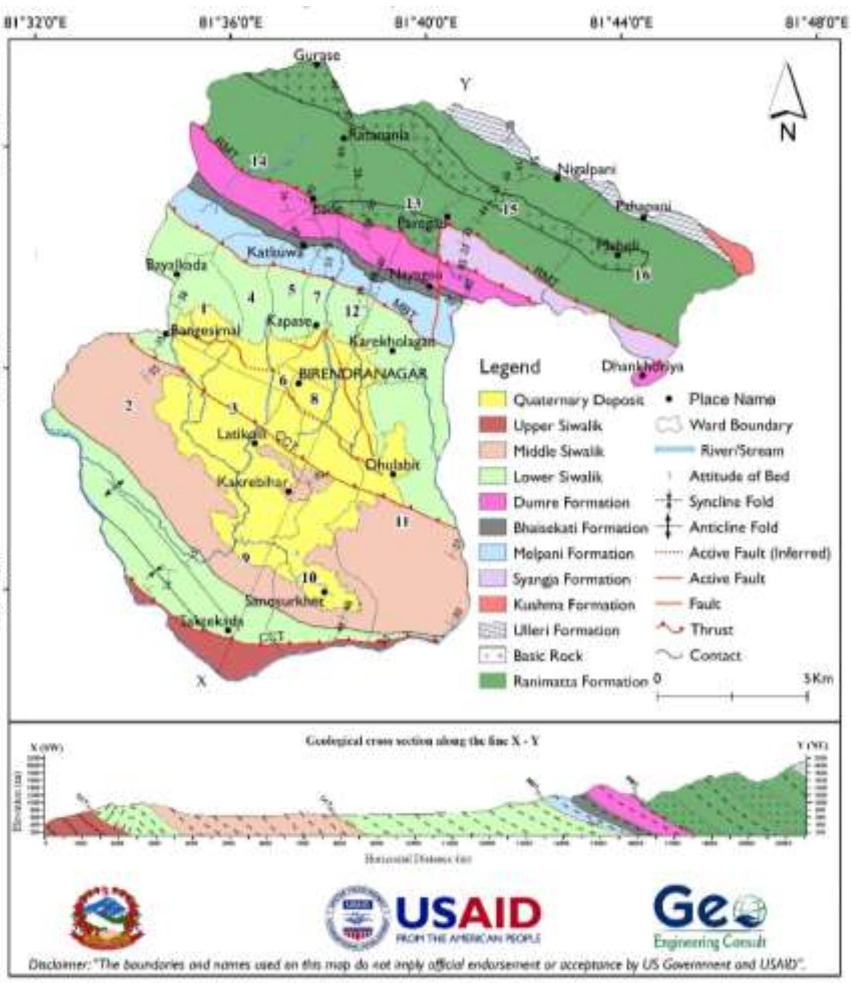


Figure 0:3 Geological map and cross-section of the Birendranagar Municipality, Surkhet, Nepal.

Syangja Formation

The Syangja Formation is represented by pink-colored and compact quartzose sandstone. The rock mass is coarse-grained slightly weathered and highly fractured rocks and differ with the quartz arenite of the Ranimatta Formation in terms of grain size and typical pink color. The attitude of the bed is N65°W/25°NE.

Figure 0:4 a) milky white thickly bedded quartz arenite, b) boulder of conglomerate rock from Ranimatta Formation, c) outcrop of Ulleri gneiss exposed near the Bubairakhe village, d) exposure of the light pink quartzite of the Syangja Formation near the Kamase Village, e) exposure of fissile shale of the Bhainskati Formation showing pencil cleavage, f) greenish grey sandstone of the Dumri Formation on the left bank of the Jhupra Khola, near Dobilla village Ulleri Formation

Kushma Formation

The northeast part of the municipal area consists of the white to grey, rippled massive quartzite of the Kushma Formation. Based on its lithological characteristics, it can be correlated with the Fagfog Quartzite of the central Nepal and Naudanda Quartzite of the west-central Nepal. The rock mass is thick-bedded and slightly weathered. The attitude of the bed is N30°W/40°NE.

The rock succession of the Surkhet Group is bounded by the Main Boundary Thrust (MBT) to the south and Ranimatta Thrust (RT) to the north and only exposed in the northern periphery of the municipal area.

Amile Formation

The Amile Formation is well exposed around Saldanda, Mallakada, Pipaldanda and Ratedanda villages. This unit consists of quartzose sandstone with shale and several beds of limestone and dolomite present in the lower portion. The attitude of the bed near the Pipaldanda is N65°W/25°NE.

Bhainskati Formation

The Bhainskati Formation (equivalent to Swat Formation) is represented by light to dark grey fissile monotonous pencil cleavage shale and well exposed in the villages like Katkuwa, Jarbutta and Thali. The rock mass is highly weathered, pencil cleaved and crushed. Due to the shale composition, numbers of landslides do present along the road cut slope between the Lade and Chheda village. The attitude of the bed near the Jarbutta village is N80°W/40°NE.

Dumri Formation

The Dumri Formation (equivalent to Suntar Formation) in the study area is represented by thick-bedded, greenish-grey and purple medium-grained sandstone with some red-purple shale. This unit is well exposed along the Surkhet-Dailekh road in the northern part of the municipality. The attitude of the sandstone bed near the Dobilla village is N65°W/85°NE.

Sub-Himalaya /Siwalik Group

The Siwalik Group represents the molasses from the Himalaya deposited in the foreland basin by the south-flowing river systems of the Himalaya. On the basis of lithological characteristics and their stratigraphic position, it has been divided into three lithological units.

Lower Siwalik

The Lower Siwalik consists of variegated and thick-bedded mudstone and fine to medium-grained sandstone and siltstone. In the study area, it is well exposed around the foothill just north of the Surkhet valley as well as in the south. This unit is exposed in Bangesimal, Bhutepokhari, Kapase, Chanaute and Guptipur areas. The attitude of the bed near the Bangesimal is N60°W/35°NE.

Middle Siwalik

The Middle Siwalik is exposed around the southern part of the municipal area viz. Kakrebihar, Latikoili and Koldanda. It is represented by thick bedded, indurated, pink to purple, coarse-grained sandstones with abundant pelitic minerals like muscovite. The attitude of bed near the Koldanda is N40°W/35°NE.

Upper Siwalik

The conglomerate beds of Upper Siwalik are exposed on the right bank of the Bheri River near the Bheri Bridge along the Nepalgunj- Birendranagar Road section. The clasts are sub-rounded to well-rounded and up to of cobble size with less than 20 % volume. The attitude of the bed, just below the Bheri bridge, is N50°W/40°NE.

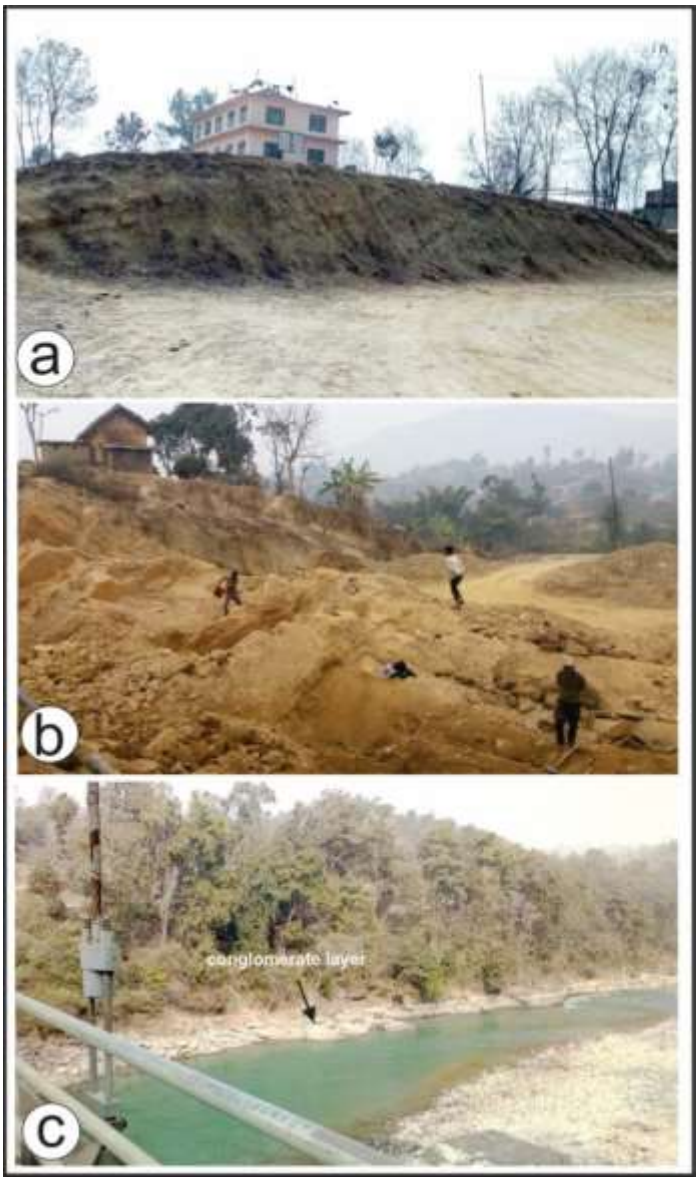


Figure 0:5 a) exposure of Lower Siwalik near the Surkhet Education Development building, b) mining of the sandstone of the Middle Siwalik for the dimension stone purpose near the Koldanda village c) exposure of conglomerate of the Upper Siwalik on the right bank of the Bheri River.

GEOLOGICAL STRUCTURES

Numbers of thrust and faults are present in the area. Some principal ones are: Ranimatta Thrust, Main Boundary Thrust, Central Churiya Thrust and some other transverse faults and active faults are also present in the area. Some local folds were also observed during the field excursion.

ENGINEERING GEOLOGICAL INVESTIGATIONS

This study has classified the engineering geology of the municipal area (valley area) into different rock and soil units based on the lithology, soil types and their engineering properties. Flood plain deposit, Colluvial soil deposit, Residual soil deposit, Terrace deposit, Itram deposit, Belghari deposit, Purano Ghusra deposit and Sanosurkhet deposit are the major units. Based on the field observation and past studies, engineering geological map of Birendranagar Municipality has been prepared including all the lithological information along with the kinematic analysis of discontinuities, landslides and other engineering geological characteristics (Figure 0:6).

Valley fill sediments

The larger space of the municipality, i.e. Surkhet valley, is filled with Quaternary sediments (heterogeneous sediments) occupying an area of about 47 km^2. In general, the sediments on the valley was deposited as a large alluvial fan in which the proximal fan on the northern portion contains sediments up to boulder size and the distal fan contains very fine-sediment like clayey silt and silty clay (Figure 0**:6**). Further, the surrounding foothill of the valley is covered by the residual and colluvium soil lying above the bedrocks. The Bangesimal, Bhureli and Utterganga areas of the valley contains dry, inorganic, pale yellow to light grey colored clayey silt with sub-rounded to rounded pebbles. The areas south of Latikoili village (Jaypur, Daulatpur, Itaura) are dominated by pale yellow to purple-brown organic-rich silty clay. The Tallo Parseni, Raharpur, Purano Ghusra and Chauke Dhunga area mainly contain organic-rich dark grey clay and brown silt, indicating the lacustrine depositional environment. The southern part of the valley, e.g. Sanosurkhet area, is characterized by pale yellow, grey and reddish brown clayey silt deposit while north of this deposit and south of Kakrebihar, sediments with gravelly silt and sand with gravel are dominant. The northern portion of the valley is generally composed of sub-rounded to rounded gravel with a matrix.

Gravel deposit

The northern part of the Surkhet valley is dominated by gravel deposits that comprise of boulder size clasts and is >10 m thick representing the proximal fan deposit. The clasts are sub-angular to rounded and the size decreases from north to south direction. Dominantly, this deposit contains more than 30 % fine particles as matrix and the clasts are mainly sandstone, quartz arenite and basic plutonic rocks. Most of the settlement areas (like Padampur, Khajur, Birendra Chok, Mangalgadi, Mulpani and Dharapani area) of Birendranagar Municipality is situated on this deposit. The depth of the groundwater table is more than 15 m in this unit, and this deposit has high bearing capacity and is very less susceptible for subsidence and liquefaction.

Gravelly silt and sand deposit

There are gravelly silt and sand deposit around the central portion of the Surkhet valley representing the middle fan deposit. The majorities of the clasts are rounded and pebble size sandstone, quartz arenite and basic plutonic rocks, and the grey, brown silt and sand is a matrix. The proportion of the gravel is higher in the northern part, gradually decreases, and almost disappears in the southern part. This deposit has moderate to high bearing capacity and low liquefaction potential. This type of deposit is common around Bhanpur, Kunti, Pateni, Uttarganga and Bhureli areas.

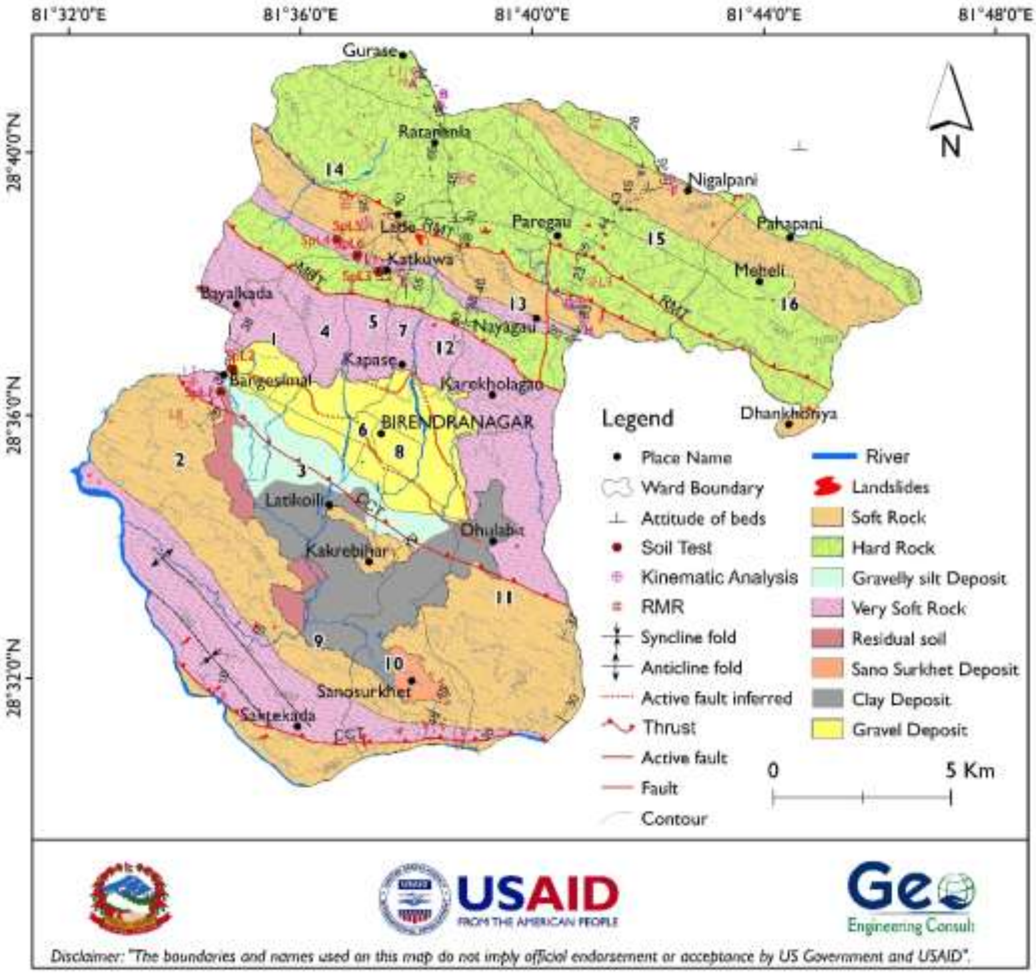


Figure 0:6: Engineering geological map of Birendranagar Municipality, Surkhet, Nepal.

Silty clay and clayey silt deposit

A larger area of the southern portion of the Surkhet valley is occupied by silty clay and clayey silt, which represents the distal fan deposit of the large alluvial fan. There are several wetlands on the southern part of the valley and contains organic-rich soil layers, further indicating the sediments were deposited in a fluvio-lacustrine environment. Typically, the area south of the Kakrebihar is a type locality while other areas like Gagretal, Chaukedhunga, Purano Ghusara, Ghogreni, Jaypur and Bhatekuna villages also share the same characteristic features. It has low bearing capacity. Due to higher potential of liquefaction and subsidence, this type of deposit is not suitable for settlement purposes; however, construction practice is being carried out. The thickness of this deposit is variable with location. From the field observation, the estimated thickness of this deposit is >18 m in the southern part.

Sanosurkhet deposit

This is the southernmost unit of the valley and is filled with yellowish-brown and reddish-brown silty clay deposit. This unit lacks organic matters. Based on the field observation, the estimated thickness of this deposit is >15 m, deposited by the fluvial system and due to pedogenesis process and surface exposure, the sediments have shown variegated color. This deposit has moderate bearing capacity and moderate to low liquefaction potential.

Residual Soil

The residual soil mark the central portion of the valley (Figure 3.6) along the northern slope of the Chure range. The soil is poorly graded and with little amount of fine particles. The colluvium deposit also marked as residual soil in the study area. This type of deposit is prone to the hazard due to the less compact and higher permeability nature.

LANDSLIDE INVESTIGATION

Landslide is one of the common natural geo-hazards especially in a country like Nepal, due to rugged topography, fragile geology, high rainfall, earthquake and anthropogenic activities. Primarily whenever rainfall crosses its threshold value, landslide triggers in the mountainous area. In monsoon season landslides occur as debris flow and interfere downstream area causing loss of lives, property and environment. Most of the rocks in the municipal area are sedimentary origin in the southern part along with few meta-sedimentary, metamorphic and igneous in the northern part. The Siwalik Group, which contains inter-bedding of mudstone, covers a large portion of the municipal area and loose and fragile sandstone rocks susceptible to landslides. The relatively harder rock masses (like quartzite, dolomite, and limestone) within the Lesser Himalayan sequence are highly fractured that increase the risk of rockslides and rock fall. The Bhainskati Formation contains highly fractured and weathered shale, which is also the main reason for the instability of slope in the northern part. Numbers of local thrusts and faults that cross-cut the municipal area add additional risk on slope. Owing to the fact that fragile geology, loosely cemented sediments and inter-bedding of soft and hard rock are the main reason of landslide in the Siwalik region.

Figure 0:7: Landslides in various locations: a) near the Siddhapaila village, b) local road joining Chheda and Saldada village, c) along the road in between the Siddhapaila and Gurase area, d) near Chheda village, along the road in between Katkuwa and Chheda.

Most of the landslides in the study area are mapped remotely using the Google Earth Imagery and presented on the Engineering geological map (Figure 3.6) and some photographs are present in Figure 3.7. The existences of such landslides are cross verified during the field visit. The observed landslides were studied in detail and documented as a model for landslide hazard modeling. The dimension, history, possible cause, impact and applied mitigation measure of the landslide has been documented and a brief description of these landslides are presented in Table 0:2.

Table 0:2 General information of the landslides, studied in detail.

S.N.	LANDSLIDE	LAT/LONG	LOCALITY	RUNOUT DISTANCE	MATERIAL		GEOLOGICAL FORMATION	CAUSES
					ROCK TYPE	**SOIL TYPE**		
1	LS1	28°40'14.82" N 81°38'39.13"E	Siddhapaila	20 m	Quartz Arenite	Residual and colluvial	Ranimatta	Rainfall, Slope modification
2	LS2	28°39' 32.57"N 81°37' 30.97"E	Chheda	30 m	Shale	colluvial	Dumri	Slope modification
3	LS3	28°39'14.13" N 81°37'6.10"E	Chheda	100 m	Sandstone and shale	Residual and colluvial	Dumri	Rainfall, sope modification
4	LS4	28°38' 55.92"N 81°37' 15.42"E	Katkuwa	30 m	Shale	colluvial	Bhainskati	Rainfall

Based on the field observations, the major cause of the landslides is found to be slope geometry modification during road construction and excessive rainfall. The observations show that most of the landslides are located in the northern part of the municipality hence, the ward 13, 14, 15 and 16 are the landslide-prone areas.

ROCK MASS AND DISCONTINUITY STUDY

Rock mass classification is an important parameter to understand the rock mass quality, which controls the engineering behavior of the rock mass. There is a specific rating system for six parameters of the rock mass and is classified based on the total score of rating values. The description of the rock mass characteristics is given below for each litho-unit.

Ranimata Formation (L1): The RMR has been performed near the Gurase village for lithic arenite of Ranimatta Formation. On the basis of these characteristics, the rock mass is assigned with Class II RMR value, which describes the rock mass as the Good Rock.

Ulleri Formation (L2): The RMR has been performed for light grey colored augen gneiss of the Ulleri Formation near the Nigalpani village. On the basis of these characteristics, the rock mass has been classified as Class I, i.e. Very Good Rock.

Syangja Formation (L3): The RMR has been performed near Kamase village from the light pink colored, slightly weathered and highly fractured quartzose sandstone of the Syangja Formation. The rating values has classified the rock mass as Class II, i. e. Good Rock.

Amile Formation (L4): The rock mass characterization has been carried out for the pale yellow colored, slightly weathered quartzose sandstone of Amile Formation near the Katkuwa village. Based on the rating values, the rock mass is classified as Class II, i.e. Good Rock.

Bhainskati Formation (L5): The Bhainskati Formation contains monotonously fissile shale throughout the study area. The UCS value of the intact rock mass is very low and the RQD is also minimal. On the basis of the field observation, the Bhainskati Formation has been assigned with the lowest class, i.e. Class V), means very poor rock quality.

Dumri Formation (L6): The RMR has been conducted in the greenish colored medium-grained sandstone of the Dumri Formation near the Chheda village. On the basis of these characteristics, the rock mass is classified as Class III, i.e. Fair Rock.

Middle Siwalik (L7): The RMR has been performed for the rock mass of pinkish grey colored, moderately weathered, coarse sandstone at Coldanda. The total rating value has classified the rock mass as Class III, i.e. Fair Rock.

Lower Siwalik (L8): The RMR has been carried out for the light grey colored, highly weathered fine sandstone of Lower Siwalik at Bangesimal. The rock mass is classified as Class IV, i.e. Poor Rock.

GEOTECHNICAL INVESTIGATIONS

Soil parameters such as cohesion and internal friction angle are essential to carry out landslides hazard assessment as these paramaters give the shear strength of soil. In order to evaluate shear strength of soil, shear strength parameters are needed which can be obtained from the laboratory tests of soil samples. In this study, representative samples were collected from different geological formations. The collected soil samples were tested for physical and mechanical properties in material testing laboratory at Kathmandu. Different tests like Natural Moisture Content test, Particle Size Distribution test, Atterberg Limit test, Specific Gravity test and Direct Shear test were conducted on soil samples so that engineering properties of soil required for slope stability analysis could be determined.

In mechanical test, the direct shear test was carried out and the results are present below. The direct shear test results are presented in terms of the failure envelops to give the angle of internal frictions (Ø) and the cohesion intercepts (c).

Lower Siwalik Group (SpL-1-2)

Two samples were analyzed from the Lower Siwalik Group. The grain size distribution curve of the sample 1 (SpL-1) is shown in Figure 3:7 and 3:8. According to Unified Soil Classification System, this soil samples is classified as Poorly Graded Gravel (GP) with a friction angle and cohesion value of 29^0 and 0 KN/m^2 respectively and specific gravity 2.61.

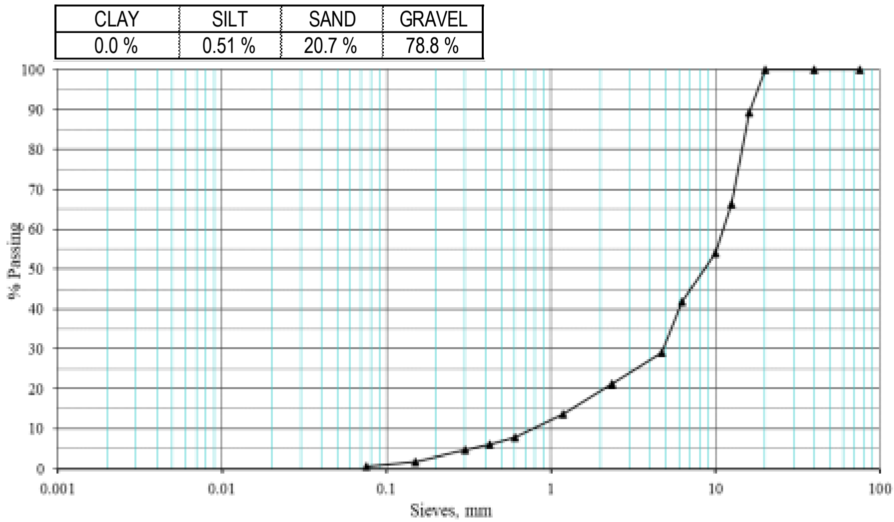


Figure 0:8 Grain size distribution curve from sample SpL-1.

Similarly, sample 2 (SpL-2), is silt dominated and the grain size distribution curve is presented in Figure 3.6. According to Unified Soil Classification System this sample is classified as Silty Sand (SM) and it has shown a friction angle and cohesion value of 29^0 and 1 KN/m^2 respectively with a specific gravity 2.67.

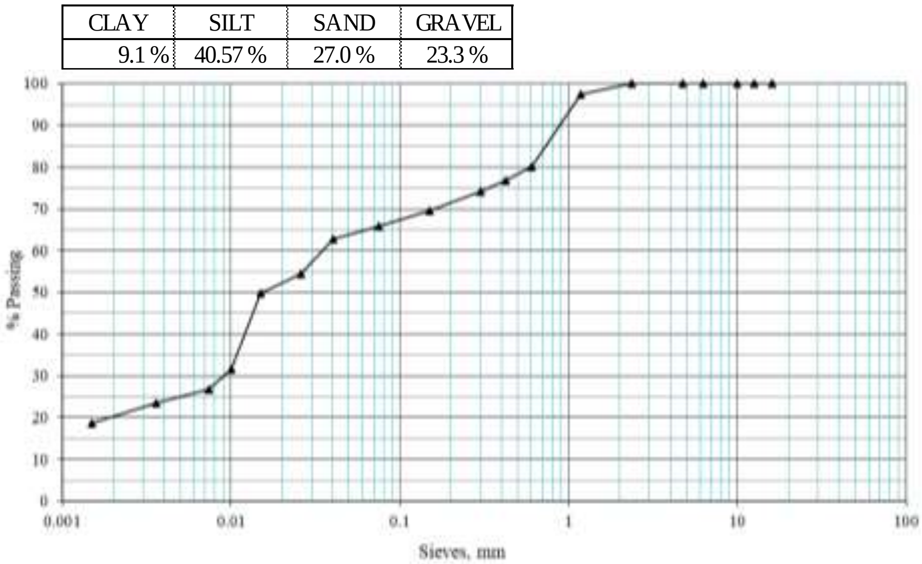


Figure 0:9 Grain size distribution curve from sample SpL-2.

Bhainskati Formation (SpL-3, 4, 5 and 6)

Four samples were collected from the Bhainsati Formation. Silty sand and low plastic silt are dominant in this formation. According to Unified Soil Classification System sample 3 & sample 4 are classified as Silty Sand (SM), whereas sample 5 and sample 6 are classified as Low Plastic Silt (ML) (Figure 3:10-3:13). In this formation, friction angle of soil sample varies from 28^0 to 29^0 , and cohesion from 1 to 6 KN/m^2. Specific gravity of soild particles is about 2.6.

CLAY	SILT	SAND	GRAVEL
0.0 %	12.08 %	48.7 %	39.2 %

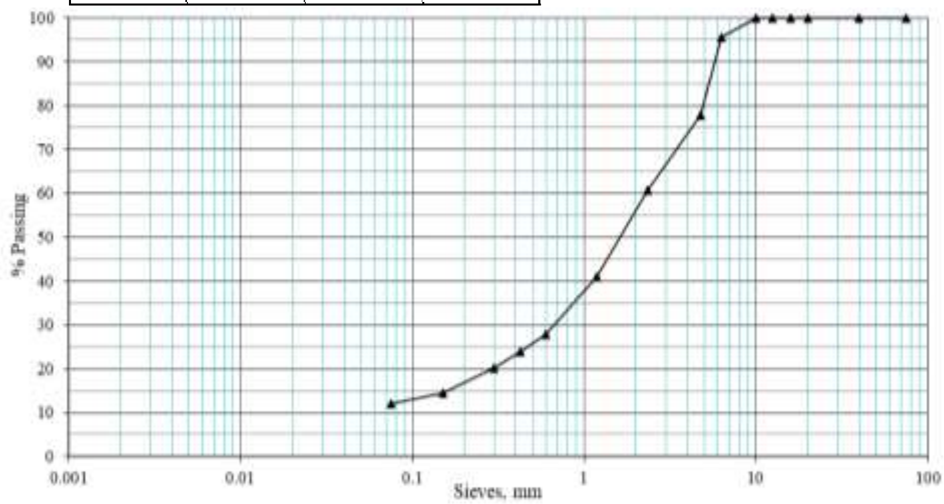


Figure 0:10 Grain size distribution curve of sample SpL-3.

CLAY	SILT	SAND	GRAVEL
0.0 %	39.15 %	30.5 %	30.4 %

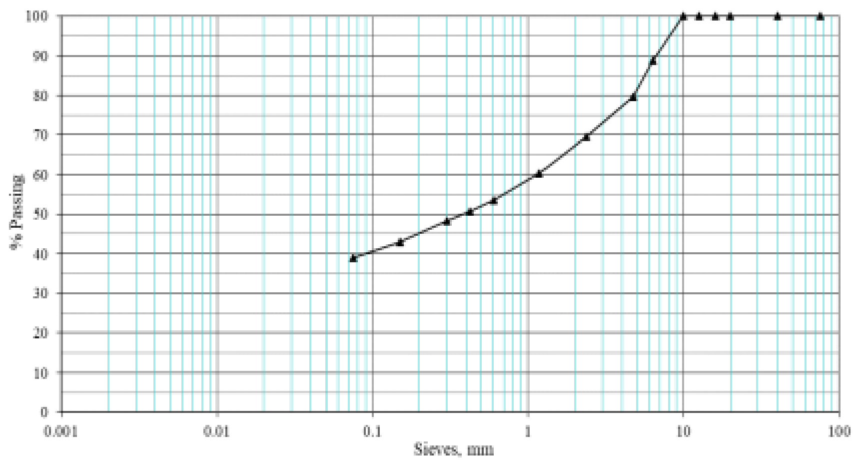


Figure 0:11 Grain size distribution curve of sample SpL-4.

CLAY	SILT	SAND	GRAVEL
11.4 %	64.05 %	20.7 %	3.8 %

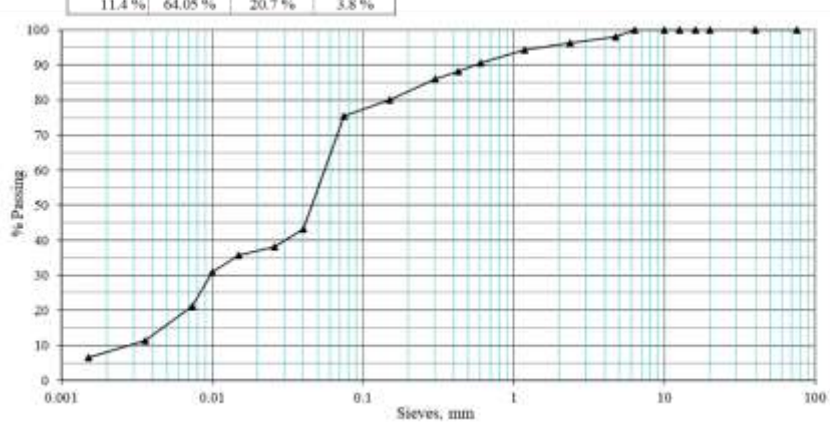


Figure 0:12 Grain size distribution curve of sample SpL-5.

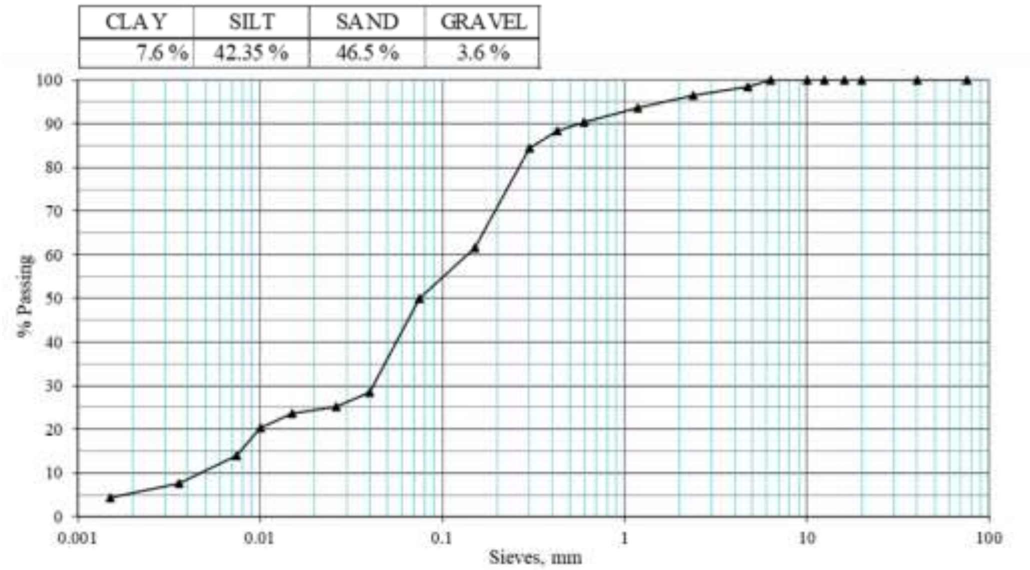


Figure 0:13 Grain size distribution curve of sample SpL-6.

CONCLUSIONS

Physiographically, Birendranagar Municipality covers Churia hill and Mahabharat range in the southern and northern parts respectively and Surkhet Dun valley is situated in the central part, which is filled up with Quaternary sediments.

The municipal area comprises of two major tectonic units i.e. Sub Himalaya (Siwalik Group) and Lesser Himalaya. The Lesser Himalayan rocks are exposed only in the northernmost part, while Siwalik Group is exposed central and southern part of municipality too. The Siwalik Group is further divided into the Lower, Middle and Upper Siwalik and each unit mainly consists of mudstone, sandstone and conglomerate respectively. The rocks of the Lesser Himalaya are subdivided into Midland Group and Surkhet Group. The Ranimatta, Ulleri, Kushma and Syangja Formations are of Midland Group whereas Amile, Bhainskati and Dumri Formations are in Surkhet Group. The Ranimatta Formation mainly consists of greenish-grey phyllite and quartzite with occasional layer of conglomerate, and exposed in northern part of the municipality. The augen gneiss is a main composition of Ulleri Formation while all the three Syangja, Kushma and Amile Formations, mainly consists of quartzite, and phyllite and each unit only differ by the color and grain size. The Bhainskati Formation is composed of pencil cleavage shale and Dumri Formation comprises of greenish-grey coarse-grained sandstone. The Ranimatta Thrust (RMT), Main Boundary Thrust (MBT) and Central Churiya Thrust (CCT) are the major thrusts in the municipal area. There is a transverse fault cutting the Lesser Himalaya sequences in the north and two active faults pass through the quaternary sediments of the Surkhet valley. Syncline and anticline folds are present within the Lower Siwalik in the southern part.

The Dun valley is filled with Quaternary sediments and classified into four units based on the nature of the sediments and their engineering properties. These units are Gravel deposit situated on northern part of the valley, Gravelly Silt and Sand deposit from the middle part of the valley Clayey Silt and Silty Clay deposit from the southern part of the valley and Sanosurkhet deposit from the Sanosurkhet area i.e. southeast of the valley. Among these, Gravel deposit has sub-rounded to rounded clasts of boulder size mainly consisting of quartzite, sandstone, and basic volcanic rocks, with matrix of silt and clay. The Gravelly silt and sand deposit consists of silt and sand with rounded clasts of pebble size. The Clayey silt and silty clay deposit dominantly comprises of organic and inorganic clay mixed with silt. The Sanosurkhet deposit is characterized by silty clay of reddish brown and yellowish brown color, dry and compact. The sediment nature and properties from the present study and previous literatures confirmed that the northern part of the valley has very low to low, central portion has moderate while the south eastern portion is has higher possibility of the liquefaction and low bearing capacity.

The rock mass of augen gneiss is found to be of Class I (Very Good Rock) and the fissile and weathered shale of the Bhainskati Formation belong to the Class V (Poor Rock). Other rock masses within the municipal area are of fair to good quality. The rock masses situated on the northern hill slope are comparatively stronger than that of the southern part. The kinematic analysis of several locations shows most of the area has risk of wedge failure with least probability of plane and toppling failures.

The municipal area found to be susceptible for the landslide hazard due to the road cut slope modification, weak rock mass, high rainfall, high degree of weathering, anthropogenic activities, presence of geologically weak thrusts and faults zone, and development activities. Most of the landslides are found to be small scale and emplacement of some general engineering geological structures and removing the debris from the existing slope could make it stable.

The Lower Siwalik soils have shown poorly graded gravel to silty sand with specific gravity of ~2.6, and friction angle and cohesion value 29^0 and 0 KN/m^2 respectively. The soils from the Bhainsakti Formation are silty sand to low plastic silt with friction angle of 28^0 to 29^0 and cohesion 1 to 6 KN/m^2 and specific gravity is about 2.6. Overall, the frictional angle and cohesion of the soils vary from 26^0-29^0 and 1-6 KN/m^2 respectively in the municipal area.

Based on the geological and engineering geological study, the area north of the Karnali Highway is more suitable for the settlement whereas further north (the hilly areas) is vulnerable due to landslides. However, the landslides are small in scale and it can be stabilized by means of some engineering structures. Moreover, more importantly the southern portion of the municipal area is more susceptible for the liquefaction. Therefore, for settlement as well as urban development the northern portion of the municipality is more applicable than southern part.

SIGNIFICANCE

The geological and engineering geological investigations are important bases for seismic microzonation, flood and landslide hazard assessments. The geological characteristics and structural system are backbone to seismic hazard assessment.

4. SESISMIC MICROZONATION STUDY

BACKGROUND

Seismic microzonation is the first step in earthquake risk mitigation, which requires multidisciplinary approach. These approaches can be geology, seismology, geophysics, geotechnical and structural engineering. It can also be done using various criteria such as liquefaction potential, landslide hazard, shear wave velocity (Vs30), fundamental frequency of soil, and amplification factor etc. Microzonation can provide basis for site-specific risk analysis, which can be used ultimately to mitigate seismic risk.

Ground motions at a particular site are largely affected by local geology, this necessitates the development of microzonation maps for rapidly growing and densely populated cities like Birendranagar Municipality. Dynamic soil characteristics such as predominant period, amplification factor, and shear wave velocity can be used for seismic microzonation. Ambient noises measurement technique, because of low cost associated with the field investigation and data analysis, becomes popular for attaining dynamic properties of soil and is being extensively used for seismic microzonation. Ambient noise measurements are easy to carry out and can be applied in the region having low seismicity such as Birendranagar Municipality.

Seismic site effect which refers to amplification of seismic waves occurs as a result of several physical phenomena such as multiple reflection, diffraction, focusing and resonance of seismic waves. Local soil condition is one of the factors that have a significant role in the amplification of seismic waves and have been experienced in the past earthquakes, e.g., 1934 Bihar-Nepal earthquake & 2015 Gorkha earthquake. Figure 4:1 shows seismic site effects in valley due to soft sediment. Damaging effects associated with soft soil sediments lead to local intensity increment as large as two-to-three-degree MMI scale (Aki & Irikura, 1991). The 1985 Michoacan earthquake, though located km away from Mexico City, caused site effects resulting into high amplification of wave energy causing severe damages. The damage to the infrastructures was extensive in the lakebed region and was minimal or nonexistent outside soft soil deposits. The 1988 Spitak, 1989 Loma Prieta, 1994 Northridge and 1995 Hyogeken Nambu (Kobe) earthquakes have underscored the importance of seismic site effects assessments.

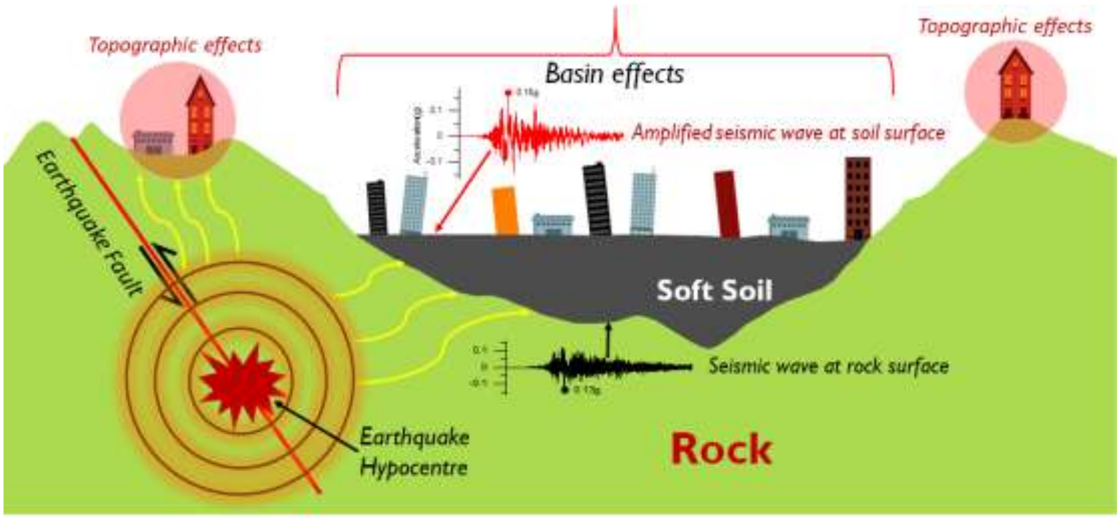


Figure 0:14 Schematic model showing seismic site effect (amplification of seismic wave due to soft soil deposit in the valley).

Similarly, seismic site effect was also occurred during the 2015, Mw 7.8 Gorkha earthquake. Different levels of damage patterns were observed in Kathmandu valley, e.g. areas like Bhaktapur, Sankhu, Bungmati, Harisiddhi and the north-eastern part of the valley were severely damaged whereas other parts remain less affected. Similar damage patterns were also observed during the 1934 Bihar-Nepal earthquake. It is believed that local soil played a significant role in amplifying or de-amplify lethal seismic waves. Being located in the valley with soft sediments, Surkhet valley of Birendranagar Municipality may face similar seismic site effects in a western Nepal overdue earthquake. Therefore, seismic microzonation study has been carried out to assess the seismic hazard and risk based on fundamental frequency, amplification factor and shear wave velocity.

OBJECTIVES

The overall objective of the project is to develop innovative and effective method for seismic hazard assessment through seismic microoznation study. The specific objectives are as follows:

- Seismic site classification of Surkhet valley of Birendranagar Municipality based on NEHRP site class.
- Seismic microzonation of the Surkhet Valley of Birendranagar Municipality based on Vs30, fundamental frequency and amplification factor.

METHODOLOGY

Seismic microzonation of the valley was conducted using natural ambient noise. Ambient noise measurement was carried out using four seismometers. Active, passive and single point measurement were performed. Dispersion curve from active and passive survey were combined and inversed to obtain shear wave velocity. Shear wave velocity, fundamental frequency, and amplification data were used for seismic microzonation. Figure 4:2 shows detailed flow chart for seismic microzonation study in Surkhet valley.

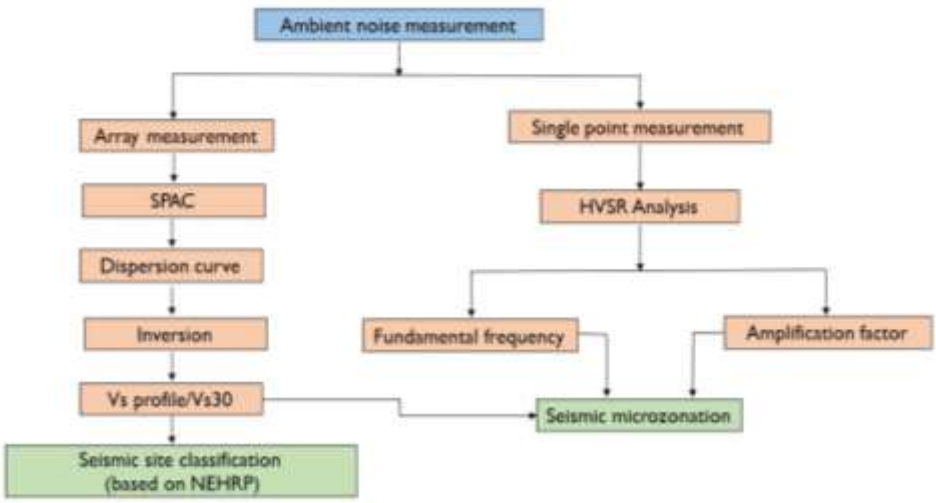


Figure 0:15 Flow chart for seismic microzonation study.

For ambient noise data acquisition, approximately 700 m by 700 m grid points in Surkhet valley were plotted over a topographic base map of Birendranagar Municipality in a GIS environment. The grid point longitude and latitude served as an ambient noise measurement site. The measurements were carried out at total of 110 grid points from February 2021 to April 2021 (Figure 4.3).

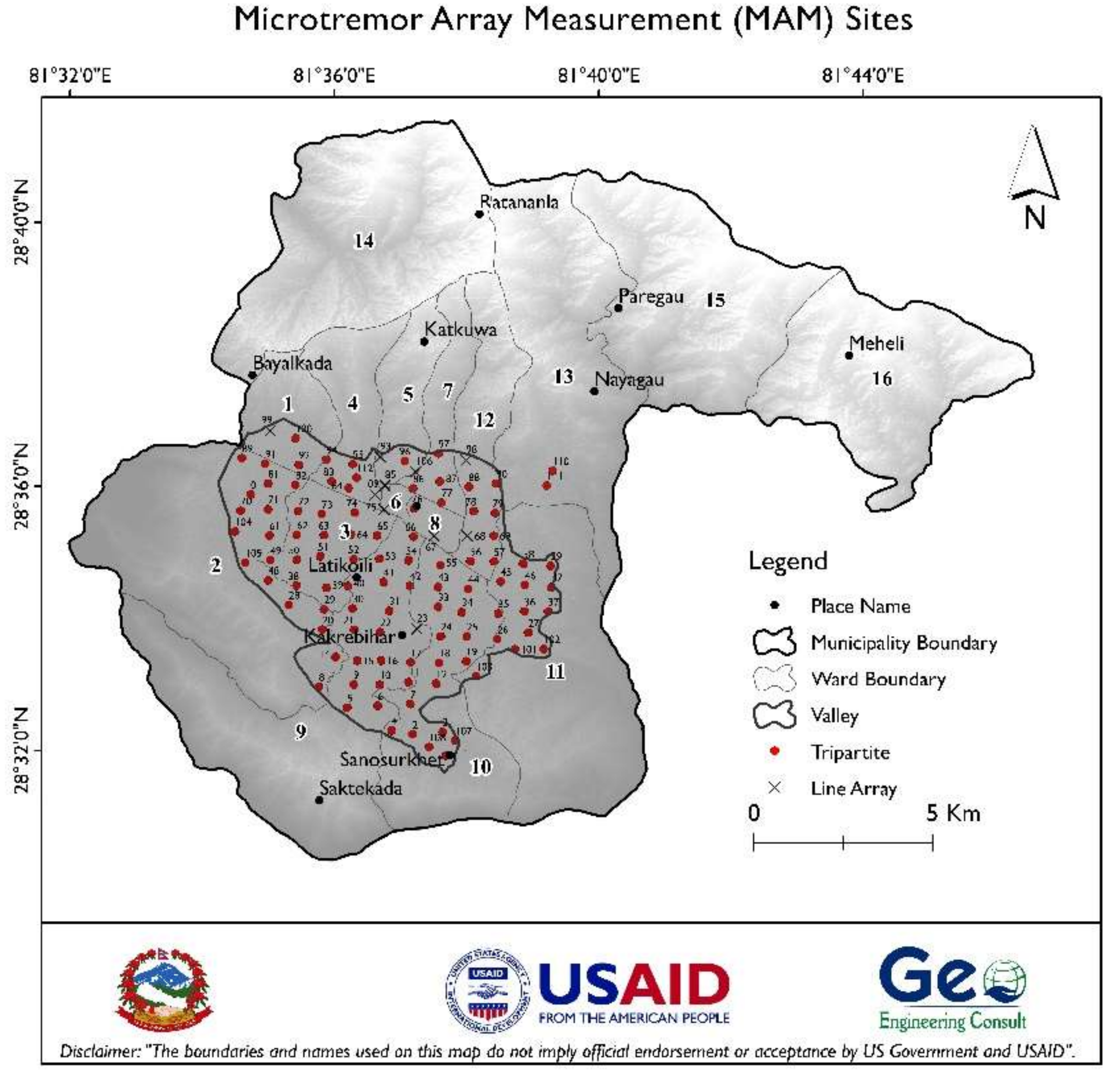


Figure 0:16 Ambient noise array measurements sites.

EQUIPMENT AND DATA COLLECTION

The Ambient noise traces are recorded simultaneously by 4 independent seismometers (1-3C Atom and 3-1C Atom, Geometrics Inc. USA) which were deployed in an array (Tripartite, Line and L-type) depending upon site conditions. Figures 4.4 and 4.5 show arrangement for tripartite and line measurements.

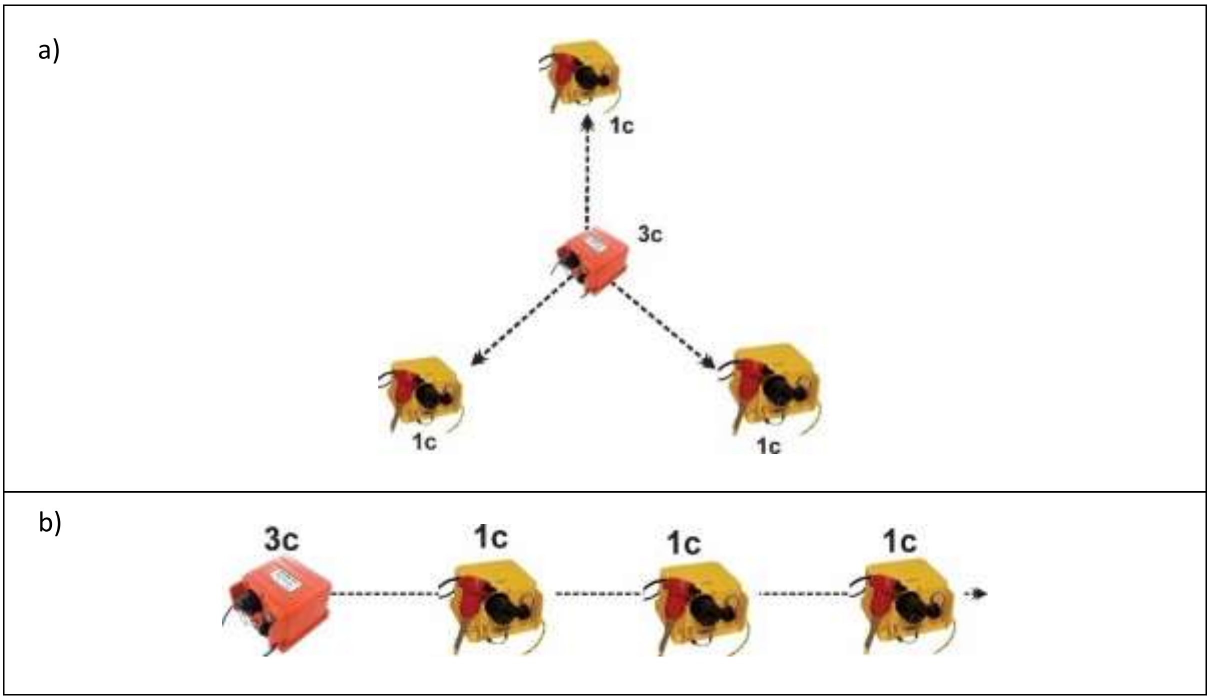


Figure 0:17 Seismometer arrangement for (a) Tripartite and (b) Line measurement.

Figure 0:18 (a) Tripartite array (b) Line array for ambient noise array measurement.

Three components atom (3C-Atom) was used to measure single point during Tripartite and Line ambient noise measurement.

In addition to the passive measurement, active measurements were also carried out at each location to obtain shear wave velocity above 5.0 m depth (Figure 4.6) as it is difficult to get shear wave velocity at depth less than 5.0 m using passive survey.

Figure 0:19 Active survey in Surkhet valley of Birendranagar Municipality.

DATA ANALYSIS

The present study uses SeisImager software from Geometrics Inc., which is based on the SPAC method to obtain a dispersion curve. In this study, dispersion curve for both passive and active measurement have been calculated and combined to obtain final dispersion curve containing wide range of frequency, usually between 5 Hz to 25 Hz. Dispersion curve is inverted to obtain average shear wave velocity (Vs30) in top 30 m depth for each point.

Single point ambient noise can be used to obtain Horizontal-to-Vertical Spectral Ratio (HVSR), which is used to obtain subsurface information. Nakamura (1989) proposed methodology to obtain fundamental frequency and amplification factor from single point ambient noise data. This study has adopted the same technique. Site effects assessment using ambient Excitations (SESAME) guideline was followed during field measurement and analysis of data. All the measured data and their analyses meet SESAME criteria.

RESULTS

The results of ambient noise survey are presented in terms of average shear wave velocity at 30 m depth (Vs30), fundamental frequency and amplification factors of the ground at each point and presented in the form of maps.

Shear wave velocity and seismic site characterization

Shear wave velocity profiles have been obtained by inversion of dispersion curves. It has been found that Vs30 in Surkhet valley varies from 160-508 m/s (Figure 4.7).

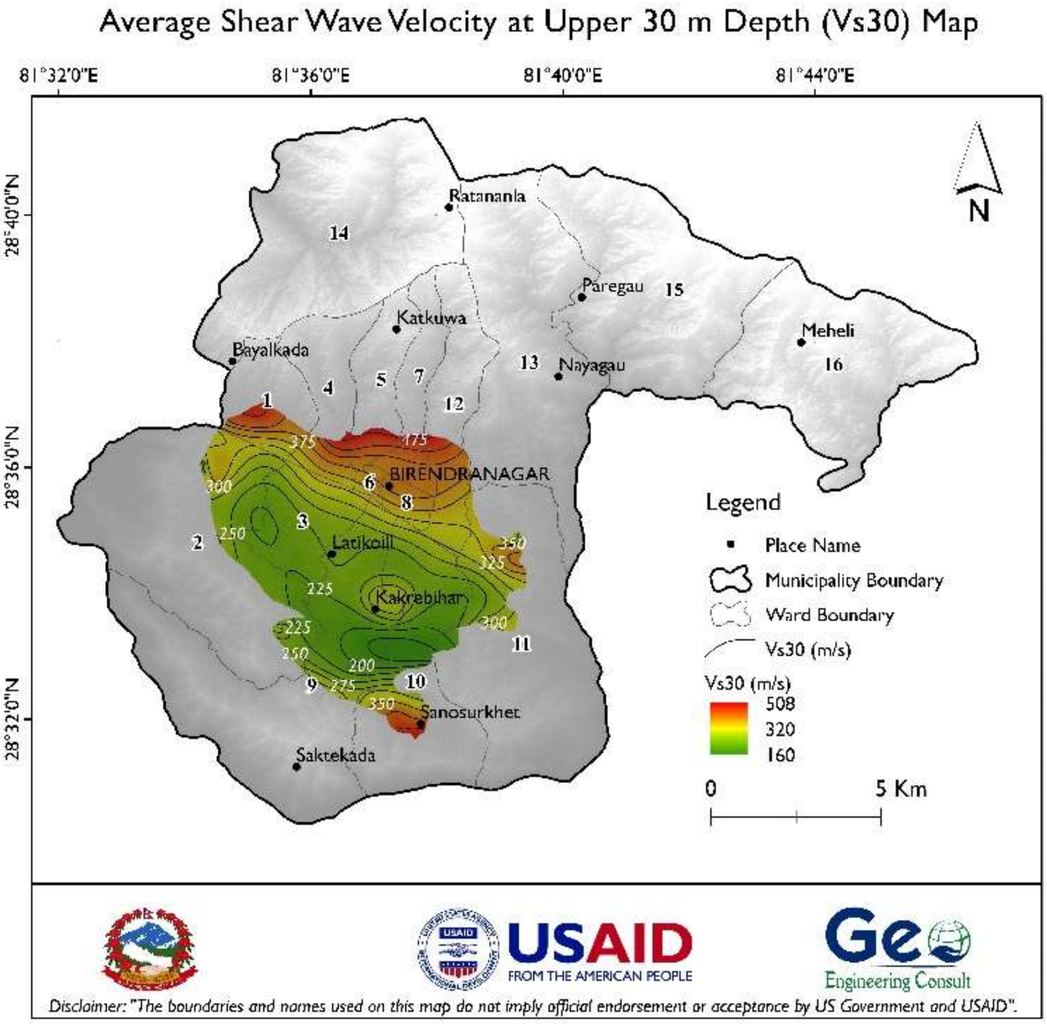


Figure 0:20 Shear wave velocity variation in Surkhet valley of Birendranagar Municipality.

The lowest Vs30 value (160 m/s) is found at the southern part of central hillock, which is a water-logged zone dominated by fine sediments. Northern part has relatively higher shear wave velocity (508 m/s) as this region has gravel and boulder deposits. Vs30 increases towards the outskirt of the valley as thickness of soft sediment decreases. Vs30 values for Purano Ghushra Formation varies from 160-250 m/s. This region is dominated by dark grey clays and black carbonaceous clays with sporadic interbedding of silty sand fine sand. Water table is at shallow depths and most of the area containing this deposit are of swampy nature, which might be the reason for low shear wave velocity in this region. Vs30 values in Belghari Deposit varies from 250 to 350m/s, which is characterized by silty clay mixed with pebbles and boulders. The Vs30 values for Itram deposit ranges from 325-508m/s and is attributed to stiff gravel and boulder deposits. Sano Surkhet area is characterized by Vs30 values from 350 to 475m/s.

In general, the Vs30 value in ward numbers 1, 4, 5, 6, 7, 8, 11 and 12 is relatively high as compared to other wards and it varies from 325 m/s to 508 m/s. Similarly, part of ward number 2 and 9, the Vs30 value ranges from 160.0 m/s to 300.0 m/s. Ward number 10 has wider variation of V30 i.e. from 160.0 m/s to 508.0 m/s.

Seismic site classification

Based on Vs30 values, National Earthquake Hazards Reduction Program (NEHRP) has divided soil into six categories: A to F (Table 4.1). Based on NEHRP classification, Surkhet valley can be divided into three categories: site class C, D and E (Figure 4.8). Majority of central part of valley falls in class D which is dominated by stiff soil, this is followed by class C having very dense soil & hard rock, northern and some southern part of valley come under this category, very small area is classified as class E having very soft soil.

Table 0:3 Site classification as per NEHRP

S. NO	NEHRP CATEGORY	GENERAL DESCRIPTION	VS30
1	A	Hard Rock	>1500
2	B	Rock	760 < Vs30 ≤ 1500
3	C	Very dense soil & soft rock	360 < Vs30 ≤ 760
4	D	Stiff soil 15 ≤ N ≤ 50 or 50 kpa ≤ Su ≤ 100 kpa	180 ≤ Vs30 ≤ 360
5	E	Soil or any profile with more than 3m of soft clay defined as soil with PI >20, w>= 40% & Su < 25kpa	≤ 180
6	F	Soil requiring site-specific evaluations	

Note: N: SPT blow count, Su: Undrained shear strength, PI: Plasticity index, w: water content

As per the NEHRP category, the valley portion of Ward number 1, 4, 6, 7, 12 and 11 are categorized as class C & D. Ward number 3 lies completely within class D. Similarly, the soils of Ward number 2 and 9 are classified as class D. However, ward number 10 has all three classes C, D & E. The sites D and E require special attention while using for the settlement purpose. Seismically, these site classes are prone to amplify of seismic wave and may suffer greater damages during an earthquake.

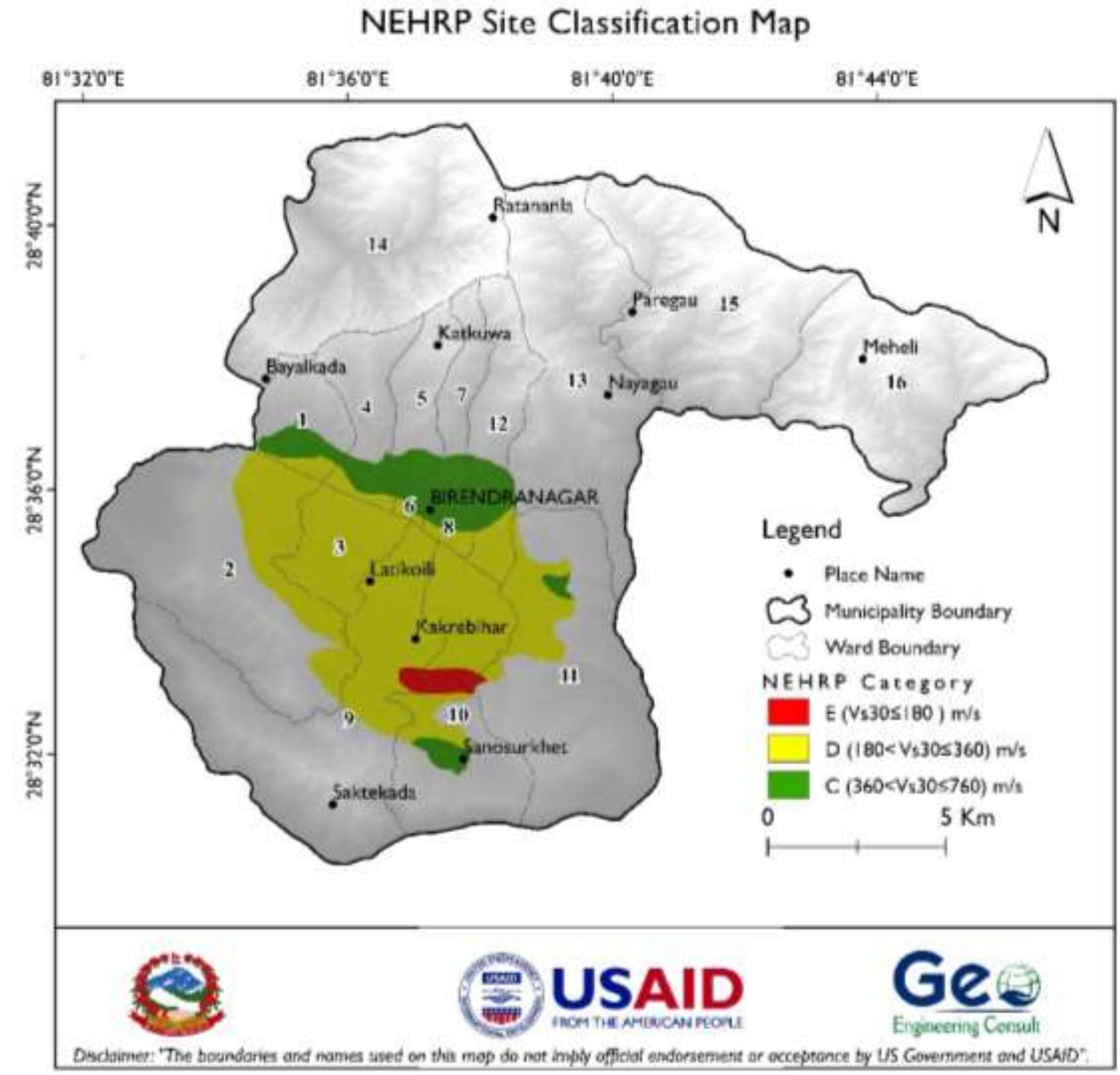


Figure 0:21 Site classification in Surkhet valley of Birendranagar Municipality as per NEHRP.

Fundamental frequency and seismic microzonation

From the HVSR analysis, it has been found that fundamental frequency in Surkhet valley of Birendranagar Municipality varies from 0.6 Hz-6.0 Hz (Figure 4.9). It varies from 0.6 to1.2 Hz at the central and northern areas of the valley and increases to maximum of 6Hz in the outskirt of the valley except at northern part. Lower fundamental frequency in the central and northern parts of Surkhet valley correlates with the higher depth of Quaternary deposit, while the higher fundamental frequency in the outskirt corresponds to shallow and stiffer deposits.

Fundamental frequency in Purano Ghushra Deposit, consisting of soft grey and carbonaceous clay, varies from 0.6 Hz to 1.0Hz. Presence of soft clay and relatively larger sediment thickness might be the reason for lower fundamental frequency. Similarly, there is a variation of fundamental frequency from 1.0 – 2.0 Hz. in Belghari Deposit, which consists of yellowish-grey silty clay deposit. The fundamental frequency of 1.5 Hz to 4 Hz have been observed in the Sano Surkhet Deposit, which consists of shallow depth of soft sediment, i.e. silty clay.

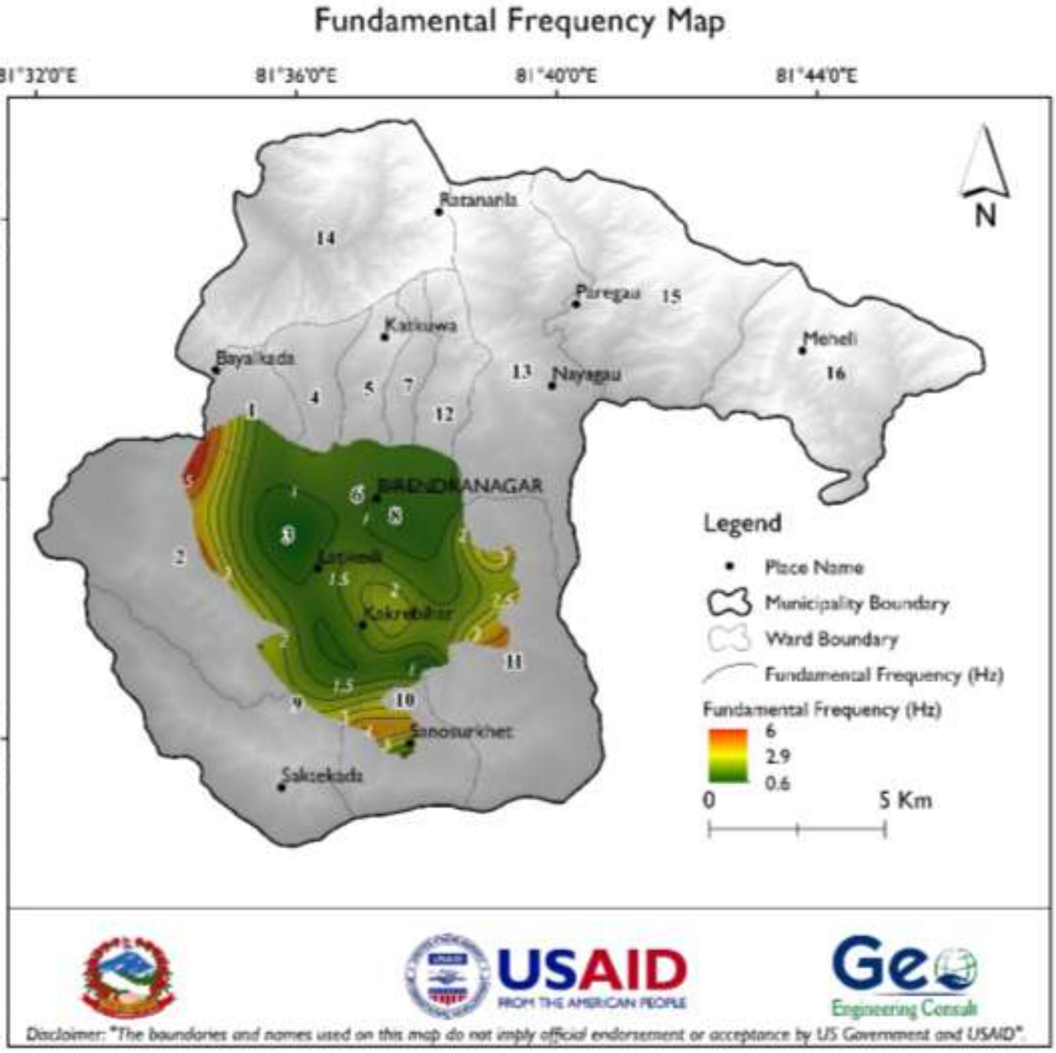


Figure 0:22 Variation of Fundamental Frequency in Surkhet valley of Birendranagar Municipality.

Valley parts of Ward number 3, 4, 5, 6, 7, 8, 9 and 12 have low fundamental frequency, which varies from 0.6 Hz to 2 Hz. However, Ward number 1, 2, 10 and 11 have relatively higher frequency which ranges from 2.5 Hz to 6 Hz.

Amplification factor

The distribution of the amplification factor for Surkhet valley is shown in (Figure 4.10). Amplification factor (H/V ratio) varies from 2 to 8. Amplification factor for the central area of Surkhet valley, dominated by soft sediment, is about 8 (the highest), which decreases towards the outskirt of the valley. This highest amplification factor is observed at the southern part of central hillock, which is a water-logged zone and is also dominated by fine sediments with greater thickness.

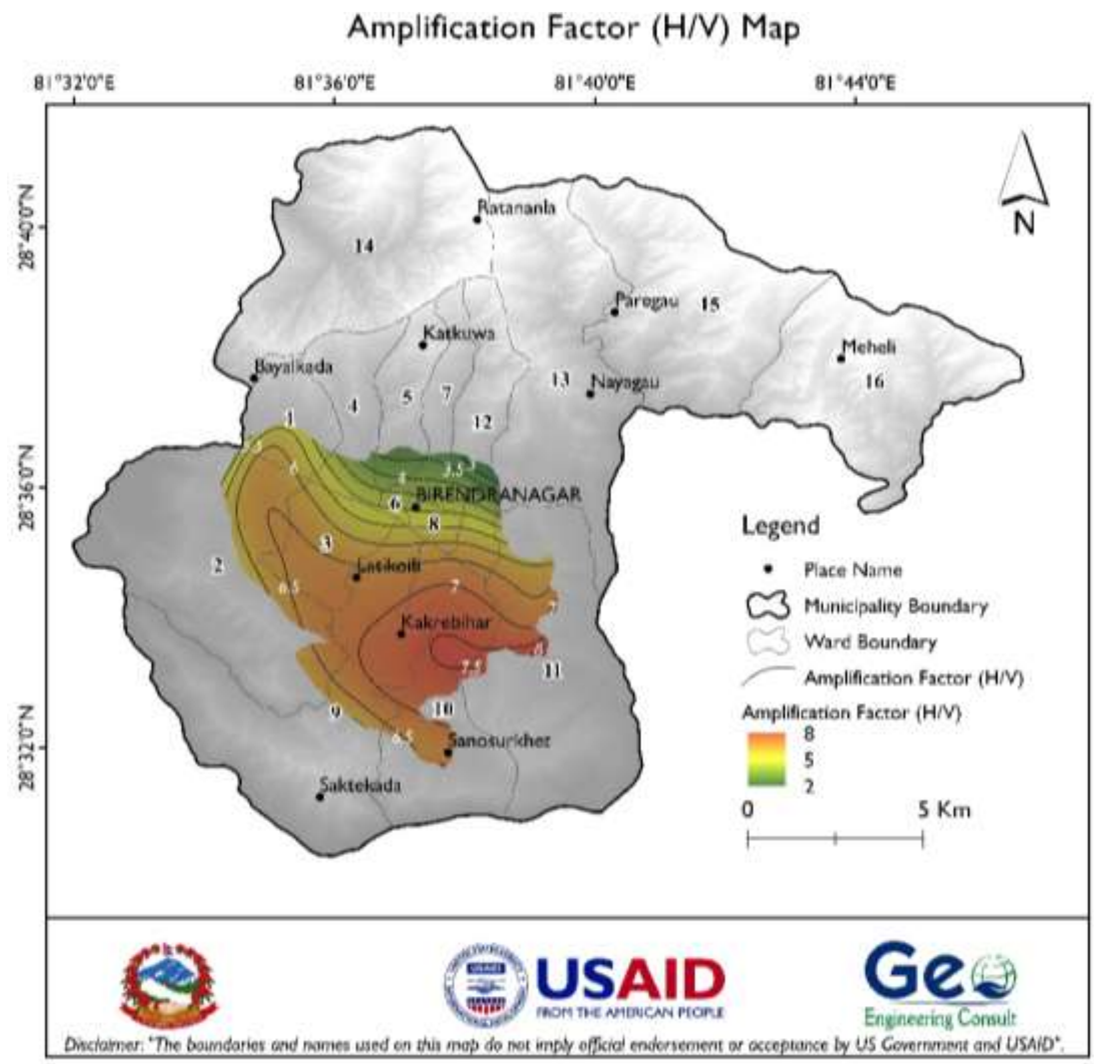


Figure 0:23 Variation of Amplification Factor in Surkhet valley of Birendranagr Municipality.

Similarly, the lowest amplification factor is observed at the northern part of valley, dominated by gravel and boulder and weathered rock. It varies from 3 to 5. Amplification factor in Purano Ghushra Deposit varies from 6.5 -8. This region is dominated by dark grey clays and black carbonaceous soft clays with sporadic inter-bedding of silty sand fine sand, which contains occasionally pebble to boulder clasts, therefore, this region has highest amplification factor as compared to other regions. In Belghari Deposit, amplification factor varies from 5 –7, silty clay mixed with pebbles and boulders is responsible for relatively higher amplification factor in this part. The amplification factor at Itram ranges from 3 – 4.5. Sano Surkhet that consists of a shallow deposit of silty clay has amplification factor around 6. The north south and east west variation of the amplification factor are shown in Figure 19 and Figure 20.

Overall, higher seismic wave amplification factor (3 to 6) is observed in the ward number 1, 2, 3, 6, 8, and 9. Central part of ward number 10 and part of ward number 11 has the highest amplification factor i.e., 8. Ward number 4, 5, 6, 7, 8 and 12 are categorized as the region having lower amplification factor which range from 2 to 4.

CONCLUSIONS

Ambient noise measurement survey was carried out in Surkhet valley of Birendranagar Municipality at 110 locations. Both single point and array type measurement were carried out. Shear wave velocity in

Birendranagar Valley varies from 160.0 to 508.0 m/s, lower value is obtained in the region having soft soil and higher velocity in the region dominated by dense gravel & boulder deposit. Based on the NEHRP site class Surkhet valley of Birendranagar Municipality can be divided into three class: C, D and E. Majority of central part of the valley has shear wave velocity of 180 to 360 m/s and classified as Class D. The northern region and small portion of southern part is classified as Class C having shear wave velocity between 360.0 to 760.0 m/s. A small region in the south of central hillock (Kakrebihar) has very low shear wave velocity, below 180 m/s. This region reflects very low bearing capacity so, special consideration is to be taken while designing foundation in this region.

The study estimated fundamental frequency between 0.6 Hz to 6.0 Hz. The higher frequency is obtained at outskirt of the valley and areas where gravel and boulder are dominated, and lower frequency is obtained at central part of valley and in areas where soft and fine sediments are dominated. Similarly, amplification factor varies from 2 to 8 Hz. There are chances of resonance of soil frequency with structure during the earthquakes so special consideration is to be made while designing and constructing structure in this region that have fundamental frequency between 0.6 to 6.0 Hz.

SIGNIFICANCES

Average Shear wave velocity up to 30.0 m depth (Vs30) given in this report can be used in seismic hazard assessment to estimate peak ground, peak spectral acceleration at ground surface. Similarly, Vs30 and site classification can be correlated with the bearing capacity and can be used to estimate safe bearing capacity of soil for shallow foundation.

Data from seismic microzonation studies in Birendranagar Municipality can be used in urban planning as it helps to identify relatively higher seismic risk areas and can estimate the impact of an overdue western Nepal earthquake. Using these information, key facilities like hospitals, fire stations, emergency operation centers etc. may be planned in area having good site class and lower amplification factor. These data are equally useful for risk sensitive land use planning.

5. SEISMIC HAZARD ASSESSMENT

BACKGROUND

The Himalayas is located in the seismically active region on the globe. Nepal, located in the central part of the Himalaya, witnessed several devastating earthquakes in the past, e.g., 1050 Western Nepal earthquake, 1934 Bihar-Nepal earthquake, 1988 Udayapur earthquake and 2015 Gorkha earthquake. The recent Gorkha earthquake caused significant damages to the buildings and civil engineering infrastructures in the central Nepal. The Birendranagar Municipality is located in the central Himalayan seismic gap. The western part of Main Himalayan Thrust (MHT) has not ruptured since 1505 and has potential to produce large earthquakes. To understand the risk of impending earthquake in the Birendranagar Municipality, a detail seismic study is necessary. This is also useful to assess the impact of the overdue earthquake event in western Nepal. Considering the inherited risk of the earthquake, the Probabilistic Seismic Hazard Assessment (PSHA) have been done for Birendranagar Municipality. The study is based on the field measurement of average shear wave velocity at 30 m depth (Vs30) using microtremor array measurement, seismic sources identified and characterized using the available literatures on geology, seismo-tectonics, active faults, and seismicity.

OBJECTIVES

The main objective of the study is to obtain bedrock and free field peak ground acceleration by using Vs30 obtained from microtremor array measurement.

METHODOLOGY

The standard methodology of PSHA (Cornell, 1968) was used to obtain seismic hazard assessment in Birendranagar Municipality. Location, size, tectonic type and recurrence rate of earthquakes defined in the source model have been used to estimate the seismic hazard.

As Nepal started monitoring earthquake since 1994; it has very short archive of earthquake events. This study, therefore, used earthquake catalogue from International Seismological Centre (ISC) and Nepal Earthquake Monitoring and Research Centre, Department of Mines and Geology, Nepal. (Figure 5:1). Recurrence parameters that estimate the yearly occurrence rates of earthquake above a certain magnitude is one of the key steps in seismic hazard assessment. After the compilation of the earthquake catalogue, declustering of dependent events were performed, and completeness analysis and recurrence parameters were estimated for each seismic domain. Table 5:1 shows the recurrence parameters for each seismic source.

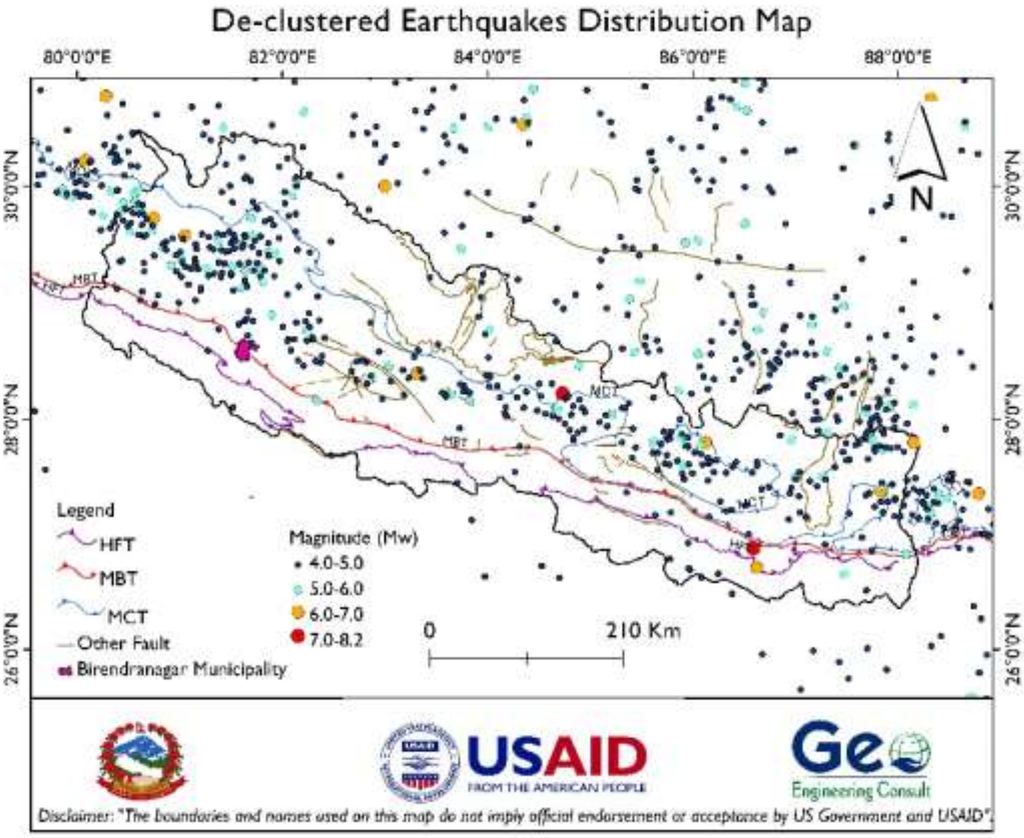


Figure 0:24 De-clustered earthquake distribution map considered for the hazard computation.

Table 0:4 Computed recurrence parameters for different source zone.

S.N	SOURCE	RECURRENCE PARAMETERS	
		A	B
1	South	4.36	1.01
2	Graben-1	4.54	1
3	Graben-2	3.86	0.82
4	Northwest	4.17	0.88
5	MHT	4.09	0.78

The calculated parameters are consistent with the studies carried out by Thapa and Wang (2013) and Rahman et al. (2017). Thapa and Wang (2013) computed b value equals to 0.85 for Nepal and its adjacent area and performed hazard calculation considering 23 seismic sources. Similarly, Rahman et al. (2017) estimated b value for MHT/MFT which varies from 0.61 to 0.71. In general, estimated recurrence parameters in this study are close to other studies.

SEISMIC SOURCE CHARACTERIZATION

Another important step in seismic hazard assessment is seismic source characterization. The present study delineated the seismic sources based on origin, type, magnitude frequency distribution of the earthquake, seismo-tectonics, neotectonic deformation, nature and activation of seismogenic faults.

The source zones are divided into two broad categories; continental collision source and aerial sources. These sources are briefly described below.

Continental collision source

Studies of Central Himalayas suggest that there are three major thrust fault system viz. MCT, MBT and MFT in Nepal, these faults branch off at depth from a single MHT. These faults are considered to be splay faults that connect to the MHT, rather than earlier interpretations which defined these faults as equivalent major faults in the upper seismogenic crust (Avouac, 2007). The MHT is the principal interface between the subducted Indian Plate and Eurasian Plate. Figure 5:2 shows the cross-section geometry of MHT and how MFT, MBT and MCT tie into the MHT. The approximate location of seismogenic depth in the Himalayas is between 10 km and 25 km (Elliott et al., 2016, Maggi et al., 2000). MHT is considered as the most seismically active fault as compared to other crustal scale faults, therefore, it has been considered for seismic hazard computation.

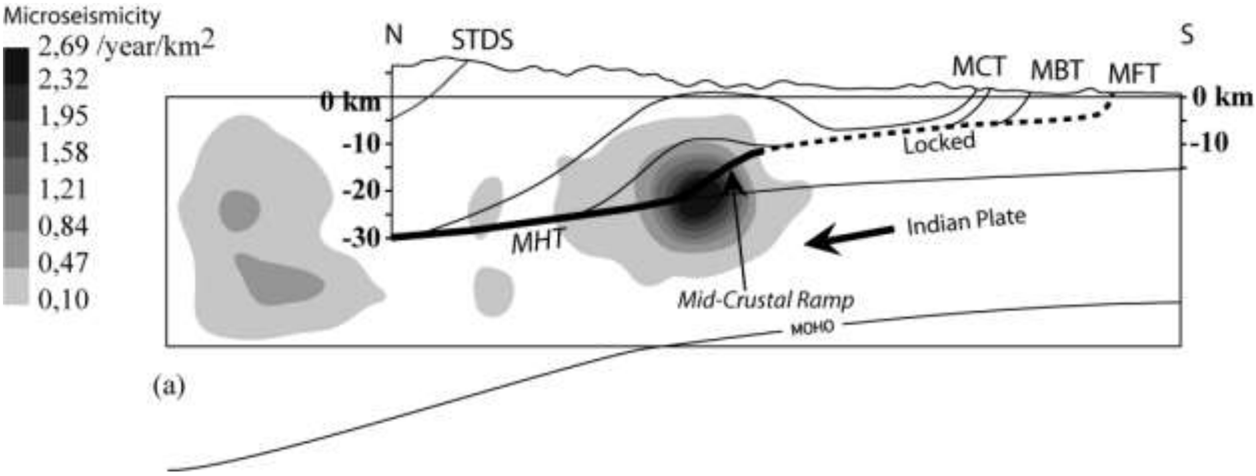


Figure 0:25 North-South geological cross-section of Nepal Himalaya showing major thrust system and microseismicity (Pandey et al., 1999).

Areal Sources

This study considers four areal sources in and around Birendranagar Municipality: one in the south and remaining three in the north (Figure 5:3). The seismogenic depth in these areal sources varies between about 15 and 25 km (Elliott et al. 2016, Maggi et al. 2000, Yang et al. 2005, and Elliott et al. 2011). The areal sources include regions of southern Tibet and western Nepal with normal and strike-slip faulting (Nakata 1989, Silver et al. 2015). Both types of fault mechanisms were included to characterize source zone. The Indo-Gangetic plain has different seismicity characteristics that are not associated with Himalayan seismicity. Seismicity patterns are random in this region. Four areal sources are described briefly below.

Grabens of southern Tibet

Graben of the southern Tibet and the Himalaya, represent the Cenozoic extensional tectonic phase, which has affected whole Tibet and northernmost part of the Himalaya. The major grabens of the Himalayan arc that extends from west to east are Burang graben, the Thakkhola graben, Gyriong graben, Kungo graben, Pum Qu graben and Yadong graben. In the Himalaya all the grabens are limited south of the Indus Tsangpo Suture Zone (ITSZ) except Yadong graben, which extends up to Gulu rift. These grabens and other faults in these regions are associated with normal type earthquake having seismicity depths about 15km. Thus, there is high chances of large earthquake in these regions and may pose hazard to the Birendranagar Municipality. For estimating hazard this study considered three grabens.

Western Nepal

Clustered seismic events are conspicuous in western Nepal (Figure 5:3). This region is dominated by strike-slip and normal faults having earthquakes focal depth of around 20 km. As this zone lies within 200km from Birendranagar Municipality, so it poses significant hazard and have been considered in seismic model.

Southern Source

The earthquake events are not frequent in Indo-Gangetic plain and there is sporadic distribution of moderate events. Seismic events are of mixed type, and this may be due to flexure of converging of Indian Plate. As this region lies close to Birendranagar Municipality, earthquake occurring in this zone may cause significant damage to the study area, so considered as potential source of hazard in the model (Figure 5:3). The maximum magnitude and seismogenic depth for each source are based on the past earthquakes.

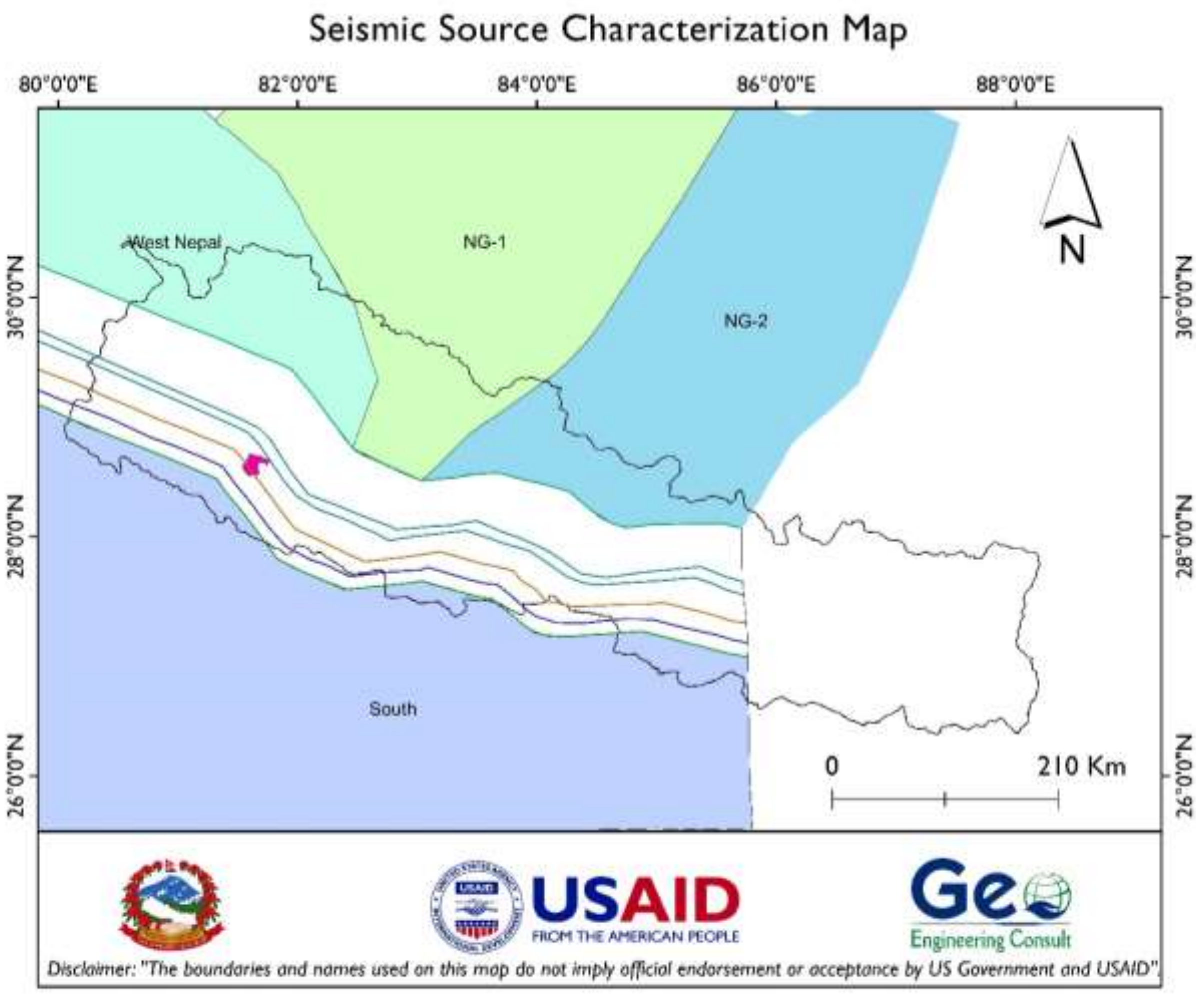


Figure 0:26 Seismic source characterization. The boundaries and names used on this map do not imply official endorsement or acceptance by the US Government or USAID.

GROUND MOTION PREDICTION EQUATIONS (GMPES)

As the Himalayas do not have GMPE, this study used GMPEs developed for similar tectonic region to estimate hazard in Birendranagar Municipality. Table 5:2 shows GMPEs used for different seismic sources.

Table 0:5 Characteristics of the adopted GMPEs.

TECTONIC ENVIRONMENT	GMPE	MAGNITUDE RANGE (MW)	DISTANCE RANGE (KM)	PERIOD RANGE (SEC)
MHT fault (Subduction Interface)	Zhao (2006)	5-9	0-300	0-5
	Atkinson and Boore (2003)	5-8.5	1-300	0 to 3.03
	Abrahamson et al. (2016)	5-9	0-300	0-10
Active Shallow Crust (grabens and southern source)	Abrahamson et al. (2014)	3-8.5	0-300	0-10
	Chiyou and Youngs (2014)	3-8.5	0-300	0-10
	Campbell and Bozorgnia (2008)	4-8.5	0-200	0-10

RESULTS

The locations, sizes, tectonics type and recurrence rate of earthquake defined in source model have been used to estimate the probabilistic seismic hazard for a grid of sites with as spacing of 500m in latitude and longitude in Birendranagar Municipality. For a given site, hazard curve and maximum acceleration level that is expected to exceed for a range of return period were computed.

Hazard estimates for Birendranagar Municipality are shown in map from Figure 5:4 to Figure 5:7. Hazard maps are constructed at bedrock using Vs30. Vs30 to compute hazard at free field are obtained from microtremor array measurement (MAM). As most of the structures in Birendranagar Municipality have fundamental period of 0.3 sec and 0.5 sec, therefore, hazard map at spectral acceleration (SA) 0.3 sec and 0.5 sec have been prepared. Maps for PGA and spectral acceleration at 0.3s and 0.5s at 10% probability of exceedance in 50 years are shown in unit of g.

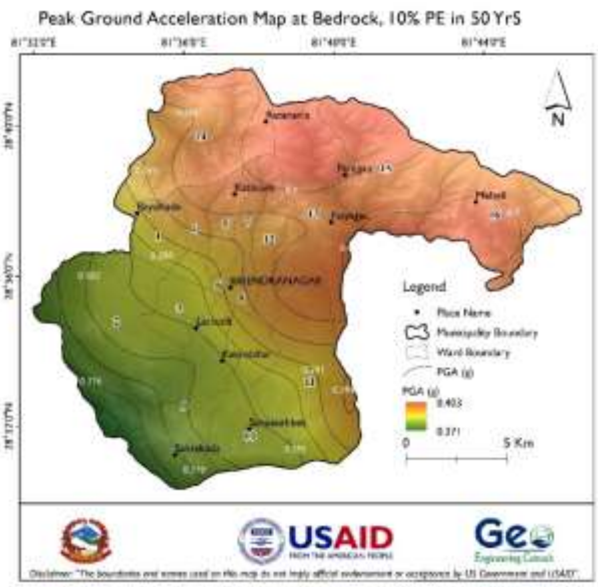


Figure 0:27 Peak ground acceleration (PGA) map at bedrock for Birendranagar Municipality at 10% probability of exceedance

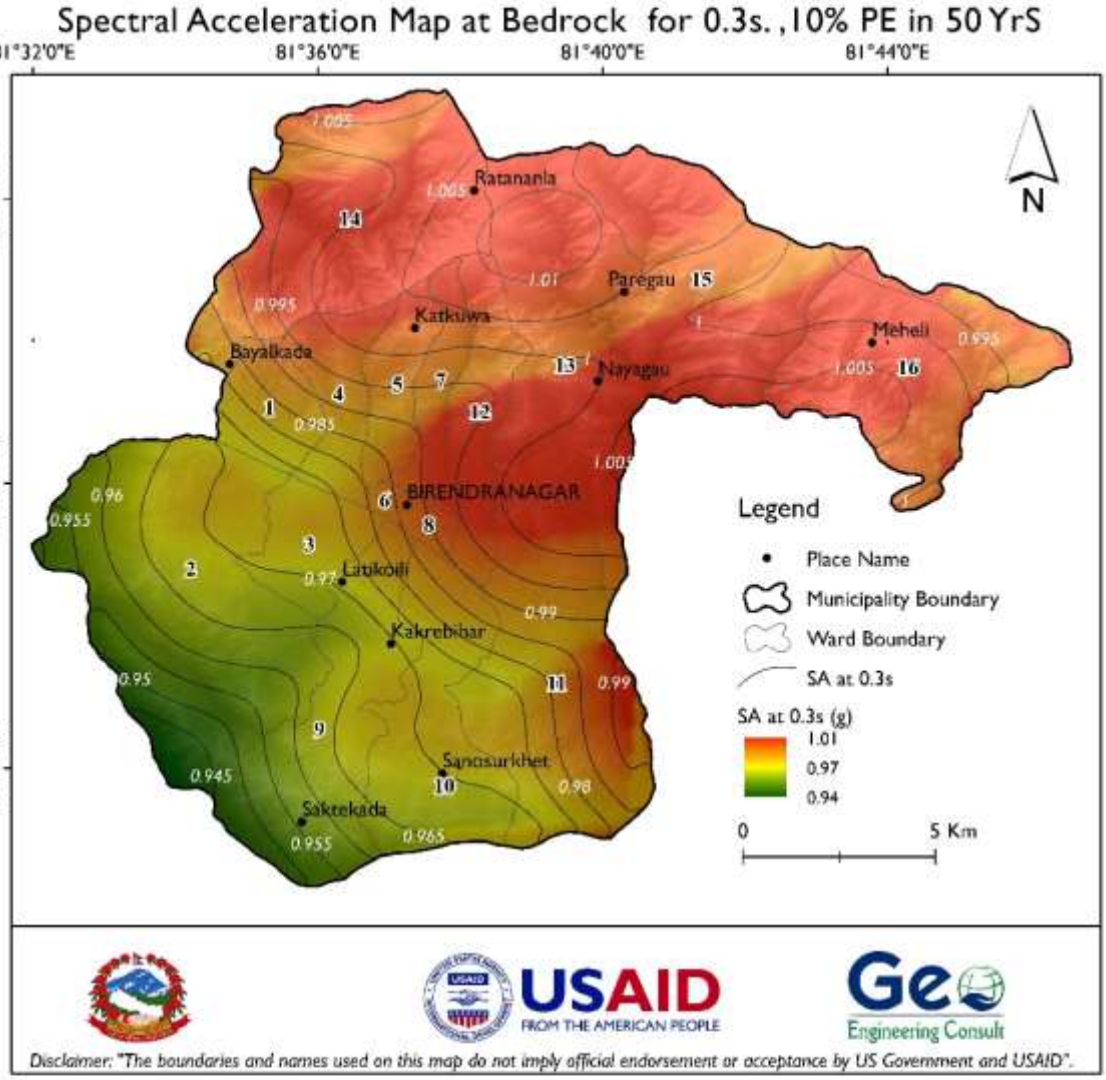


Figure 0:28 Spectral acceleration (SA) map at bedrock at 0.3 sec for Birendranagar at 10% probability of exceedance.

The seismic hazard at bedrock for 475-year return period (Figure 5:4) varies from 0.376g to 0.40g in Birendranagar Municipality. The northern part relatively shows higher hazard compared to southern part of the municipality. Similar trend is also observed for spectral acceleration at 0.3s and 0.5s (Figures 5:5 & Figure 5:6).

Spectral acceleration at 0.3s has the highest value (1.01g) in the northern part of the municipality and the lowest value (0.945g) at the southern part. Likewise, spectral acceleration at 0.5 sec has the highest value of 0.705g at the northern and the lowest value of 0.655g in the southern part (Figure 5:6).

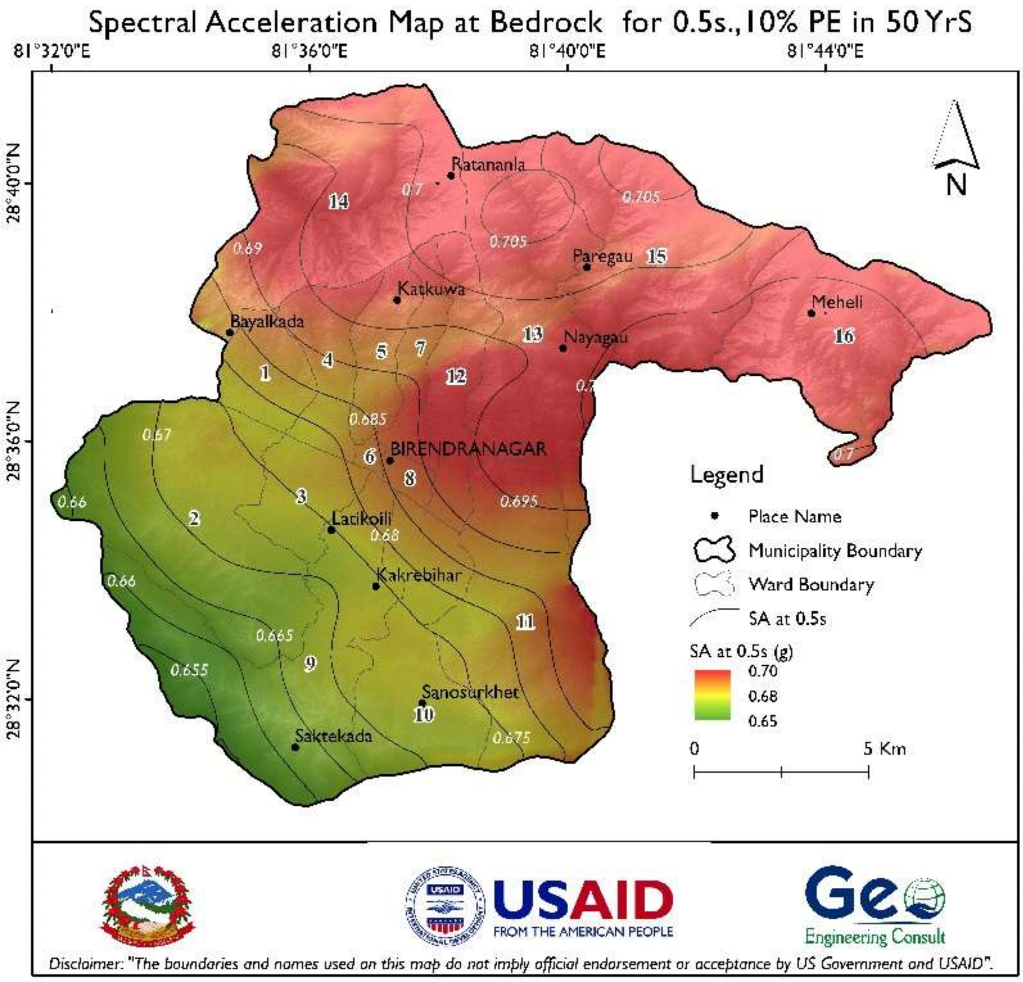


Figure 0:29 Spectral acceleration (SA) map at bedrock at 0.5 sec for Birendranagar at 10% probability of exceedance.

The pattern of seismic hazard at ground surface is different to that of the bedrock level. The seismic hazard for 475-year return period shows the highest value at the central part of the Surkhet valley and decreases towards outskirt of the valley (Figure 5:7). The highest value is attributed to lower Vs30 and its fragile geology. The central part is dominated by soft sediment having shear wave velocity ranging from 160.0 m/s to 508.0 m/s. Highest PGA (0.75g) is observed at the region having the lowest shear wave velocity (Vs30) i.e. 160.0 m/s at the southern part of Kakrebihar. PGA value is low in the region, where dense gravel and bedrock is dominantly present. Similar trend is observed for the spectral acceleration at 0.3s and 0.5s. The highest hazard at both periods (i.e. 0.3s and 0.5s) are obtained in the region dominated by soft soil (i.e. at the central part of Surkhet valley) and the lowest in the region dominated by bedrock. Spectral acceleration at 0.3 sec varies from 1.1g to 1.8g at central part and outskirt of Birendranagar valley respectively (Figure 5:8). Similarly, spectral acceleration at 0.5 sec (Figure 5:9). has the highest value (1.82g) in the central part and the lowest value (0.66g) at the outer part of valley where dense soil and rock are present.

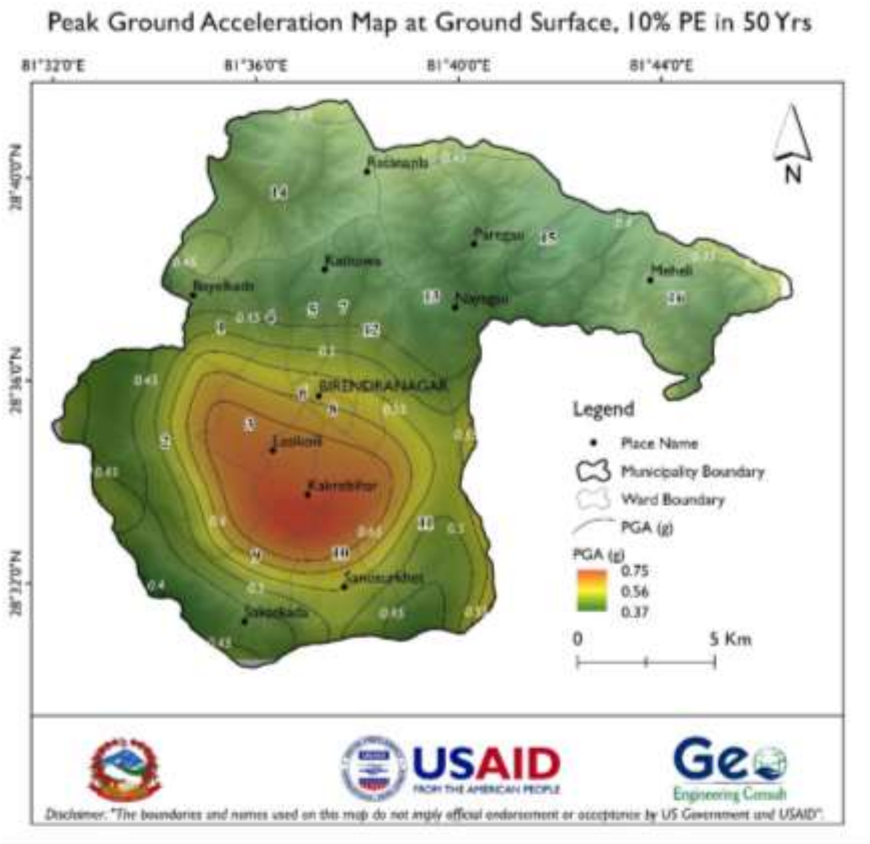


Figure 0:30 Peak ground acceleration (PGA) map at ground surface for Birendranagar Municipality at 10% probability of exceedance.

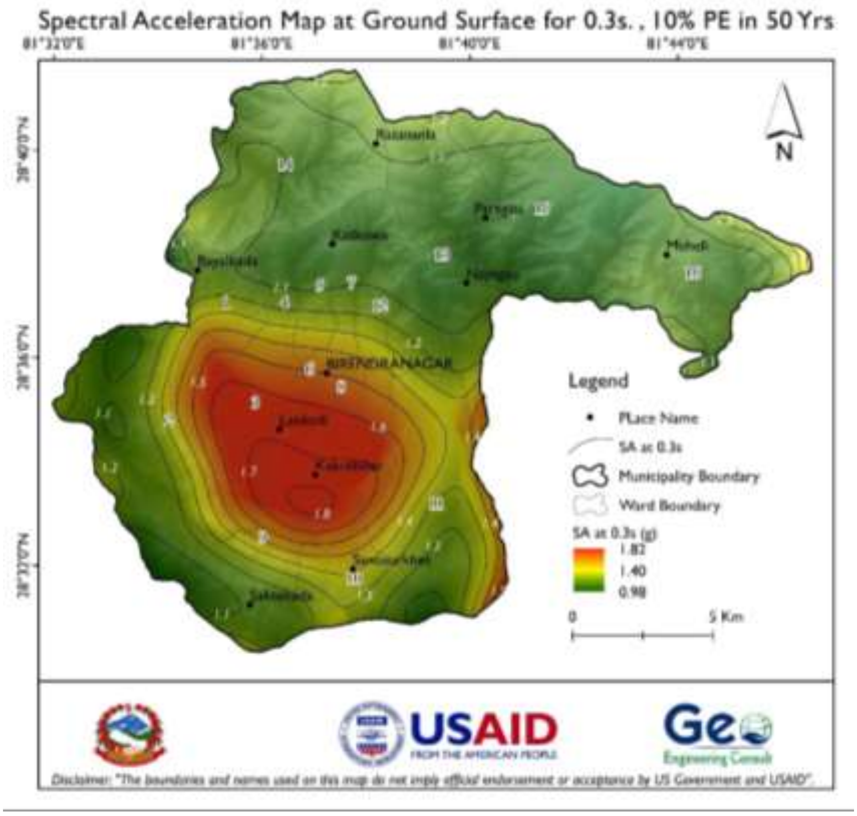


Figure 0:31 Spectral acceleration (SA) map at ground surface at 0.3 sec for Birendranagar at 10% probability of exceedance.

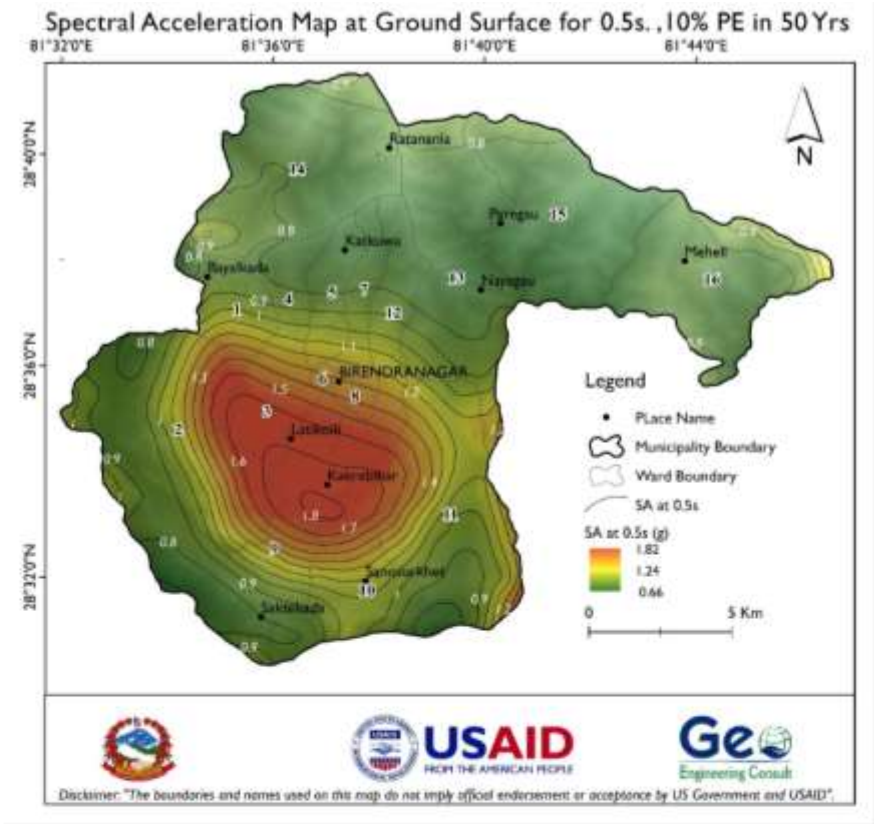


Figure 0:32 Spectral acceleration (SA) map at ground surface at 0.5 sec for Birendranagar at 10% probability of exceedance.

Disaggregation

Disaggregation of hazard shows the contributions to the hazard estimates according to magnitude and source-to-site distance. Disaggregation for central part of Birendranagar Municipality at 10% probability of exceedance at bedrock and ground surface are shown Figure 5:10-5:11. The results show most contribution of hazard to the Birendranagar municipality is by magnitude range from Mw 6.0 to Mw 8.0 at distance from 10km to 40km. The highest contribution to the hazard is by magnitude Mw 8.0 from a 40km distance.

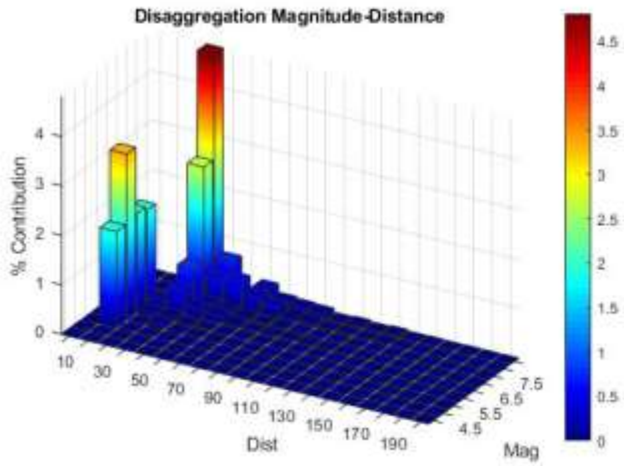


Figure 0:33 Disaggregation graph (at bedrock) for central part of Birendranagar Municipality at 10% probability of exceedance in 50 year.

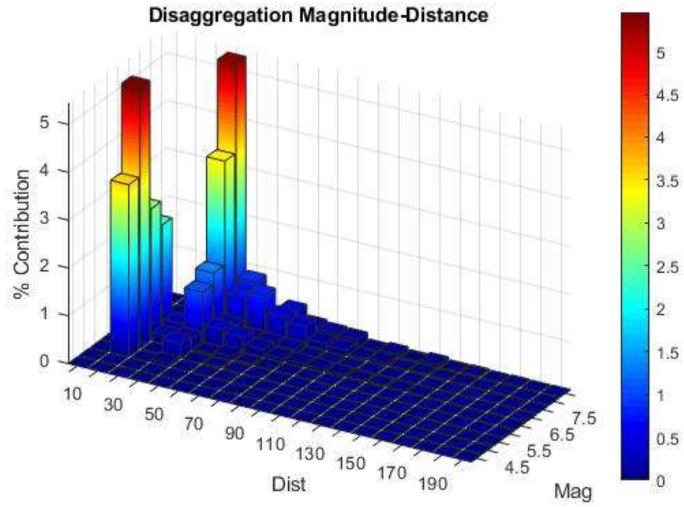


Figure 0:34 Disaggregation graph (at ground level) for central part of Birendranagar Municipality at 10% probability of exceedance in 50 year.

CONCLUSIONS

Probabilistic seismic hazard map has been prepared for Birendranagar Municipality. Three-dimensional double ramp model source has been used for the Main Himalayan Thrust and areal for other sources. Earthquake recurrence interval has been estimated using the historical data from International Seismological Centre (ISC) and different sources and Nepal Earthquake Monitoring and Research Centre, Department of Mines and Geology, Nepal. Bedrock and free field PGA and spectral accelerations have been estimated. Vs30 measured from microtremor array measurement have been used to estimate free field ground motion. Bedrock PGA in Birendranagar Municipality varies from 0.373g to 0.4g at 10 % probability of exceedance in 50 year. Free field PGA in Birendranagar Municipality varies from 0.45g to 0.6g.

SIGNIFICANCE

Peak ground acceleration and spectral acceleration value at 0.3 sec and 0.5 sec can be used for seismic risk analysis of various infrastructure in Birendranagar Municipality. Similarly, PGA and spectral acceleration value can be used to construct design response spectra, which is the basis for earthquake force in static and dynamic analysis of buildings, bridges, and other infrastructure. The results are useful for multi hazard risk assessment and risk sensitive land use plan.

6. SEISMIC RISK ASSESSMENT

BACKGROUND

Nepal is located in seismically active region with a history of strong earthquakes. The subduction of Indian plate underneath the Eurasian plate is the main cause of seismic activities in Nepal. (Khattrai, 1987). Major earthquakes in Nepal occurred in years 1255, 1408, 1681, 1803, 1810, 1833, 1934, and 1988 (Bilham et al. 1995; Pandey et al., 1995). Nepal and adjoining Himalayan arc have experienced some great historical earthquakes, including the 1897 Shillong earthquake, 1905 Kangara earthquake, 1934 Bihar-Nepal earthquake, and 1950 Assam earthquake (Chaulagain et al., 2015). Recent research on fault modeling of Nepal Himalayan arc has also shown continuous accumulation of elastic strain to reactive older geological faults, which may generate earthquakes of strong magnitude (Chamlagain and Hayashi, 2004 and 2007). The most recent devastating earthquake was the Gorkha earthquake of 2015, which was M 7.8 earthquake that occurred as the result of thrust faulting on or near main thrust interface between the subducting India plate and the overriding Eurasia plate to the north. (USGS , 2015). 8790 fatalities and 22,300 injuries were caused by this earthquake and additionally, affected approximately 8 million people. Post-disaster need assessment conducted by National Planning Commission of Nepal estimated overall loss due to this earthquake to be USD seven billion. (National Planning Commission (NPC), 2015). This earthquake caused a loss of 498,852 buildings and caused partial damage to additional 256,697 buildings (Gautam, 2017). However, this earthquake left western Nepal relatively unscathed.

The last known major event to have affected western Nepal, rupturing a long portion of the Main Frontal Thrust (MFT), was the Ms ~8.2 earthquake of 1505 AD (Yule et al., 2006). The intervening 500 years have resulted in the accumulation of a >10 m slip deficit along this segment of the MFT, leading to the concept of a seismic gap in western Nepal, which could potentially trigger a great earthquake in the near future. (Stevens & Avouac, 2016) (Rajendran, John, & Rajendran, 2015)

A seismic event or earthquake of any significance has potential to deal a lot of structural damage, resulting not only in loss of property, but also, and perhaps more importantly, loss of lives. Most deaths and physical losses from earthquakes are caused by buildings or other human constructions collapsing during or after an earthquake (Thapaliya, 2006). Damages that are caused by earthquakes can be mitigated with buildings of high-quality construction that follow proper building codes. In case of existing buildings that may or may not be code-compliant, an investigation into their vulnerability to a future earthquake can help prepare and alleviate what might otherwise become a catastrophic loss.

Birendranagar municipality was established in 2033 B.S. (1976 AD). As the major city within Surkhet district, which is the provincial capital of Karnali province, Birendranagar municipality is ongoing rapid development, the bulk of which appears to be haphazard. The municipality has a mix of buildings of old construction – primarily masonry of brick and stone constructions, while newer buildings are constructed as frame structures built of reinforced concrete. Given that the building codes of Nepal were published first in 1994, it is safe to assume that old constructions do not follow any code and therefore, probably have no seismic resistant features to them. Newer construction of reinforced concrete also may or may not have followed building codes of any kind. Hence, building stocks available here can probably be separated into a number of different generalized categories, each category showing a markedly different response to a seismic event (earthquake). How a building responds to an earthquake can provide an insight into the susceptibility of that particular category of buildings, which in turn gives way into investigation of structural risks associated with a seismic event.

OBJECTIVE

This project aims to focus on ward-6 of Birendranagar municipality for the purpose of structural seismic risk assessment. The project's objectives are:

- To generate fragility function of building stocks in ward-6 of BMC
- To generate Damage Distribution Map
- Economic Loss Calculation in case of a seismic event.

With this goal in mind, the following activities have been identified to be carried out:

- Perform building survey of Birendranagar Ward 6
- Categorize building stocks into different categories
- Development of building Exposure Map based upon survey data
- Development of Fragility Models for each identified building typology
- Development of Vulnerability Models
- Development of Damage Distribution Map
- Perform Structural Seismic Risk Analysis

METHODOLOGY

The basic methodology for structural vulnerability and risk assessments and economic damage calculation comprises desk study, field survey, analytical modeling (Figure 6:1).

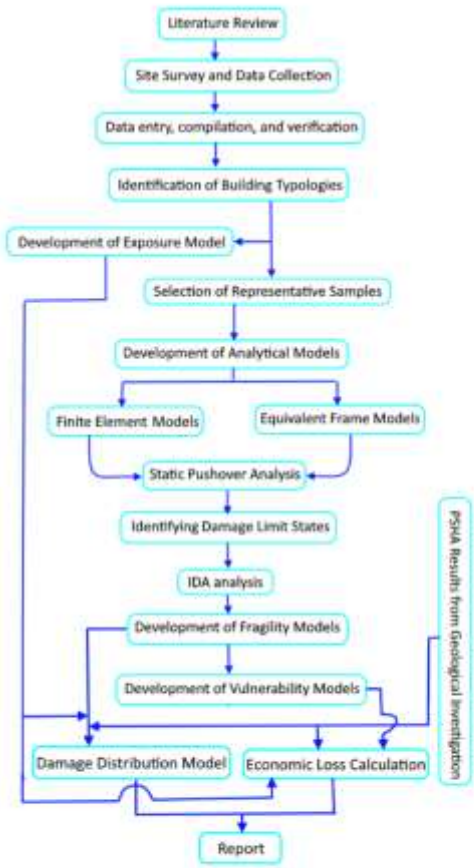


Figure 0:35 Flowchart of Methodology.

EXPOSURE MODEL

Exposure model was developed from data of each asset (individual buildings). The data consists of location (GPS coordinate), typology, plinth area, and cost of building per unit area for each asset. OpenQuake engine's *Input Preparation Toolkit* was utilized for assistance in preparation of this exposure model.

Kathmandu District Administration Offices' Approved Wages and Construction Materials Cost for Kathmandu District for f/y 2077-78 was utilized for generation of cost per unit area of buildings for Birendranagar municipality (Table 6:1). Surkhet district also has its own district cost rate approved for f/y 2077-78, however they do not have an estimate for building cost per unit area. A comparison was made of basic building materials for both districts and we reached a conclusion that the cost per unit area for buildings as given by Kathmandu district could be used. For a more accurate estimate, this report suggests performing rate analysis of building stocks based on actual market prices and averaging out the costs to obtain average cost of each building stock per unit area (Table 6:2).

Table 0:6 Cost comparison of labor and materials between Surkhet and Kathmandu districts.

	SURKHET (NPR)	KATHMANDU (NPR)	UNIT
LABOR (UNSKILLED)	630.00	750.00	day
LABOR (SKILLED)	945.00	1070.00	day
CEMENT (OPC, 43)	820.00	825.00	bag
AGGREGATES	3000.00	3105.00	cu. m.
SAND	3000.00	3105.00	cu. m.
TOR STEEL REBAR	96.00	79.00	kg
1ST CLASS CHIMNEY BRICKS	17.79	16.43	Nos.
TIMBER	5361.95	5600.00	cu. ft.

Table 0:7 Cost per area for individual building typologies used in Exposure Model.

TYPOLOGY	COST PER SQ. M (NPR)	TYPOLOGY	COST PER SQ. M (NPR)	TYPOLOGY	COST PER SQ. M (NPR)
RCE-1	25940.39	BMC-R-1	24694.94	SMC-R-1	24694.94
RCE-2	51880.78	BMC-R-2	49389.88	SMC-R-2	49389.88
RCE-3	77821.17	BMC-R-3	74084.82	SMC-R-3	74084.82
RCE-4	103761.56	BMC-F-1	23733.84	SMC-F-1	23733.84
RCE-5	129701.95	BMC-F-2	47467.68	SMM-R-1	22173.11
RCN-1	25940.39	BMC-F-3	71201.52	SMM-R-2	44346.22
RCN-2	51880.78	BMM-R-1	22173.11	SMM-R-3	66519.33
RCN-3	77821.17	BMM-R-2	44346.22	SMM-F-1	18944.02
RCN-4	103761.56	BMM-R-3	66519.33	SMM-F-2	37888.04
RCN-5	129701.95	BMM-F-1	18944.02	SMM-F-3	56832.06
		BMM-F-2	37888.04		
		BMM-F-3	56832.06		

VULNERABILITY MODEL

OpenQuake engine requires a vulnerability model that contains vulnerability function for each building typology that is defined in the exposure model.

A vulnerability function is a function that describes the probability distribution of loss ratio, conditioned on an intensity measure level. Loss ratio for each building typologies were derived from fragility functions and damage states. For the purpose of loss ratio computation, we redefined previously defined FO, IO, LS, CP, and SC damage states into undamaged, slight damage, medium damage and severe damage, which is further elaborated in *Damage Distribution Model* below.

Loss ratio was constructed for seismic activity in two directions for each building typology: a. parallel to street and b. perpendicular to street. The effects of both of these were considered and critical result chosen for later analysis.

DAMAGE DISTRIBUTION MODEL

The damage distribution for each building typology was determined by utilizing OpenQuake engine (version 3.11.4). Classical Probabilistic Seismic Damage Analysis feature of OpenQuake was utilized. The classical PSHA-based damage calculator integrates the fragility functions for an asset with the seismic hazard curve at the location of the asset to give the expected damage distribution for the asset within specified time period, which describes the probability of the asset being in different damage states. The main results of this calculator are the expected damage distribution for each asset (individual building), which describes the probability of the asset being in different damage states, and collapse map for the region, which describes the probability of collapse for different assets in the portfolio over the specified time. As discussed above, this time was taken to be 50 years.

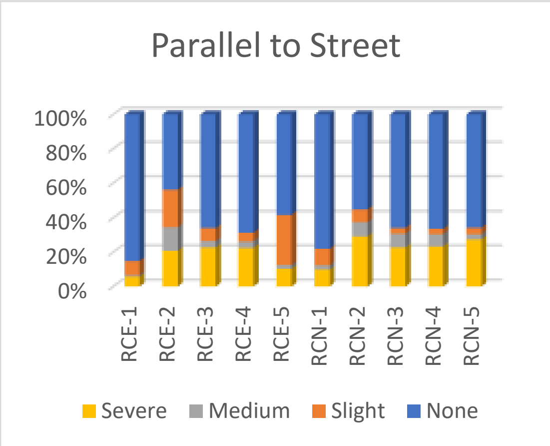
While damage states defined for the purpose of this calculation by OpenQuake were still defined as FO, IO, LS, CP, and SC, for the purpose of generation of damage distribution model, we have revised the definition of damage into a more readily understood terms. These damage states were picked based upon action that is expected for a building to undergo after experiencing a seismic event. The necessary courses of action could be: a. no action necessary, b. minor repair required, c. retrofitting required, d. replacement required. The damage states are now redefined as follows–

a) No damage: this state encompasses fraction of fragility curve up till the threshold of Fully Operational limit state that was previously used for generation of Fragility functions. Buildings that are in this damage state do not need repair of any type.
b) Slight damage: this state encompasses fraction of fragility curve between thresholds of Fully Operational and Immediate Occupancy limit states. Buildings and structures that are indicated by this damage state require general repair works.
c) Moderate damage: this state encompasses fraction of fragility curve between thresholds of Immediate Occupancy and Life Safety limit states. Buildings that lie in this damage state are assumed to necessarily require structural retrofitting.
d) Severe damage: this state encompasses the fraction of fragility curve that exceeds the threshold of Life Safety. This damage state includes both Collapse Prevention and Sidesway Collapse limit states. In other words, the building or structure indicated is beyond repair.

The average probability of damage states are listed, based upon whether they are Reinforced Concrete, Brick Masonry, or Stone (rubble) masonry, in Table 6:3-6:5 and Figure 6:2-6:4.

Table 0:8 Damage State Probability Distribution for Reinforced Concrete structures

TYPOLOGY	DAMAGE PROBABILITY: PARALLEL TO STREET				DAMAGE PROBABILITY: PERPENDICULAR TO STREET			
	NONE	SLIGHT	MEDIUM	SEVERE	NONE	SLIGHT	MEDIUM	SEVERE
RCE-1	0.8508	0.0847	0.0085	0.0560	0.8823	0.0591	0.0118	0.0468
RCE-2	0.4380	0.2190	0.1353	0.2077	0.4257	0.2129	0.1559	0.2055
RCE-3	0.6610	0.0751	0.0368	0.2270	0.6727	0.0502	0.0387	0.2384
RCE-4	0.6879	0.0502	0.0376	0.2244	0.6736	0.0512	0.0587	0.2164
RCE-5	0.5825	0.2913	0.0208	0.1054	0.5562	0.2781	0.0297	0.1361
RCN-1	0.7806	0.0945	0.0258	0.0991	0.7441	0.1386	0.0222	0.0951
RCN-2	0.5513	0.0754	0.0835	0.2898	0.7980	0.0535	0.0394	0.1091
RCN-3	0.6605	0.0331	0.0798	0.2267	0.7246	0.0397	0.0583	0.1774
RCN-4	0.6656	0.0312	0.0705	0.2328	0.7222	0.0172	0.0635	0.1971
RCN-5	0.6592	0.0383	0.0295	0.2730	0.4776	0.2388	0.0277	0.2559



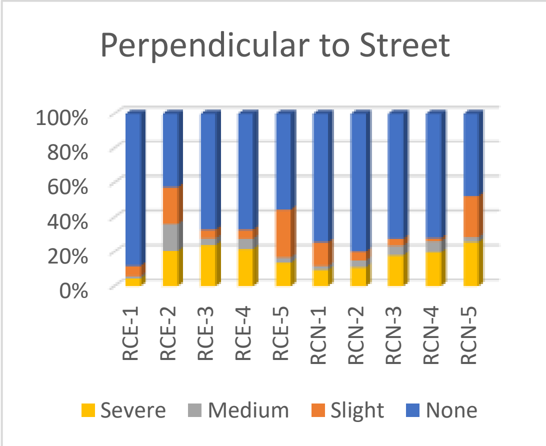
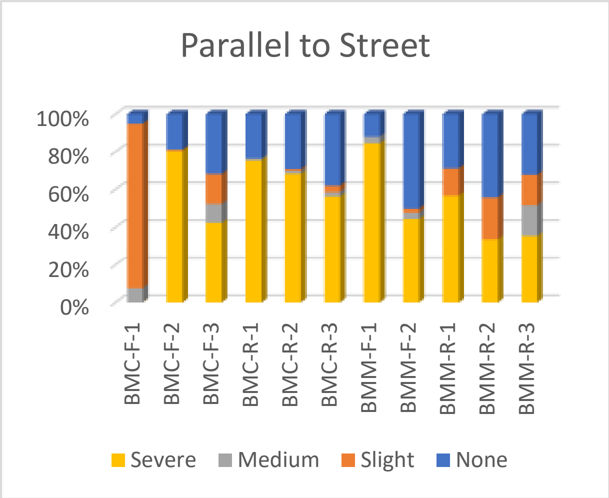


Figure 0:36 Damage State Probability Distribution for Reinforced Concrete structures.

Table 0:9 Damage State Probability Distribution for Brick Masonry structures.

TYPOLOGY	DAMAGE PROBABILITY: PARALLEL TO STREET				DAMAGE PROBABILITY: PERPENDICULAR TO STREET			
	NONE	SLIGHT	MEDIUM	SEVERE	NONE	SLIGHT	MEDIUM	SEVERE
BMC-F-1	0.0507	0.8741	0.0742	0.0010	0.0082	0.9916	0.0002	0.0000
BMC-F-2	0.1885	0.0056	0.0000	0.8059	0.5994	0.3653	0.0329	0.0024
BMC-F-3	0.3180	0.1590	0.0995	0.4235	0.3751	0.1875	0.0823	0.3551
BMC-R-1	0.2424	0.0000	0.0106	0.7722	0.2631	0.0310	0.0472	0.6586
BMC-R-2	0.2931	0.0101	0.0138	0.6830	0.1400	0.0014	0.0296	0.8289
BMC-R-3	0.3800	0.0346	0.0223	0.5631	0.4049	0.0650	0.0426	0.4875
BMM-F-1	0.1189	0.0000	0.0350	0.8475	0.0263	0.0000	0.0000	0.9758
BMM-F-2	0.5015	0.0211	0.0337	0.4437	0.2226	0.1113	0.0802	0.5859
BMM-R-1	0.2890	0.1445	0.0000	0.5665	0.1056	0.0153	0.0129	0.8661
BMM-R-2	0.4426	0.2213	0.0000	0.3361	0.2640	0.1320	0.1320	0.4720
BMM-R-3	0.3227	0.1614	0.1614	0.3545	0.1915	0.0957	0.0957	0.6171



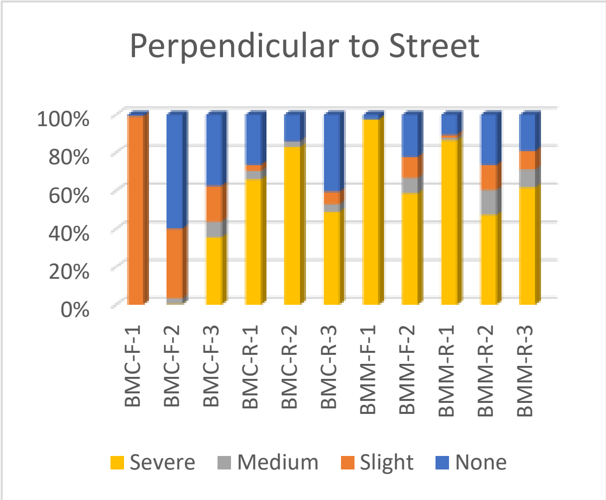
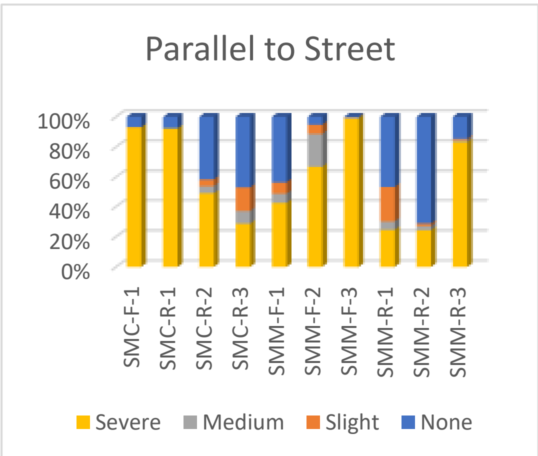


Figure 0:37 Damage State Probability Distribution for Brick Masonry structures

Table 0:10 Damage State Probability Distribution for Stone Masonry structures

TYPOLOGY	DAMAGE PROBABILITY: PARALLEL TO STREET				DAMAGE PROBABILITY: PERPENDICULAR TO STREET			
	NONE	SLIGHT	MEDIUM	SEVERE	NONE	SLIGHT	MEDIUM	SEVERE
SMC-F-1	0.0679	0.0011	0.0019	0.9290	0.0209	0.0005	0.0016	0.9771
SMC-R-1	0.0762	0.0000	0.0012	0.9228	0.0111	0.0005	0.0006	0.9879
SMC-R-2	0.4162	0.0439	0.0510	0.4889	0.5255	0.0216	0.0733	0.3795
SMC-R-3	0.4694	0.1593	0.0837	0.2876	0.2914	0.1012	0.1343	0.4731
SMM-F-1	0.4364	0.0779	0.0607	0.4250	0.2720	0.0929	0.0538	0.5814
SMM-F-2	0.0520	0.0615	0.2175	0.6691	0.2919	0.1459	0.1246	0.4376
SMM-F-3	0.0002	0.0021	0.0105	0.9872	0.3333	0.1667	0.1667	0.3333
SMM-R-1	0.4652	0.2326	0.0566	0.2456	0.1859	0.0929	0.0837	0.6375
SMM-R-2	0.7122	0.0161	0.0281	0.2436	0.3136	0.0496	0.0811	0.5556
SMM-R-3	0.1449	0.0082	0.0132	0.8337	0.7672	0.0241	0.0320	0.1768



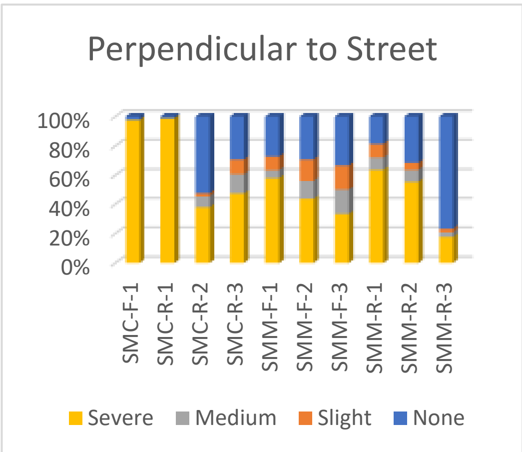
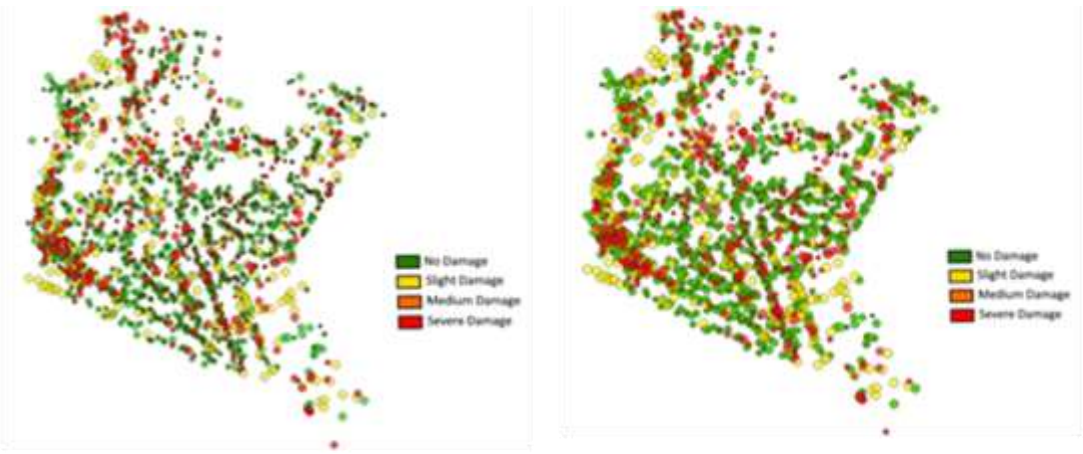


Figure 0:38 Damage State Probability Distribution for Stone Masonry structures

The damage distribution diagrams show a clear distinction of building behavior based upon their construction material. Reinforced Concrete buildings, both engineered as well as non-engineered, of all stories have the highest probability of remaining undamaged and the lowest probability of suffering severe damage. On the other hand, stone (rubble) masonry buildings have the highest probability of suffering severe damage and lowest probability of remaining undamaged.

The damage distribution also show that masonry building with rigid floor diaphragm have less probability of suffering severe damage than do buildings with flexible floor diaphragm.

Applying these damage states to each corresponding assets now provides us with damage distribution map for each of the damage state. An overall damage distribution map has been generated by superimposing the damage distribution map for each individual damage state (Figure 6:5). Every point in the map is an asset that has certain probability of being in all four damage states defined above, represented by four different points in same geographical coordinates. The four points are weighted and hence, the higher probability damage state is more clearly visible in superimposed image.



Damage Distribution: Parallel to Street

Damage Distribution: Perpendicular to Street

Figure 0:39 Damage Distribution Map of Birendranagar municipality ward-6.

ECONOMIC VALUE CALCULATION

OpenQuake engine was utilized to perform Classical Probabilistic Seismic Risk Analysis. OpenQuake's classical PSHA-based risk calculator utilizes probabilistic vulnerability functions for an asset with seismic hazard curve at the location of asset to calculate the loss distribution of the asset within a specified time period. An exposure model, a vulnerability model derived from fragility model, and seismic hazard curve were used as input for this calculation. The use of logic-trees allows for consideration of model uncertainties in the choice of ground motion prediction equation for different tectonic region types.

Seismicity in both building plan directions (parallel to the street and perpendicular to the street) were considered and the result analysed to come at the most critical economic loss.

Losses were calculated for 10% probability of exceedence in 50 years (475 years return period), and 2% probability of exceedence in 50 years (2475 years return period) (Table 6:6).

The total structural economic cost for 10% exceedence was evaluated to be NPR 4,983,780,304.80

The total structural economic cost for 2% exceedence was evaluated to be NPR 7,898,798,054.40

Table 0:11 Average structural economic cost based upon construction material.

MATERIAL	PER ASSET COST (NPR)	
	0.1 poe 50 yrs	0.02 poe 50 yrs
Reinforced Concrete	3,402,792.65	6,071,563.07
Brick Masonry	2,101,720.45	2,313,293.53
Stone Masonry	1,206,406.99	1,211,294.75

The economic cost for Reinforced Concrete buildings is NPR 3,402,792.65 for an earthquake with 10% probability of exceedance (poe) in 50 years, and NPR 6,071,563.07 for an earthquake with 2% poe in 50 years.

For buildings of brick masonry construction, economic cost corresponding 10% poe is NPR 2,101,720.45 and that corresponding 2% poe is NPR 2,313,293.53

For buildings of stone masonry construction, economic cost corresponding 10% poe is NPR 1,206,406.99 and that corresponding 2% poe is NPR 1,211,294.75

The difference per asset in cost between 10% poe and 2% poe events is NPR 2,668,770.42 (a 78.43% increase) for an RC building, NPR 211,573.08 (a 10.06% increase) for brick masonry buildings, and NPR 4,887.76 (a 0.40% increase) for stone masonry buildings. This is an indication that most brick masonry and almost all stone masonry buildings are unable to survive a seismic event of 10% poe in 50 years (475 years return period).

CONCLUSION

Nepal is a seismically active country, with the most recent earthquake being the 2015 Gorkha earthquake. Even so, the concept of a seismic gap in western Nepal, which could potentially trigger a great earthquake in the near future, exists. Hence it is prudent to assess the current seismic capacity scenario in western Nepal so as to better enable policymakers to formulate a well-designed mitigation plan for future earthquakes.

This project focuses on structural seismic risk assessment, damage distribution and economic loss calculation for buildings located in ward-6 of Birendranagar municipality, Surkhet.

The project conducted building survey of every building located in ward-6 of BMC. Data was collected from a total of 1849 buildings. Depending upon their structural system, construction material, number of stories, and floor diaphragm, a total of 32 different building typologies were identified. Fragility functions were derived for 31 out of the 32 identified typologies. While there have been previous studies that derived fragility functions for building stocks in Nepal (either empirically or analytically), this project is the first to do so with consideration for numbers of stories, and hence, building height.

Ground motion based on classical PSHA with 2% and 10% probability of exceedance was utilized for performing damage distribution and economic loss calculations for building stocks for a period of 50 years.

The results of damage distribution calculations indicate that Reinforced Concrete buildings are relatively less susceptible to seismic events while load bearing masonry buildings have a higher degree of vulnerability. This is in line with research performed by (Gautam et al., 2018), whose research on derivation of fragility function for Nepali residential buildings presents interesting facts regarding survival or low damage extent of substandard RC buildings in Nepal, whereas, probability of extensive damage in case of brick and stone masonry buildings is depicted to be higher than other damage states. Damage distribution data also show that for masonry structures, buildings with flexible diaphragm have a higher probability of being in a more severe damage state than those with rigid diaphragm.

Economic loss calculations were performed by assuming that cost of repair would be 10% of total building cost, cost of retrofit would be 30% of building cost and dismantle would be 100%. Slight damages were expected to be repairable, medium damages expected to be remedied by retrofitting, while buildings with severe damages were expected to be dismantled. For a seismic event of 10% probability of exceedance in 50 years period (475 years return period), total expected damage was NPR 4,983,780,304.80. Average per asset breakdown of this cost amounts to NPR 3,402,792.65 for an RC building, NPR 2,101,720.45 for a brick masonry building, and NPR 1,206,406.99 for a stone masonry building.

Similarly, for a seismic event of 2% probability of exceedance in 50 years period (2745 years return period), total expected damage was NPR 7,898,798,054.40. Average per asset breakdown of this cost amount to NPR 6,071,563.07 for an RC building, NPR 2,313,293.53 for a brick masonry building, and NPR 1,211,294.75 for a stone masonry building.

The following course of actions can be recommended for mitigative actions –

- Reduction of vulnerability of buildings by making it mandatory to follow seismic codes for new constructions.
- Promote retrofitting of existing RCE and BMC buildings.
- Encourage replacement of BMM, SMC, and SMM buildings.
- Discourage haphazard development and development of land use regulations and urban planning.
- Increase level of preparedness of earthquake disaster among the population.

7. FLOOD HAZARD ASSESSMENT

BACKGROUND

Birendranagar Municipality of Nepal's Surkhet district is rapidly urbanizing due to high rates of migration from the rural area of Karnali province. During July and August 2014, flooding in the rapidly urbanizing city of Birendranagar intensified, resulting in severe loss of life and property. Steep topography, excessive land utilization, fragile physiographic structure, and intense monsoonal precipitation aggravate hazards locally. In addition, the loss of forest cover contributed significantly to increase flood hazards. As in Nepal, generally, the sustainable development of the Birendranagar Municipality has been risked by a disregard for integrated flood-hazard mapping, accounting for historical land-cover changes. Therefore, this assessment aims to provide essential input information on flood hazard assessment for improved urban-area planning. To that end, this assessment uses appropriate high-resolution digital elevation models (DEMs), observed data from the Department of Hydrology and Meteorology, DHM Nepal to forecast different return period floods using Geographical Information System (GIS), Hydrological Engineering Centre – Geospatial River Analysis System (HEC-GeoRAS) and Hydrologic Engineering Centers River Analysis System (HEC-RAS) modeling along with field verification processes to identify flood-risk hazards underlying the Birendranagar city. The task is completed using desk studies as well as field verification techniques.

METHODOLOGY

The methodology for assessing flood hazards begins with the acquisition and processing of adequate DEM data, as well as the collection of rainfall and runoff data for the research area from the DHM, Nepal (Figure 7:1). Furthermore, utilizing reliable foresting methodologies, different return period floods were anticipated using DEM and rainfall-runoff data. Along with floods, topographic information was obtained from the DEM with help of GIS to give the input to the hydraulic model. These all works were completed in the first step of the desk study. The second part of the study, modeling, and mapping was completed using GIS and HEC-RAS-1D (one dimensional) using the GeoRAS extension in the GIS environment. The flood hazard map was developed after parametric sensitivity analysis and optimizing model parameters with the help of the literature review of similar watersheds. The model output was then validated using historical data, aerial photographs, a field study, and published literature.

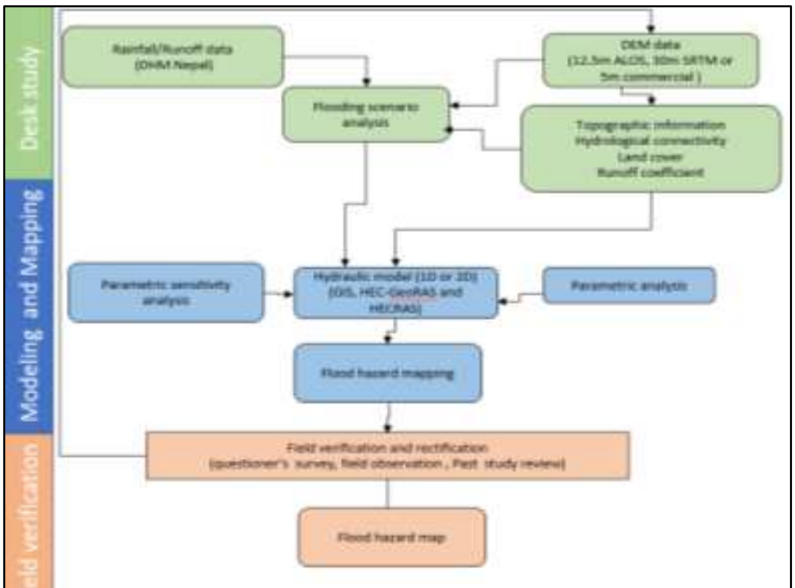


Figure 0:40 Flow chart of methodologies followed during flood hazard

RESULTS

The results of the study has been presented in the form of inundation depth. The inundated area for each ward of Birendranagar Municipality has been quantified for 2, 10, 50, 100 and 500 years return period according to three depth classes (<1m, 1 to 4m, and >4m) using 1D steady model. The results show that Wards 2 and 11 are at high risk for all three depth classes. As these wards lie at the lower elevation of the watershed and major confluence of rivers occur in those wards whereas Wards 3, 9, 10, 13, and 15 are at moderate risk, as major tributaries of the Bheri river flow along 13 and 15 wards and remaining wards lie at major river confluence at the lower elevation of the watershed. The model and field visit findings were compared at 10 major cross-sections along the Khorke, Itram, and Neware Khola in flood-prone areas. The coefficient of determination (R^2) for the experienced depth and simulated flood depth for 10 years return period and 50 years return period to check reliable flood events. The value of (R^2) for 10 years return period and 50 years return period were found to be 0.879 and 0.853 respectively. Thus, the statistical results show that the flood events of 2014 might be of 10 years return period, meaning that they can recur at any moment throughout the ten-year term. This assessment provides essential input information for improved urban-area planning in the future.

The inundated area for each ward of the Birendranagar Municipality has been quantified for 2, 10, 50, 100, and 500 years return period based on three depth classes, as shown in Tables 7:1 and 7:2 and Figure 7:1. The results show inundated area for higher depth class i.e. 3 increases with increasing return period and lower depth class i.e. 1 decreases with increasing return period. This implies a high threat of getting flooded with increased depth from higher return period flood.

The results show that Ward 2 and 11 are at high risk for all three depth classes. Whereas Wards 3, 9, 10, 13 and 15 are at moderate risk, and the remaining wards are at lower risk.

The model results and field data were compared at ten major cross-sections along the Khorke, Itram, and Neware Khola, all of which have flood risk is high. The cross-section for these locations has been shown in figure 6. The coefficient of determination (R^2) for the experienced depth and simulated flood depth for 10 years return period and 50 years return period was calculated to check reliable flood events and the values were found to be 0.879 and 0.853 respectively. Thus, the statistical results show that the flood events of 2014 might be of 10 years return period which can occur during the interval of 10 years at any time.

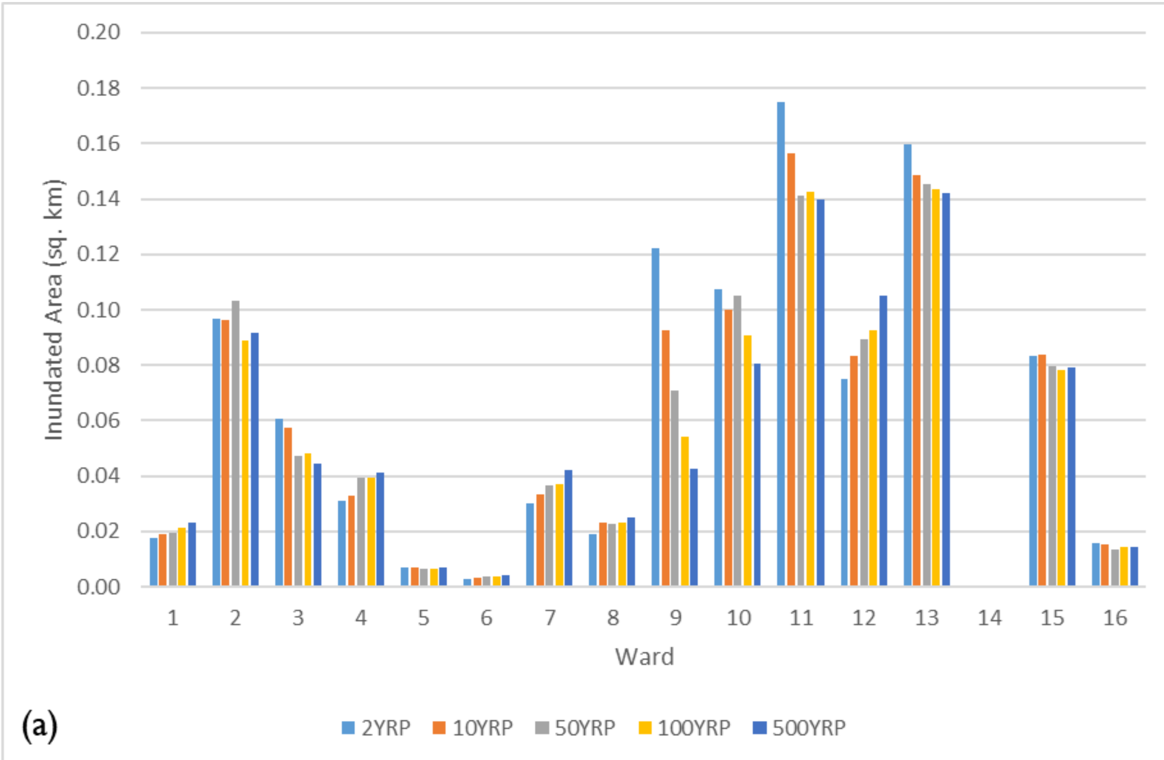
The comparison of the ward-wise inundated area for depth Class1, 2, and 3 at different return period has been shown in Table 7:2. Similarly, inundation map for 100 year return period is shown in Figure 7:2. The southern part of the municipality around the Nikash Khola has chances of inundation during flooding (Figure 7:3-7:5).

Table 0:12 Inundated area according to different depth classes for the various return period.

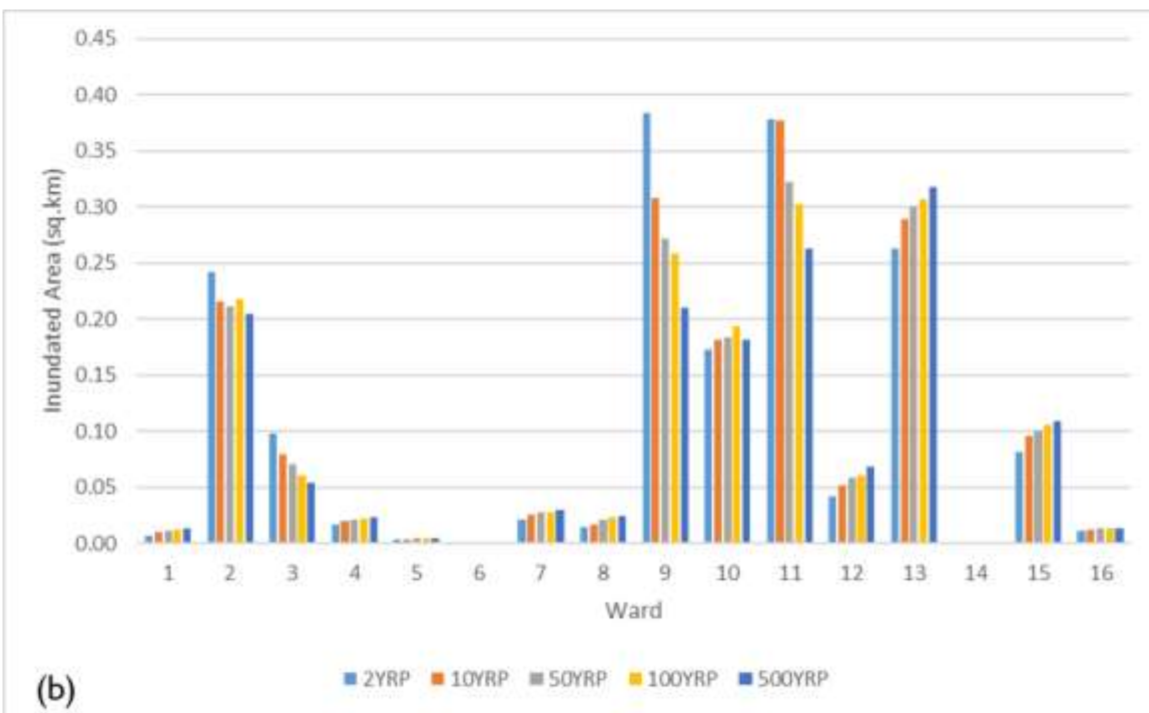
DEPTH CLASS	2YRP	10YRP	50YRP	100YRP	500YRP
	AREA (SQ. KM)	AREA (SQ. KM)	AREA (SQ. KM)	AREA (SQ. KM)	AREA (SQ. KM)
1 (<1m)	1	0.95	0.92	0.89	0.88
2 (1-4m)	1.73	1.69	1.62	1.61	1.52
3 (>4m)	3.63	4.21	4.67	4.84	5.19
Total	6.36	6.85	7.21	7.34	7.59

Table 0:13 Ward wise inundated area according to depth class for the various return period.

WARDS	2YRP DEPTH CLASS AREA (SQ. KM)			10YRP DEPTH CLASS AREA (SQ. KM)			50YRP DEPTH CLASS AREA (SQ. KM)			100YRP DEPTH CLASS AREA (SQ. KM)			500YRP DEPTH CLASS AREA (SQ. KM)		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1	0.02	0.01	0.00	0.02	0.01	0.00	0.02	0.01	0.00	0.02	0.01	0.00	0.02	0.01	0.00
2	0.10	0.24	0.77	0.10	0.22	0.87	0.10	0.21	0.95	0.09	0.22	0.98	0.09	0.20	1.05
3	0.06	0.10	0.50	0.06	0.08	0.58	0.05	0.07	0.62	0.05	0.06	0.64	0.04	0.05	0.67
4	0.03	0.02	0.00	0.03	0.02	0.00	0.04	0.02	0.00	0.04	0.02	0.00	0.04	0.02	0.00
5	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.03	0.02	0.00	0.03	0.03	0.00	0.04	0.03	0.00	0.04	0.03	0.00	0.04	0.03	0.00
8	0.02	0.01	0.00	0.02	0.02	0.00	0.02	0.02	0.00	0.02	0.02	0.00	0.03	0.02	0.00
9	0.12	0.38	1.12	0.09	0.31	1.33	0.07	0.27	1.46	0.05	0.26	1.51	0.04	0.21	1.61
10	0.11	0.17	0.80	0.10	0.18	0.88	0.11	0.18	0.94	0.09	0.19	0.97	0.08	0.18	1.03
11	0.17	0.38	0.33	0.16	0.38	0.43	0.14	0.32	0.54	0.14	0.30	0.58	0.14	0.26	0.65
12	0.08	0.04	0.00	0.08	0.05	0.00	0.09	0.06	0.00	0.09	0.06	0.00	0.11	0.07	0.00
13	0.16	0.26	0.06	0.15	0.29	0.08	0.15	0.30	0.10	0.14	0.31	0.10	0.14	0.32	0.12
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.08	0.08	0.04	0.08	0.10	0.04	0.08	0.10	0.05	0.08	0.11	0.05	0.08	0.11	0.05
16	0.02	0.01	0.00	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total	1.00	1.73	3.63	0.95	1.69	4.21	0.92	1.62	4.67	0.89	1.61	4.84	0.88	1.52	5.19



0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Inundated Area (sq. km)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Ward
(a)
2YRP
10YRP
50YRP
100YRP
500YRP



0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Inundated Area (sq.km)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Ward
(b)
2YRP
10YRP
50YRP
100YRP
500YRP

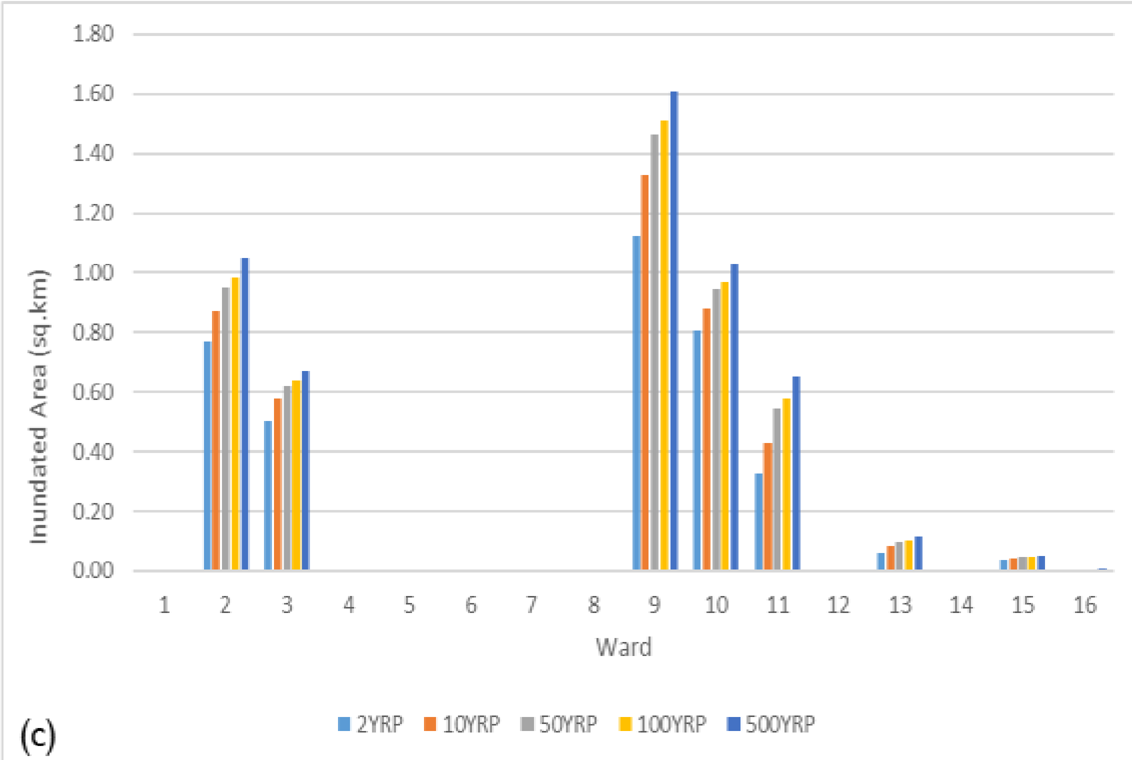


Figure 0:41 Ward wise inundated area for different return periods for depth class 1, 2 and 3 respectively in a, b and c. (For depth class 1, Wards 2, 11 and13 are at high, Wards 3, 9, 10, 12, and 15 are at moderate and remaining are at low/no risk. For depth class 2, Wards 2, 9, 10, 11 and 13 are at high, Wards 3, 12 and 15 are at moderate and remaining wards are at low/no risk. For depth class 3, Wards 2, 3, 9, 10 and 11 are at high risk, Wards 3 and 14 are at moderate and remaining wards are at low/no risk).

Note: The average inundated area less than 0.05 km2 is taken as low/no risk, 0.05km2- 0.1 km2 is taken as moderate risk and greater than 0.1km2 is taken as the high risk.)

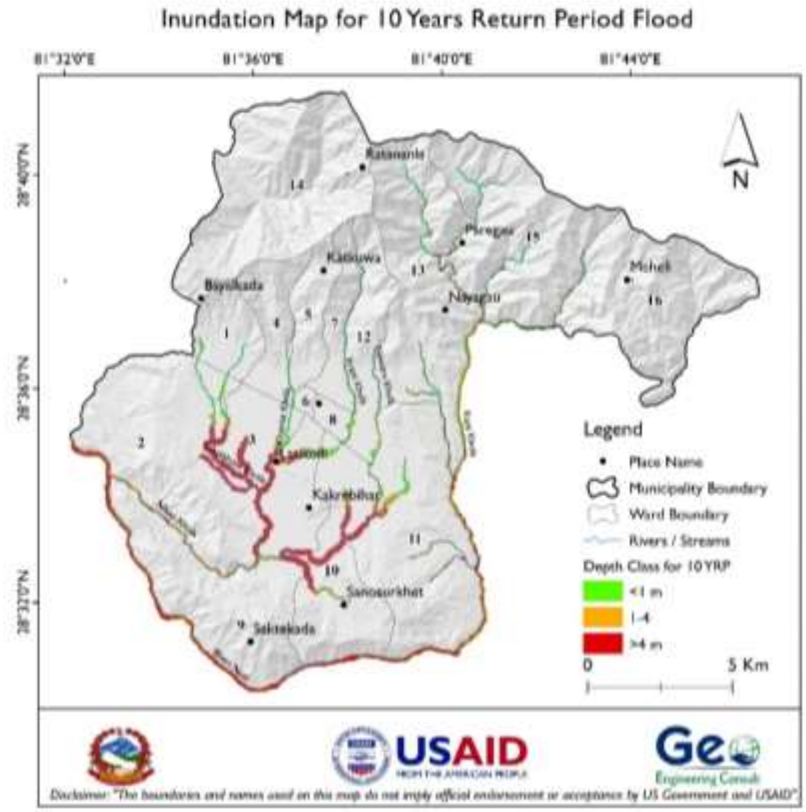


Figure 0:42 Inundation map of Birendranagar Municipality at 10-year return period.

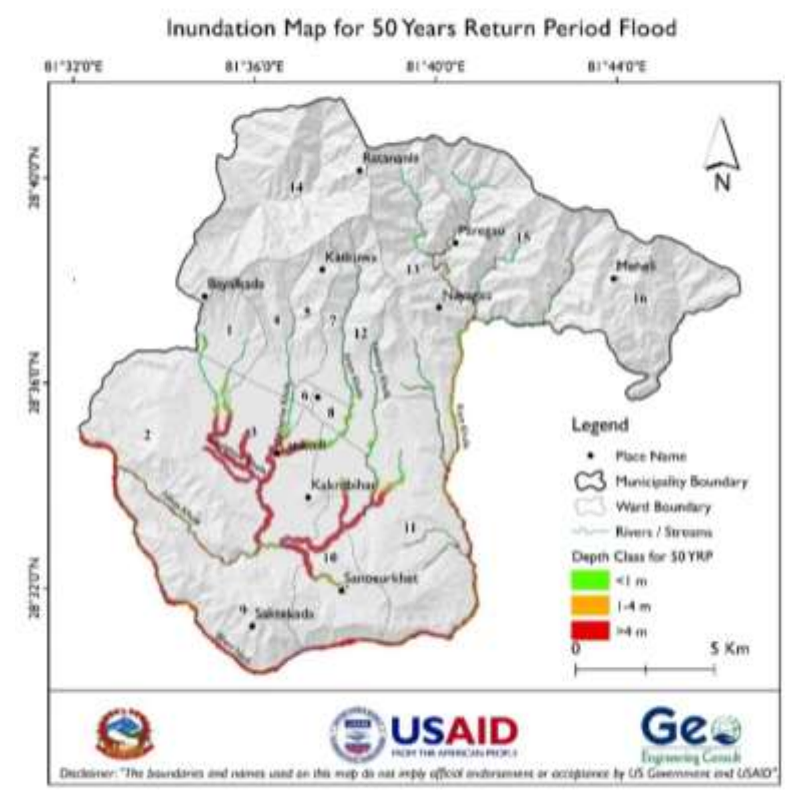


Figure 0:43 Inundation map of Birendranagar Municipality at 50 year return period.

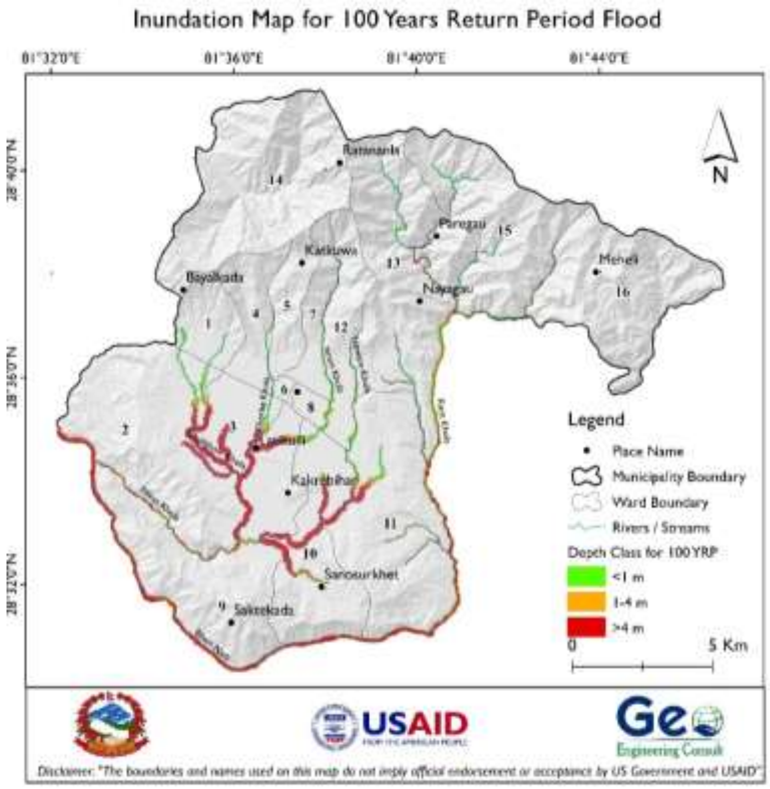


Figure 0:44 Inundation map of Birendranagar Municipality at 100 year return period.

FIELD VERIFICATION

The model relies on the resolution of different parameters such as DEM, hydrological data, channel geometry, and roughness of the river bed. After the preliminary model run, the field visit is one of the approaches to check the reliability of the model's results. The results of the preliminary model run showed that the Itaram, Khokre, and Neware were the rivers posing a threat of frequent floods which was a fundamental tool for field verification for the model simulation. For this study, a field visit has been conducted in July 2021, where cross-section data at the critical locations were identified and collected by model and historical image on Google Earth. Furthermore, surveys were carried out among the population to obtain historical flood information for the Itram, Khorke, and Neware rivers at significant cross-sections.

According to the historical images from Google Earth, one of the flood occurrences happened in 2014, which was also supported by the preliminary model result and survey with locals, as shown in For **depth class 2, Wards 2, 9, 10, 11 and 13 are at high, Wards 3, 12 and 15 are at moderate and remaining wards are at low/no risk. For depth class 3, Wards 2, 3, 9, 10 and 11 are at high risk, Wards 3 and 14 are at moderate and remaining wards are at low/no risk).**

Note: The average inundated area less than 0.05 km2 is taken as low/no risk, 0.05km2- 0.1 km2 is taken as moderate risk and greater than 0.1km2 is taken as the high risk.)

. However, for some reaches, the DEM does not accurately depict the terrain, thus cross-section data for those reaches was gathered during the field visit and corrected for the final model run. The historical flood depth experienced by the residents has been gathered for model validation. Table 1 shows the tabulation of the data obtained during the field visit.

CONCLUSIONS

The 1D HEC-RAS model, one of the most extensively used models in Nepal (Shrestha et al., 2020; Thapa et al., 2020) was used in this work to generate flood hazard maps based on flow depth and extent. The study by Rijal et al, 2018 identified the flood risk locations of the area based on the field survey which lacked the use of the hydraulic model. The Khorke, Neware, and Itram Khola were the major rivers posing risk to the communities in both studies. The findings of the flood depth and extent from the model for different return times in flood risk zones, on the other hand, may be utilized for planning and policy levels during the development of buildings and infrastructures.

The model results are highly influenced by the resolution of the used DEM (Shrestha et al., 2021). However, with the fine DEM, the DEM may not accurately reflect all existing streams, causing challenges in determining flood risk zones. Although the research employed a 5m resolution, the DEM required to be adjusted from field data for several of the stream sections.

The field verification was the major challenge for the study and surveying was only the suitable approach due to the lack of properly documented flood event records. So, the field verification was done from field survey by collecting information of flow depth and flood extent of the 2014 flood with the help of local people and from observing landscape change along the riverbanks after the major flood of 2014.

The results show that wards 2 and 11 are at high risk for all three depth classes. As these wards lie at the lower elevation of the watershed and major confluence of rivers occur in those wards whereas Wards 3,9,10,13 and 15 are at moderate risk, as major tributaries of the Bheri river flow through 13 and 15 wards and remaining wards lie at major river confluence at the lower elevation of the watershed.

The coefficient of determination (R^2) for the experienced depth and simulated flood depth for 10 years returns period and 50 years return period was calculated to check reliable flood events. The value of R^2 for 10 years return period and 50 years return period were found to be 0.879 and 0.853 respectively. Thus, the statistical results show that the flood events of 2014 might be of 10 years return period which can occur during the interval of 10 years at any time. This assessment provides reliable essential input information for improved urban-area planning in the future.

These results are important to understand flood hazard scenario for different return period. In addition, the results are integrated to estimate the multi hazards in the municipality.

8. LANDSLIDE HAZARD ASSESSMENT

BACKGROUND

Seismic activity, floods, cyclones, landslides, thunderstorms, volcanic activity, and other natural tragedies are examples of natural catastrophes. Landslides are amongst the most destructive natural catastrophes, inflicting substantial financial losses and hundreds of mortalities worldwide every year.

Landslides are becoming increasingly common in Nepal, and their incidence is expected to grow as precipitation patterns become more severe and road-building increases (Sudmeier-Rieux et al., 2012). A rapid increase in the development of roads, electricity, and reservoirs with little or no regard for natural risks has significantly contributed to the unleashing of landslides in the Himalayan highlands. Similarly, due to significant growth in population throughout the Himalayan highlands over the last three decades, the tendency of dwelling in somewhat dangerous places is on the upswing. Each year, as the rainy season begins, the likelihood of additional landslides increases. The potential of hillside collapse in those steep and susceptible basins grows when torrential rain and runoff descend upon slopes destabilized by the tremor and successive waves. Additionally, when the need for new construction space and supplies for old wrecked homes rises, natural resources such as deforestation and soil exploitation throughout the hillsides may be tapped, further undermining the slope. There are fissures in the hills above the road due to the earthquake, so there is a possibility of a catastrophic landslide.

Rainstorms are widely acknowledged as significant landslide-triggering events in hilly landscapes (Iverson 2000). Earthquakes can also trigger the rapid movement of earth materials down slopes. When an earthquake occurs on areas with steep slopes, soil and rocks fall, causing landslides. In recent decades, many researchers have investigated earthquake-induced landslide susceptibility models based on statistical methods (Bird and Bommer 2004; Lee and Evangelista 2006; Abella and Van Westen 2007; Keefer 2011; Tang et al. 2011; Shrestha and Kang 2017).

To stop or oversee issues caused by large movements, it is critical to perform a thorough investigation of landslide occurrences, comprising susceptibility mapping, hazard mapping, and risk analysis. The evaluation of landslide hazards is a complex procedure that frequently depends on an indicator, a statistical connection, or a physical process.

OBJECTIVES

It is important to recognize that is not possible to prevent landslide events from occurring and some may occur in such close proximity as to affect the settlements or to operation of the road network. The work undertaken and set out in this report is therefore targeted at developing the evidence base for allocating resources to reduce the exposure to landslide hazards and/or to reduce the physical hazard. Notwithstanding this, the latter actions involve higher cost solutions and are likely to be applied only in rare cases.

The general objective of the work commissioned was to assess the probable occurrences of landslide under extreme rainfall and seismic excitation and its propagation. The following are the specific objectives:

- To assess probability of occurrences of landslide using machine learning method

- To assess probability of landslide occurrences coupling rainfall return periods and earthquake
- To identify landslide initiation area and assess the propagation of landslides

METHODOLOGY

In this study, an integrated process based on three different modeling approaches has been proposed. First, a probabilistic approach of landslide susceptibility modeling was used to find the probable occurrences of landslide distribution which incorporates several CFs, incorporating data on geo-environmental factors related to landslide occurrence; second, developed a physically-based model coupling steady-state rainfall infiltration into a seismic slope, and used a pseudo-static stability model to evaluate the factor of safety (FS) of the optimal representative sampling points. And, third, a likelihood landslide initiation area was located applying failure criteria and then a runout model was used to assess the probability propagation of failure material. The main difference between the present study and previous studies is that the FS calculation based on a physical model is incorporated into landslide CFs to obtain the predicted FS of the entire study area.

In statistical methods, relationships between landslide locations and independent causative factors (CFs) are established in the form of empirical parametric functions, which are then used to develop landslide susceptibility maps of the target area. Statistical probability-based methods can take into account several CFs that affect the stability of slopes, such as topographic attributes, hydrology, forest, soil, and geology (Pradhan et al. 2019). However, these statistical methods do not incorporate geo-mechanical processes and hillslope hydrology.

Several researchers have proposed different physical approaches based on infinite slope stability models. In infinite slope models, the casual factors are either expressed in terms of the factor of safety (FS) (Clough and Chopra 1966; Stewart et al. 2003; Saygili and Rathje 2008; Keefer 2011) or extended to produce permanent displacements of hillslope models (Newmark 1965; Jibson 2011). Although physical models are easy to understand and have strong predictive capabilities, they depend on the spatial distribution of various geotechnical data, which are very difficult to obtain at the regional scale. Therefore, the application of physically-based models to large areas, or replication from one catchment to another based on the same set of geo-mechanical and hydrological parameters, is difficult due to limitations in the availability of these parameters (Acharya et al. 2016).

The procedure used for landslide susceptibility mapping in this study is shown in Figure 8:1. The proposed method of landslide susceptibility assessment comprised a physical module, a statistical module, and an ensemble module.

This study was performed in three steps: 1) collection of landslide inventory data and the CF database; subjecting the inventory to the machine-learning MaxEnt model to delineate landslide-susceptible areas 2) deterministic modeling coupling rainfall and seismic data to find factor of safety (FS) and 3) integrate the above-mentioned outcomes to find the landslide initiation area and assess landslide propagation zones.

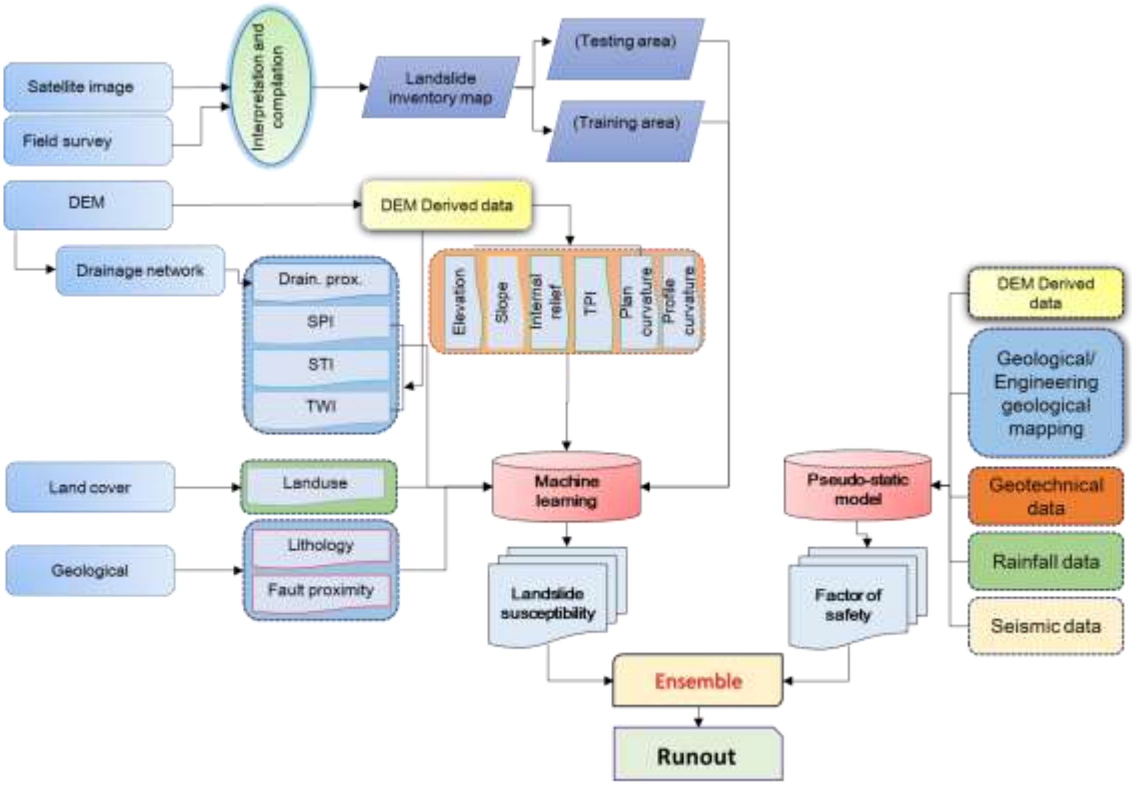


Figure 0:45 Architecture of the study.

LANDSLIDE SUSCEPTIBILITY ASSESSMENT

Preliminary landslide locations were delineated in a Google Earth™-aided recognition survey and Sentinel-2 multispectral images. The landslides were verified by comparing the imagery with that captured in Google earth's historical archives to confirm that all the identified landslides as shown in

Figure 0:46. Once identified on the Google Earth platform, landslides were assigned an identification code using an available tool in Google Earth and all landslides were imported into the geographical information system (GIS) environment. Thus delineated landslides on Google earth were verified in the field. The number of landslides studied during this research was 95 in total. Although more locations were marked as probable sites, they were validated in the field and canceled after the field observation. It was observed that the most number of landslides occurred in the northern part of the study area. The biggest landslide in Birendranagar Municipality is having an area of 38,692 m^2.

Figure 0:46 and 8:3 show landslides observed in the field and landslides identified using remote sensing technique.

Causative factors are properties that influence the driving and opposing forces of landslide direction of travel and their equilibrium. On a regional scale, there are different geological, geomorphological, and environmental features of the ground. In other words, conditioning variables set the stage for the landslides to occur. Causative factors in landslide investigations are often chosen based on examining the landslide types and the features of the research region. The relevance and accessibility of causative variables influence the selection of these causative factors.

Elevation, slope angle, plan curvature, and distance to drainage networks are all standard causative variables. However, most academics produced landslide susceptibility maps by arbitrarily and subjectively selecting causative elements such as geological, geomorphological, hydrological, and human factors. As a result, the selection of landslide causative variables and their classifications is critical in landslide susceptibility modeling research. 12 CFs were considered in this research to determine the landslide susceptibility feeding as input to the machine learning model (Table 8:1).

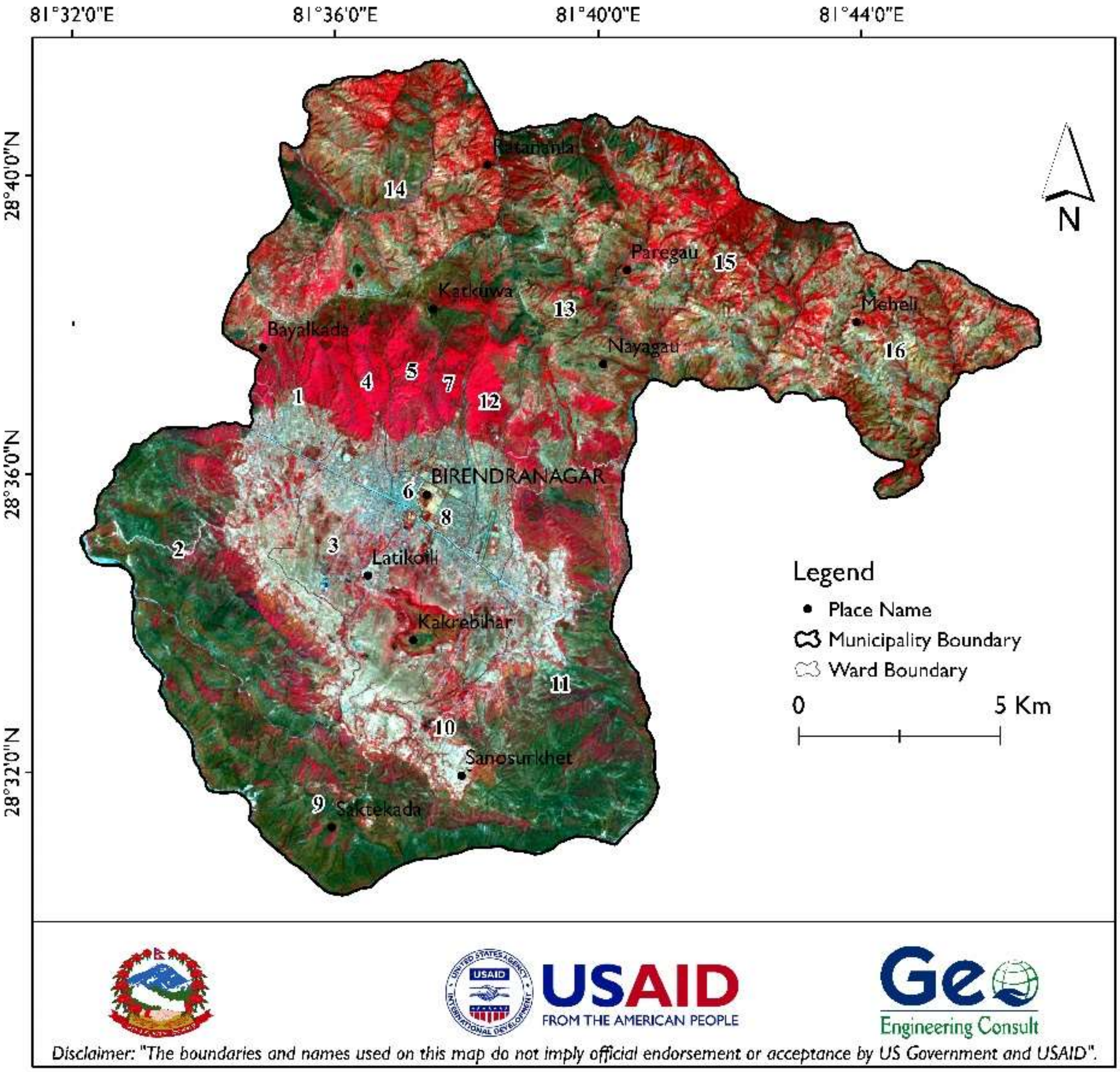


Figure 0:46 Sentinel-2 data used for landslide identification.

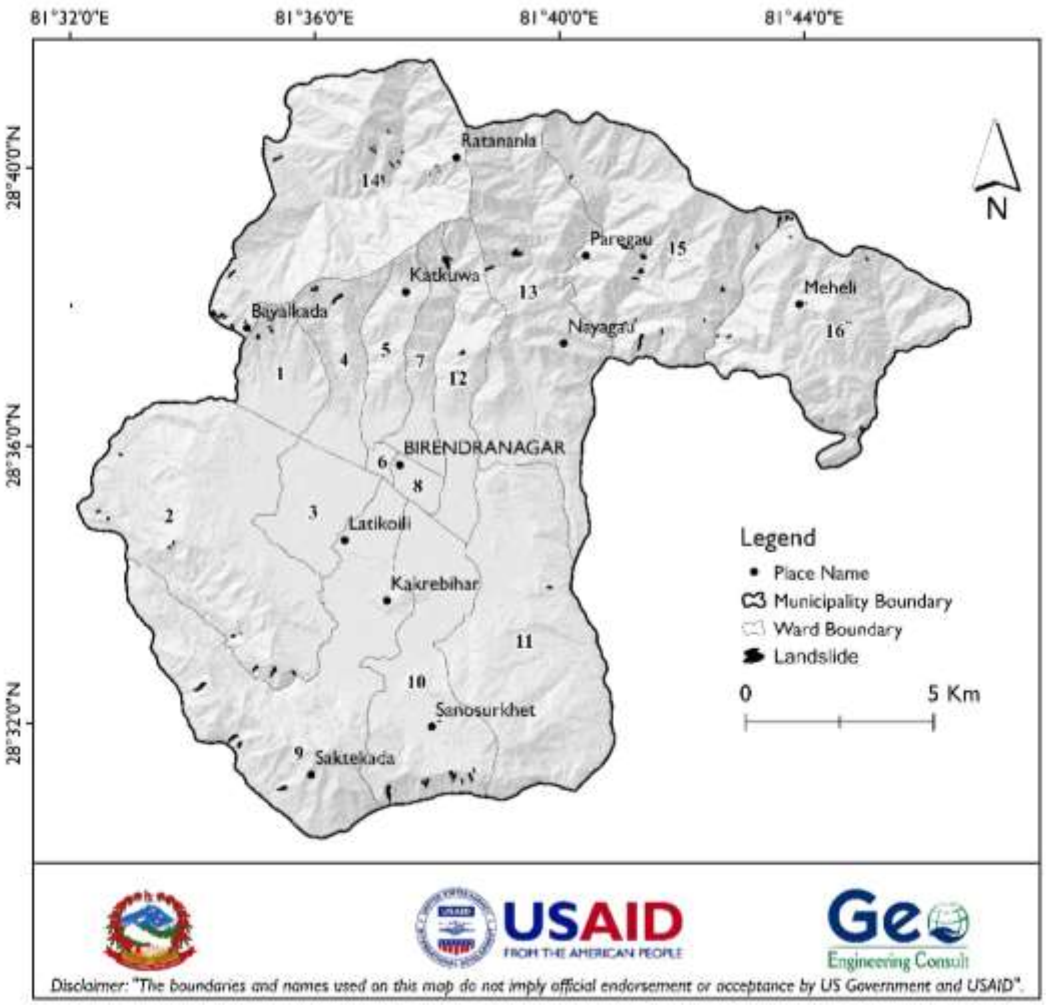


Figure 0:47 Landslide inventory map.

Table 0:14 Landslide data layers and their features.

TYPE	CAUSATIVE FACTORS	SIGNIFICANCE	SOURCE
Topographic	Elevation	Weather, vegetative cover, and potential energy are all subject to change with elevation resulting in variation in the likelihood of landslides (Ercanoglu et al. 2004)	High-resolution DEM provided by USAID
	Slope	Steeper slopes have less friction; landslides are more likely to happen(Catani et al. 2013)	
	Plan Curvature	The convergence or divergence of slide material and water in the path of landslide velocity is influenced by plan curvature (Young et al. 1973).	

TYPE	CAUSATIVE FACTORS	SIGNIFICANCE	SOURCE
	Profile Curvature	The driving and resistive forces inside a landslide are influenced by profile curvature in the direction of movement (Ohlmacher 2007).	
	Relative Relief	Relative relief depicts significant fissures in slopes and reflects the energy available for slope failures and soil degradation (Pradhan and Kim 2021).	
	Topographic Roughness Index	Express the amount of elevation difference between adjacent cells of a DEM (Riley et al. 1999).	
Hydrologic	Drain Proximity	Distance from river lineament	High resolution DEM provided by USAID
	Topographic Wetness Index	The impact of topography on hydrological cycle (Kavzoglu et al. 2014a)	
	Sediment Transport Index	Depicts the erosion and sedimentation processes (Moore and Burch 1986b).	
	Stream Power Index	A measure of the stream's erosive strength (Moore and Burch 1986a)	
Geologic	Geology	Each lithological unit is associated with a particular degree of weathering (Yalcin 2007).	Department of Mines and Geology
	Fault Proximity	Distance from fault lines	Department of Mines and Geology, GIS

The DEM to be utilized was provided by the USAID at a resolution of 4.36m×4.36m (Figure 8:4). Ten geomorphological conditioning factors were created using the DEM: elevation, slope, curvature, plan curvature, profile curvature, topographic wetness index (TWI), sediment transport index (STI), stream power index (SPI), topographic position Gautam al index (TPI), and relative relief (RR) (Figure 8:5-8:13).

It is crucial to assume similar circumstances to the past (Lee and Talib, 2005). Probabilistic (statistical) approaches are based on links among each landslide component and the pattern of past landslides, which may be assessed using the frequency ratio model. The landslide factors addressed in this study are geology, elevation, slope, profile, and plan curvatures, and the numerous indices used to illustrate this relationship with landslides.

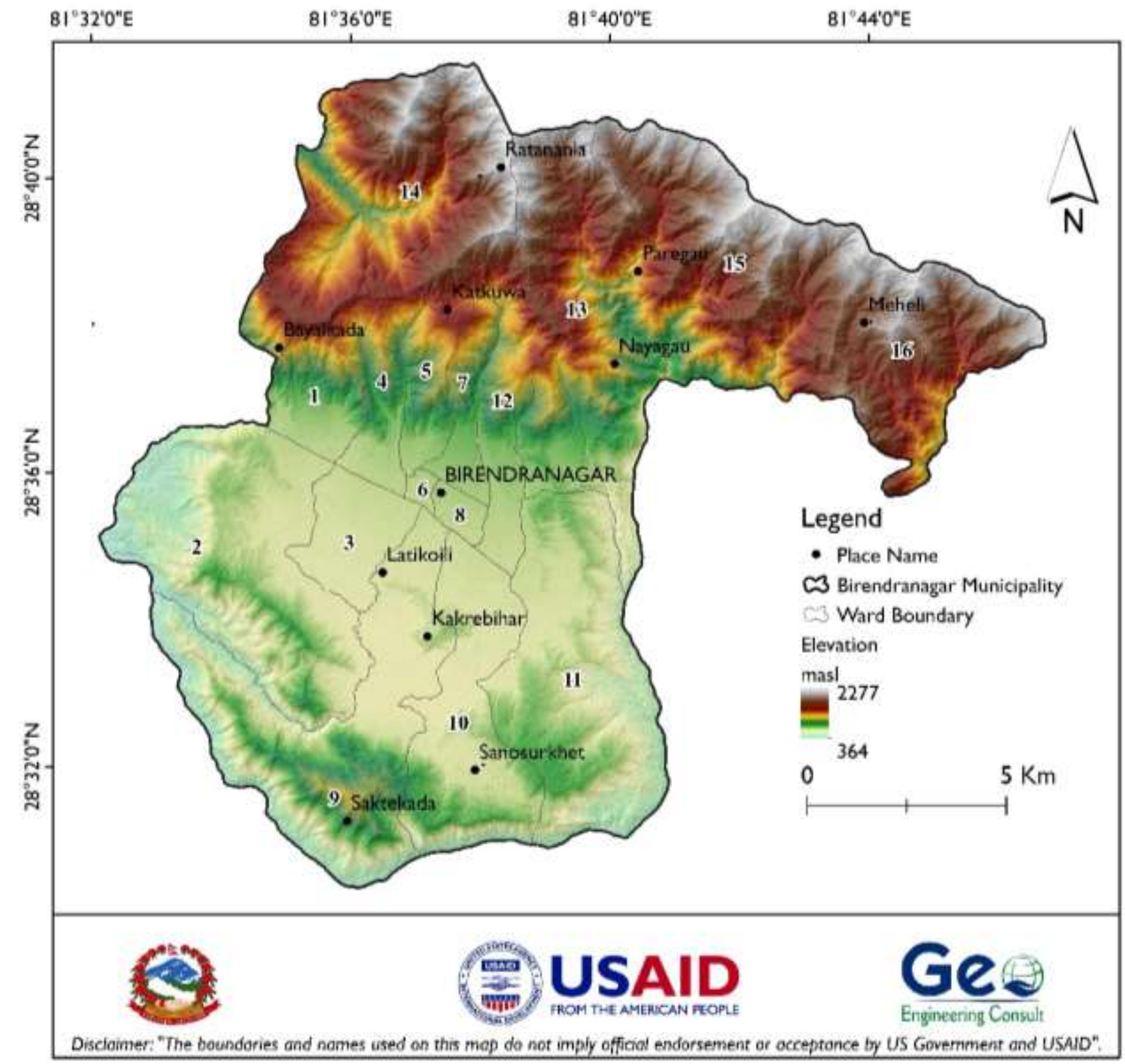


Figure 0:48 Elevation distribution map of Birendranagar Municipality.

Numerous scholars defined slope as an input variable in susceptibility studies. It is the tangential angle representation of the rate of the vertical distance to the horizontal separation between two defined locations. It features a 0°-90° scale, with 0° indicating the horizontal area and 90° denoting the vertical area. In essence, the slope is the inclination created between each ground segment and a baseline reference point that measures the rate of increase in height and permits water and other resources to flow in the slope's direction in order of the steepest drop in slope for elevation. The slope is a derivation of the digital elevation model that is evaluated in the topographical attribute classification as shown in Figure 8:5.

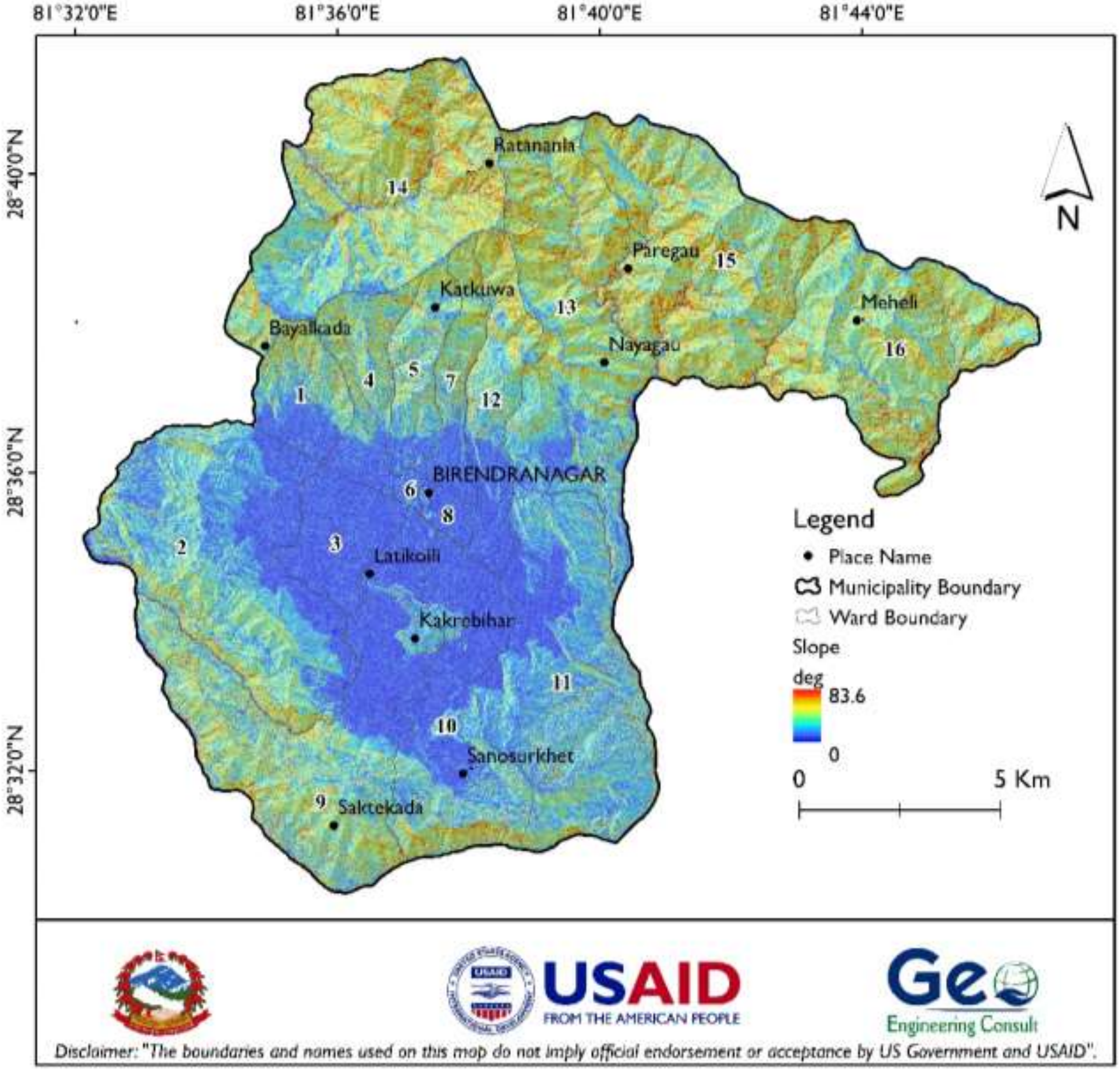


Figure 0:49 Slope distribution map of Birendranagar Municipality.

The relative relief is considered to be a major relief property for representing the morphological characteristics of any terrain (Smith 1935). Relative relief corresponds to local differences between maximum and minimum altitudes within a unit area (Oguchi 1997; Hengl et al. 2003). Relative Relief provides a sign of the potential energy available for mass wasting and soil erosion and shows major breaks in slopes (Zhou et al. 2012; Pradhan and Kim 2014) as presented in Figure 8:6.

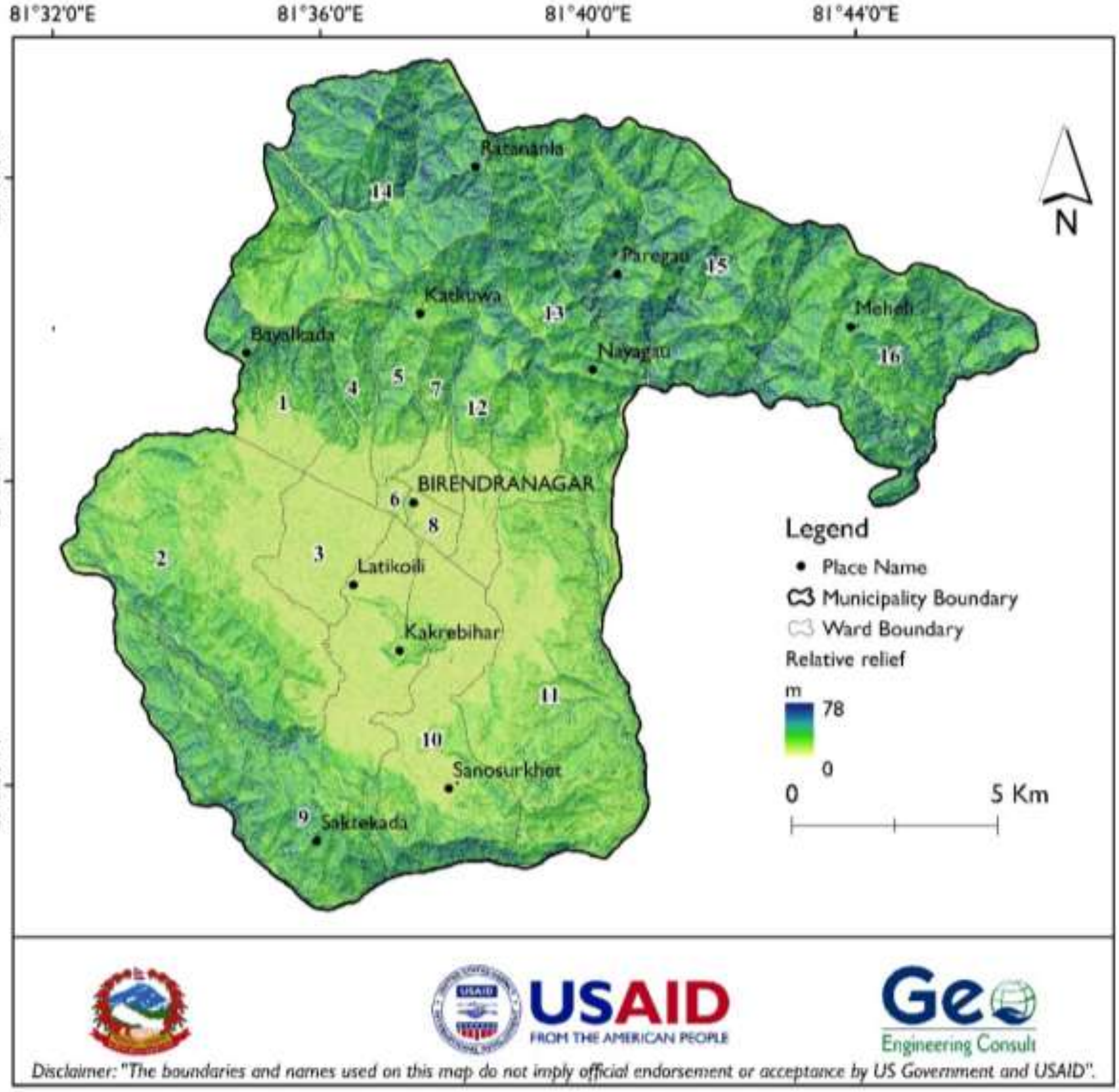


Figure 0:50 Relative relief map of Birendranagar Municipality.

Landslide susceptibility is impacted by both profile and plan curvatures. Profile curvature in the direction of the velocity influences the pushing and opposing stresses within a landslide (Figure 8:7). Plan curvature governs the convergence or dispersion of landslide substances in the path of landslide velocity (Figure 8:8). The symbol of the curvature value determines if the curve is concave or convex. For both profile and plan curvature images, negative and positive indices express concave and convex shapes. Based on the plan curvature, hillside slopes can be categorized as hollows, noses, or generally flat portions. Hollows are where the contouring plan curvature is a concave downward slope, and groundwater would concentrate as it flowed downslope (Reneau and Dietrich 1987). The term "noses" or "coves" refers to places where the outline plan curvature is convex in the downhill slope direction, and the groundwater diverges (Hack and Goodlett 1960). Plan curvature values are near to zero in generally flat regions.

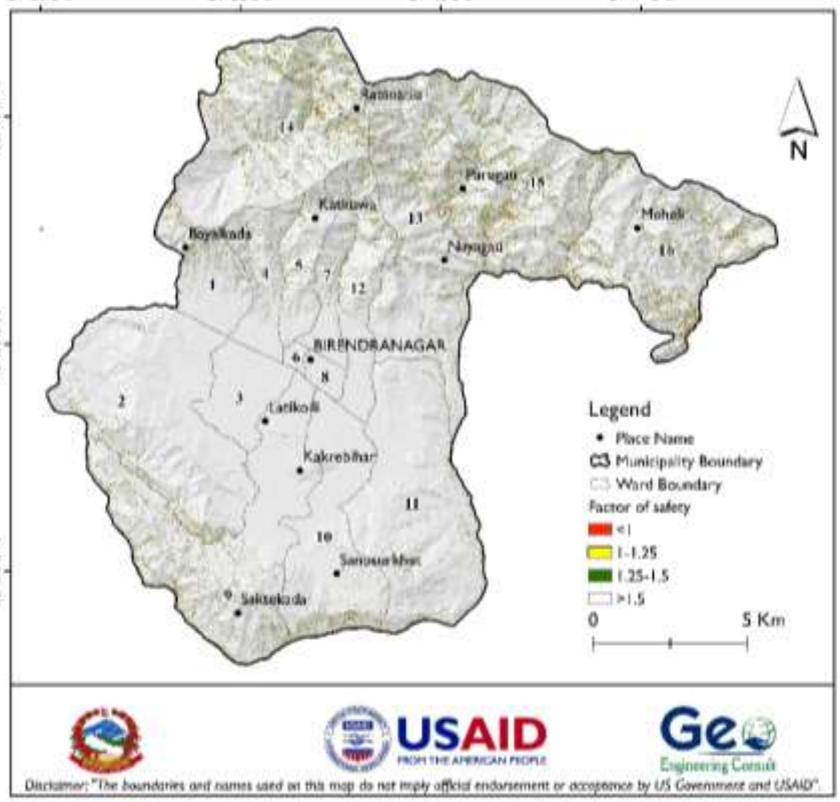


Figure 0:51 Profile curvature map of Birendranagar Municipality.

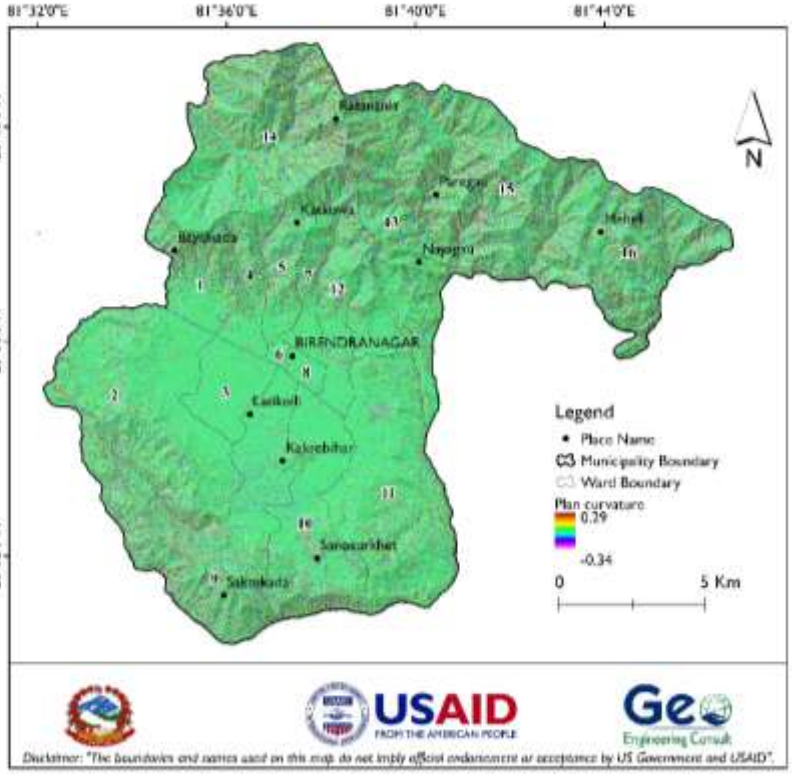


Figure 0:52 Plan curvature map of Birendranagar Municipality.

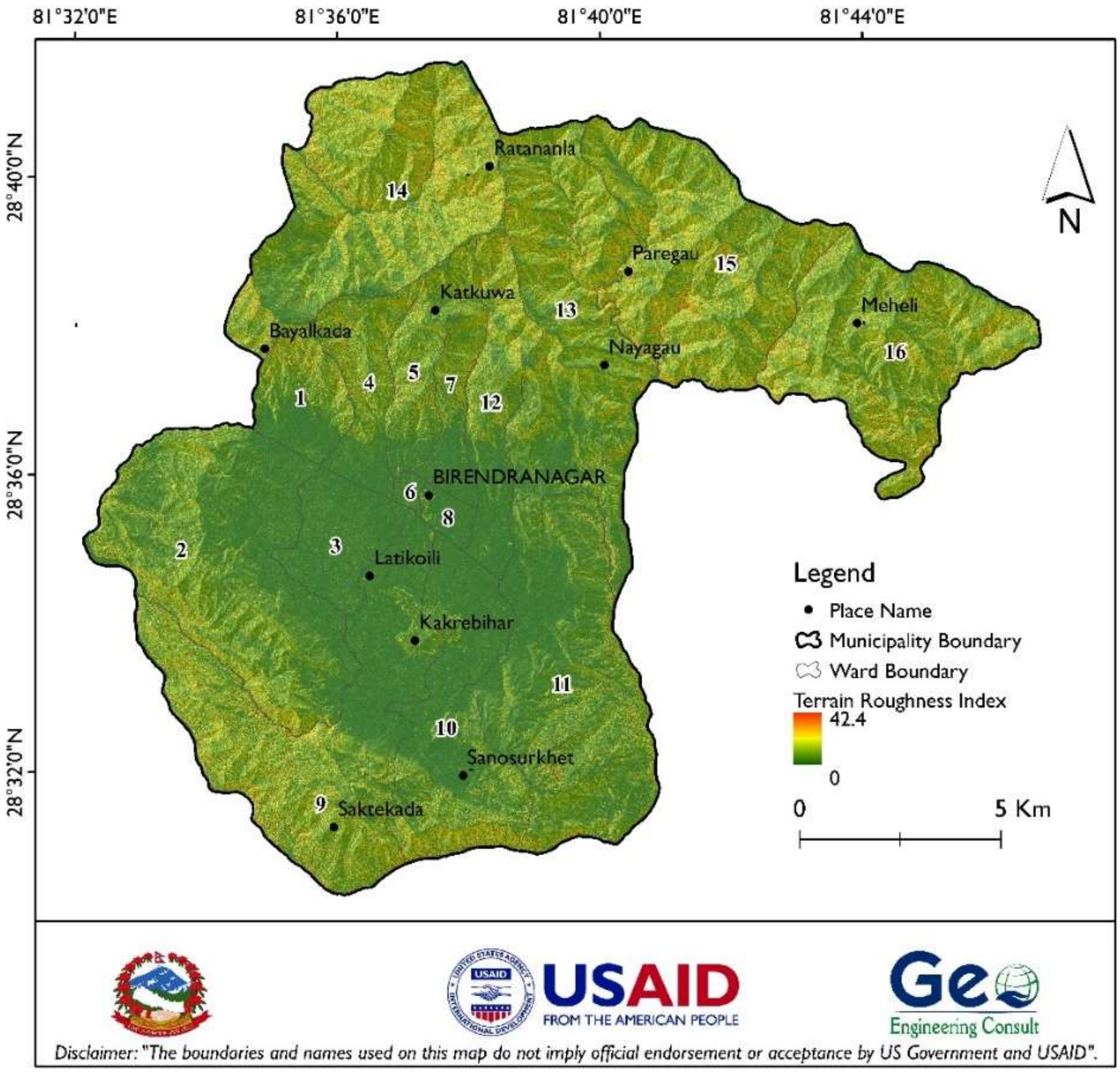


Figure 0:53 Terrain roughness index map of Birendranagar Municipality.

Terrain roughness (surface roughness, ruggedness, terrain rugosity, micro topography, micro-relief) is defined as the variability or irregularity in elevation (highs and lows) within a sampled terrain unit as depicted in Figure 8:9.

Streams play an essential role in creating an environment conducive to the formation of landslides. River courses, depending on their energy and flow velocity, operate as both erosional and depositional forces. River undermining decreases the stability of the slope, increasing the likelihood of landslides and mass movement. It is assumed that the hillslope nearby the river gets saturated and leads to instability. The river proximity of the study area is shown in Figure 8:10.

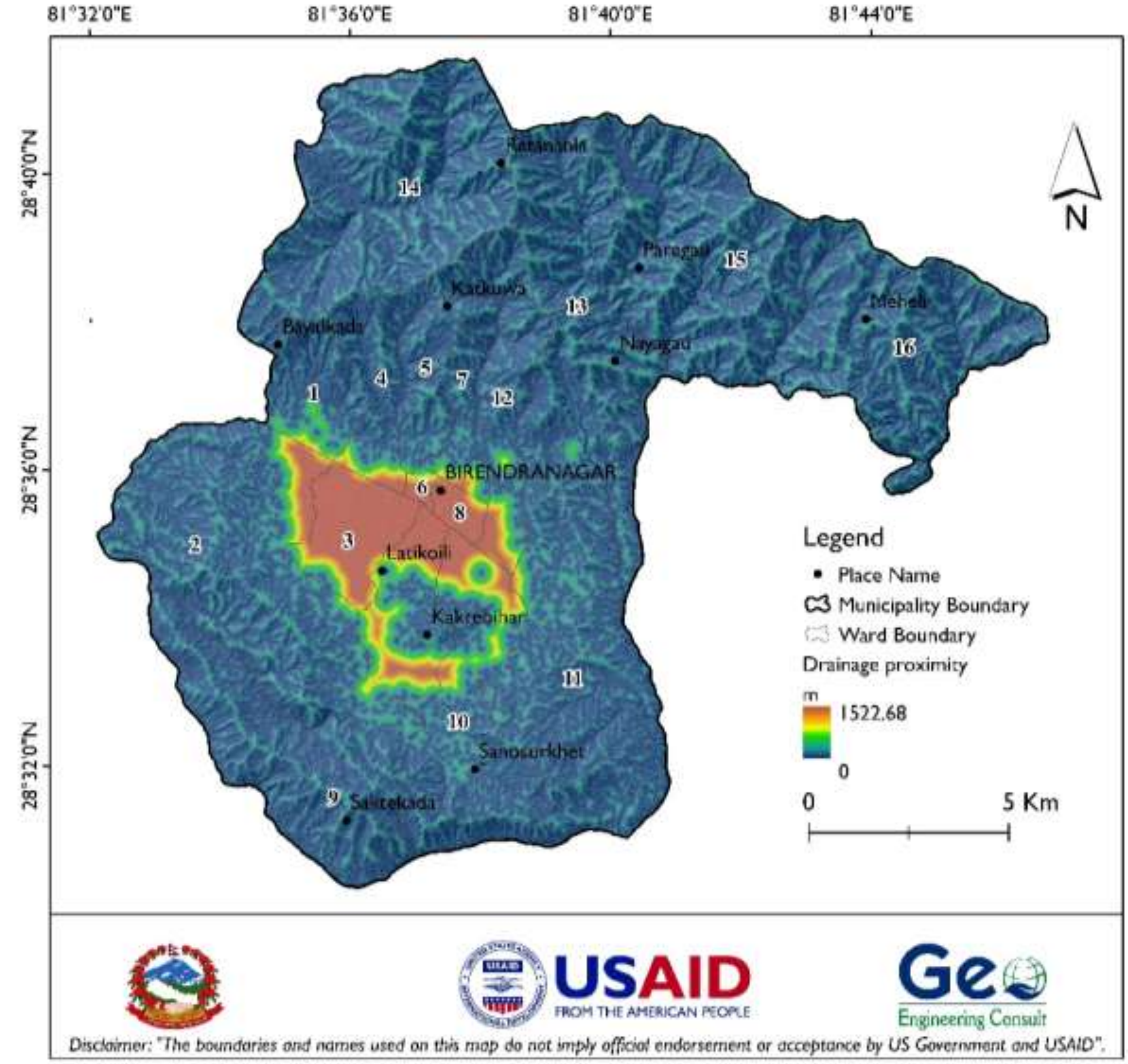


Figure 0:54 Drainage proximity map of Birendranagar Municipality.

The topographic wetness index (TWI) established by Beven and Kirkby (1979) well within the flow model is defined as equation (1):

$$\text{TWI} = \ln \frac{\alpha}{\tan\beta} \tag{1}$$

Where α is the localized upslope region flowing via a specific location per unit contour distance, and $\tan\beta$ is the native gradient. The TWI is used to investigate the impact of geographical scale on the hydrological cycle. Water penetration into subgrade soil increases pore water stresses and reduces the strength of the soil. The topographic wetness index (TWI) has been used extensively to describe the effect of topography on the location and size of saturated source areas of runoff generation. TWI is shown in Figure 8:11.

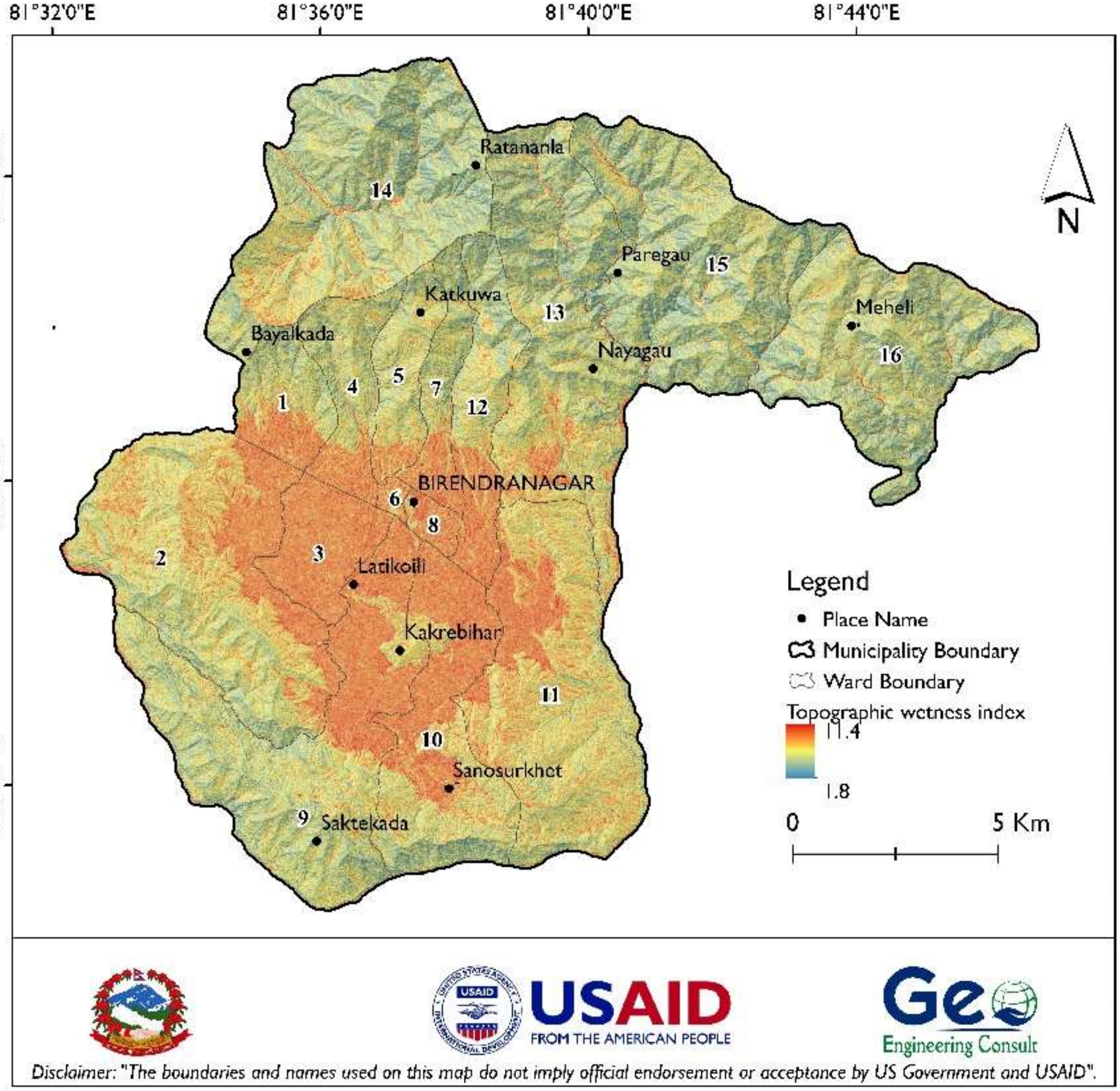


Figure 0:55 TWI distribution map of Birendranagar Municipality.

The sediment transport index (STI) depends on the catchment size and slope angle in a nonlinear fashion (Moore and Burch 1986), as shown in equation (2):

$$\text{STI} = \left(\frac{A_s}{22.13}\right)^{0.6}\left(\frac{\sin\beta}{0.0896}\right)^{1.3} \qquad (2)$$

The slope of an area has two components: the slope length (L) and the slope steepness (S). Soil loss is the combined effect of L and S. The LS factor in the universal soil loss equation (USLE) is a measure of the sediment-transport capacity of overland flow. STI distribution in the study area is presented in Figure 8:12.

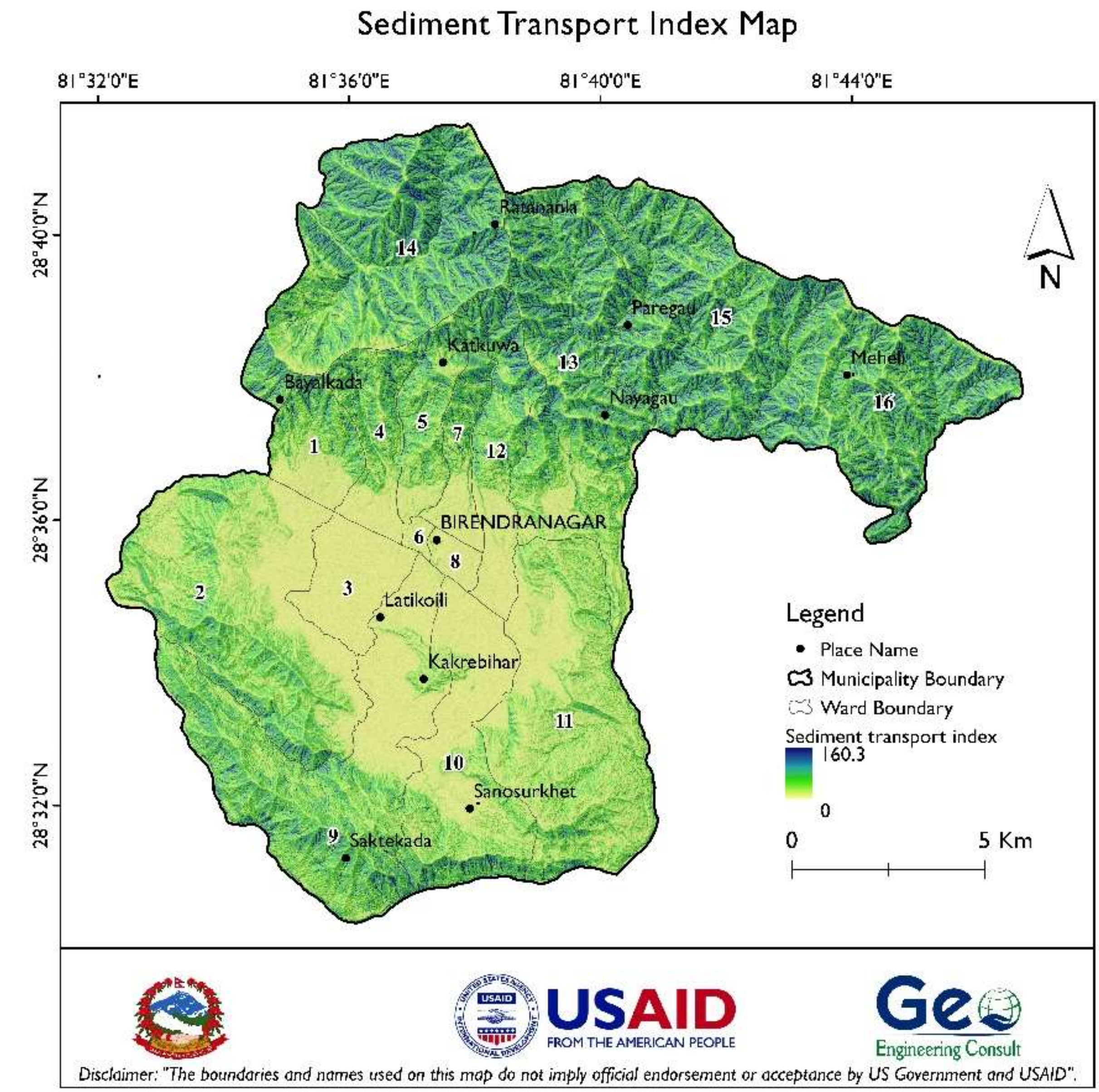


Figure 0:56 Spatial distribution of sediment transport index (STI) map of Birendranagar Municipality.

Stream power index (SPI) can be used to describe potential flow erosion at the given point of the topographic surface (Figure 8:13). As watershed area and slope gradient increase, the amount of water contributed by upslope areas and the velocity of water flow increase, hence stream power index and erosion risk increase. The SPI, an indicator of the stream's abrasive wear force, was calculated for the research region. SPI can be defined as in equation (3).

$$SPI = A_s \times \tan\beta \tag{3}$$

Where A_s is the particular catchment extent and β is the native slope grade in degrees.

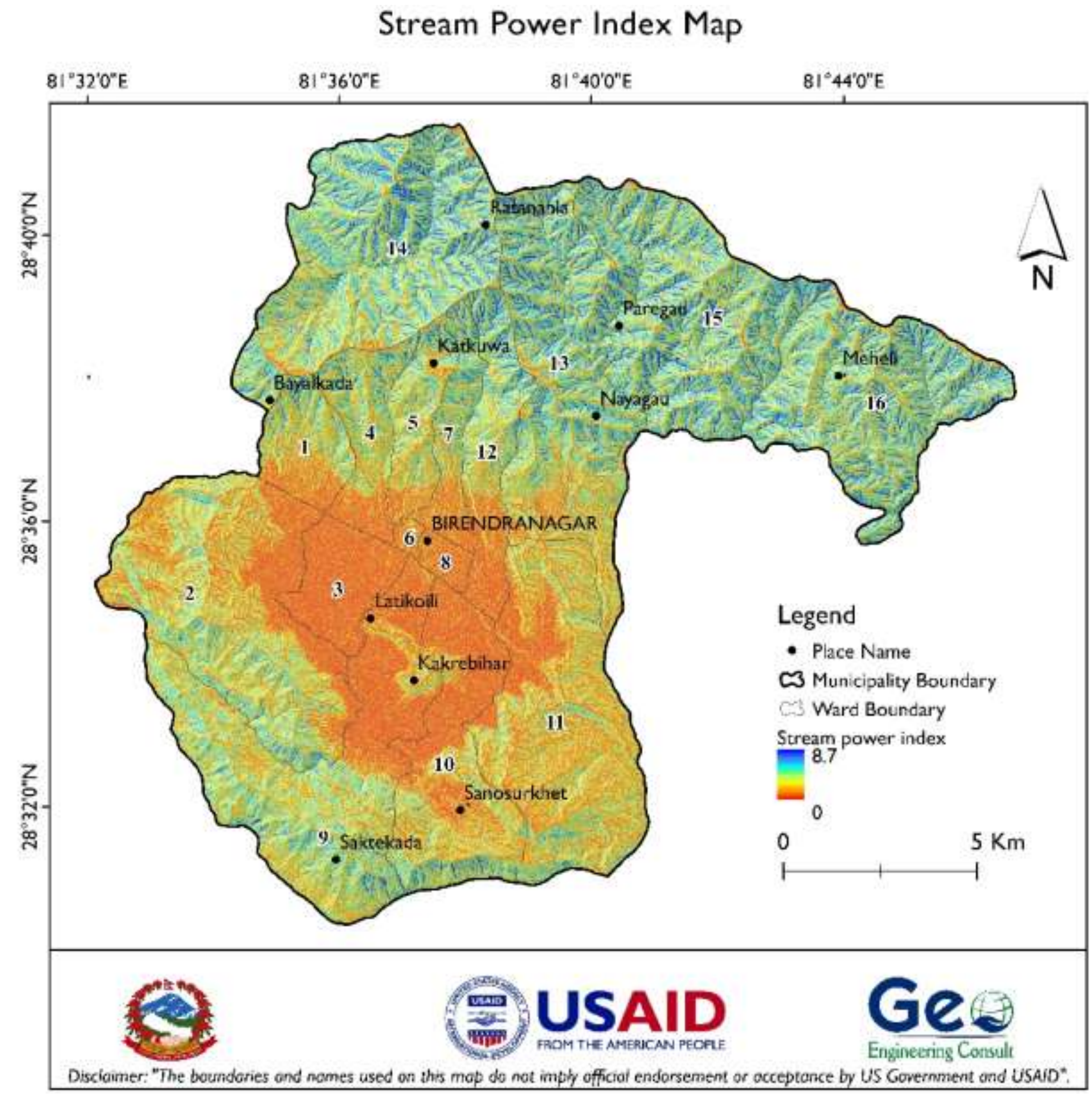


Figure 0:57 Spatial distribution of stream power index (SPI) map of Birendranagar Municipality.

Landslides are controlled by the geological characteristics of the significant ground surface since different lithologic units have different landslide susceptibility zones (Pradhan and Kim 2014b). For susceptibility mapping, it is crucial to take into account the contributions of the individual units. Therefore, it is important to properly group rock properties (Mejia-Navarro and Garcia 1996; Luzi and Pergalani 1999; Carrara and Pike 2008). As mentioned above, the study area consists of the Lesser Himalaya and Siwalik Zones. Twelve lithological layers as shown in Figure 8:14 were created for the study area based on the geological map.

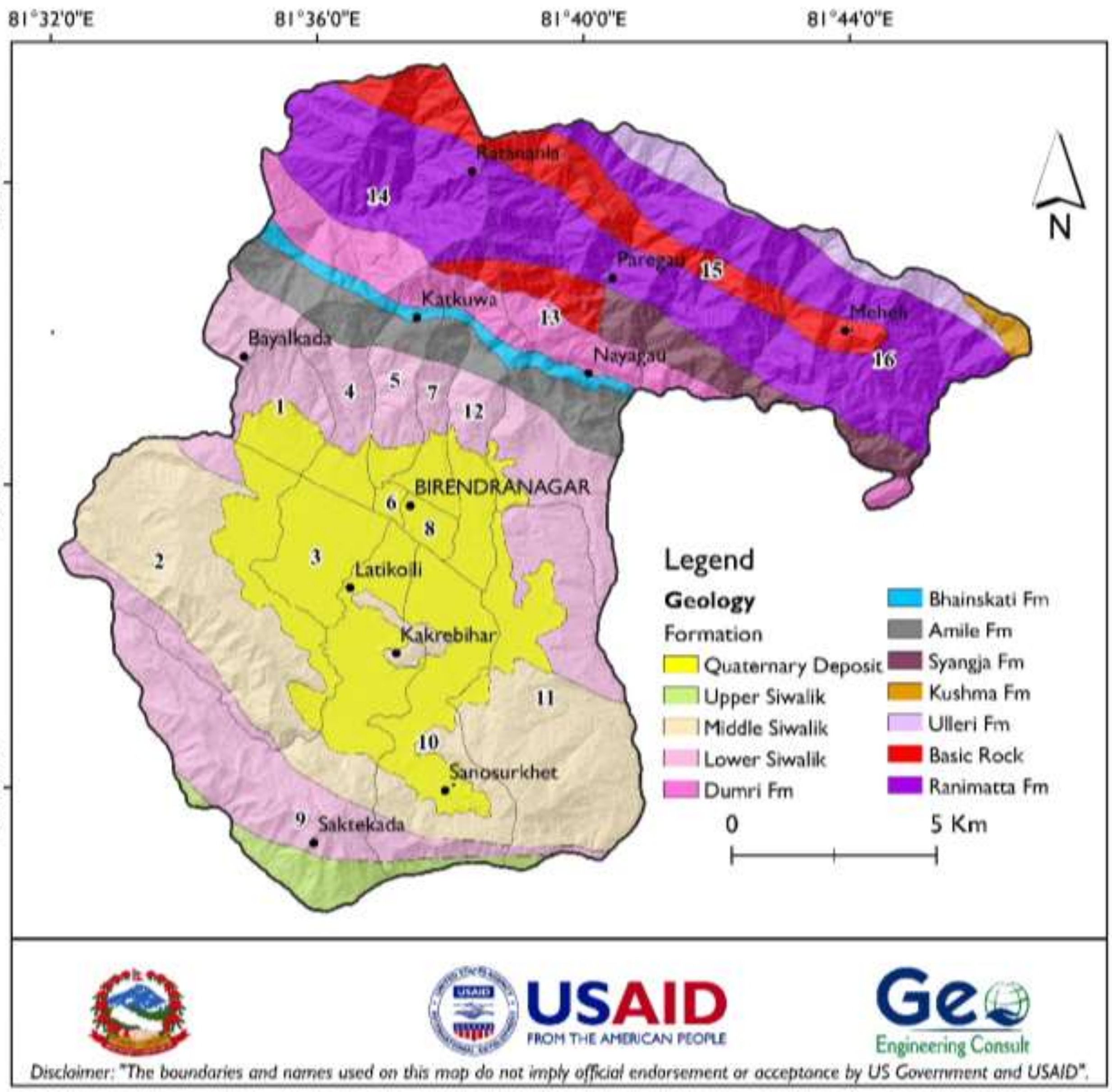


Figure 0:58 Lithological map of Birendranagar Municipality.

The strength of rock mass decreases in the proximity of active faults, which weakens the hillslope which led to further instability (Korup et al. 2006). A fault map was extracted from the geological map published by the DMG, and the distances from the extracted faults were obtained by calculating Euclidian distances from the faults, as shown in Figure 8.15.

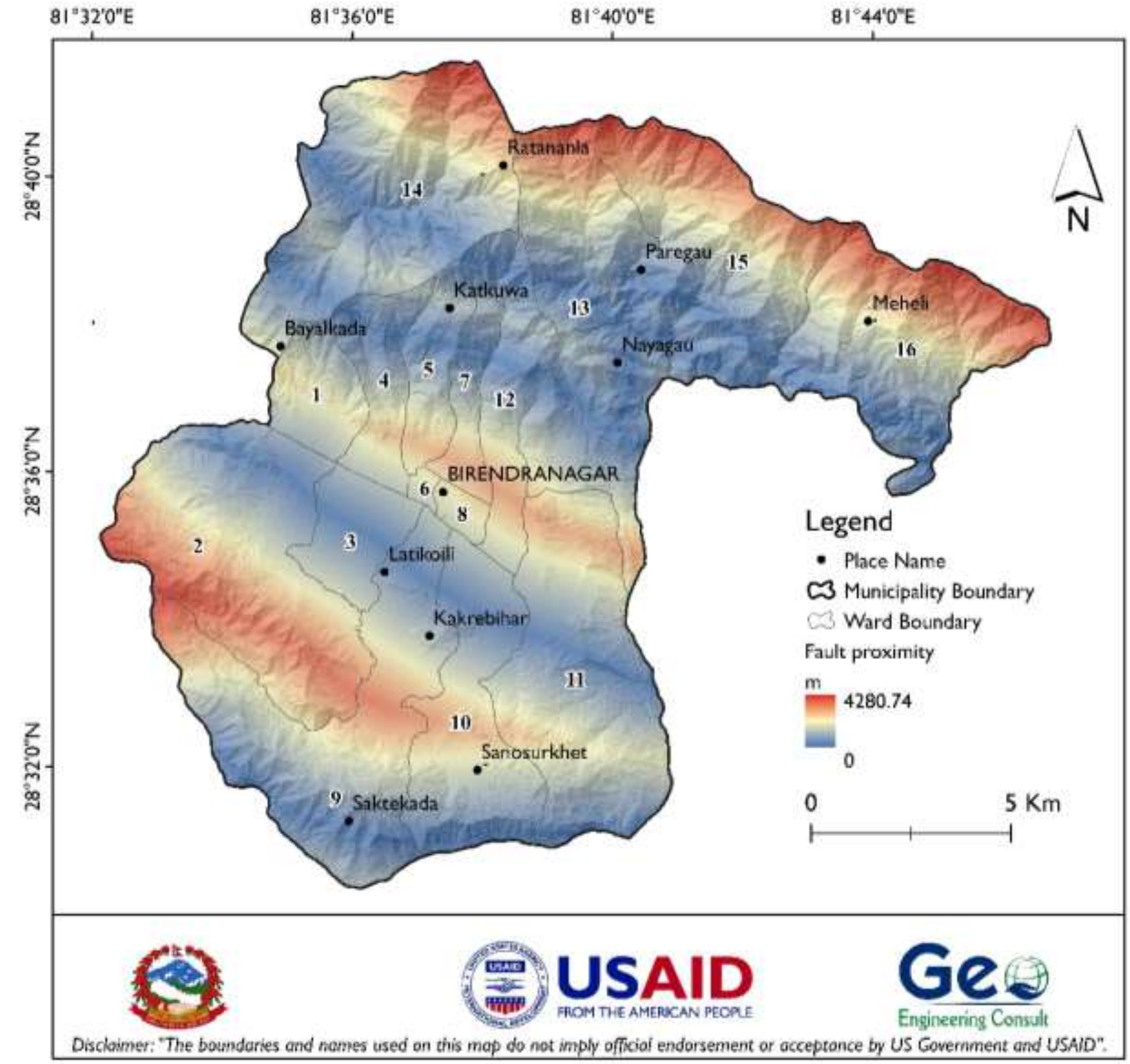


Figure 0:59 Fault proximity map of Birendranagar Municipality.

Variable selection

All CFs were rasterized into 4.36m×4.36m pixels for analysis. Before the core modeling process, carried out a Pearson correlation analysis to measure the linear correlation between the continuous CFs. The value of Pearson's correlation coefficient lies between +1 and -1, where 1 indicates a total positive linear correlation, 0 indicates no correlation, and -1 indicates total negative linear correlation (Pearson 1895). Figure 16 presents the correlation matrix of the 11 CFs. The correlation analysis revealed that the slope is highly positively correlated with the Relative relief and topographic roughness index, similarly, STI is highly correlated with SPI.

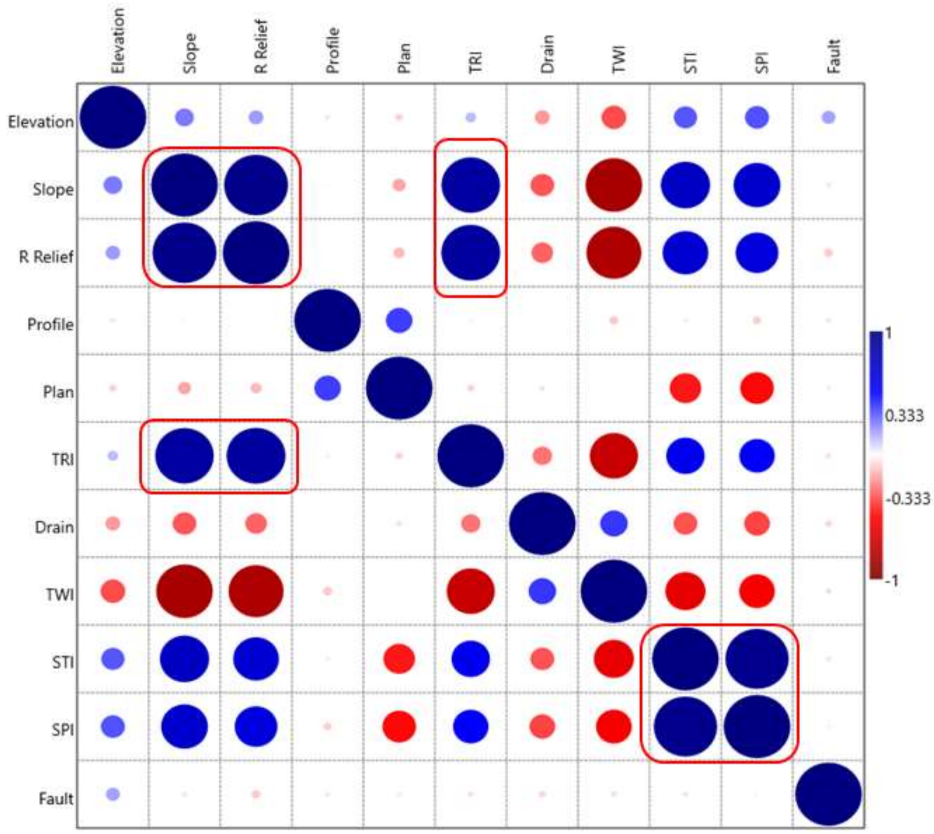


Figure 0:60 Pearson's correlation analysis of CFs.

For the susceptibility analysis, the independent datasets were processed through a multi-collinearity test. Multi-collinearity occurs when independent variables in a regression model are correlated. This correlation is a problem because CFs should be independent of each other. As discussed by Soeters and van Westen (1996), the analysis need not include all parameters, only the relevant CFs. The multi-collinearity can cause problems when fitting the model and interpreting the result (Draper and Smith 1998; Burnham and Anderson 2002). To overcome this, a multi-collinearity test was performed to customize the dimension of the data and select applicable CFs from the set of collected CFs. The variance inflation (VIF) and tolerance (TOL) are widely used indexes of the degree of multi-collinearity (Kavzoglu et al. 2014b; Pradhan et al. 2019). A VIF value greater than or equal to 10 and a TOL value less than 0.2 indicates a serious multi-collinearity problem (Menard 1995; O'Brien 2007):

$$\mathrm{TOL} = 1 - R^2 \tag{4}$$

$$\mathrm{VIF} = \frac{1}{\mathrm{TOL}} \tag{5}$$

where R^2 is the coefficient of determination, i.e., the proportion of the variance in the dependent variable that can be predicted from the independent variables (Belsley et al. 1980; Slinker and Glantz 1985, 2008) (Tables 8:2 and 8:3).

After excluding the variables which were failed in the multi-collinearity test, all to gather 10 CFs were used to make a landslide susceptibility map.

Table 0:15 Initial multi-collinearity test

STATISTIC	R^2	TOLERANCE	VIF
Elevation	0.259	0.741	1.349
Slope	0.949	0.051	19.436
R Relief	0.928	0.072	13.976
Profile	0.206	0.794	1.259
Plan	0.449	0.551	1.816
TRI	0.805	0.195	5.132
Drain Proximity	0.231	0.769	1.301
TWI	0.791	0.209	4.795
STI	0.918	0.082	12.131
SPI	0.916	0.084	11.926
Fault Proximity	0.091	0.909	1.100

Remarks: The bold numbered cells represent factors that failed in the multi-collinearity test.

Table 0:16 Final multi-collinearity test.

STATISTIC	R^2	TOLERANCE	VIF
Elevation	0.238	0.762	1.312
Slope	0.814	0.186	5.368
Profile	0.168	0.832	1.202
Plan	0.429	0.571	1.751
Drain Proximity	0.219	0.781	1.280
TWI	0.775	0.225	4.453
SPI	0.672	0.328	3.046
Fault Proximity	0.069	0.931	1.074

Landslide susceptibility modeling

Landslides have intrinsic and extrinsic causes. Intrinsic factors include geological, geotechnical, and morphological causes. The geological and geotechnical causes are weak or sensitive materials, weathered materials, and adversely oriented discontinuities, such as faults and thrusts. Morphological causes include tectonic or volcanic uplift, glacial rebound, and fluvial, wave, or glacial erosion of the slope toe or lateral margins. Extrinsic causes include triggering factors such as rainfall, earthquakes, and human activities. As rainfall infiltrates soils, it increases the pore pressure and reduces the matric suction of soils, decreasing the shear strength of the slip surface. Human activities include excavation of the slope or its toe, loading of the slope or its crest, and mining.

MaxEnt provides the least biased estimate from the given information (Jaynes 1957); i.e., it is maximally noncommittal concerning missing information and is a machine learning model to calculate patterns and processes, while not requiring the incorporation of large amounts of information. MaxEnt is based on a presence-only machine learning statistical methodology and can generate correlations between occurrence points and predictor variables by removing patterns to maximize randomness. This model has previously been used to predict species distributions in ecosystems and is a pattern-orientated model (Paola and Leeder 2011). MaxEnt is used to detect the driving set of variable patterns where this set of variables creates the most susceptible conditions and is a spatially dependent variable (Convertino et al. 2013). It is considered a general method for determining the constraints of the best positive distribution from incomplete data (Skilling 2013) and is therefore ideally suited to the analysis of the variety of geospatial and geologic variables that contribute to landslide hazards. MaxEnt has generally proven to be a powerful statistical prediction tool, with the very exemplification of it in a recent study by Convertino et al. (2013).

To estimate the landslide susceptibility, both the occurrence and background samples, on which MaxEnt is dependent, are used. All of the locations or a random sample of pixels within the landscape provide the background points over which MaxEnt assesses the relationships between the variables and landslide susceptibility Convertino et al. (2013). For this study 10,000 random background points were selected within the landscape. In MaxEnt density estimation, the true distribution of a landslide is shown as a probability distribution π over the set x of sites in the study area. Thus, π assigns a non-negative value to every site π , and the values $p(\pi)$ sum to 1. A random site x is chosen from the set x of sites and if there is a landslide x, 1 is recorded; if there is no landslide, then 0 is recorded. The response variable (presence or absence) can be denoted as y , so $\pi(x)$ is the conditional probability $P(x \mid y=1)$; i.e., the future occurrence of the observer being at x, given that the landslide is present. From Bayes' rule,

$$P(y=1 \mid x) = \frac{P(x \mid y=1)P(y=1)}{P(x)} = \pi(x)P(y=1) \mid X \mid \tag{6}$$

The quantity $P(y=1|1)$ is the probability that the landslide occurs at the site x. Equation (6) shows that π is proportional to the probability of presence. However, the landslide's prevalence cannot be determined by considering only the occurrence data (Phillips and Dudík 2008). Therefore, instead of estimating $P(y=1|x)$ directly, the distribution p can be estimated. The MaxEnt distribution belongs to the group of Gibbs' distributions, which is derived from the set of features $f_1, \cdots, f_n$. Gibbs distributions are exponential distributions parameterized by a vector of feature weights $\lambda = (\lambda_1, \cdots, \lambda_n)$ and can be defined by (Phillips and Dudik 2008):

$$q_\lambda(x) = \frac{\exp \Sigma_n^{j=1} \lambda_j f_j(x)}{Z_\lambda} \tag{7}$$

where Z_λ is a normalization constant assuming that the probabilities $q_\lambda(x)$ sum to 1 over the study area. Therefore, the value of the MaxEnt model q_λ at a site x relies only on the feature values at x, and hence only on the environmental variables at x.

The Maxent model was coupled with the GIS to map landslide susceptibility from low to high. In this study, the landslide susceptibility index was classified using the natural break algorithm in the GIS environment as presented in Figure 8:17.

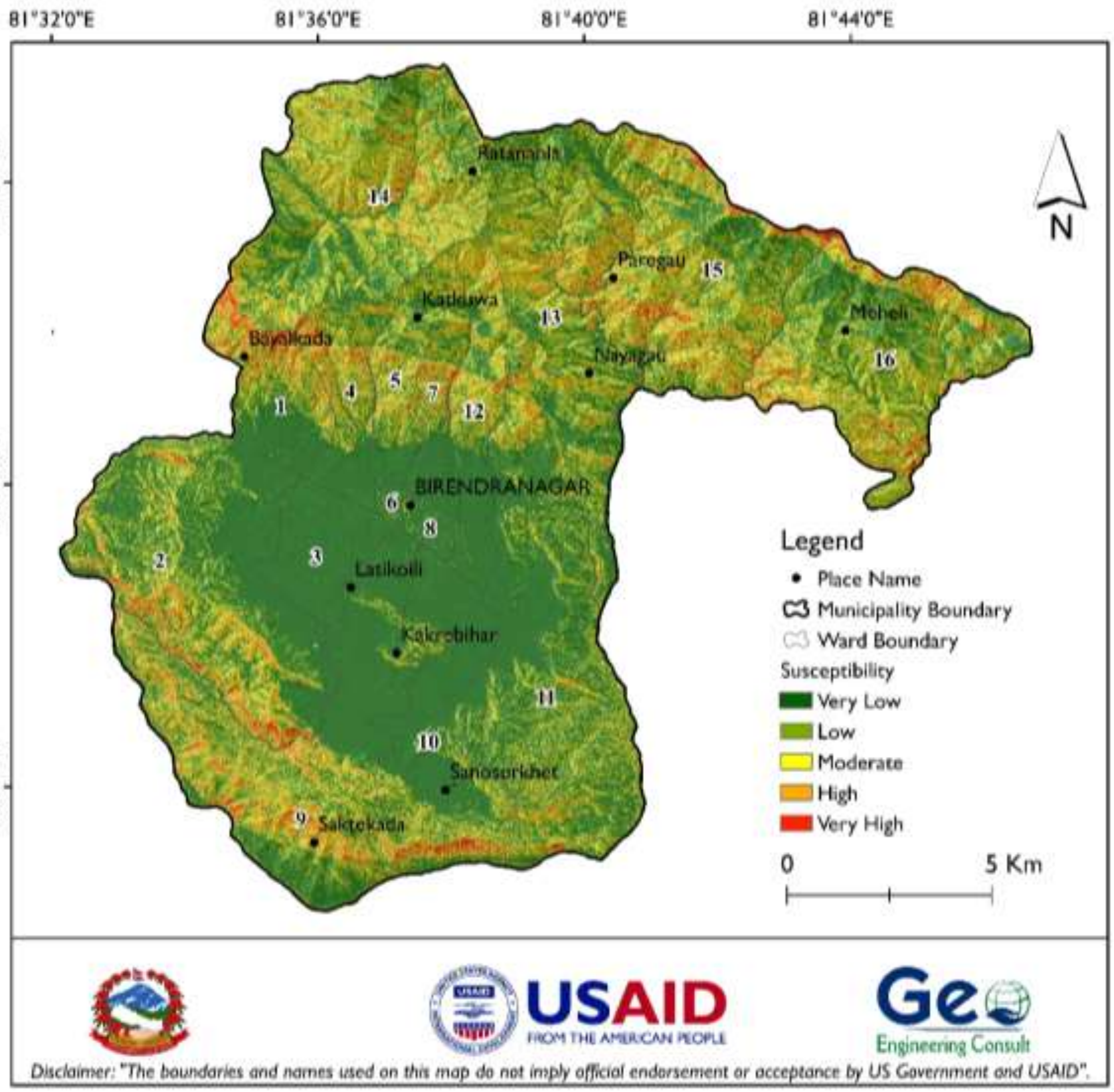


Figure 0:61 Landslide susceptibility distribution in Birendranagar Municipality.

The response curves were developed to show how each CF affects the MaxEnt prediction. The curves show how the predicted probability of presence changes as each environmental variable is varied, keeping all other CF at their average sample value. In other words, the curves show the marginal effect of changing exactly one variable, whereas the model may take advantage of sets of variables changing together. The logistic relationship between probable landslide occurrence and CF is shown in Figure 8:18.

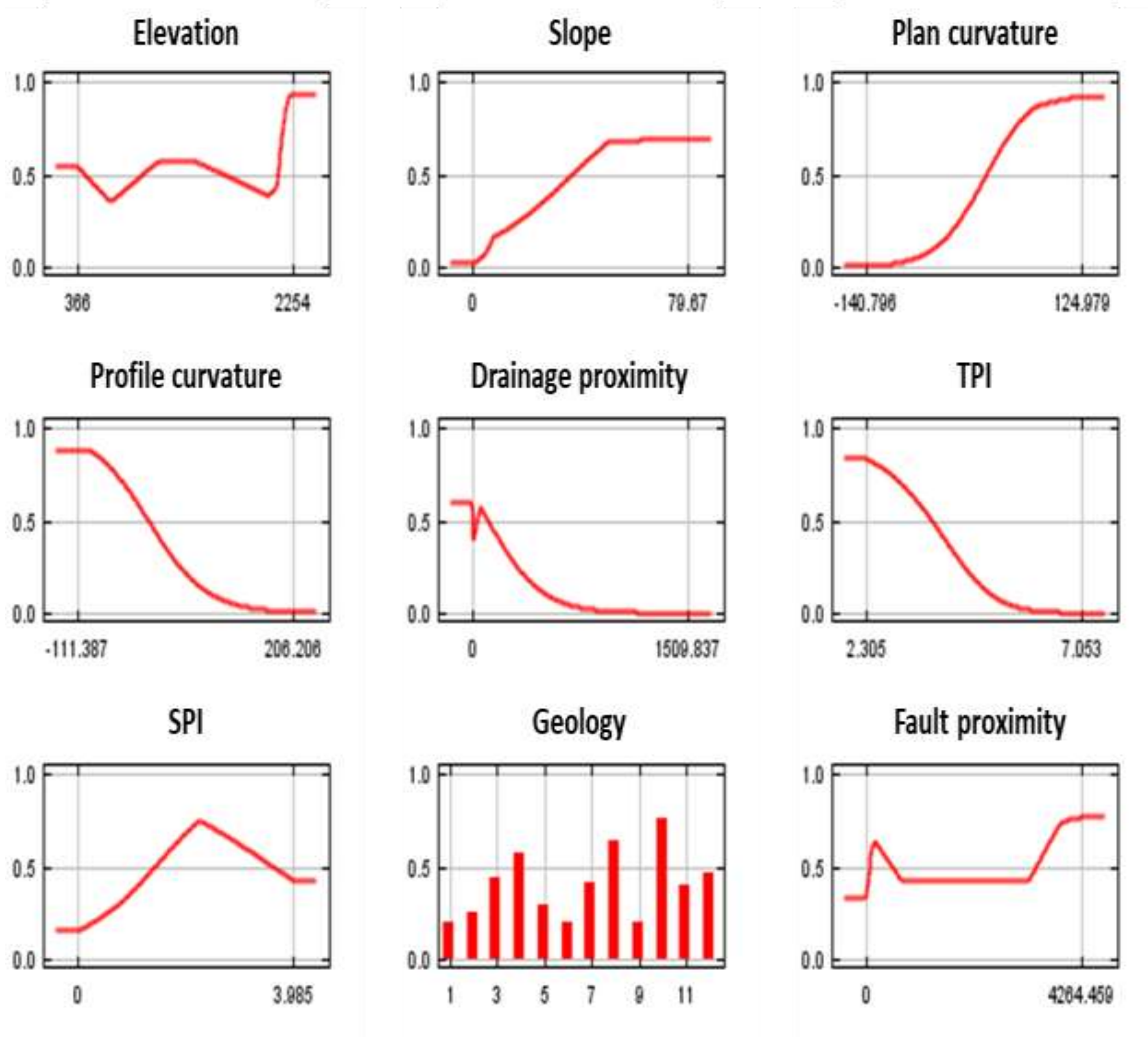


Figure 0:62 Response curves.

ASSESSMENT AND RESULT OF LANDSLIDE SUSCEPTIBILITY

There are different ways to validate a landslide susceptibility zonation map. Reliability of a landslide susceptibility model is always a difficult task. As landslide susceptibility maps predict future events, the best method to validate would be “wait and see” for the next landslide event and validate physically in the field. This is generally not considered a practical solution, which is rather a difficult and time-consuming job. Validation is a fundamental step in the development of a susceptibility map and in determining its prediction capability. A receiver operating characteristic curve (ROC) method was used to validate the result. The ROC curve is created by plotting the true positive rate (TPR) against the false positive rate (FPR) at various threshold settings. The true-positive rate is also known as sensitivity, recall, or probability of detection. The area under ROC curve showed 0.892 which means that the accuracy of the result is 89.2% as presented in Figure 8:19. The predictive rate is 87.6%.

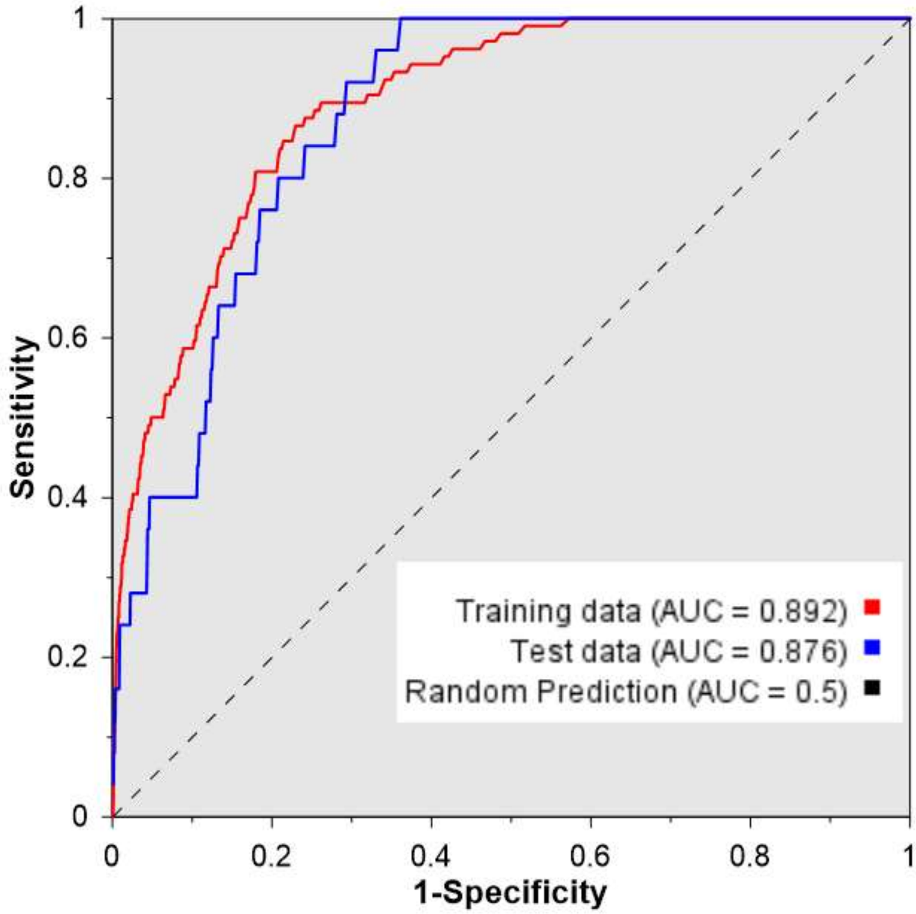


Figure 0:63 ROC curve for landslide susceptibility model validation.

A total of 46.82 % of the area was categorized as having a very low susceptibility, 25.36 % as low susceptible, 15.49% as moderate, 8.60% as high and the remaining 3.73 % were considered to have very high susceptibility. Analysis of the landslide distribution concerning the susceptibility classes was an important part of this study. About 69.77 % of landslide data were located in the high- or very-high-susceptibility class, demonstrating the reliability of the map. About 19.38 % of landslides were in areas having moderate susceptibility, 10.08 % were in low-susceptibility areas, and 0.78 % of the landslides fell within a very low class.

The MaxEnt method of determining landslide susceptibility does not identify the causes of landslides but only indicates the relationships between landslides and terrain properties. Nevertheless, such information may yield insight into landslide occurrences and pinpoint which terrain features are responsible or have an impact on landslides. However, in general, one must assume that landslide occurrence is determined by landslide-related factors and that future landslides will occur under the same conditions as past landslides.

The overlay analysis of landslide susceptibility classes and wards of Birendranagar Municipality was performed. The analysis shows ward numbers 15, 1, 4, and 16 12 are relatively vulnerable to landslide as shown in Table 8:4.

Table 0:17 Ward-wise landslide susceptibility distribution.

WARD NO	AREA PERCENTAGE				
	VERY LOW	LOW	MODERATE	HIGH	VERY HIGH
1	52.20	17.70	13.68	10.30	6.12
2	55.93	21.37	11.71	6.89	4.10
3	98.17	1.78	0.05	0.00	0.00
4	42.96	23.69	16.80	11.07	5.49
5	42.46	29.67	16.74	8.30	2.83
6	88.38	9.62	1.77	0.23	0.01
7	49.49	22.37	15.68	9.02	3.45
8	88.62	9.19	1.72	0.43	0.04
9	52.60	20.17	13.80	8.99	4.45
10	70.58	14.15	7.92	4.68	2.68
11	61.43	23.54	10.05	3.92	1.06
12	50.49	21.45	16.30	8.98	2.79
13	37.88	32.09	18.16	8.96	2.91
14	28.63	34.39	21.89	11.10	3.98
15	25.63	32.12	22.50	13.33	6.42
16	28.62	33.37	21.05	11.99	4.97

SEISMIC HILL SLOPE EVALUATION UNDER EXTREME RAINFALL CONDITIONS

The most suitable method for developing physically based models in GIS environments is the one-dimensional infinite slope model. It is the only model that can be calculated on a pixel-by-pixel basis. In this study, the pseudo-static infinite slope model was used that was proposed by Ambraseys and Menu

(1988) and later modified by Matasovic (1991) and Jibson (2011), defined in equation (8). The pseudo-static method for seismic slope stability analysis is based on assumptions about the limit equilibrium. Conceptually, once the FS_{ps} value drops below 1, a slope failure is likely to occur and is still the preferred method of practicing engineers:

$$FS_{ps} = \frac{c' + \left\{ \left(\gamma - \frac{h}{z}\gamma_w \right) z\cos^2\theta \right\} \tan\phi' - k_h \gamma z \sin\theta\cos\theta\tan\phi'}{\gamma z \sin\theta\cos\theta + k_h \gamma z \cos^2\theta}, \tag{8}$$

where c′ is the effective cohesion, φ′ is the effective friction angle, θ is the slope angle, γ is the unit weight of the soil, γ_w is the unit weight of water, z is the thickness of the soil, h/z is the saturation index, i.e., h is the saturated depth, and k_h is the horizontal seismic coefficient, which represents the horizontal inertial forces induced by the earthquake. It would be too conservative to use the peak ground acceleration (PGA) because the PGA lasts for a very short time and appears only once in the record. Therefore, instead of the PGA, a fraction of it was used, kh=ξ×PGA/g. Various researchers have proposed different values of ξ. Marcuson (1981) has suggested that ξ lies between 1/2 and 1/3 for the analysis of earth-fill dams. In this study, ξ =0.65 was used for landslide study as quoted and used by Taniguchi and Sasaki (1985).

The steady-state hydrological model was applied to estimate the saturated depth (h). According to Iida (1984), the saturated through flow in the soil layer follows Darcy's law and h can be calculated as:

$$h = \frac{R}{\mu}\left[t + \left(\frac{\varepsilon}{2} \right) V_s t^2 \right], \tag{9}$$

where *R* is the rainfall (mm), t is the time (d), V_s is the horizontal velocity component (m/d), ε is the curvature of a particular terrain cell (m−1), and μ is the effective porosity. V_s can be calculated in terms of the saturated hydraulic conductivity and effective porosity as follows:

$$V_s = \frac{k_s}{\mu} sin\theta\, cos\theta, \tag{10}$$

where k_s is the saturated hydraulic conductivity (m/d).

Rainfall data

To analyze the factor of safety, the maximum precipitation in one day was considered to be effective rainfall with the nearest rainfall station at Birendranagar airport. In total 35 years of data were used to calculate the return period of maximum one-day rainfall. The mean rainfall was found to be 125.937mm and the standard deviation was 66.55. Figure 8:20 presents the distribution of maximum 24 hr rainfall and Table 8:5 illustrates the rainfall calculations and Figure 8:21 depicts the relationship between precipitation and return periods.

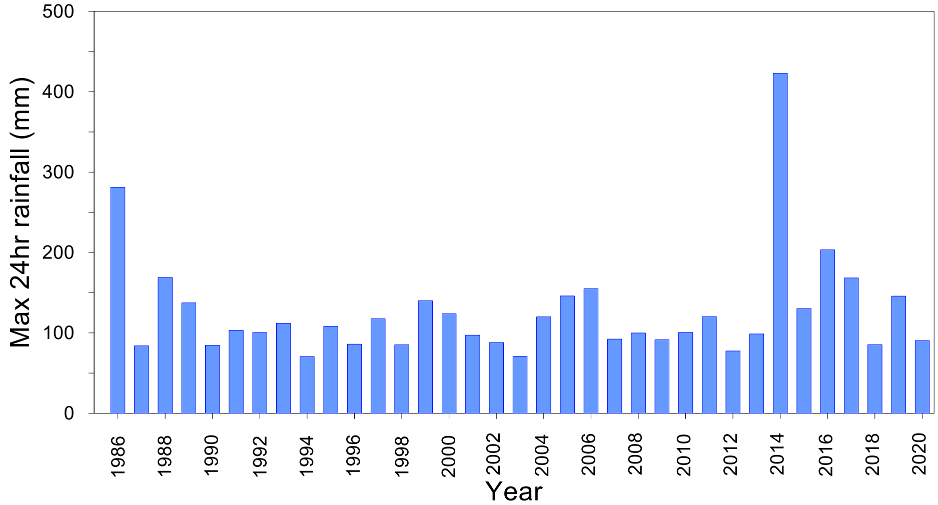


Figure 0:64 Max 24 hr rainfall from 1986 to 2020.

Table 0:18 Calculation of Max 24 hr rainfall return period.

RETURN PERIODS	REDUCED VARIATE	MAX 24 HRS RAINFALL (MM)	
T	YT=-ln(ln(T/(T-1)))	KT	XT
2	0.3665	-0.155	115.65
5	1.4999	0.845	182.17
10	2.2504	1.507	226.21
15	2.6738	1.880	251.06
20	2.9702	2.142	268.46
25	3.1985	2.343	281.86
30	3.3843	2.507	292.77
50	3.9019	2.963	323.15
100	4.6001	3.579	364.13
200	5.2958	4.193	404.95
500	6.2136	5.002	458.82
1000	6.9073	5.614	499.53

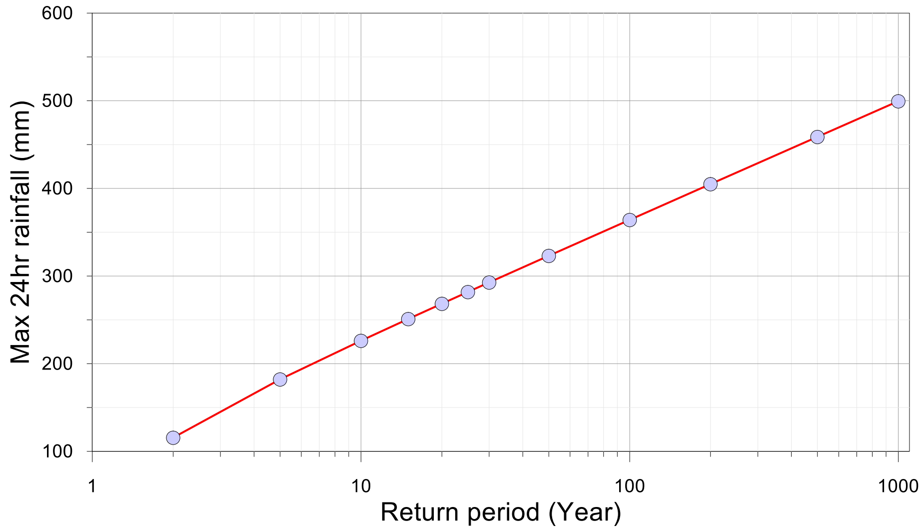


Figure 0:65 Relationship between rainfall return period and Max 24 hr rainfall.

The maximum one-day rainfall is 423.1 mm in the year 2014 and a minimum value of 70.6 mm was found in the year 1994. Return periods of 2-, 5-, 10- and 100-years were used for assessing the factor of safety. The return period of maximum one-day rainfall was calculated by Gumbel Type I Extreme distribution methods.

Soil parameters

Strength parameters of soil are required to be identified for the coupled hydrological and infinite slope stability model to calculate factors of safety. The main parameters are ϕ (internal friction angle), Υ_s (unit weight), Υ_{sat} (saturated unit weight), (effective porosity), and *k* (hydraulic conductivity). However, it is almost impossible to determine these values for every slope unit. Thus, parameter values were determined from field tests, laboratory tests, and various published sources as per Table 8:6.

Table 0:19 Geotechnical parameters used during Pseudo-static model.

PROPERTIES	AVERAGE VALUE
Cohesion	1 (kPa)
Internal frictional angle	28 °
Hydraulic Conductivity	0.00002 (m/s)
Unit weight	17.7 (KN/m3)
Assumed soil depth	3 (m)

Seismic data

The standard methodology of PSHA (Cornell 1968) has been used to obtain a probabilistic seismic hazard map of Birendranagar Municipality. Seven seismotectonic sources have been identified in Nepal and its periphery, and these are the main source of earthquakes that can cause severe damage in Birendranagar

Municipality. In this study, only peak ground acceleration (PGA) for a return period of 475 years has been used (Figure 8:22).

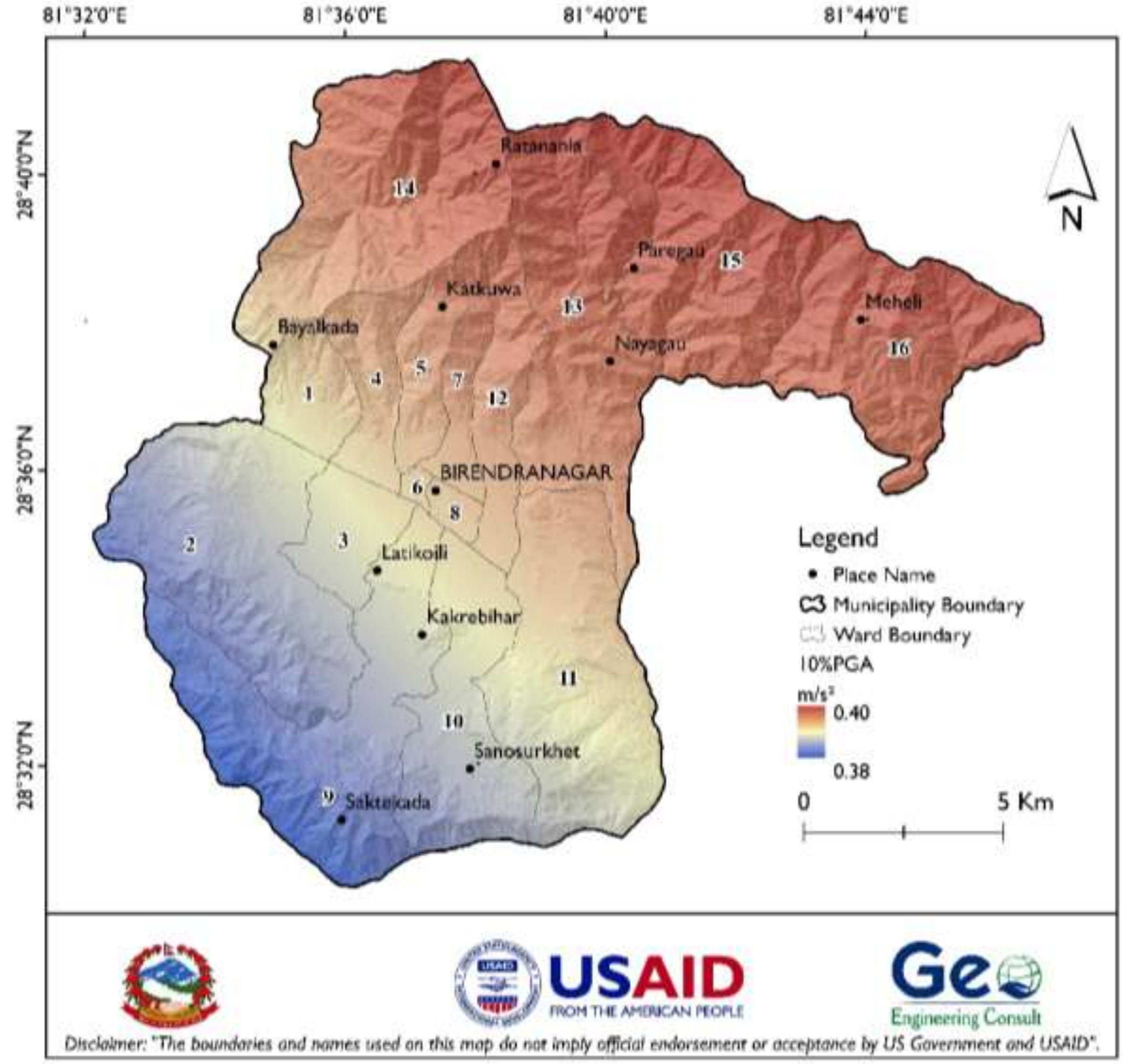


Figure 0:66 Seismic hazard map of Birendranagar Municipality at 10% probability of exceedance in 50 years (i.e. 475 year return period). Factor of safety calculation for different extreme rainfall.

A factor of safety refers to the required margin of safety for a hillslope. For the determination of factor safety, a script was developed using equations (9) & (10) to calculate the depth of saturation in different scenarios of rainfall which was used along with other strength parameters in equation (8). Here the value of factor of safety is classified into four groups FOS<1, 1<FOS<1.25, 1.25<FOS<1.5, and FOS>1.5.

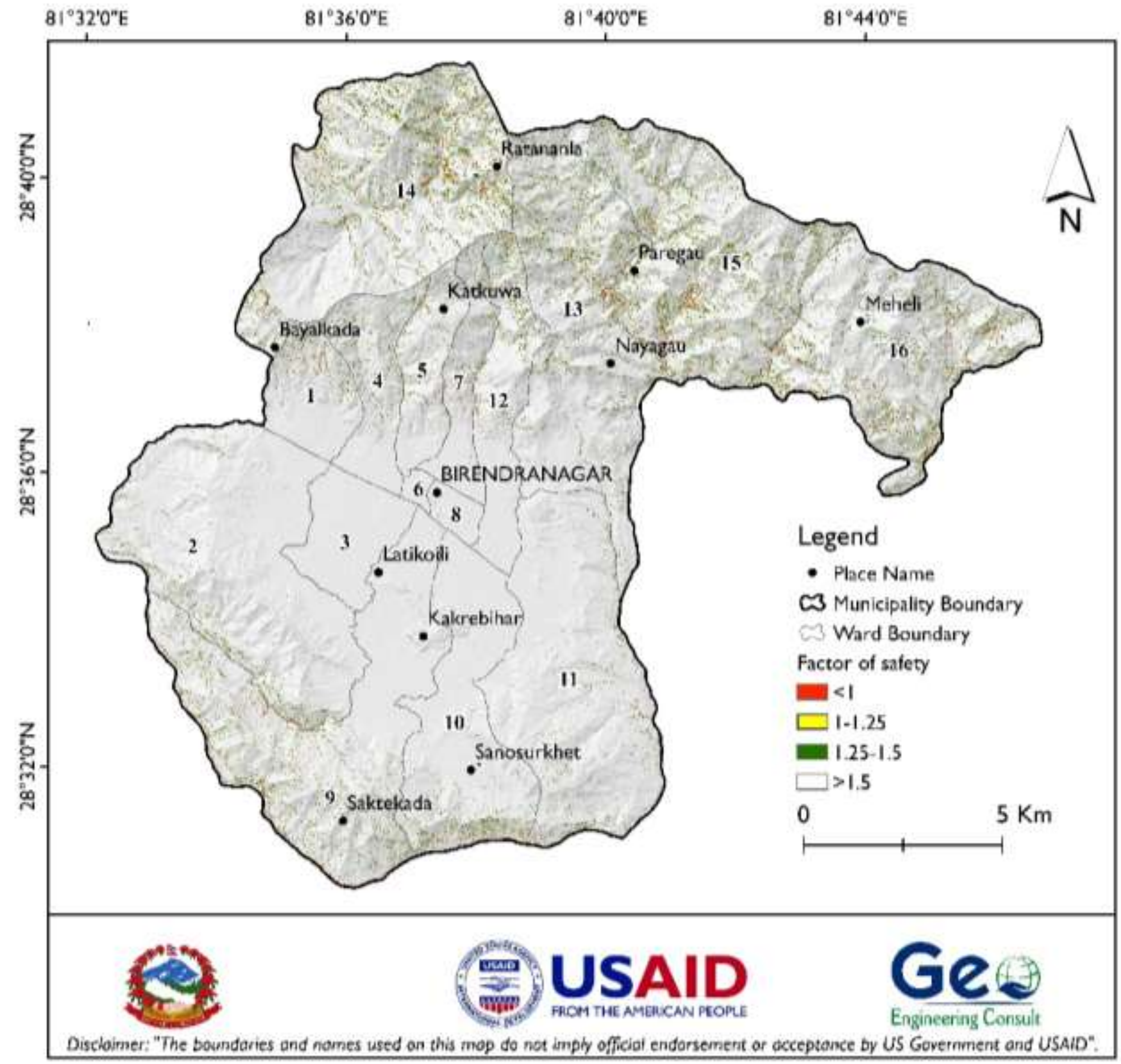


Figure 0:67 Factor of safety of 2 yr extreme rainfall and peak ground acceleration at 10% of exceedance in 5o years.

The area that has values less than 1 is prone to landslide failure and fatalities. The calculations were done for rainfalls of four return periods: 2, 5 10, and 100 year return periods and their maps are shown in Figure 8:23- Figure 8:27 below.

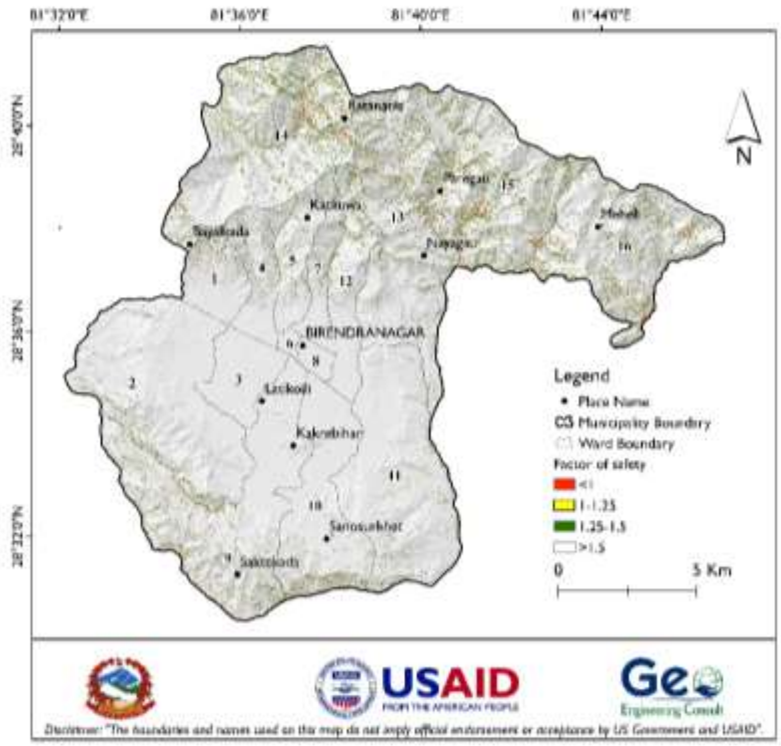


Figure 0:68 Factor of safety of 5-year extreme rainfall and peak ground acceleration at 10% of exceedance in 5o years.

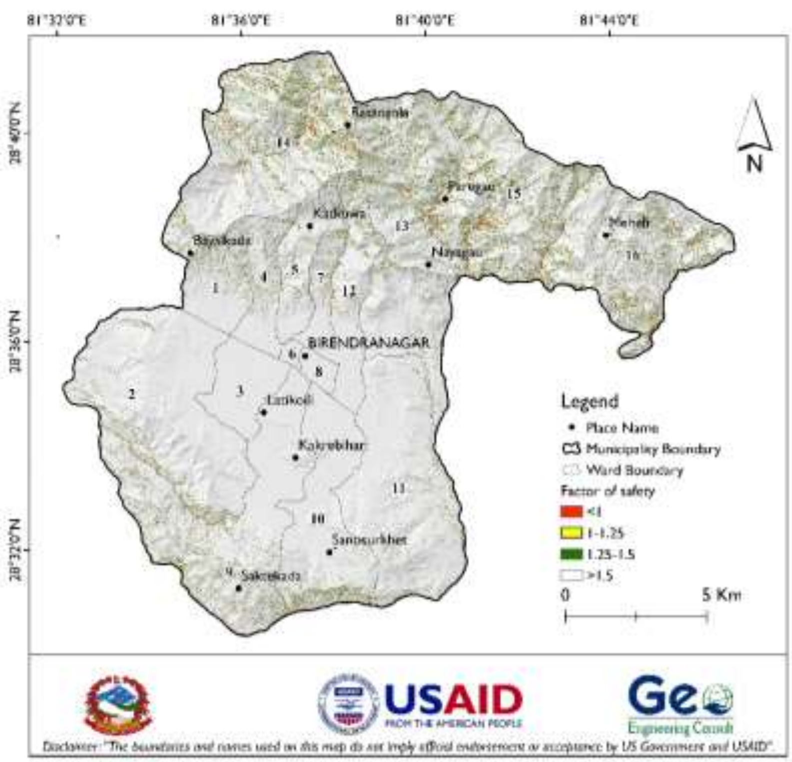


Figure 0:69 Factor of safety of 10-year extreme rainfall and peak ground acceleration at 10% of exceedance in 5o years.

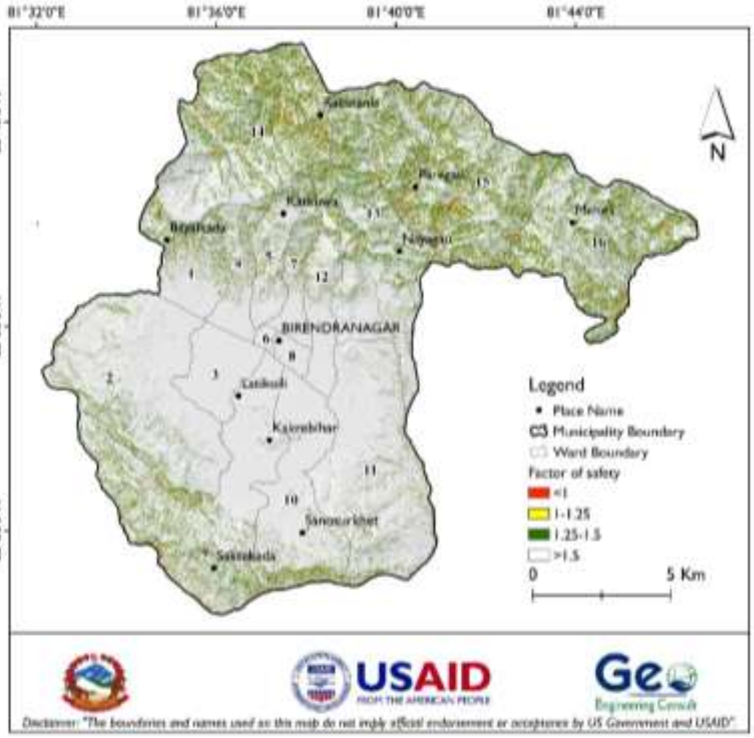


Figure 0:70 Factor of safety of 50-year extreme rainfall and peak ground acceleration at 10% of exceedance in 5o years.

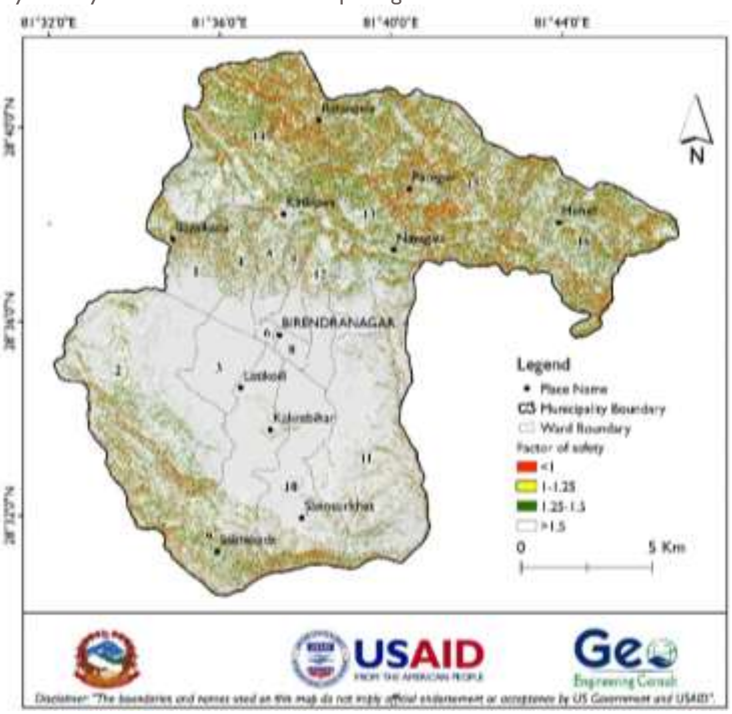


Figure 0:71 Factor of safety of 100-year extreme rainfall and peak ground acceleration at 10% of exceedance in 5o years.

Here, the percentage of areas that are prone to failure from landslides for a 2 year up to 100 year return period is shown in Figure 28. As the return period of rainfall increases, this percentage goes up as more portions of the land become vulnerable to landslides. The reason may be as this study is governed by a 1-

D infinite slope model and steady-state hydrological mode, which assumes all rainfall infiltrates into the soil and travels as subsurface flow. Thus more precipitation results in more subsurface flow that increases the risk of failure of slope. This phenomenon combined with the steeply sloping topography gives rise to fatal landslide events. If the percentage area falling under a particular factor of safety range is plotted against the factor of safety for rainfalls of different return periods, the following graph can be obtained showing the trend of increase in unstable area with rainfall of higher return periods.

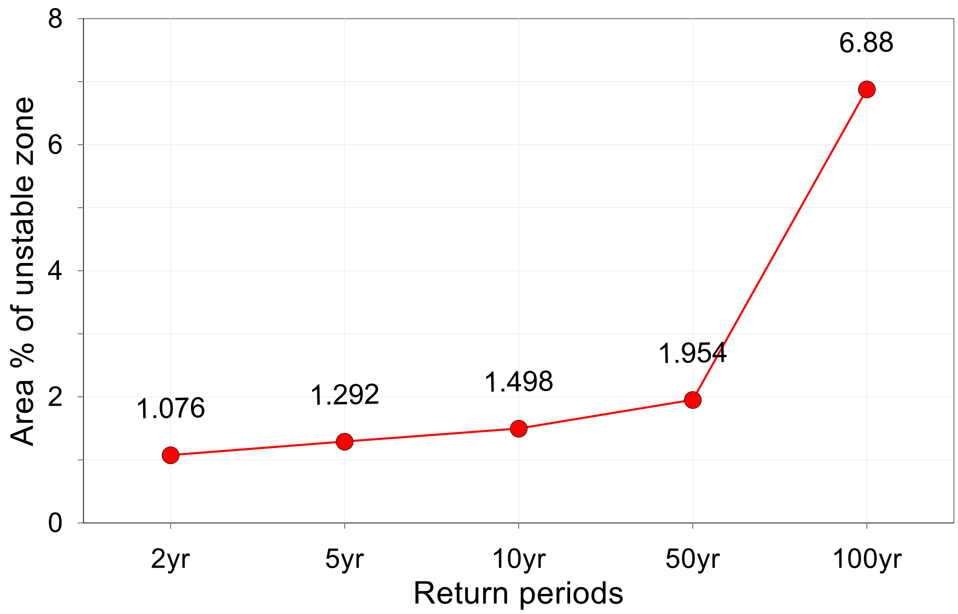


Figure 0:72 Area percentage of unstable zones in corresponding rainfall return periods.

The distribution of FS in the Birendranagar Municipality was done by overlay analysis between FS for 100 return period and ward boundary. The analysis shows that the unstable area (FS<1) is highly distributed in the wards containing hilly areas. Ward No. 15 is occupied by a 14.18% unstable area. Similarly, ward numbers 14 and 16 contain 12.43% and 11.20% unstable areas, respectively. The total distribution of FS is presented in Table 8:7.

Table 0:20 Ward-wise distribution of FS.

WARD NO.	AREA PERCENTAGE			
	FS<1	FS1-1.25	FS 1.25-1.5	FS>1.5
1	4.96	4.10	10.86	80.07
2	2.14	2.24	7.87	87.76
3	0.00	0.00	0.01	99.99
4	5.01	4.77	13.96	76.25
5	4.23	4.30	13.84	77.63

6	0	0.02	0.21	99.77
7	4.80	5.11	14.66	75.43
8	0.22	0.24	0.66	98.88
9	5.51	4.50	12.40	77.59
10	3.13	2.31	6.09	88.48
11	1.75	1.54	5.63	91.08
12	6.42	5.64	14.10	73.84
13	8.24	7.93	19.82	64.01
14	12.43	9.93	22.77	54.87
15	14.18	11.27	24.89	49.66
16	11.20	10.04	24.73	54.02

RUNOUT ZONATION

Topography, soil type, land use, debris volume, and the amount of interstitial fluids are essential parameters to estimate runout behavior. In this study, the probabilistic runout was calculated using a multiple-flow-direction algorithm which defines the propagation of flow from one cell to the surrounding and algorithms that determine the runout distance (Horton et al. 2008). Generally flow direction algorithms are classified into single-direction and multiple-direction. Single-direction algorithms are extensively used in hydrological flow analysis (Tesfa et al. 2009). Despite computational efficiency and extensive use, single-direction algorithms have been criticized for producing unrealistic straight and parallel flow paths because single-direction algorithms are restricted to flow from the steepest downslope. The multiple-flow-direction algorithms which spread flow on a partition basis over several neighboring downward slopes are more realistic. Holmgren (1994) modified the multiple-flow-direction algorithm adding a parameter as an exponent x allowing control over the spreading. For x = 1, the spreading is similar to the multiple-direction algorithms. As x increases, the divergence is reduced, resulting in a single flow direction when x $\rightarrow\infty$. Based on field measurement and laboratory experiments, Claessens et al. (2005) suggested a value of the exponent equal to 4 for mass flows. The modified multiple-direction algorithm (Holmgren 1994) is presented by the following equation:

$$p_i^{fd} = \frac{(\tan\beta_i)^x}{\sum_{j=1}^{8}(\tan\beta_j)^x}, \qquad (10)$$

Where *i* and *j* are the flow directions, p_i^{fd} is the susceptibility in direction *i*, tan β_i is the slope gradient between the central cell and the cell in direction *i*, and *x* is the variable exponent that controls the spreading.

The distance of reach was assessed based on simple energy-based calculation without considering source volume. This algorithm controls the runout distance and reduces lateral spreading. The kinetic energy E_{kin}^i of the cell in a direction i can be obtained using the following formula:

$$E_{kin}^i = E_{kin}^0 + \Delta E_{pot}^i - E_f^i , \qquad (11)$$

where E_{kin}^0 is the kinetic energy of the central cell, ΔE_{pot}^i is the change in potential energy, and E_f^i is the constant loss of energy. To estimate the energy loss, a constant friction loss angle, angle of reach, concept (Corominas 1996) is added. The angle of reach is an imaginary line connecting the source area and the endpoint of the flow. The runout susceptibility map was prepared using the open-source software Flow-R, which has been developed at the University of Lausanne (Harton et al. 2008).

Flow-R provides a variety of algorithms to analyze debris flow. Spreading algorithms control the path and the spreading of debris flow. Friction law determines the runout distance. The parameters for simulating Flow-R have to be calibrated and verified using actual data. But such a data set is not provided in Nepal Himalaya. So this study has no choice but to use the reference values from previous researches as shown in Table 8:8.

Table 0:21 Implemented travel angles for spreading**.**

RESEARCHES	TRAVEL ANGLE	REMARKS	COUNTRY
Haeberli (1983)	~11°	Glacier floods	Swiss
Rickenmann and Zimmermann (1993)	~11°		Swiss
Zimmermann et al. (1999)	7°~11°	Grained distribution	Swiss
Prochaskaet al. (2008)	~6.5°		USA, Canada, Australia
Bathurst et al. (1997)	11°		Japan
Huggelet al. (2002)	~11°		Canada and Swiss
Lariet al. (2011)	5°~11°	Water content	Italy

In this study, an angle of reach has chosen as 11° as suggested by Rickenmann and Zimmermann (1993).

The Flow-R simulation model was used to estimate probable runout propagation assessment. The runout distance assessment is based on simple frictional laws; as the source mass is unknown, the energy balance is unitary. The processing takes place at the cell level and controls which other cells the flow would be able to reach. Thus, these algorithms control the runout distance and, in addition, may reduce lateral spreading (when a cell on the border of the spreading cannot be reached because of insufficient energy).

The simplified friction-limited model is based on the maximum possible runout distance, which is characterized by a minimum travel angle, also named the angle of reach. It is the angle of the line connecting the source area to the most distant point reached by the debris flow, along its path:

$$E_i^f = g\Delta x \tan\varphi, \quad (12)$$

where E_f^i is the energy lost in friction from the central cell to the cell in direction i, Δ x the increment of horizontal displacement, $\tan\varphi$ the gradient of the energy line, and *g* the acceleration due to gravity.

A selection criterion was made to consider the landslide source area. For this, a combination of 80% probability of occurrence landslide from landslide susceptibility map and the hillslope area which has a factor of safety less than 1 has selected as highly vulnerable hillslope condition as illustrated in Figure 8.31.

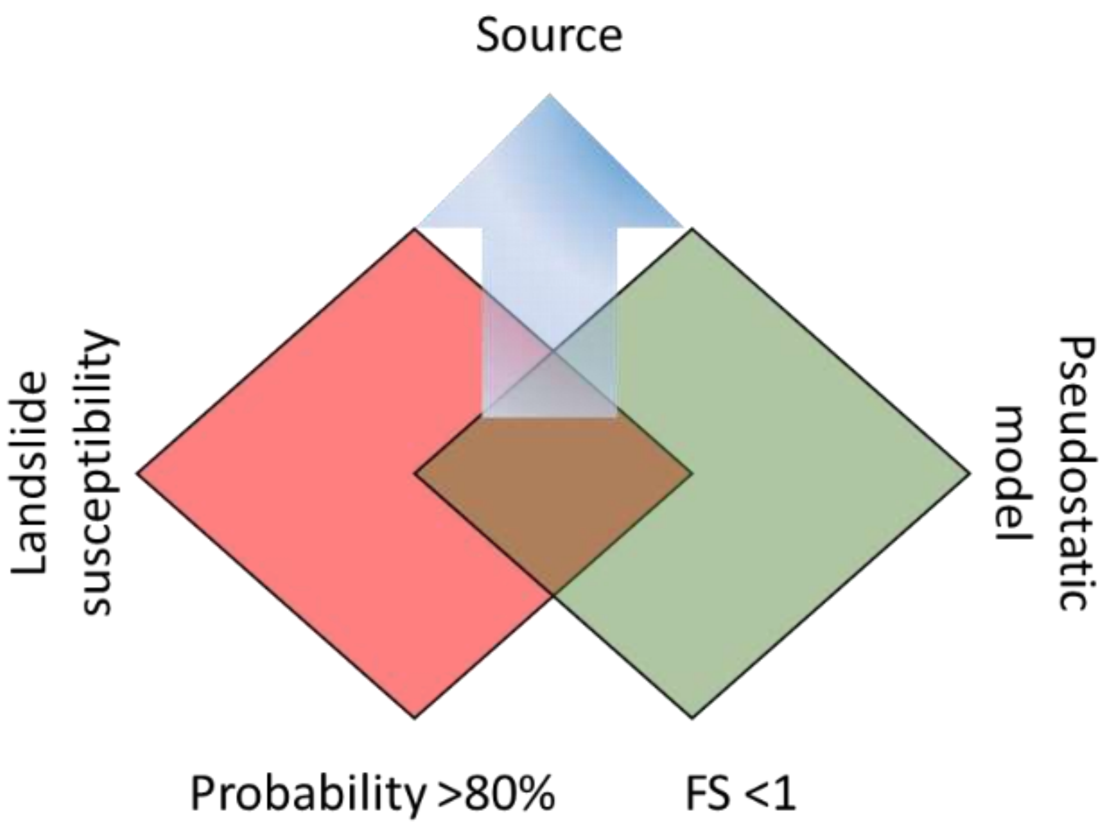


Figure 0:73 Runout source selection criteria.

Thus selected source area was subjected to runout simulation for different rainfall return periods. The propagated probable runout zones are presented in Figures 8:30-8:34.

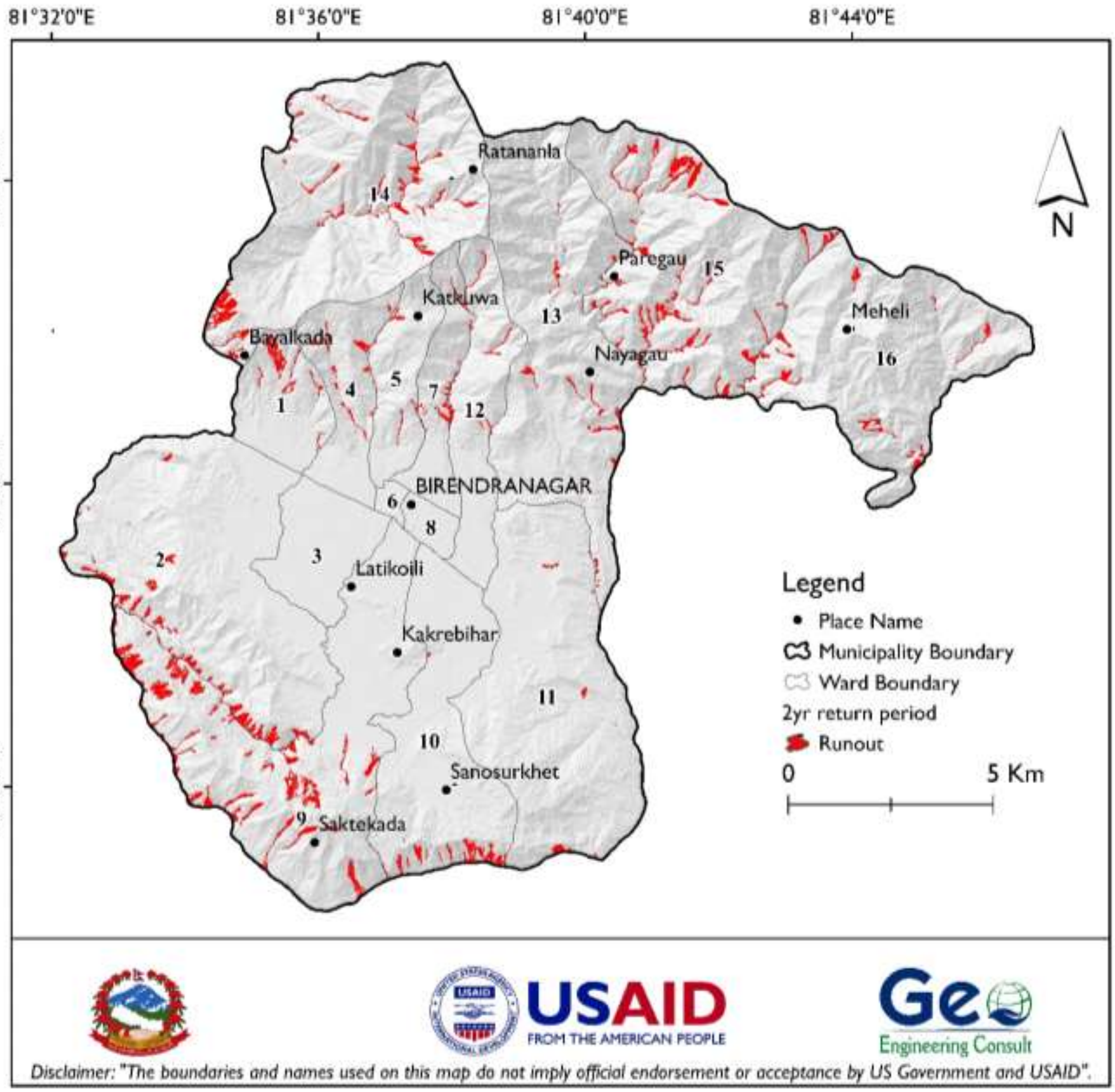


Figure 0:74 Simulated propagation zone for rainfall 2 year return period.

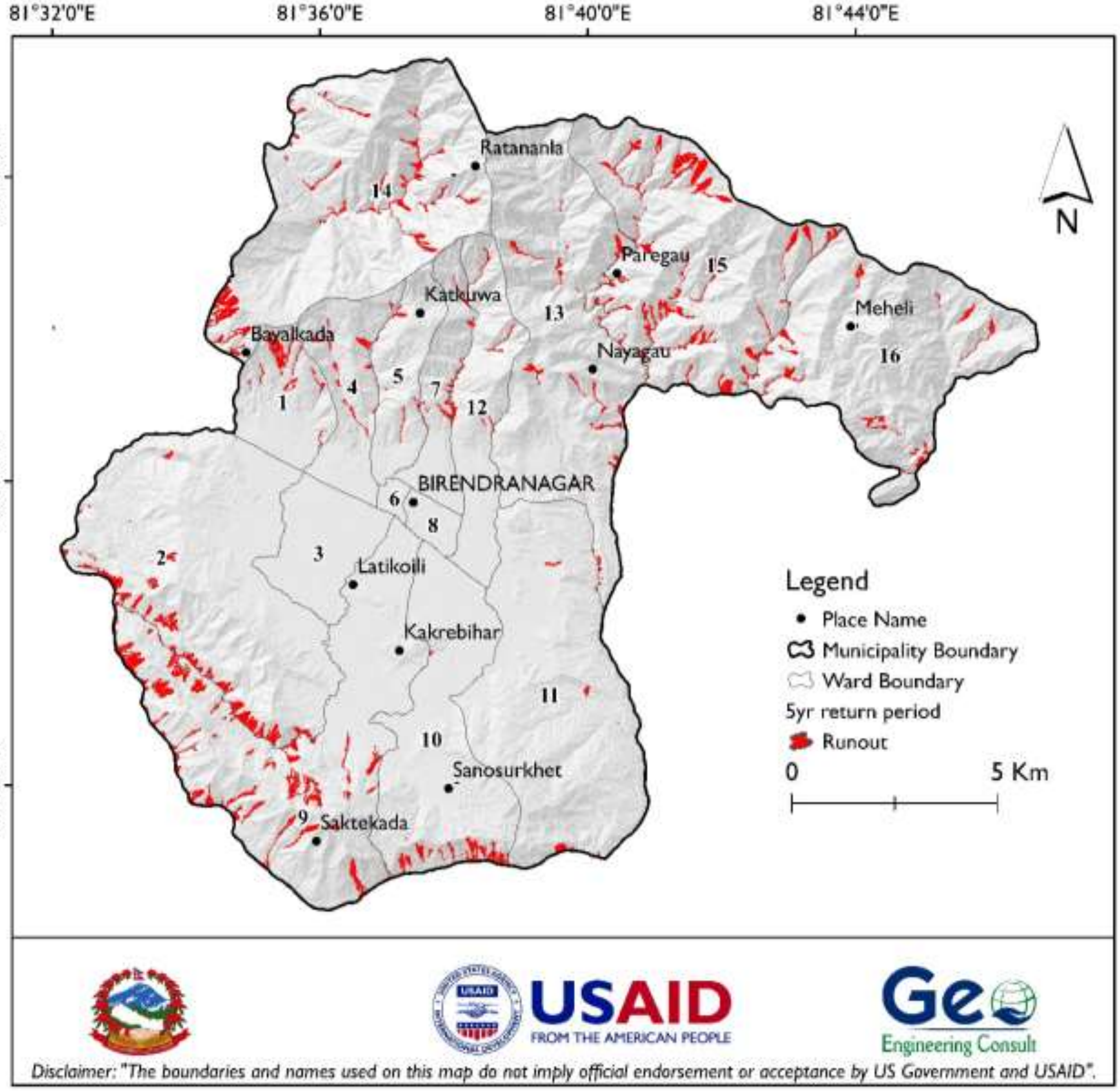


Figure 0:75 Simulated propagation zone for rainfall 5yr return period.

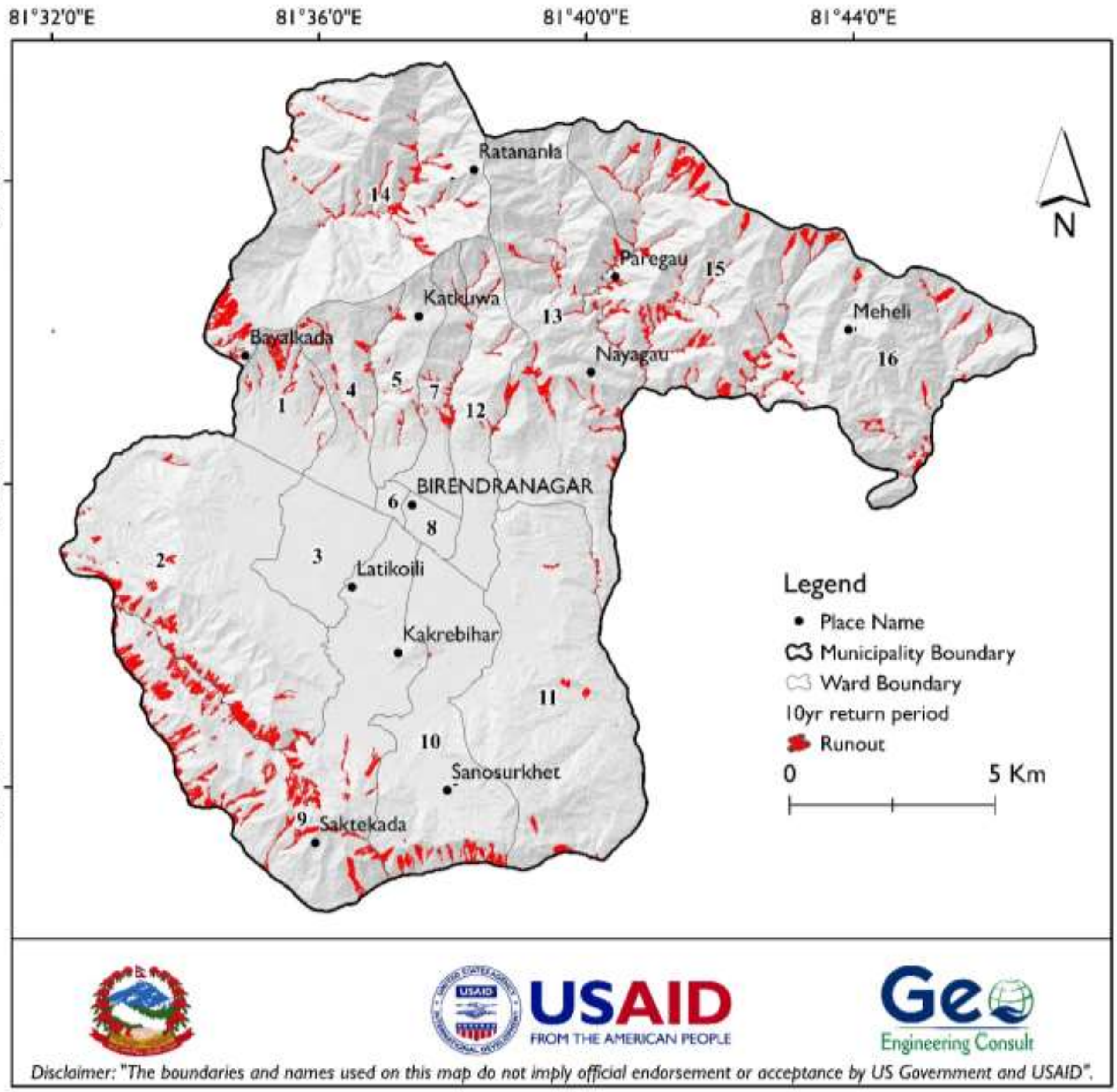


Figure 0:76 Simulated propagation zone for rainfall 10yr return period.

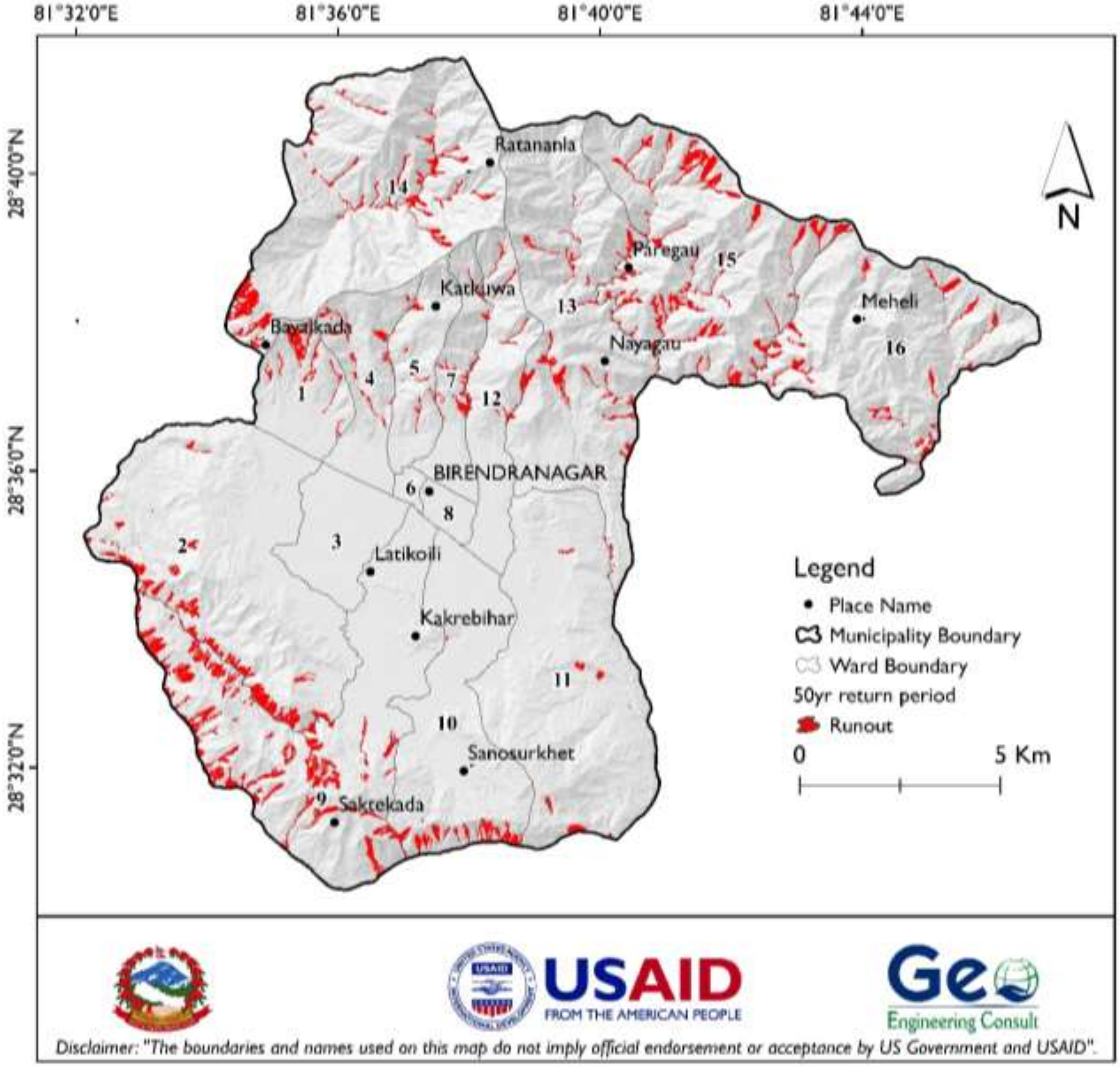


Figure 0:77 Simulated propagation zone for rainfall 50yr return period.

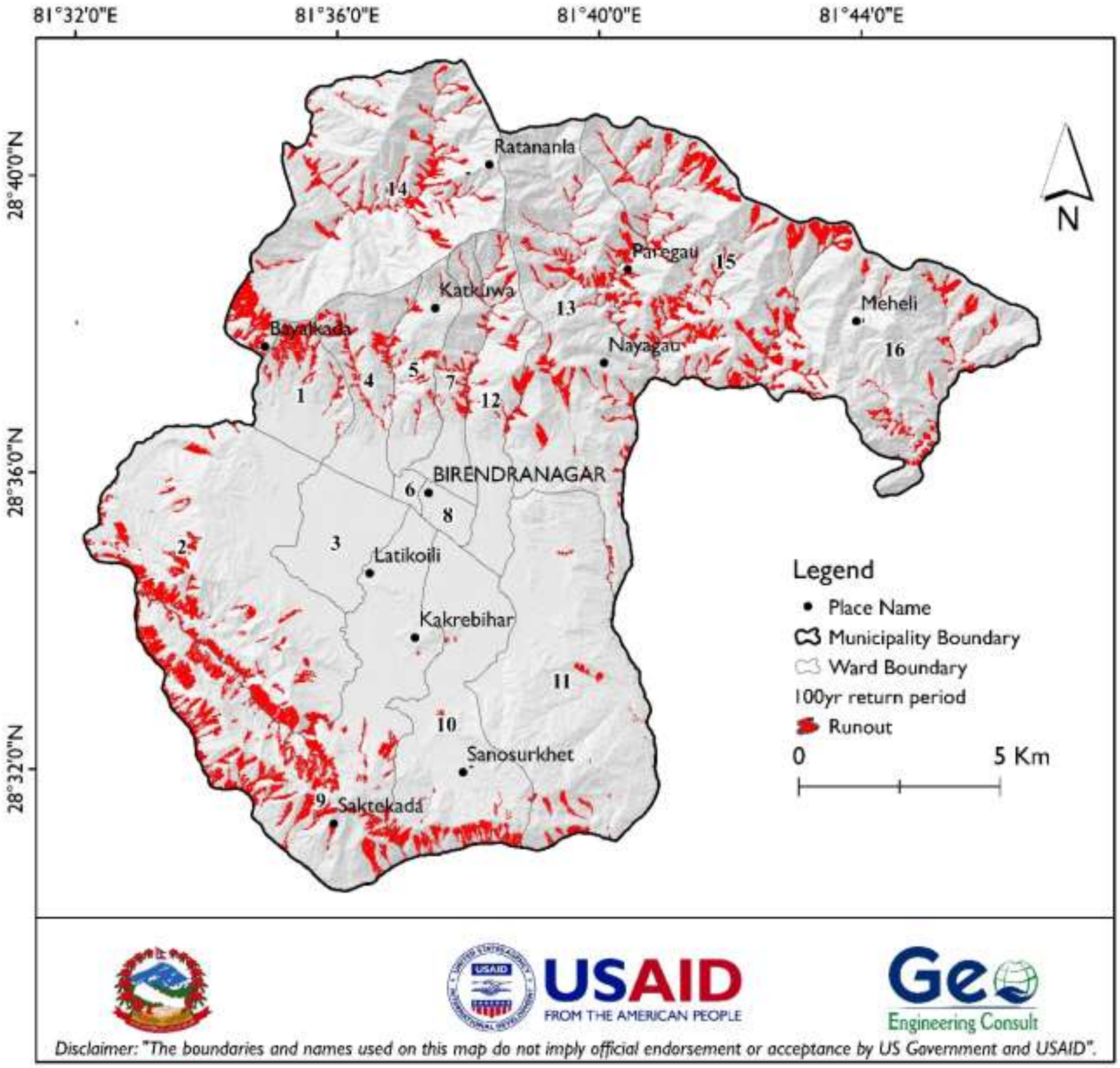


Figure 0:78 Simulated propagation zone for rainfall 100yr return period.

Flow-like landslides, such as debris flows travel at extremely rapid velocities and can impact large areas far from their source. When hazards like these are identified, runout analyses are often needed to delineate potential inundation areas. The ward-wise frequency ratio analysis of shows ward no 9 is the highest vulnerable in terms of runout followed by ward no 15. Tables 8:9 represents the ward-wise frequency analysis of the runout zone. Ward no 3, 6 and 8 are free from any runouts.

Table 0:22 Implemented travel angles for spreading.

WARD NO.	AREA OF WARD (M^2)	AREA OF RUNOUT ZONE (M^2)	FREQUENCY RATIO
1	6094673.471	804112.3325	0.132
2	29111718.76	2816381.421	0.097
3	6606783.56	0	0
4	7044113.268	688488.9587	0.098
5	5764868.601	407526.2534	0.071
6	590206.1297	0	0
7	5237714.309	383115.3947	0.073
8	1408739.705	0	0
9	28782426.57	5002780.034	0.174
10	16982019.77	1044891.301	0.062
11	26664754.56	510002.3915	0.019
12	8808474.578	616340.8868	0.070
13	25865606.42	2134818.069	0.083
14	28924526.1	2908754.546	0.101
15	24583412.14	4149579.615	0.169
16	22207852.84	1879445.858	0.085

MULTI-HAZARD PROBABILITY ASSESSMENT

Nepal is exposed to a variety of natural hazards that cause disastrous damage to the built environment and result in the loss of lives and properties. The most destructive natural hazards in Nepal are floods, landslides, debris flow and earthquakes. Young and fragile geology, very high relief, steep slopes, variable climatic conditions, and active tectonics trigger several natural hazards in Nepal every year. Furthermore, marginally planned and overpopulated settlements are the major factors that aggravate the impacts of disaster. Nepal lies in the 20th, 4th, 11th, and 30th rank worldwide in terms of multi-hazards, climate change-related hazards, earthquakes, and flood risks, respectively, as depicted by the 2004 study (UNDP 2004). Most of the studies are limited to a single natural hazard, variance in methodology, and study area coverage, which restrict decision-makers from determining areas susceptible to multiple hazards and from taking initiatives. Although the multi-hazard occurrence is well supported by historical scenarios, multi-hazard risk studies are limited in Nepal.

Hazard maps for different natural processes usually differ in definition/detail of hazard, Spatio-temporal scales of the processes, and handling/integration of epistemic and aleatory uncertainties. Such maps are challenging to incorporate in policymaking, preparedness initiatives, and resource allocation efforts. In reality, natural hazards are complex processes and have cascading, triggering, knock-on, and domino effects. Risk mitigation and planning for such complex processes requires holistic treatment of different hazards and their interactions, i.e., multi-hazard assessment. Therefore, a multi-hazard assessment is an effective tool in disaster and risk reduction, which depicts the coverage of potentially hazardous areas considering overall hazards.

Methods such as heuristic and Multi-Criteria Decision Analysis (MCA), statistical methods, deterministic methods, probabilistic methods, and artificial intelligence have been employed in hazard assessments in published literature. The MCA can be implemented in frameworks such as the analytical hierarchy process (AHP), fuzzy logic, and weight overlay method. The AHP is one of the most popular MCA approaches. The AHP comprises problem definition, goals, alternatives determination, and formulation of pair-wise comparison matrix, weight determination, and finding an overall priority. It can be applied in absolute or relative measurements (experience and ability to judge observations) of connection between influencing factors and hazards that do not need a historical database and are simply based on the judgment of relative significance of each parameter class. However, the major demerits of this technique lie in its subjectivity in assigning weight and ratings for the parameter classes and lack of uncertainty estimation. Thus, the AHP method is effectively usedin scenarios. This term was first presented internationally in the context of sustainable development.

The study performs multi-hazard risk assessment and maps the same for Birendranagar Municipality by optimizing the existing AHP method. This is achieved by integrating the AHP with a geographic information system (GIS). The blending of the AHP in GIS enhances the decision-making process with better illustration and mapping capabilities to facilitate the development of hazard maps. Such mapping helps to identify the highly susceptible areas for single hazard as well as multi-hazards that can play a significant role to address disaster risk reduction and also provide a guide for policymakers.

Modeling approach

Spatial multi-criteria evaluation (SMCE) is a technique that assists stakeholders to make decisions concerning a particular goal (in this case multi-hazard). The input is a set of maps that are spatial representations of the criteria, which are grouped, standardized, and weighted in a criteria tree. The theoretical background for SMCE is based on the analytic hierarchical process (AHP) developed by Saaty (1980), which is used to determine the weight of each criterion and analyze the relative importance of the criteria. SMCE can be defined as a decision aid and mathematical tool allowing the comparison of different alternatives according to many criteria, often conflicting, to guide decision-makers toward a judicious choice. To determine relative weights, AHP is used to compare factors using a scale (intensity of importance) from 1 to 9 if the factors have a direct relationship and a scale from 1/2 to 1/9 if the factors have an inverse relationship(Saaty 1977). Another appealing feature of the AHP is its ability to evaluate pairwise rating inconsistency. Saaty (2000) proved that for a consistent reciprocal matrix, the largest eigenvalue λMax is equal to the number of comparisons n. A measure of consistency, called the consistency index (CI), is defined as follows:

$$CI = \lambda Max / n - 1 \qquad (13)$$

where CI gives information about logical consistency among pairwise comparison judgments in a perfect pairwise comparison case. When CI = 0, there is no logical inconsistency among the pairwise comparison judgments or the judgment is considered 100% consistent. Saaty (2000) also randomly generated reciprocal matrices using the scales 1/9, 1/8,…, 1,… 8, 9 to evaluate a random consistency index (RI): Table 5 lists the standard values of RI.

Saaty (1977) introduced a consistency ratio (CR), which is a comparison between the consistency index and the RI:

$$CR = CI / RI, \tag{14}$$

where RI is a random index and depends on the order of the matrix. If the threshold of CR is achieved (CR < 0.1), the weights of each row of the matrices are calculated. The illustration of the modelling approach is presented in Figure 37.

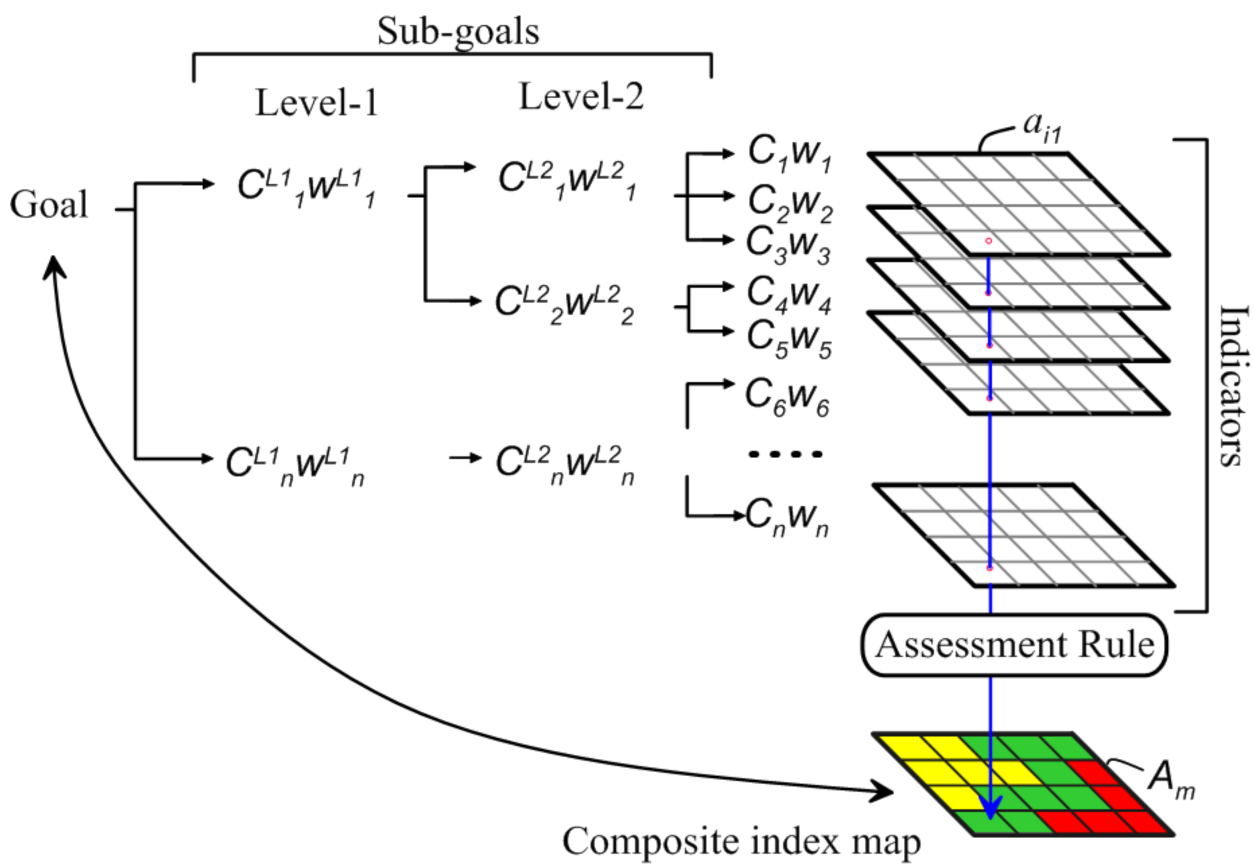


Figure 0:79 Modeling approach of SMCE.

Hazard parameters

A Multi-hazard map was produced with the help of three hazard maps (i.e. earthquake, flood, and landslide and runout hazard). For the multi-hazard assessment, seismic hazard map of the municipality at 10% probability of exceedence for 50 years at bedrock level, flood hazard assessments for 2, 5, 10, 50, 100 and

500 yrs return period and landslide hazard and runout assessments are integrated following SMCE approach.

Results

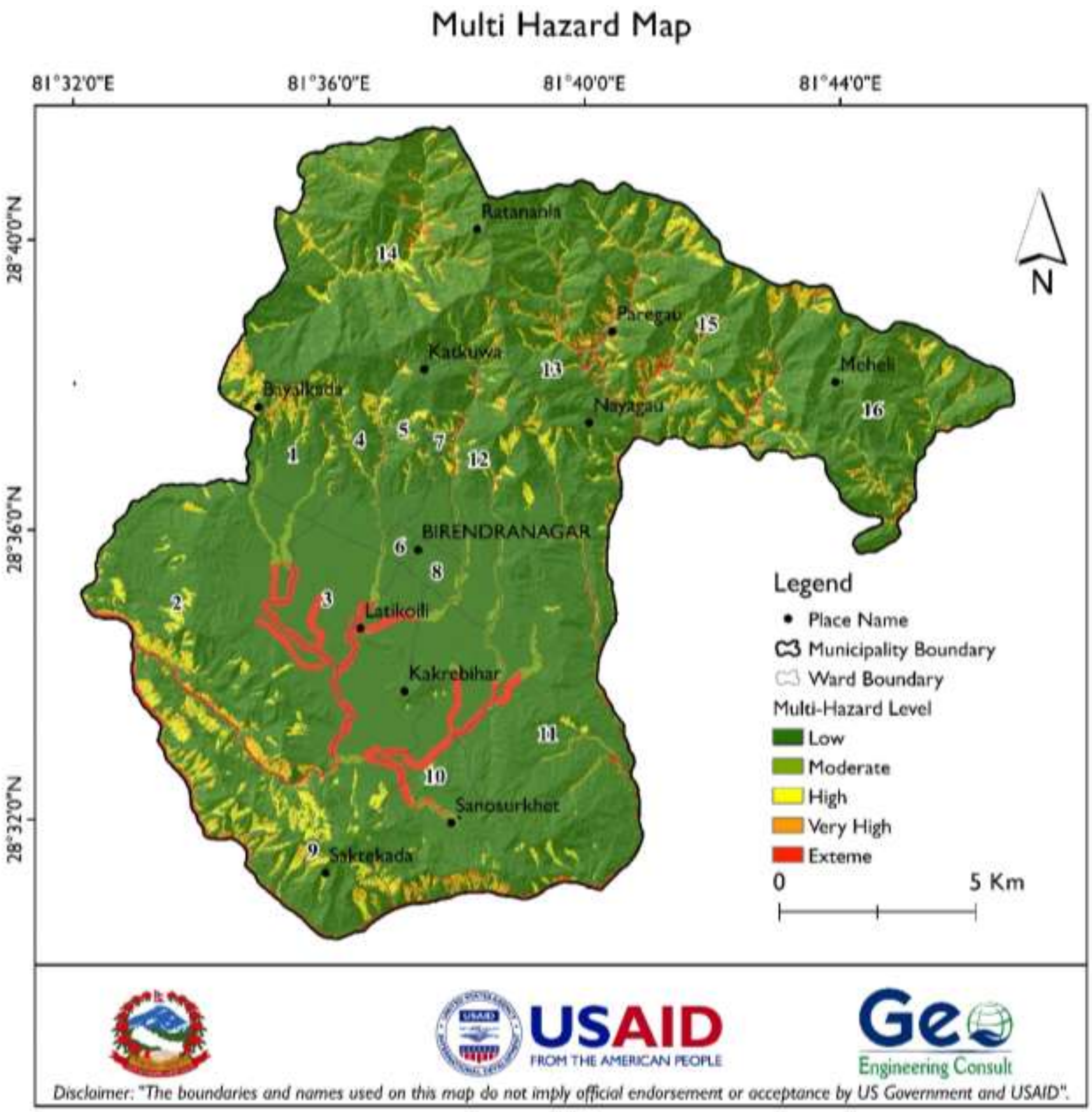


Figure 0:80 Multi-hazard map of Birendranagar Muncipality.

The different hazard maps were integrated using SMCE. The integrated values were classified into five classes namely Low, Moderate, High, Very High and Extreme integrated hazards as shown in Figure 44.

Among 16 wards, Ward No-3 is occupied by14.47% extreme integrated hazard as shown in Figure 45 and Table 10.

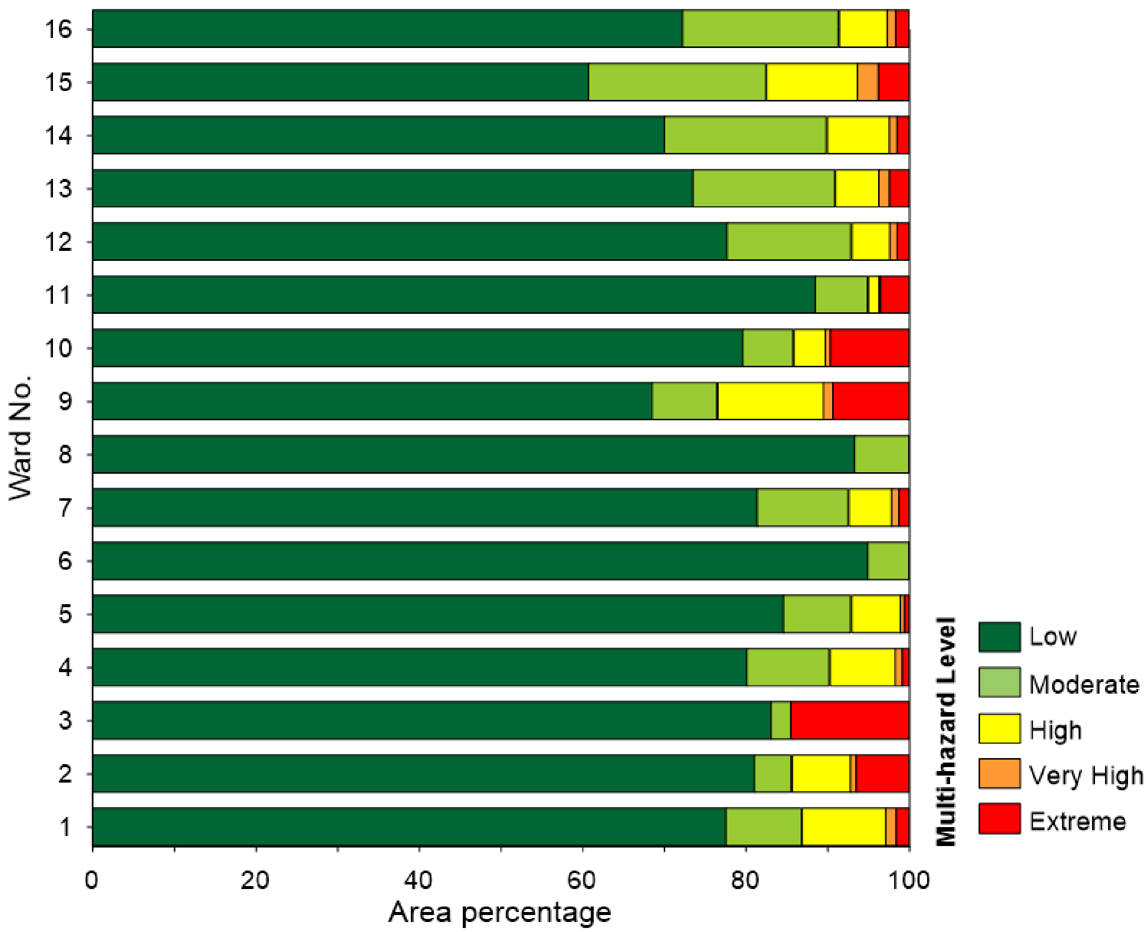


Figure 0:81Word-wise multi-hazard distribution of Birendranagar municipality.

Densely populated settlements, old settlements and the central part of the valley depict the extreme level of multi-hazard risk. These areas are consistently characterized by high flood hazards. The eastern, southern, and northern parts and surrounding mountains of the study area comprise very low to the extreme of multi-hazard level because these regions are dominated by moderate to a high level of landslide and runout hazards, seismic hazards have very low and low susceptibility, in the southern part and slightly higher in the northern part, respectively.

Table 23 Ward-wise area distribution of hazard level.

WARD NO.	HAZARD AREA PERCENTAGE				
	LOW	MODERATE	HIGH	VERY HIGH	EXTREME
1	77.57	9.21	10.31	1.32	1.58
2	81.07	4.51	7.21	0.69	6.52
3	83.12	2.41	0.00	0.00	14.47
4	80.15	10.07	8.03	0.89	0.87
5	84.61	8.26	6.02	0.50	0.62
6	94.93	5.07	0.00	0.00	0.00
7	81.42	11.12	5.24	0.96	1.26
8	93.31	6.69	0.00	0.00	0.00

9	68.55	7.91	13.00	1.15	9.38
10	79.65	6.16	3.89	0.65	9.65
11	88.52	6.36	1.37	0.22	3.52
12	77.71	15.18	4.69	0.94	1.48
13	73.52	17.37	5.33	1.35	2.42
14	70.05	19.83	7.65	0.97	1.49
15	60.76	21.71	11.14	2.61	3.78
16	72.26	19.09	5.92	1.07	1.66

Multi-hazard interaction

Some issues cause major challenges in multi-hazard analysis such as differences in characteristics of the hazard, inter-relationship of hazard that causes triggering and cascading effects, natural processes that employ heterogeneous impacts on elements at risk, and methods to describe vulnerability that varies between hazards.

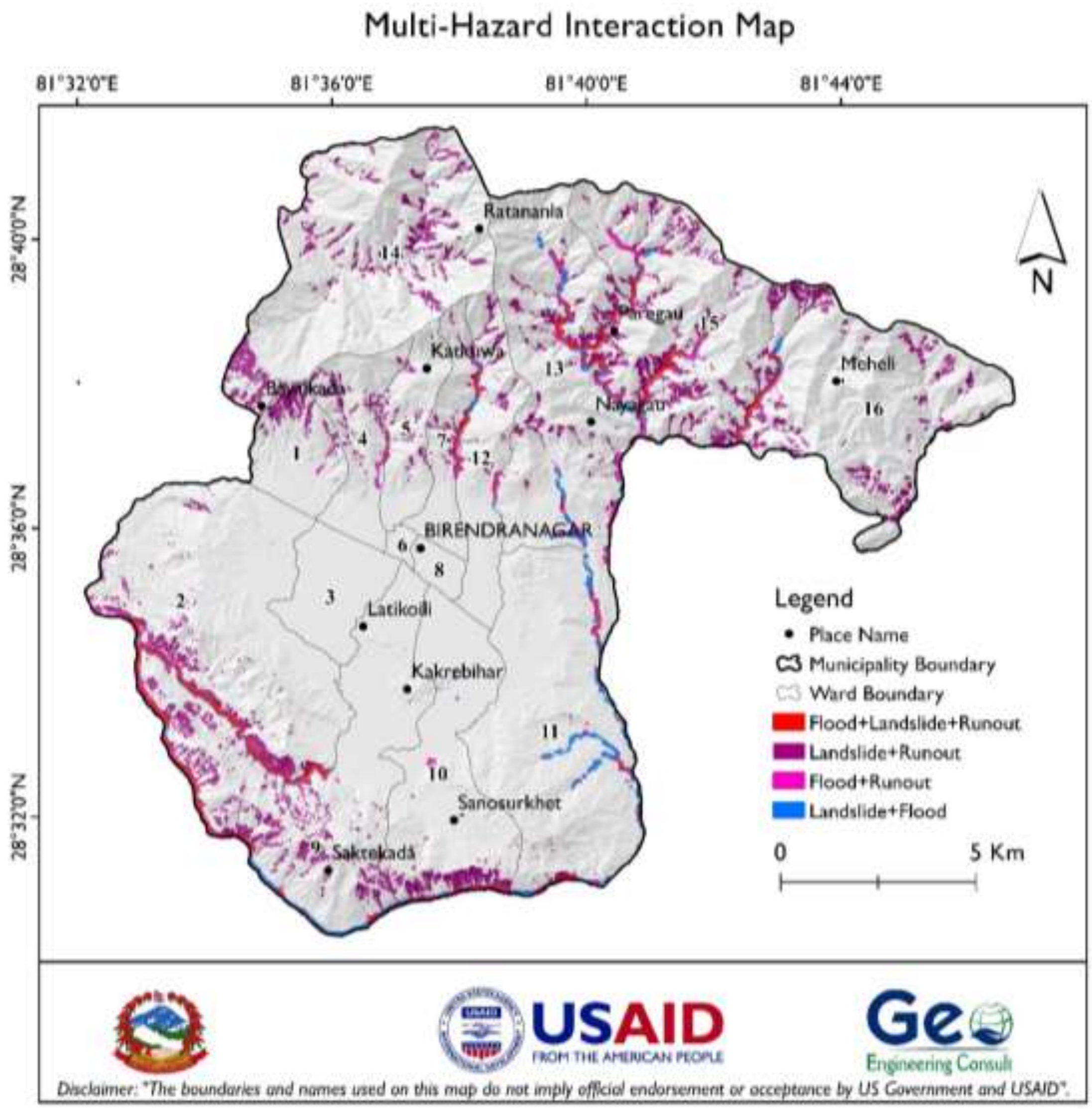


Figure 0:82 Multi-hazard map of Birendranagar Municipality.

Sometimes, the superposition of different hazard maps to produce a multi-hazard map may not be exhaustively representative. Since these hazards arise from landscape characteristics common to all four individual models, areas of high multi-hazard susceptibility can be determined by the overlap of multiple individual hazard. Multi-hazard environments differ from single-hazard environments by the mechanistic connections between hazards, where one hazard cascades from or compounds the effects of another.

To complement the models of hazard distribution, a multi-hazard matrix is assembled to describe the interactions between hazards in the study area. Hazard interaction matrices identify the influence of one hazard on another and binary combination of different hazards. Figure 46 shows the multi-hazard

CONCLUSIONS

Birendranagar Municipality is the capital of the Karnali Province with the active condition of erosion, transportation and deposition. It is one of the major tourist spots as well as densely populated areas, so the possible problems that may come due to these natural processes shouldn't be ignored. The presented modelling results should be considered as good approximations however many relevant assumptions had to be made during the calculation.

The major points that can be concluded about the study area are as follows:

- Floods and landslides displaced a total of 1045 families in Birendranagar and other adjacent areas.
- The Birendranagar area, Surkhet comprises weak geology, fragile topography and high relief. The main problems are the landslides materials of the upper part of the Birendranagar basin that becomes debris during summer monsoon times and hits the downstream area. So, landslide susceptibility is the key to finding out the possible failure zones of landslides that can be used for the mitigation of the primary as well as the secondary disasters.
- Altogether, 95 landslides were studied for this research within the study area. The majority of them occurred in the forest between 40-70° slopes.
- Most of the existing landslides are along the road cut sections and mine a site which indicates the haphazard way of infrastructure development in the area. So, proper study and measures should be taken during road excavation to minimize the effects.
- For landslide hazard modeling 24hr extreme rainfall was analyzed and factor safety of hillslope was calculated for different rainfall return periods.
- Landslide runout analysis is the analysis of post-mobilization landslide motion. Flow-like landslides, such as debris flows and rock avalanches, travel at extremely rapid velocities and can impact large areas far from their source. When hazards like these are identified, runout analyses are often needed to delineate potential inundation areas, estimate risks, and design mitigation structures.
- In terms of the unstable zone, ward nos. 14, 15 and 16 are vulnerable than others. While in case of runout zonation, ward nos. 9 and 15 areas highly vulnerable.
- The multi-hazard map was created utilizing the SMCE method. The outcome shows ward no. 3 is a hazard condition because of flooding and followed by wards no 3, 9 and10.

9. CONCLUSIONS AND RECOMMENDATIONS

The followings are the overall conclusions and the recommendations of the study.

CONCLUSIONS

I. Birendranagar municipality is characterized by Siwalik Hills in the south and Lesser Himalaya in the north and Dun valley in the central part.

II. Geologically, the municipality is characterized by sedimentary rocks in the southern part and low grade metamorphic rocks of lesser Himalaya in the northern part and valley fill soft Quaternary deposits in the central part.

III. The seismic microzonation study has revealed that the average shear wave velocity at 30 m depth (Vs30) ranges from 160.0 m/s to 508.0 m/s. The highest Vs30 is obtained in the region dominated by gravel deposit, and the lowest at region dominant by soft sediments.

IV. The fundamental frequency varies between 0.6Hz to 6Hz and amplification factor is in the range of 2 to 8. As per the NEHRP seismic site class, majority of areas in Surkhet valley of Birendranagar Municipality is classified into class C, D and E.

V. The probabilistic seismic hazard assessment (PSHA) has shown bedrock Peak Ground Acceleration (PGA) in between 0.37g and 0.4g for 475 years return period.

VI. An economic loss of NPR 4,983,780,304.80 and NPR 7,898,798,054.40 for the seismic events of 475 years and 2475 years return period respectively for all buildings located in ward-6 of Birendranagar Municipality has been estimated.

VII. A flood hazard assessment of Birendranagar Municipality has shown that the wards 2 and 11 are at high risk for all three depth classes, i.e. <1m, 1 to 4m, and >4m. The statistical results show that the flood events of 2014 might be of 10 years return period, meaning that they can recur at any moment throughout the ten-year period.

VIII. The results of landslide susceptibility have shown that the southern and northern hills are susceptible to landslide hazard.

IX. The distribution of FS in the Birendranagar Municipality for 100 return period has shown that the unstable area (FS<1) is highly distributed in the wards containing hilly areas. Ward No. 15 is occupied by a 14.18% unstable area where, ward numbers 14 and 16 contain 12.43% and 11.20% unstable areas, respectively.

X. The ward-wise frequency ratio analysis shows ward no 9 is the highest vulnerable in terms of runout followed by ward no 15 and ward no 3, 6 and 8 are free from run outs.

XI. The multi hazard assessment shows that the ward numbers 15, 1, 4, 16 and 12 are relatively vulnerable to landslides. The ward no. 3 is an extreme hazard condition because of flooding and followed by wards no 3, 9 and 10.

RECOMMENDATIONS

I. The study has brought enormous data of multi hazard status of Birendranagar Municipality. This data should be utilized to develop evidence based municipal policy and strategic action plan on Disaster Risk Reduction and Management (DRRM).

II. The data should also be utilized to develop detail Risk Sensitive Land Use Plan (RSLUP) at the community level.

III. The outcomes of the study is important to implement National Building Code-105. It is, therefore, inevitable to conduct detail training on building design and construction based on the findings of the study.

IV. The seismic risk estimation has been done in Ward No. 6 only as a pilot project. It is recommended to conduct such study in remaining fifteen wards of the municipality.

V. The outcomes of the multi hazard assessment should be utilized while formulating urban development plan, smart city planning and any other infrastructure development.

VI. Since this study, utilizing cutting-edge technology, has developed innovative methods for seismic hazard and risk assessment at municipal scale, an intensive training is required for the engineers to implement the findings of the study. The replication of this study will beneficial to other municipalities throughout the country.

10. REFERENCES

Abella, E. A. C., & Van Westen, C. J. (2007). Generation of a landslide risk index map for Cuba using spatial multi-criteria evaluation. Landslides, 4(4), 311–325. https://doi.org/10.1007/s10346-007-0087-y

Abrahamson, N. A., Silva, W. J., & Kamai, R. (2014). Summary of the ASK14 ground motion relation for active crustal regions. Earthquake Spectra, 30(3), 1025–1055.

Abrahamson, N., Gregor, N., & Addo, K. (2016). BC hydro ground motion prediction equations for subduction earthquakes. Earthquake Spectra, 32(1), 23–44. doi:10.1193/051712EQS188MR.

Acharya, K. P., Yatabe, R., Bhandary, N. P., & Dahal, R. K. (2016). Deterministic slope failure hazard assessment in a model catchment and its replication in neighbourhood terrain. Geomatics, Natural Hazards and Risk, 7(1), 156–185. https://doi.org/10.1080/19475705.2014.880856

Ader, T., et al. (2012). Convergence rate across the Nepal Himalaya and interseismic coupling on the Main Himalayan Thrust: Implications for seismic hazard, J. Geophys. Res., 117, B04403, doi:10.1029/2011JB009071.

Aki, K. (1957). Space and time spectra of stationary stochastic waves, with special reference to microtremors. Bull. Earthquake Res. Inst. Tokyo Univ., 35, 415–456.

Aki, K., & Irikura, I. (1991). Characterization and Mapping of Earthquake Shaking for Seismic Zonation. Proceedings of the 4th International Conference On Seismic Zonation, 1, 61-110. Stanford, California.

Al-Chaar, G., Lamb, G. E., & Abrams, D. P. (2003). Effect of Openings on Structural Performance of Unreinforced Masonry Infilled Frames. International Concrete Abstracts Portal (pp. 247-262). Symposium Paper.

Ambraseys, N. N., & Menu, J. M. (1988). Earthquake-induced ground displacements. Earthquake Engineering & Structural Dynamics, 16(7), 985–1006. https://doi.org/10.1002/eqe.4290160704

ASCE. (2000). Prestandard and Commentary for the Seismic Rehabilitation of Buildings. Washington, D.C.: Federal Emergency Management Agency.

ASCE. (n.d.). FEMA 389. Washington, D.C.: Federal Emergency Management Agency.

Atkinson, G.M., Boore, D.M. (2003). Empirical ground-motion relations for subduction zone earthquakes and their application to Cascadia and other regions. Bull Seismol Soc Am 93(4):1703–1729.

Avouac, J.-P., Meng, L., Wei, S. Wang, T. and Ampuero J.-P., (2015b). Lower edge of locked Main Himalayan Thrust unzipped by the 2015 Gorkha earthquake. Nat. Geosci. 8, 708–711.

Avouac, J-P. (2007). Dynamic Processes in Extensional and Compressional Settings – Mountain Building: From Earthquakes to Geological Deformation. Chapter 6.09, Treatise on Geophysics, Elsevier.

Avouac, J-P. (2015a). From geodetic imaging of seismic and aseismic fault slip to dynamic modeling of the seismic cycle. Annual Review of Earth and Planetary Sciences, 43:233-71.

Baker, J. W. (2015). Efficient analytical fragility function fitting using dynamic structural analysis. Earthquake Spectra, 31(1), 579-599.

Baltzopoulos, G., Baraschino, R., Iervolino, I., & Vamvatsikos, D. (2017). SPO2FRAG: Software for seismic fragility assessment based on static pushover. Bulletin of Earthquake Engineering, 15: 4399-4425.

Baltzopoulus, G., Baraschino, R., Iervolino, I., & Vamvatsikos, D. (2017). SPO2FRAG: software for serismic fragility assessment based on static pushover. Bulletin of Earthquake Engineering, 4399-4425.

Belsley, D., Kuh, E., & Welsch, R. (1980). Detecting and Assessing Collinearity. In Regression Diagnostics: Identifying Influential Data and Sources of Collinearity (pp. 85–91). https://doi.org/10.1002/0471725153.ch3

Beven, K. J., & Kirkby, M. J. (1979). A physically based, variable contributing area model of basin hydrology. Hydrological Sciences Bulletin, 24(1), 43–69. https://doi.org/10.1080/02626667909491834

Bilham R., Bodin, P. and Jackson, M. (1995). Entertaining a great earthquake in western Nepal: historic inactivity and geodetic tests for the present state of strain. Journal of Nepal geological society 11 (1), 73-78.

Bilham R., Larson, K., Freymueller J. and Idylhim members, (1997). GPS measurements of present-day convergence across the Nepal Himalayas. Nature, 386, 1-94.

Bilham, R., Bodin, P., & Jackson, M. (1995). Entertaining a great earthquake in western Nepal: historic inactivity and geodetic tests for the present state of strain. J Nepal Geol Soc, 11(1):73–78.

Bird, J. F., & Bommer, J. J. (2004). Earthquake losses due to ground failure. Engineering Geology, 75(2), 147–179. https://doi.org/10.1016/j.enggeo.2004.05.006

Bodin, P. and Horton, S. (1999). Broadband microtremor observation of basin resonance in the Mississippi embayment, Central US. Geophysical Research Letters, 26(7), 903–906.

Bonnefoy-Claudet, S., Cotton, F. and Bard, P. Y. (2006). The nature of noise wavefield and its applications for site effects studies: A literature review. Earth-Science Reviews, 79, 205–227.

Brown L.D. et al., 1996. Bright spots, structure, and magmatism in southern Tibet from INDEPTH seismic reflection profiling. Science 274, 1688–1690.

Brzev, S., Scawthorn, C., Charleson, A. W., & Jaiswal, K. (2012). Interim Overview of GEM Building Taxonomy V2.0, Report produced in the context of the GEM Building Taxonomy Global Component, Version 1.0. GEM Foundation.

Build Change. (2019). Laboratory test report on stone masonry in mud mortar. Build Change report. Kathmandu.

Burnham, K. P., & Anderson, D. R. (2002). Model selection and multimodel inference: a practical information-theoretic approach. In Ecological Modelling (Vol. 172, Issue 1). https://doi.org/10.1016/j.ecolmodel.2003.11.004

Campbell, K.W., Bozorgnia, Y. 2008. NGA ground motion model for the geometric mean horizontal component of PGA, PGV, PGD and 5 % damped linear elastic response spectra for periods ranging from 0.01 to 10 s. Earthq Spectra 24(1):139–171

Carrara, A., & Pike, R. J. (2008). GIS technology and models for assessing landslide hazard and risk. In Geomorphology (Vol. 94, Issues 3–4, pp. 257–260). https://doi.org/10.1016/j.geomorph.2006.07.042

Catani, F., Lagomarsino, D., Segoni, S., & Tofani, V. (2013). Landslide susceptibility estimation by random forests technique: sensitivity and scaling issues. Natural Hazards and Earth System Sciences, 13(11), 2815–2831. https://doi.org/10.5194/nhess-13-2815-2013

Cattin, R., and Avouac, J. P., 2000. Modeling mountain building and the seismic cycle in the Himalaya of Nepal. J. Geophys. Res., 105(B6), 13389–13407, doi:10.1029/2000JB900032.

Chamlagain, D., & Hayashi, D. (2004). Numerical simulation of fault development along NE–SW Himalayan profile in Nepal. *J Nepal Geol Soc*, 29:1–11.

Chamlagain, D., & Hayashi, D. (2007). Neotectonic fault analysis by 2D finite-element modeling for studying the Himalayan fold-and-thrust belt in Nepal. *J Asian Earth Sci*, 29:473–489.

Chaulagain, H., Rodrigues, H., Silva, V., Spacone, E., & Varum, H. (2015). Earthquake loss estimation for the Kathmandu Valley. Bulletin of Earthquake Engineering, 59-88.

Claessens, L., Heuvelink, G. B. M., Schoorl, J. M., & Veldkamp, A. (2005). DEM resolution effects on shallow landslide hazard and soil redistribution modelling. Earth Surface Processes and Landforms, 30(4), 461–477. https://doi.org/10.1002/esp.1155

Clough, R. W., & Chopra, A. K. (1966). Earthquake Stress Analysis in Earth Dams. Journal of the Engineering Mechanics Division, 92(2), 197–212.

Convertino, M., Troccoli, A., & Catani, F. (2013). Detecting fingerprints of landslide drivers: A MaxEnt model. Journal of Geophysical Research: Earth Surface, 118(3), 1367–1386. https://doi.org/10.1002/jgrf.20099

Cornell, C. A. (1968). Engineering seismic risk analysis. Bulletin of the Seismological Society of America, 58(5), 1583–1606. https://doi.org/10.1785/BSSA0580051583

Corominas, J. (1996). The angle of reach as a mobility index for small and large landslides. Canadian Geotechnical Journal, 33(2), 260–271. https://doi.org/10.1139/t96-005

Draper, N. R., & Smith, H. (1998). Applied Regression Analysis. Technometrics, 47(3), 706. https://doi.org/10.1198/tech.2005.s303

Elliott, J. R., Jolivet, R., González, P. J., Avouac, J. P., Hollingsworth, J., Searle, M. P., & Stevens, V. L. 2016. Himalayan megathrust geometry and relation to topography revealed by the Gorkha earthquake. Nature Geoscience, 9(2), 174-180

Elliott, J. R., Parsons, B., Jackson, J. A., Shan, X., Sloan, R. A., & Walker, R. T. 2011. Depth segmentation of the seismogenic continental crust: The 2008 and 2009 Qaidam earthquakes. Geophysical research letters, 38(6).

Ercanoglu, M., Gokceoglu, C., & Van Asch, T. W. J. (2004). Landslide susceptibility zoning north of Yenice (NW Turkey) by multivariate statistical techniques. Natural Hazards, 32(1), 1–23.

Gardner, J., & Knopoff, L. 1974. Is the sequence of earthquakes in southern California, with aftershocks removed, Poissonian. Bulletin of the Seismological Society of America, 64(5), 1363–1367.

Gautam, D. (2017). Unearthed lessons of 25 April 2015 Gorkha earthquake (MW 7.8): geotechnical earthquake engineering perspectives. Geomatics, Natural Hazards and Risk, 8:2, 1358-1382.

Gautam, D., Fabbrocino, G., & de Magistris, F. S. (2018). Derive empirical fragility functions for Nepali residential buildings. Engineering Structures, 617-628.

Hack, J. T., & Goodlett, J. C. (1960). Geomorphology and Forest Ecology of a Mountain Region in the Central Appalachians. In USGS Professional Paper (Vol. 347).

Hengl, T., Gruber, S., & … D. S.-. (2003). Digital terrain analysis in ILWIS. Earth Observation Enschede. http://cnrfiles.uwsp.edu/turyk/Database/Development/MJB/private/Thesis/JournalArticles/hengl_digital demtalk.pdf

Holmgren, P. (1994). Multiple flow direction algorithms for runoff modelling in grid based elevation models: An empirical evaluation. Hydrological Processes, 8(4), 327–334. https://doi.org/10.1002/hyp.3360080405

Horton, P., Jaboyedoff, M., & Bardou, E. (2008). Debris flow susceptibility mapping at a regional scale. 4th Canadian Conference on Geohazards: From Causes to Management, 399–406. http://www.geohazard.ggl.ulaval.ca/alea/horton.pdf

Iida, T. (1984). A hydrological method of estimation of the topographic effect on the saturated throughflow. Japanese Geomorph. Union Trans., 5(1), 1–12. https://ci.nii.ac.jp/naid/10006613576/

Iverson, R. M. (2000). Landslide triggering by rain infiltration. Water Resources Research, 36(7), 1897–1910. https://doi.org/10.1029/2000WR900090

Jaynes, E. T. (1957). Information Theory and Statistical Mechanics. Physical Review, 106(4), 620. https://doi.org/10.1103/PhysRev.106.620

Jibson, R. W. (2011). Methods for assessing the stability of slopes during earthquakes-A retrospective. Engineering Geology, 122(1–2), 43–50. https://doi.org/10.1016/j.enggeo.2010.09.017

Kathmandu District Administration Office. (2020). Approved Wages and Construction Material Costs for Kathmandu District. Kathmandu: Kathmandu District Administration Office.

Kavzoglu, T., Sahin, E. K., & Colkesen, I. (2014a). Landslide susceptibility mapping using GIS-based multi-criteria decision analysis, support vector machines, and logistic regression. Landslides, 11(3), 425–439. https://doi.org/10.1007/s10346-013-0391-7

Kavzoglu, T., Sahin, E. K., & Colkesen, I. (2014b). Landslide susceptibility mapping using GIS-based multi-criteria decision analysis, support vector machines, and logistic regression. Landslides, 11(3), 425–439. https://doi.org/10.1007/s10346-013-0391-7

Keefer, D. K. (2011). Toward the next generation of research on earthquake-induced landslides: Current issues and future challenges. Engineering Geology, 122(1–2), 1–8. https://doi.org/10.1016/J.ENGGEO.2011.06.001

Khattrai, K. N. (1987). Great earthquakes, seismicity gaps and potential for earthquake disaster along the Himalaya plate boundary. Tectonophysics, 138:79–92.

Korup, O., Strom, A. L., & Weidinger, J. T. (2006). Fluvial response to large rock-slope failures: Examples from the Himalayas, the Tien Shan, and the Southern Alps in New Zealand. Geomorphology, 78(1–2), 3–21. https://doi.org/10.1016/j.geomorph.2006.01.020

Lave, J., Yule, D., Sapkota, S. N., Basant, K., Madden, C., Attal, M. and Pandey, M. R. 2005. Evidence for a Great Medieval Earthquake (~1100 A.D.) in the central Himalayas, Nepal, Science, 307, 1302–1305.

Le Fort, P., 1975. Himalayas: The collided range. Present knowledge of the continental arc. Ame. Jour. Sci., v. 275-A, pp. 1-44.

Lee, S., & Evangelista, D. G. (2006). Earthquake-induced landslide-susceptibility mapping using an artificial neural network. Natural Hazards and Earth System Sciences, 6, 687–695. http://adsabs.harvard.edu/abs/2006NHESS...6..687L

Lee, S., & Talib, J. A. (2005). Probabilistic landslide susceptibility and factor effect analysis. Environmental Geology, 47(7), 982–990. https://doi.org/10.1007/s00254-005-1228-z

Luzi, L., & Pergalani, F. (1999). Slope Instability in Static and Dynamic Conditions for Urban Planning: the 'Oltre Po Pavese' Case History (Regione Lombardia – Italy). Natural Hazards, 20(1), 57–82. https://doi.org/10.1023/A:1008162814578

Maggi, A., Jackson, J. A., Priestley, K., & Baker, C. 2000. A re-assessment of focal depth distributions in southern Iran, the Tien Shan and northern India: Do earthquakes really occur in the continental mantle?. Geophysical Journal International, 143(3), 629-661.

Marcuson, W. F. (1981). Moderator's report for session on "Earth dams and stability of slopes under dynamic loads." International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, 3, 1175.

Matasovic, N. (1991). Selection of Method for Seismic Slope Stability Analysis. Proc., 2nd International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, 1057–1062.

Medvedev, S. W., Sponheuer, W., & Karnik, V. (1965). Seismic intensity scale version MSK 1964. Paris: United Nation Educational, Scientific and Cultural Organization.

MEJIA-NAVARRO, M., & GARCIA, L. A. (1996). Natural Hazard and Risk Assessment Using Decision Support Systems, Application: Glenwood Springs, Colorado. Environmental & Engineering Geoscience, II(3), 299–324. https://doi.org/10.2113/gseegeosci.II.3.299

Menard, S. (1995). Applied logistic regression analysis. In Sage university paper series on quantitative applications in the social sciences.

Moore, I. D., & Burch, G. J. (1986). Sediment Transport Capacity of Sheet and Rill Flow: Application of Unit Stream Power Theory. Water Resources Research, 22(8), 1350–1360. https://doi.org/10.1029/WR022i008p01350

Moore, Ian D., & Burch, G. J. (1986). Physical Basis of the Length-slope Factor in the Universal Soil Loss Equation1. Soil Science Society of America Journal, 50(5), 1294. https://doi.org/10.2136/sssaj1986.03615995005000050042x

Nakamura, Y. (1989). A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. Quarterly Report of the Railway Technical Research Institute, 30, 25–33.

Nakata, T. 1989. Active faults of the Himalaya of India and Nepal, in Tectonics of the Western Himalayas, edited by L. L. Malinconico Jr. and R. J. Lillie, pp. 243–264, Geol. Soc. of Am., Boulder, Colorado.

National Planning Commission (NPC). (2015). Post-disaster Need Assessment, vol. A and B. Kathmandu: Govt. of Nepal.

Newmark, N. M. (1965). Effects of earthquakes on dams and embankments. Geotechnique, 15(2), 139–160.

O'Brien, R. M. (2007). A caution regarding rules of thumb for variance inflation factors. Quality and Quantity, 41(5), 673–690. https://doi.org/10.1007/s11135-006-9018-6

Oguchi, T. (1997). Drainage density and relative relief in humid steep mountains with frequent slope failure. Earth Surface Processes and Landforms, 22(2), 107–120. https://doi.org/10.1002/(SICI)1096-9837(199702)22:2<107::AID-ESP680>3.0.CO;2-U

Ohlmacher, G. C. (2007). Plan curvature and landslide probability in regions dominated by earth flows and earth slides. Engineering Geology, 91(2–4), 117–134. https://doi.org/10.1016/j.enggeo.2007.01.005

Pandey, M. R., Tandukar, R. P., Avouac, J. P., Lave, J., & Massot, J. P. (1995). Interseismic strain accumulation on the Himalayan crustal ramp (Nepal). Geophys Res Lett, 22(7):751–754.

Pandey, M.R., Tandukar, R.P., Avouac, J.P., Vergne, J., Heritier, Th., 1999. Seismotectonics of the Nepal Himalaya from a local seismic network. Journal of Asian Earth Sciences 17, 703-712.

Paola, C., & Leeder, M. (2011). Simplicity versus complexity. Nature 2011 469:7328, 469(7328), 38–39. https://doi.org/10.1038/469038a

Pearson, K. (1895). Note on Regression and Inheritance in the Case of Two Parents. Proceedings of the Royal Society of London (1854-1905). https://doi.org/10.1098/rspl.1895.0041

Penna, A., Senaldi, I., Magenes, G., & Galasco, A. (2014). Pushover Analysis of Unreinforced Masonry Buildings with Different Levels of Diaphragm Stiffness. Second European Conference on Earthquake Engineering and Seismology. Istanbul.

Phillips, S. J., & Dudík, M. (2008). Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography, 31(2), 161–175. https://doi.org/10.1111/j.0906-7590.2008.5203.x

Pradhan, A. M. S., & Kim, Y. T. (2014a). Relative effect method of landslide susceptibility zonation in weathered granite soil: A case study in Deokjeok-ri Creek, South Korea. Natural Hazards. https://doi.org/10.1007/s11069-014-1065-z

Pradhan, A. M. S., & Kim, Y. T. (2014b). Relative effect method of landslide susceptibility zonation in weathered granite soil: A case study in Deokjeok-ri Creek, South Korea. Natural Hazards, 72(2), 1189–1217. https://doi.org/10.1007/s11069-014-1065-z

Pradhan, A. M. S., & Kim, Y. T. (2021). Development and Evaluation of Relative Relief Based Soil Thickness Model: A Comparative Study in Hilly Terrain, South Korea. KSCE Journal of Civil Engineering, 25(6), 2186–2198. https://doi.org/10.1007/s12205-021-1379-9

Pradhan, A. M. S., Kang, H. S., Lee, J. S., & Kim, Y. T. (2019). An ensemble landslide hazard model incorporating rainfall threshold for Mt. Umyeon, South Korea. Bulletin of Engineering Geology and the Environment, 78(1), 131–146. https://doi.org/10.1007/s10064-017-1055-y

Rahman, M.M., Bai, L., Khan, N.G., and Li, G. 2018. Probabilistic Seismic hazard assessment for Himalayan-Tibetan region from historical and Instrumental earthquake catalogs. Pure Appl. Geophys. 175, 685–705.

Rajendran, C. P., John, B., & Rajendran, K. (2015). Medieval pulse of great earthquakes in the central Himalaya: Viewing past activities on the frontal thrust. J. Geophys. Res., 120, 1623–1641.

Reneau, S. L., & Dietrich, W. E. (1987). The importance of hollows in debris flow studies; examples from Marin County, California. Debris Flows/Avalanches, 165–180. https://doi.org/10.1130/reg7-p165

Riley, S. J., DeGloria, S. D., & Elliot, R. (1999). A Terrain Ruggedness Index that Qauntifies Topographic Heterogeneity. In Intermountain Journal of Sciences (Vol. 5, Issues 1–4, pp. 23–27). https://doi.org/citeulike-article-id:8858430

Saygili, G., & Rathje, E. M. (2008). Empirical Predictive Models for Earthquake-Induced Sliding Displacements of Slopes. Journal of Geotechnical and Geoenvironmental Engineering, 134(6), 790–803. https://doi.org/10.1061/(ASCE)1090-0241(2008)134:6(790)

Schelling, D., and Arita, K., 1991. Thrust tectonics, crustal shortening, and the structure of the far-eastern Nepal Himalaya. Tectonics 10 no. 5, 851–862.

SESAME. (2004). Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations measurements processing and interpretation. SESAME European

Shrestha, S., & Kang, T. S. (2017). Assessment of seismically-induced landslide susceptibility after the 2015 Gorkha earthquake, Nepal. Bulletin of Engineering Geology and the Environment, 1–14. https://doi.org/10.1007/s10064-017-1191-4

Shrestha, B. R., Rai, R. K., & Marasini, S. (2020). Review of Flood Hazards Studies in Nepal. The Geographic Base, 7, 24–32. https://doi.org/10.3126/tgb.v7i0.34266

Silver, C. R. P., M. A. Murphy, M. H. Taylor, J. Gosse, and T. Baltz 2015. Neotectonics of the Western Nepal Fault System: Implications for Himalayan strain partitioning, Tectonics, 34.

Skilling, J. (2013). Maximum Entropy and Bayesian Methods: Cambridge, England, 1988 (Vol. 36). Springer Science \& Business Media.

Slinker, B K, & Glantz, S. a. (1985). Multiple regression for physiological data analysis: the problem of multicollinearity. The American Journal of Physiology, 249(1 Pt 2), R1–R12.

Slinker, Bryan K., & Glantz, S. A. (2008). Multiple linear regression: Accounting for multiple simultaneous determinants of a continuous dependent variable. In Circulation (Vol. 117, Issue 13, pp. 1732–1737). https://doi.org/10.1161/CIRCULATIONAHA.106.654376

Smith, G.-H. (1935). The Relative Relief of Ohio. Geographical Review, 25(2), 272. https://doi.org/10.2307/209602

Soeters, R.;van Westen, C. J. (1996). Slope instability recognition, analysis, and zonation. In Landslides: Investigation and Mitigation: Vol. Special Re (pp. 129–177).

Sponheuer, W., & Karnik, V. (1964). Neue seismische Skala. Proceedings of the 7th Symposium of (pp. 69-76). Jena: Veröffentlichungen des Instituts für Bodendynamik und.

Stevens, V. L., & Avouac, J. P. (2016). Millenary Mw > 9.0 earthquakes required by geodetic strain in the Himalaya. Geophys. Res. Lett, 43, 1118–1123.

Stewart, J. P., Blake, T. F., & Hollingsworth, R. A. (2003). A Screen Analysis Procedure for Seismic Slope Stability. In Earthquake Spectra (Vol. 19, Issue 3, pp. 697–712). https://doi.org/10.1193/1.1597877

Sudmeier-Rieux, K., Jaquet, S., Derron, M. H., Jaboyedoff, M., & Devkota, S. (2012). A case study of coping strategies and landslides in two villages of Central-Eastern Nepal. Applied Geography, 32(2), 680–690. https://doi.org/10.1016/j.apgeog.2011.07.005

Tang, C., Zhu, J., Qi, X., & Ding, J. (2011). Landslides induced by the Wenchuan earthquake and the subsequent strong rainfall event: A case study in the Beichuan area of China. Engineering Geology, 122(1–2), 22–33. https://doi.org/10.1016/J.ENGGEO.2011.03.013

Taniguchi, E., & Sasaki, Y. (1985). Back analysis of landslide due to the Naganoken Seibu earthquake of September 14, 1984. Proc. of 11th International Conference on Soil Mechanics and Foundation Engineering, Sanfrancisco, 1–55.

Tesfa, T. K., Tarboton, D. G., Chandler, D. G., & McNamara, J. P. (2009). Modeling soil depth from topographic and land cover attributes. Water Resources Research, 45(10). https://doi.org/10.1029/2008WR007474

Thapa D.R., Wang G. 2013. Probabilistic seismic hazard analysis in Nepal. Earthq Eng Eng Vib 12:577–586.

Thapa, S., Shrestha, A., Lamichhane, S., Adhikari, R., & Gautam, D. (2020). Catchment-scale flood hazard mapping and flood vulnerability analysis of residential buildings: The case of Khando River in eastern Nepal. Journal of Hydrology: Regional Studies, 30(March), 100704. https://doi.org/10.1016/j.ejrh.2020.100704

Thapaliya, R. (2006). Assessing Building Vulnerability for Earthquake Using Field Survey and development Control Data: A Case Study in Lalitpur Sub-Metropolitan City, Nepal. Enschede: Urban Planning and Land Management, International Institute for Geo-Information Science and Earth Observation.

Tokimatsu, K., Shinzawa K., and Kuwayama, S. (1992). Use of short period microtremors for Vs profiling. Journal of Geotechnical and Geoenvironmental Engineering, 118, 1544.

Yalcin, A. (2007). The effects of clay on landslides: A case study. Applied Clay Science, 38(1–2), 77–85. https://doi.org/10.1016/J.CLAY.2007.01.007

Yang, Z. X., Waldhauser, F., Chen, Y. T., & Richards, P. G. (2005). Double-difference relocation of earthquakes in central-western China, 1992–1999. Journal of Seismology, 9(2), 241-264.

Young, A., Carson, M. A., & Kirkby, M. J. (1973). Hillslope Form and Process. The Geographical Journal, 139(1), 140. https://doi.org/10.2307/1795822

Yule, D., Dawson, S., Lave, J., Sapkota, S., & Tiwari, D. (2006). Possible evidence for surface rupture of the Main Frontal Thrust during the great 1505 Himalayan earthquake, far-western Nepal. Am. Geophys. Union Fall Meeting Abstracts, #S33C–05.

Zhao, J. X., Zhang, J., Asano, A., Ohno, Y., Oouchi, T., Takahashi, T. (2006). Attenuation relations of strong ground motion in Japan using site classification based on predominant period. Bulletin of the Seismological Society of America, 96(3), 898–913.

Zhou, Z. X., Li, J., & Ren, Z. Y. (2012). The relief degree of land surface and population distribution in Guanzhong-Tianshui economic region using GIS. Scientia Geographica Sinica, 32(8), 951–957.

11. WORKSHOPS

OUTCOME SHARING WORKSHOP

An outcome sharing workshop was organized on 14th January 2022 at Hotel Suva, Birendranagar, Surkhet. The program was organized on the occasion of 24th Earthquake Safety Day (**Error! Reference source not found.Error! Reference source not found.**). The objective of this workshop is:

- To disseminate the findings of the study and collect feedback from the local government representatives, municipal officials and related stakeholders

There were 43 participants including Chief District Officer, Khagendra Prasad Rijal (Photograph 11-1), Mr. Dev Kumar Subedi, Mayor, Mrs. Mohan Maya Dhakal, Deputy Mayor, SP Nepal Police, DSP Nepal Armed Police, Major Nepal Army, and Ward Chairman of Birendranagar Municipality (Photograph 3). Similarly, Mr. Hari Prasad Devkota, Chief Administrative Officer (C.A.O) of Birendranagar Municipality, was also present at the workshop. There were representatives from various government organizations and I/NGOs. Mr. Rajesh Shoni, Field Officer, TAYAR Nepal Project of USAID along with Er. Dilli Upadhaya also joined the workshop. Dr. Deepak Chamlagain, Team Leader/Engineering Seismologist, Dr. Upendra Baral, Geologist, Er. Bibek Raj Shrestha, Structural Engineer, and Er. Helen Upadhyay, Civil Engineer were present from Geo Engineering Consult Pvt. Ltd.

Photograph 0-3Chief District Officer, Mr. Khagendra Prasad Rijal .

Photograph 0-4 Participants of the workshop.

Among the 43 participants, the majority number of participants were male (91 %) while 9% were female participants (Figure 11:1, Photo 11-2). Among them 5 participants were between the age group of 25-29 years while 38 participants were 30+ years (Figure. 2). Ten personnels from security agencies, e.g. Nepal Army, Nepal Armed Police, Nepal Police including government officials, ward chairman along with the officials of Birendranagar municipality were present. Similarly, two participants from I/NGOs were present and 8 participants from the media also attended the workshop. Based on the community group, there were 29 participants representing Brahmin/Chhetri community, 5 from each Dalit and Janajati community and 4 participants from other group (Figure 3).

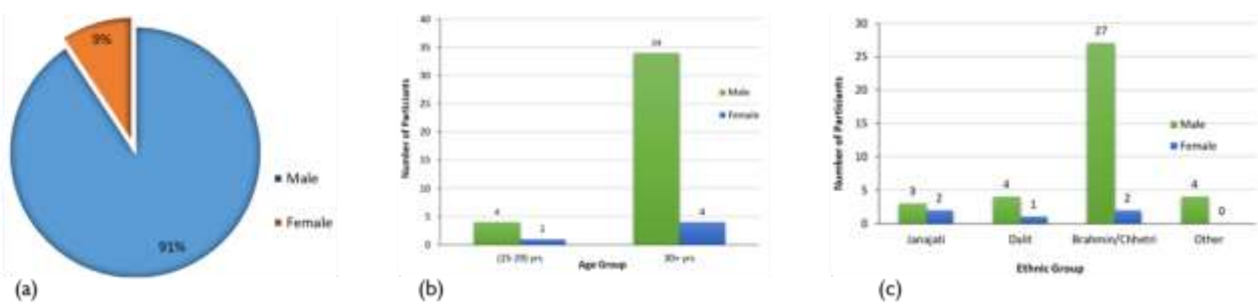


Figure 0:83 Distribution of participants based on (a) Sex (b) Age group and (c) Ethnic group.

EVENT OVERVIEW

The master of ceremony was Mr. Rajesh Soni from Tayar Nepal project of USAID. The program was chaired by Mayor Dev Kumar Subedi, and the Chief Guest was Mr. Khagendra Prasad Rijal, Chief District

Officer, Surkhet. The special guest of the program was Mrs Mohan Maya Dhakal, Deputy Mayor, Birendranagar Municipality. At first, Mr Rajesh Soni highlighted the objectives of the Tayar Nepal project of USAID and existing projects in Birendranagar Municipality (Photograph 11-3). He also stressed that how the program was started and what the Geo Engineering Consult team has done since the initial days to present stage. He also thanked Geo Engineering Consult Pvt. Ltd. for their hard works to make it happened successfully.

Photograph 0-5 Mr. Rajesh Soni (Tayar Nepal) conducting the program.

Introductory Session

The session was started with self-introduction of the participant. Mr. Hari Prasad Devkota Chief Administrative Officer, Birendranagar Municipality welcomed all the participants and thanks all for their presence (Photograph 11-4). He further highlighted the current scenario of the natural disasters in Birendranagar. He also stressed on the importance of the present study.

Photograph 0-6 Mr. Hari Prasad Devkota, Chief Administrative Officer, Birendranagar Municipality delivering welcome speech.

Technical Session

After the brief introductory session, the floor was opened for the technical session. As the program is organized on the occasion of 24th Earthquake Safety Day, Er. Ram Krishna Acharya gave a short presentation on the bylaws, building codes and their various provision (Photograph 11-5). The slogan of this year's earthquake safety day is "भूकम्पीय सचेतना सुरक्षित संरचना".

Photograph 0-7 Er. Ram Krishna Acharya gave a short presentation about the building codes and its application

In the second presentation, Dr. Deepak Chamlagain, Team Leader of the project, executed by the Geo Engineering Consult, presented the outcomes of the study in detail (Photograph 11-6). After the presentation, the floor was opened for the discussion and suggestions from the participants.

Photograph 0-8 Dr. Deepak Chamlagain, Team Leader from Geo Engineering Consult Pvt. Ltd. presented the findings of the study.

Discussion Session

Dr. Chamlagain clarified the queries raised by the participants on the findings of the study. Mr Pradeepta Poudel of Nepal Red Cross Society pointed out the issues of thunderstorm and lightening hazards and advised to incorporate them where possible.

Report Handover Session

On behalf of Geo Engineering Consult Pvt. Ltd., Dr. Chamlagain handed over the draft report to Mr. Subedi, Mayor of Birendranagar municipality (Photograph 11-7). Dr. Chamlagain requested Mayor to display the maps in each ward office and disaster-prone areas of the municipality to aware community people on existing hazards and multi-hazard.

Closing Session

On behalf of Tayar Nepal Project/USAID, Mr. Shoni delivered a vote of thanks speech. Finally, the program was concluded with remark from Mr. Subedi, Mayar of Birendranagar Municipality. Mr. Subedi, greeted and thanked all the participants and Geo Engineering Consult Pvt. Ltd. and Tayar Nepal Project/USAID for conducting this important study. He also mentioned that the Birendranagar municipality would work with different stakeholders to implement the finding of the study. He also stressed that the government should strongly monitor the under-construction building. He requested Tayar Nepal to provide the results in a short form (2-3 pages) in Nepali language so that municipality can distribute to every individual who come to the municipality for building construction permission.

Photograph 0-9 Dr. Chamlagain handed over the draft report to Mr. Subedi, Mayor of Birendranagar municipality.

Photograph 0-10 Concluding remarking from concluded by the speech from Mr. Dev Kumar Subedi, Mayar of Birendranagar Municipality

WARD WISE GROUP DISCUSSION

Introduction

A Ward wise group discussion was organized in three different dates, i.e. 13th, 17th and 18th January at Birendranagar Municipality, Surkhet. **Error! Reference source not found.**In this program, the ward r epresentatives along with the personnel related to disaster risk and management from individual ward were invited. Four to six representative from each ward participated in the program. The main objective of the workshop is to disseminate the finding of our study and make aware the local people about the hazard prone areas within the Municipality. The detail program outline is given in Annex-I. The key objectives of this workshop are:

- To share the outcomes of the study conducted by Geo Engineering Consult Pvt Ltd under the technical assistance of Tayar Nepal Project/USAID in Birendranagar Municipality
- To sensitize community people on existing hazards and collect feedback on the outcomes of the study from local government and other stakeholders

Participant

Fifty-eight ward representatives participated in three different events (Table 11:1). In these events, male participants were 31 in number, while the female were 27 (Figure 11:3). Among them only 6 participants were below 20 yrs while 52 were of above 30 yrs of age (Figure 11:4). There were 37 participants from Brahmin/Chhetri, 12 from Dalit and 8 from Janajati community (Figure 11:5).

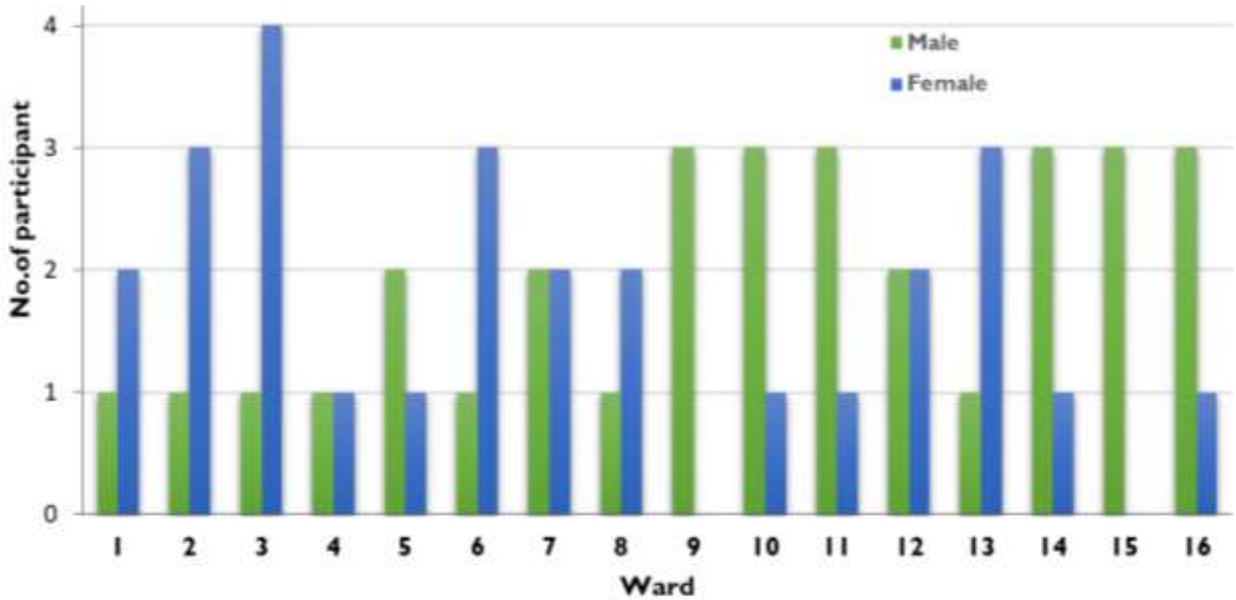


Figure 0:84 Distribution of male/female participants from each ward.

Table 0:24 Distribution of participants with respect to sex, age, and social group.

WARD	*PARTICIPANTS (NO.)*	*MALE*	*FEMALE*	*(15-19)YR*	*(20-24)YR*	*(25-29)YR*	*30+ YR*	*BRAHMIN/ CHHETRI*	*DALIT*	*JANAJATI*	*NEWAR*
1	3	1	2	0	0	0	3	3	0	0	0
2	4	1	3	0	0	0	4	3	1	0	0
3	5	1	4	0	1	1	3	2	2	1	0
4	2	1	1	0	1	0	1	1	1	0	0
5	3	2	1	0	0	0	3	1	1	1	0
6	4	1	3	0	0	0	4	4	0	0	0
7	4	2	2	0	0	0	4	3	1	0	0
8	3	1	2	0	0	0	3	2	0	1	0
9	3	3	0	0	0	1	2	2	0	0	1
10	4	3	1	0	0	0	4	3	0	1	0
11	4	3	1	0	0	0	4	3	1	0	0
12	4	2	2	1	0	0	3	3	1	0	0
13	4	1	3	0	0	0	4	1	2	1	0
14	4	3	1	0	0	0	4	2	1	1	0
15	3	3	0	0	0	0	3	2	0	1	0
16	4	3	1	0	1	0	3	2	1	1	0
Total	58	31	27	1	3	2	52	37	12	8	1

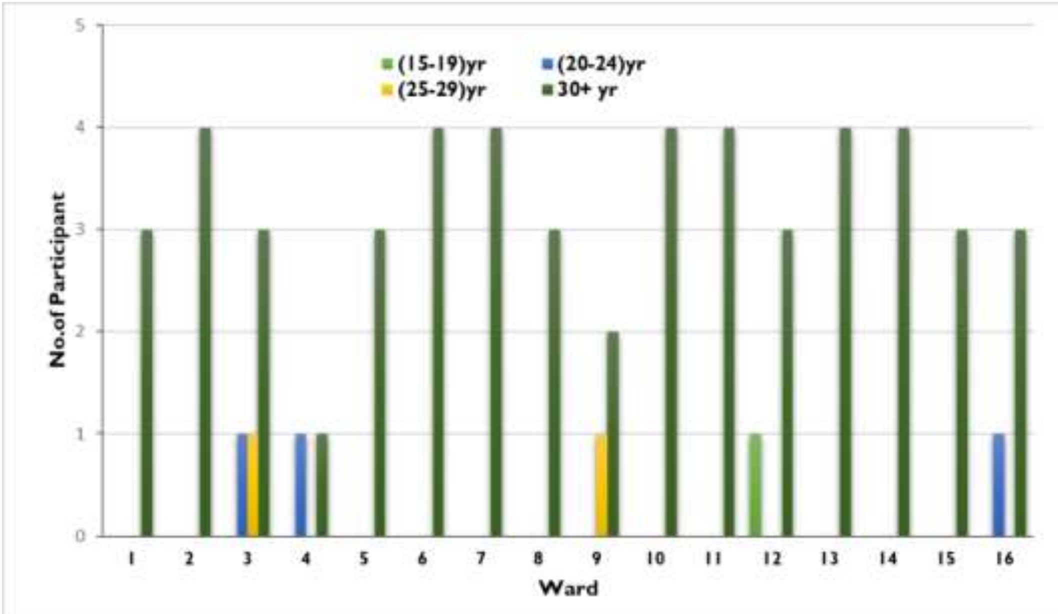


Figure 0:85 Distribution of participants based on various age group from individual ward

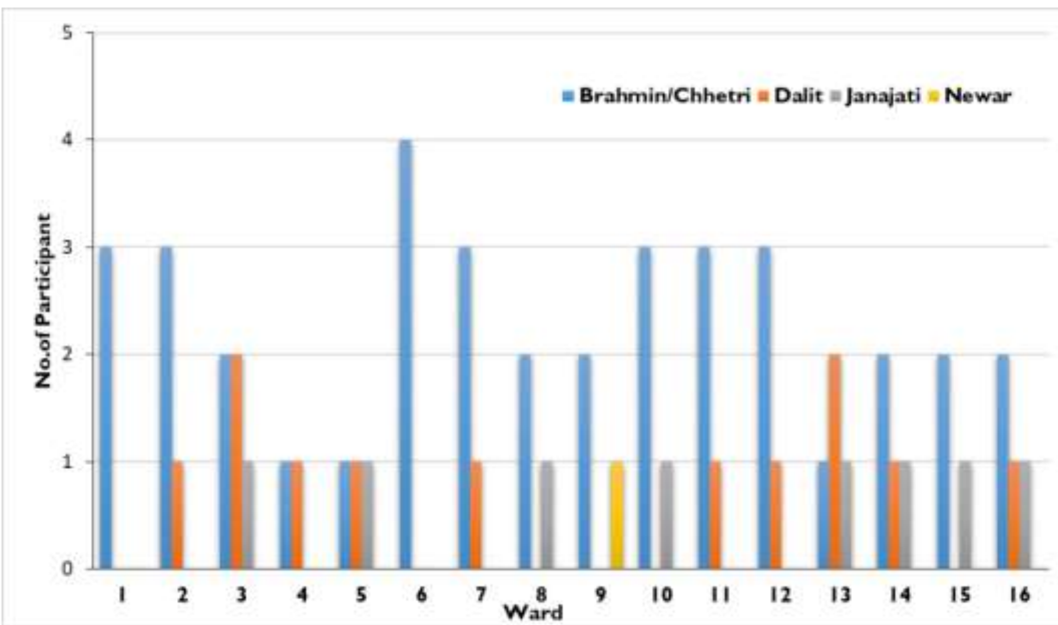


Figure 0:86 Distribution of participants of each ethnic group from individual ward

Event Overview

Introductory Session

All the programs were facilitated by Mr. Rajesh Soni, Field Officer of Tayar Nepal and moderated by Mr. Yam Lal Giri of Birendranagar Municipality (Photograph 11-9). At first, Mr. Shoni welcomed all participants, described the current activities' of USAID Tayar Nepal, and facilitated the introduction session. Following the self-introduction of the participants, Mr. Giri delivered a welcome speech and expressed his gratitude on behalf of Birendranagar Municipality.

Technical Session

During the technical session, in day one, Dr. Deepak Chamlagain, Team Leader from Geo Engineering Consult Pvt. Ltd delivered a brief presentation on the outcomes (Photograph 11-10) while in remaining events Dr. Upendra Baral, Geologist, Geo Engineering Consult Pvt. Ltd made a brief presentation (Photograph 11-11). Similarly, Er. Helen Upadhyay, GESI Focal Person, Geo Engineering Consult Pvt. Ltd, highlighted the importance of GESI issues in disaster management (Photograph 11-12). In addition to this, she also highlighted the Municipality's role to address GESI issues and protection of women and children before, during and after the disaster.

Photograph 0-11 Mr. Rajesh Shoni of Tayar Nepal delivering welcome speech.

Photograph 0-12Dr. Deepak Chamlagain, Team Leader, Geo Engineering Consult Pvt. Ltd presenting the outcomes of the study.

Photograph 0-13Dr. Upendra Baral, Geologist, Geo Engineering Consult Pvt. Ltd delivering the presentation.

Photograph 0-14 Ms Helen Upadhyay, GESI Focal Person, Geo Engineering Consult Pvt. Ltd delivering orientation talk on GESI issues in DRRM.

Group exercise

Following the presentation and question/answer session, there was a group exercise (Photograph 11-13). In this session, the participants from individual ward were divided into a group ward wise. Participants were asked to discuss the outcomes and answer the specific question developed for group exercise. The main objective of this group exercise is to make individual aware on existing hazard and risk as well as collect the feedback from the participant. The participants answered the well-structured questionnaire on frequently occurring hazard like earthquake, landslide and flood, possible contribution from community on DRRM, utilization of the hazard maps, future programs on DRRM, requirement of resources and facilities to mitigate disaster risk etc.

Photograph 0-15 Participants busy in a group exercise.

Closing Session

Mr. Yam Lal Giri from Birendranagar Municipality concluded the discussion. Mr Rajesh Shoni gave a final remark on behalf of Tayar Nepal Project/USAID. He stated that the outcomes of the project could be used to generate effective awareness and design fruitful preparedness using research findings.

ORIENTATION WORKSHOP

Introduction

An orientation Program was organized on 19th January 2022 at Birendranagar Municipality Conference Hall, Birendranagar, Surkhet. The program was organized within the municipality periphery to drive the maximum number of participation from the policy makers as well as stakeholders in Disaster Risk Management (DRM) from the municipality. The objective of this workshop is:

- To disseminate the findings of the study and orient representatives of local government and municipal officials

Participant

Due to the government rules/regulation on COVID-19, the program was attended by 25 participants including Mr. Dev Kumar Subedi, Mayor, Mrs. Mohan Maya Dhakal, Deputy Mayor, Mr. Hari Prasad Devkota, and Chief Administrative Officer (C.A.O) of Birendranagar Municipality (Photograph 11-15). Similarly, in the program there was participation of Mr. Prakash Poudel, DRR focal person of

Birendranagar Municipality. Technical officials Er. Bishal Adhikari, and Er. Tej Bahadur Sahi, from Municipality joined the program.

Photograph 0-16 Participants of the workshop.

Mr. Rajesh Shoni, Field Officer, TAYAR Nepal Project of USAID also joined the workshop and facilitated the program too. Dr. Upendra Baral, Senior Geologist, and Er. Helen Upadhyay, Civil Engineer were present from Geo Engineering Consult Pvt. Ltd.

Among the 25 participants, the majority number of participants were male (23 numbers: 96 %) while 4% were female participants (Figure 11:6a). Beside a single participant of below 30 years, remaining 24 were above 30 years age group (Figure. 11:6b). Based on the community group, there were 22 participants representing Brahmin/Chhetri community, 2 from Dalit and one from other group (Figure 11:6c).

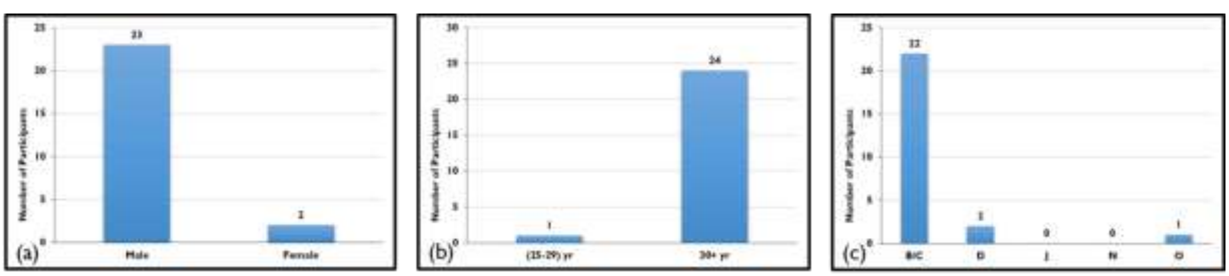


Figure 0:87 Distribution of participant based on (a) Sex (b) Age (c) Ethnic group. B/C: Brahmin/Chhetri; D: Dalit; O: Other

Event overview

The master of ceremony was Mr. Rajesh Soni from Tayar Nepal project of USAID. The program was chaired by Mayor Mr. Dev Kumar Subedi. The special guest of the program was Mrs Mohan Maya Dhakal, Deputy Mayor, Birendranagar Municipality. At first, Mr Rajesh Shoni underlined the current programs of Tayar Nepal project of USAID within the Birendranagar Municipality (Photograph 3). He mentioned the entire work stages of the project. On behalf of Tayar Nepal, he also expressed his sincere thanks to Geo Engineering Consult Pvt. Ltd. for their dedication on the work to make it happened rewardingly.

Introductory Session

The session was started with self-introduction of the participant. Mr. Rajesh Soni, Tayar welcomed all the participants and thanks all for their presence. He further stressed on the importance of the present study (Photograph 11-16).

Technical Session

Following the short introductory session, the floor was opened for the technical session. In this session, Dr. Upendra Baral from Geo Engineering Consult Pvt. LTD briefly shared the outcomes of the study (Photograph 11-17). After the presentation, the floor was opened for the discussion and suggestions from the participants. An exercise was also conducted using the specific questionnaire.

Photograph 0-17 Mr. Rajesh Shoni (Tayar Nepal) facilitating the program.

Photograph 0-18 Dr. Upendra Baral of Geo Engineering Consult Pvt. Ltd. presented the findings of the study.

Discussion Session

In this session, Dr. Baral explained all the queries raised from participants regarding the findings of the present study. Mayor Mr. Dev Kumar Subedi raised some of the issues regarding the proper implementation of the findings. The participants mentioned that there is a high risk of landslides in the hilly wards of Birendranagar municipality and the measures need to be taken to reduce it. Similarly, they mentioned that ward 6 and 8 also usually inundate due to the blockage of canals run through these wards. The plinth level of the structures should be implemented near the riverbank. From the maps, the participants clearly understand that south of the Karnali Highway the area is in higher risk of earthquake, so while constructing infrastructures special attention has to be paid. Ward 3, 9 and 10 are higher risk of multi hazard so municipality should take action while undertaking urban planning in those areas. The municipality should implement building bylaws as well as should allocate budget for hazard mitigation. It is emphasized that the local consulting firm and construction company should be informed on these findings.

Report Handover Session

On behalf of Municipality, Mr. Prakash Poudel DRR focal person handover the compiled list of each suggestion and comment raised by the participants to Dr. Baral of Geo Engineering Consult Pvt. Ltd., (Photograph 11-18).

Photograph 0-19 Dr. Upendra Baral received the compilation of suggestion/comments raised by the participants.

Closing Session

On behalf of Tayar Nepal Project/USAID, Mr. Shoni delivered a vote of thanks speech. Finally, the program was concluded with remark from Mr. Prakash Poudel, DRR Focal Person of Birendranagar Municipality and he greeted and thanked all the participants and especially Geo Engineering Consult Pvt. Ltd. for hard work and sharing the best results. Additionally, he thanked Tayar Nepal Project/USAID for conducting this important study (Photograph 11-19). He also mentioned that in near future the municipality would work the stakeholders to improve the building plan as well as better implementation of the study.

Photograph 0-20 Vote of thanks from Mr. Prakash Poudel of Birendranagar Municipality

Suggestion from Birendranagar Municipality

The following suggestion have been forwarded to Tayar Nepal Project/USAID, especially by the Mayor:

i. Preparation and dissemination of brochure of the finding therefore everyone easily get aware about the existing hazard and risk conditions.
ii. Preparation of an Atlas of the outcomes.
iii. Prepare a Nepali version of the report along with the action plan to municipality.
iv. Modify (in short form) this report as a manual form so everyone can use it while implementing the building bylaws.

12. PROGRESS AGAINST ACTIVITY TARGETS

SN.	ACTIVITIES	UNIT	TARGET	ACTUAL	EXPLANATION AND JUSTIFICATION FOR DEVIATION
1	Activity 1.1: Coordination meeting	Meeting	1	1	
2	Activity 1.2: Consultation workshop	Workshop	1	1	
3	Activity 1.3: Ward wise focus group discussion	Event	16	3	Due to COVID-19 pandemic and government's COVID-19 guideline.
4	Activity 1.4: Geological/Engineering geological mapping and geotechnical investigation	Map	2	2	
5	Activity 1.5: Ambient noise (microtremor) measurement and seismic microzonation	Sites	110	110	
6	Activity 1.6: Probabilistic Seismic Hazard Assessment	Map	2	6	Conducted additional investigations for detailed hazard assessment
7	Activity 1.7: Site survey and data collection	Ward	1 (i.e. ward 6)	1 (1847 buildings were surveyed	
8	Activity 1.8: Development of fragility curves	Report	1	1 (64 fragility curves were developed)	Developed more than expected fragility curve depending upon building typology
9	Activity 1.9: Damage distribution model and economic value calculation	Ward	1	1 (for two scenario of seismic hazard)	
10	Activity 2.1: Landslide hazard assessment	Map	1	40	Different approaches have been adopted and produced more maps than previously anticipated
11	Activity 2.2: Flood hazard assessment	Map	1	5	2, 10, 50, 100, and 500 year of return period have been considered.
12	Activity 2.3: Multi hazards assessment	Map	1	2	One more map has been produced to see the contribution of each hazard for multi hazard map
13	Activity 2.4: Workshop on sharing of the outcomes of the study	event	1	1	
14	Activity 3.1: Orientation to representative of local government and community people	event	1	1	

PROGRESS AGAINST INDICATORS

INDICATOR NO. AND NAME	QUANTITATIVE PROGRESS	EXPLANATION
Number of Geological map prepared/develop	2	As per the target, two geology related maps have been prepared, i.e. geological and engineering geological maps.
Number of assessments conducted (Seismic microzonation, seismic, Land slide, Flood and multi hazards)	53	Three thematic hazard assessments have been conducted, i.e. earthquake, landslide and flood. Altogether 53 maps were/figures were developed. Integrating seismic, landslide and flood hazard maps a multi hazard map of Birendranagar municipality has been prepared. Overall, through these activities, 53 maps were developed that is beyond the target.
T09: Number of innovations supported through USG assistance (STIR-10)	**3**	Three innovations have been established. These innovations are methodological for seismic hazard, landslide hazard and seismic risk assessment. First, an innovative method has been developed in seismic hazard assessment using seismic-microzonation techniques. Second, an innovative method has been developed on seismic risk assessment. Third, an innovative method for landslide hazard assessment has been developed using seismic force and rain fall data to compute factor of safety and run out simulation.
T02: Number of people trained in disaster preparedness (includes DRRM) as a result of USG assistance (HA.2.1-1)	**171**	During the project period, four events (consultation workshop, ward wise discussion, outcomes sharing workshop and orientation workshop) were organized focusing on the DRRM sensitization. Altogether 171people trained on DRRM issues in these events. Due to strict health protocol, limited number of participants were involved.
T03: Number of persons trained with USG assistance to advance outcomes consistent with gender equality or female empowerment through their roles in public or private sector institutions or organizations (GNDR-8)	**46**	The project is of technical type and mainly focused on innovation establishment. Therefore, there were less interaction with the community. However, in different consultation and outcomes sharing events, significant female participants were involved. Altogether 46 female participants were involved and get acquainted on status of multi hazard in Birendranagar municipality and established innovations.

MAJOR ACHIEVEMENTS AGAINST GESI PLAN

- Underrepresentation of women, persons with disability, Dalits and Janajatis in the coordination meeting and consultation workshop from among the municipal staff as there was limited diversity among the total municipal staff relevant to the DRR field.
- GESI issues (agendas) were not identified and discussed in any part of the meeting and the workshop.
- Participation from elderly population was limited. Few of Ward Chairs belonged to elderly population.
- Representation of persons with disability could not be made possible in any of our activity. Since our expert, intern and trainee should have technical knowledge it became very hard for us to incorporate persons with disability who met our needs.
- LGBTIQ+ community also could not be represented in any of our activity. Blue Diamond Society of Birendranagar was contacted for volunteers for site survey and data collection but we did not get an enthusiastic response.
- There was no representation of persons with disability in the orientation and consultation workshops. It is due to their lack of presence in ward committee and disaster management committee.
- There are very limited women expert and from other excluded groups in technical task.

13. SUCCESS STORIES

TAYAR NEPAL BUILDS CAPACITY THROUGH KNOWLEDGE SHARING

USAID/Nepal's Tayar Nepal has provided grant support to Geo Engineering Consult Pvt. Ltd. to implement a 12 months project titled, 'Establishing the Innovative Method for Seismic Hazard and Risk Assessment through Seismic Micro zonation Study and their integration in Multi Hazard Assessment". The prime objective of the grant is to develop innovative and effective method for seismic micro zonation study, seismic hazard, and risk assessment against the overdue earthquake event in Birendranagar, Surkhet. In all the activities executed till date in the project and in the activities that are still to be accomplished, Gender Equality and Social Inclusion (GESI) has been a prerequisite.

In our recent activity 'Site survey and data collection' for building survey in Birendranagar, Surkhet, Mr. Sarpa Raj Pandey was involved as one of the two trainees. Mr. Pandey, 28, is a permanent resident of Kalikot district of Karnali province. In this activity, a data collection application called KoBoToolbox was used. He received one day training on the use of this application. Similarly, with the support of Er. Bibek Shrestha, He also received two days training on data collection for building survey. He had never participated in any trainings and survey like this before and expressed gratitude to be able to learn them. He devotedly involved himself in building survey and data collection for forty three days. He later shared "This survey has been more than a job to me. It taught me to use software applications that I had never imagined I would ever use. I got to learn about building survey and my senior engineers also shared some theoretical aspect of survey to me. From this job I also got to learn about disaster risk management. No job I had earlier gave me this much knowledge."

Photograph 0-21 Photograph 1 Mr. Pandey doing Schmidt hammer test.

Photograph 0-22 Mr. Pandey measuring the size of column.

TAYAR NEPAL TRANSFERS AN INNOVATIVE TECHNOLOGY TO LOCAL GOVERNMENT FOR SEISMIC MICROZONATION

USAID/Nepal's Tayar Nepal has provided grant support to Geo Engineering Consult Pvt. Ltd to establish the innovative method for seismic hazard and risk assessments through seismic microzonation study and their integration in multi hazard assessment. The principal focus of Geo Engineering Consult Pvt. Ltd under this grant is to assess multi hazards analysis by establishing innovative methods on seismic, flood and landslide hazard in the Birendranagar municipality. One of the key activities under this grant is to aware local government and technical officials at local level on innovative tools and techniques.

Since western part of Nepal is in threat of another devastating earthquake, USAID through Tayara Nepal Project, decided to carry out seismic microzonation study through innovative technique of ambient noise measurement in rapidly urbanizing Surkhet valley. An array and single point ambient noise measurement was carried out from 15th February to 9th April in Surkhet valley of Birendranagar municipality by Geo Engineering Consult team. The main aim of ambient noise measurement is to depict the city into various zones based on seismic characteristic, e.g. average shear wave velocity at 30 m depth, fundamental frequency and wave amplification factor. As per the objective of the project, a visit of Mr Dev Kumar Subedi, Mayor, Tika Ram Dhakal, Chief Administrative Officer (CAO), engineers and other officials of municipality visited the measurement sites at Bhairavsthan on April 7, 2021 (Photograph 14-3).

Photograph 0-23 Geophysicist, Geo Engineering Consult Pvt. Ltd. briefing the ambient noise measurement technique to the municipal team.

Geo Engineering Consult team demonstrated the innovative approach of seismic microzonation study through ambient noise measurement. During the demonstration, as a technology transfer, a detailed methodology, data acquisition, expected outcomes and application of the results have been explained to the municipal team. In addition, both active line array and passive circular array were demonstrated in the site (Photograph 14-4). The importance of microtremor and its advantages over the other seismic methods like zero destruction in nature, environment friendly, easy to measure in urban area and inexpensive were briefed. The queries raised by the municipal team were also addressed by Geo Engineering Consult team. The municipal technical team were provided with the demonstration on data acquisition, analysis and interpretation.

Photograph 0-24 Geophysicist, Geo Engineering Consult Pvt. Ltd. demonstrating the active seismological survey technique to the municipal team.

The municipal team has shown immense interest on the technique and pleased with the demonstration. Mayor and other officials were of opinion that this innovative technique could also be useful for other municipalities located in the valley and Terai of Nepal to minimize seismic risk, which they were facing and helpful for them to formulate evidence based policy and plan. With this successful technology transfer, Mr Hari K.C., civil engineer, Birendranagar municipality was delighted to get acquainted with the innovative technique that is very much useful even in the urban area.

Photograph 0-25 Geophysicist, Geo Engineering Consult Pvt. Ltd. demonstrating the data analysis technique to the municipal team.

14. INNOVATIONS

INNOVATION-1
PROBABILISTIC SEISMIC HAZARD ASSESSMENT UTILIZING SHEAR WAVE VELOCITY DERIVED THROUGH AMBIENT NOISE MEASUREMENTS

The Himalayas is located in the seismically active region in the world. Nepal, located in the central part of the Himalaya, witnessed several devastating earthquakes in the past, e.g., 1934 Bihar-Nepal earthquake, 1988 Udayapur earthquake and 2015 Gorkha earthquake. The recent 2015 Gorkha earthquake caused significant damages to the buildings and civil engineering infrastructures in the central Nepal. Birendranagar Municipality lies in the Himalayan seismic gap, a potential source of earthquake event. The Main Himalayan Thrust (MHT) has not ruptured since 1505 and has potential to generate large earthquakes. To assess the risk of the residential buildings due to impending earthquake in western Nepal, a detail seismic hazard assessment method has been developed in an innovative way considering Birendranagar municipality as a pilot area.

In Nepal, a classical approach of probabilistic seismic hazard assessment (PSHA) is in practice. The classical approach usually adopted the literature based Vs30 value, which don't capture the seismic site effects realistically as a result there is always over or underestimate of earthquake hazard. However, in this innovation, different method is developed, in which detailed microtremor (ambient noise) measurement is required using highly sensitive seismographs and average shear wave velocity at 30 m depth (Vs30) should be estimated (**Error! Reference source not found.**). The obtained Vs30 values are utilized in G round Motion Prediction Equations (GMPEs) to compute the seismic hazard at ground surface. This approach has been successfully tested and implemented in Birendranagar municipality and developed seismic hazard maps for both at bedrock level and ground surface.

The classical approach of PSHA has been changed with the introduction of seismic microoznation study using ambient noise measurement. The utilization of ambient noises enable us to determine Vs30 of the site that characterizes the site seismically. The classical approach of PSHA has been replaced by seismic microzonation technique and utilization of Vs30 values in GMPEs. This innovative methodology has also been shared with the technical officials of Birendranagar municipality, which has certainly strengthened the capacity of local government in seismic hazard and risk assessment at municipal level.

The classical approach of PSHA does not consider seismic microzonation and do not use measured value of Vs30 before. The use of Vs30 has changed the hazard result significantly in a realistic way. For example, Figure 1 shows hazard level at bedrock without use of Vs30, while Figure 2 shows hazard level by introducing realistic Vs30 values. The hazard level and resulting pattern are completely different in these two maps. Peak ground acceleration (PGA) at bedrock is about 0.4g while at ground surface is around 0.75g in the valley part of Birendranagar municipality (Figure 15:1and.15:2). In Figure 15:1, high hazard level can be seen in the valley as compared to peripheral rocky terrain. The reason for these variation of hazard level and pattern is amplification of acceleration due to introduction of actual Vs30 values that usually reflect the local site effects of geology. These differences in PGA clearly reflect the effects of Vs30 in PSHA. And it is true that the amplification of seismic wave's energy is higher in soft soil than the bed rock, which has been clearly observed in the outcomes of the present study. Thus, for the first time in Nepal, integration of seismc microzonation in PSHA has been done innovatively.

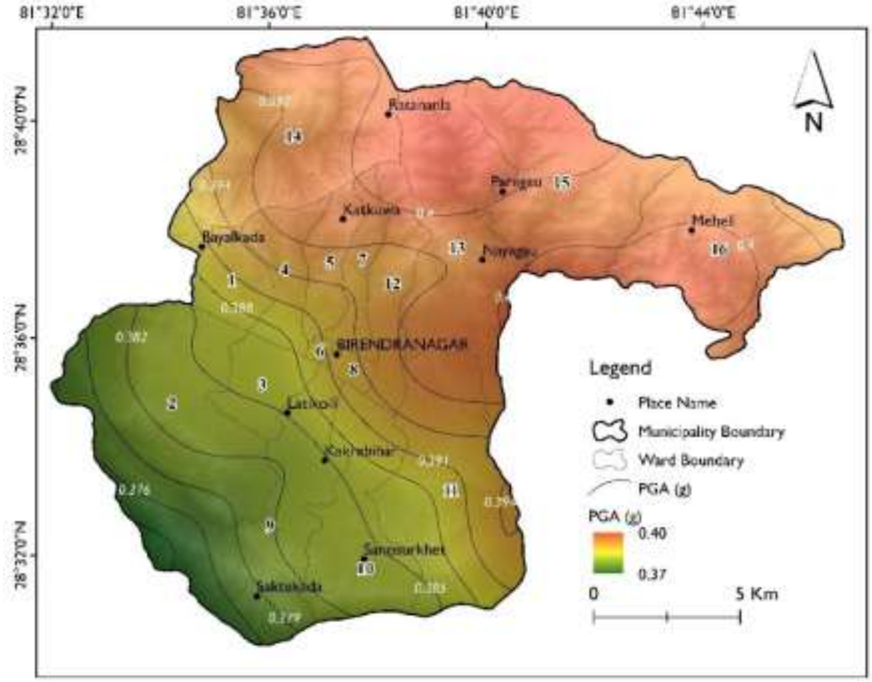


Figure 0:88 Peak ground acceleration (PGA) map at bedrock for Birendranagar municipality at 10% probability of exceedance.

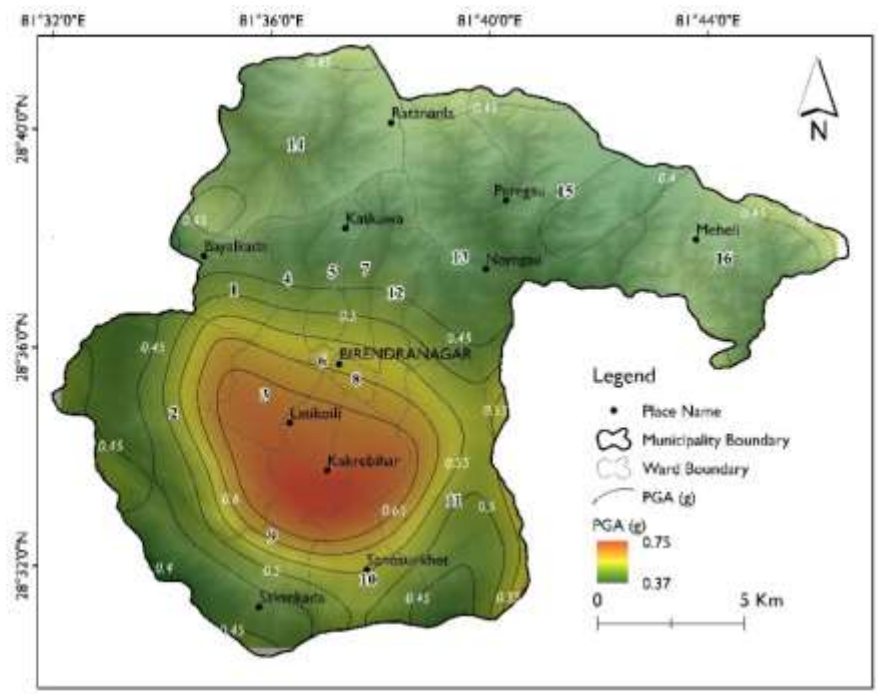


Figure 0:89 Peak ground acceleration (PGA) map at ground surface for Birendranagar municipality at 10% probability of exceedance.

INNOVATION-2
DEFINING NEW BUILDING TYPOLOGIES, DERIVATION OF THEIR FRAGILITY FUNCTIONS, DAMAGE DISTRIBUTION, AND ECONOMIC LOSS CALCULATION FOR RESIDENTIAL BUILDINGS

Evaluation of earthquake vulnerability of buildings can be carried out by employing fragility curves. Fragility curves represent the probability of exceedance of a certain limit state, of a given type of building, for a given intensity measure. Seismic response of a building can vary depending upon a few different parameters. The buildings in a certain locality can be grouped together based upon the aforementioned parameters such that buildings in the group demonstrate similar response to a ground motion field. Each such group of buildings can be identified as a distinct Building Typology. Each separate building typology defines the level of vulnerability of buildings in that group to seismic events. Fragility curve derived for a building typology can be employed to determine the probability of exceedance for a given limit state or a damage state of that typology.
For the purpose of earthquake loss estimation studies, it is important to group buildings of similar expected vulnerability into distinct categories. These categories can be termed as building typologies. There are existing building classification schemes, such as MSK-64, and EMS-98. These existing classifications mainly focus on building construction material and overlook other factors that might play a role in determining building vulnerability, such as building height. Among various different factors, the following factors were considered to be primary attributes in categorizing building vulnerability types: a. *building structural system* (viz, frame structure or load-bearing masonry structure), b. *building construction material* (reinforced concrete, brick/stone masonry in cement/mud mortar, adobe, etc.), c. *building height* (story height and number of stories), and d. *building diaphragm* (floor and roof construction material and type). These factors were considered in development of building typology classes for performing seismic risk assessment of Birendranagar Municipality ward-6 using the probabilistic seismic hazard assessment based on seismic microzonation technique.

It is expected that the building typology classification system developed in this project can also be utilized for identification of building vulnerability classes all over the country.

The fragility functions developed should be usable by local level technical manpower (e.g., municipal engineers) to perform a quick vulnerability assessment for building stocks located in their jurisdiction, both for the purpose of performing a technical analysis, as well as to illustrate the capacity of different types of building to resisting seismic forces to their community. A layperson, with some training, should be able to use the fragility curves to understand vulnerability level of a given building typology.

The fragility function should further be usable by local level technicians, with some training, to perform damage distribution and economic loss forecast in conjunction with ground motion data.

Although building vulnerability classes based upon MKS-64 and EMS-98 have been employed to define building typologies of building stocks all over Nepal, these systems primarily focus on building construction material while largely overlooking other sensitive aspects such as building height, number of stories, and type of floor diaphragm. The typologies defined in this project address such shortcomings in the previously defined vulnerability classes.

The newly developed approach of building typology classification is more scientific than older, generalized approach. It follows that further works based upon this innovative building classification system (fragility functions, damage distribution and economic loss calculations) are also innovative.

INNOVATION-3
AN INNOVATIVE ENSEMBLE METHOD OF LANDSLIDE HAZARD ASSESSMENT THROUGH COUPLING OF RAINFALL AND SEISMIC FORCE

Nepal's urbanization process is rapid and imbalance compared to regional context. A rapid increase in the development of roads, electricity, and reservoirs with little or no regard for natural risks has significantly contributed to the unleashing of landslides in the Himalayan highlands. Similarly, due to significant growth in population throughout the Birendranagar Municipality over the last three decades, the tendency of dwelling in somewhat dangerous places is on the upswing. Seismic factor of hillslope is very important in the Himalayan terrain but in previous methods, seismic factor did not take into the account to evaluate hill slope. The potential of hillside collapse in those steep and susceptible basins grows when torrential rain and runoff descend upon slopes destabilized by the tremor and successive waves. There are fissures in the hills above the road due to the earthquake, so there is a possibility of a catastrophic landslide. In earthquake prone areas, susceptibility assessments of hill slope stability is very important to support safety planning, disaster management, and hazard mitigation. It is crucial to consider the effects of natural hazards on this type of infrastructure to prevent or mitigate damage to property and people.

This study presents a complete set of methods and applications for assessment of landslide hazards. The proposed method of landslide susceptibility assessment comprised a physical module, a statistical module, and an ensemble module. This study was performed in three steps: 1) collection of landslide inventory data and the causative factor (CF) database; subjecting the inventory to the machine-learning MaxEnt model to delineate landslide-susceptible areas 2) deterministic modeling coupling rainfall and seismic data to find factor of safety (FS) and 3) integrate the above mentioned outcomes to find the landslide initiation area and assess landslide propagation zones. For the determination of factor of safety (FS) of a hill slope, a script was developed to calculate the depth of saturation in different scenario of rainfall which was used along with other strength parameter to determine the Factor of Safety. Digital data processing mainly includes digital elevation model (DEM)-based parameterization for modelling. Average factor of safety map were prepared and variance of safety factor was calculated. Finally, probability maps of various rainfall scenarios were prepared.

The technology transfer to the local governmental officials enhances the level of capacity to lead and implement systems and policies to effectively manage landslide disaster risk.

In the authoritative researches, the landslide hazard only consider landslides in probabilistic manner. This research introduces the physical-based pseudo static model, which incorporates rainfall return periods and corresponding runout propagation. In this research, it is also focused in evaluating hillslope stability in Birendranagar Municipality considering earthquake under a historical heavy rainfall event, which could be responsible for landslide events. An innovative ensemble method was developed to find the landslide source area by coupling machine learning, Maximum Entropy (MaxEnt) and pseudo-static models. This approach is innovative in landslide hazard assessment.The landslide susceptibility map is presented in Figure 1. Figure 2 shows the distribution of FS of 100-year extreme rainfall and peak ground acceleration at 10% of exceedance in 5o years.

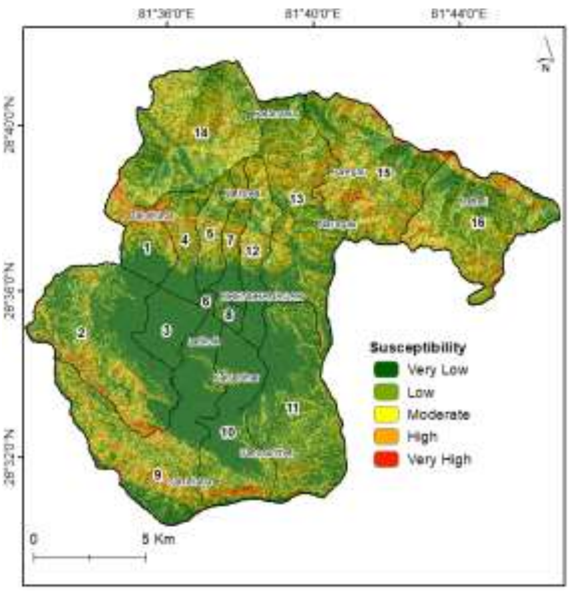


Figure 0:90 Landslide susceptibility using MaxEnt.

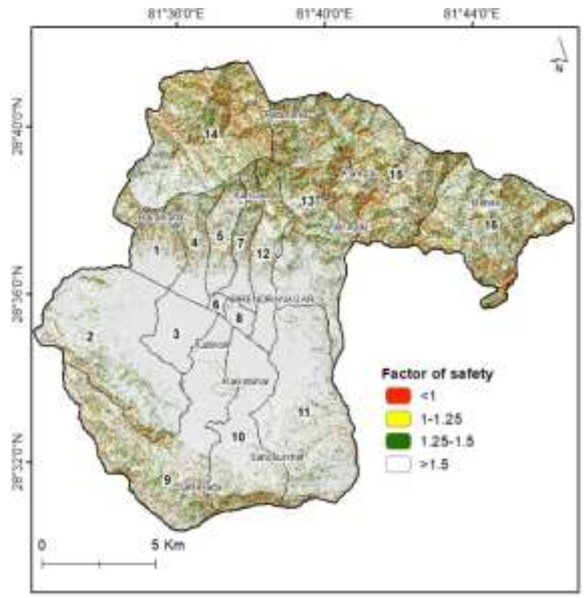
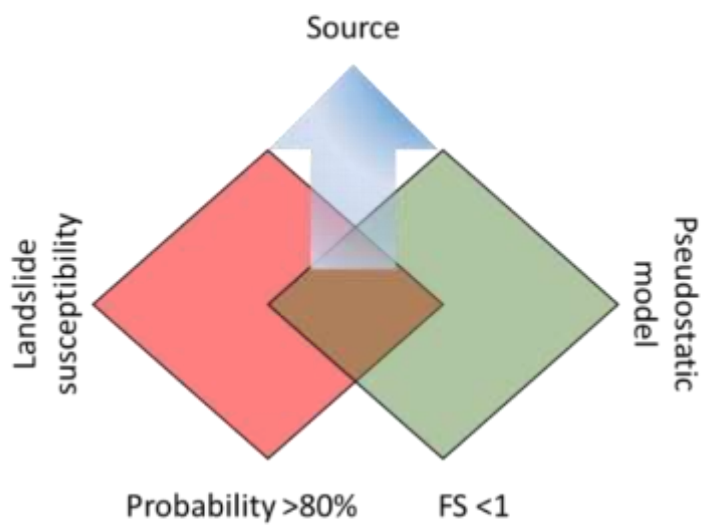


Figure 0:91 FS of 100-year extreme rainfall and peak ground acceleration at 10% of exceedance in 5o years.

There is no a straightforward method to classify landslide susceptibility zones because there are no statistical rules for categorizing continuous data automatically. In this study, an assumption was made that the classification method should satisfy the principle that higher landslide susceptibility classes capture more or most of the landslide occurrences. For the selection criteria for landslide source area, a combination of 80% probability of occurrence landslide cutoff value from landslide susceptibility map (which captures most of the landslides) and the hill slope area which has a factor of safety less than one (FS<1 mean unstable zone under calculated rainfall and earthquake scenario) has selected as highly vulnerable hill slope condition as shown in Figure 3. With introduction of these novel approaches, an innovation has been developed on landslide hazard assessment taking Birendranagar Municipality as a pilot area.



15. CHALLENGES AND LESSON LEARNED

CHALLENGES

1. The major challenge was on survey of individual buildings in Ward-6 of Birendranagar Municipality as some of the house owners did not permit for detail inspection and data collection. The issue was solved by explaining the purpose of the study and showing the authorization letter from Birendranagar municipality.
2. The seismic microzonation is one of the principal components of the project. The measurements had to carry out in more than 100 sites for detail investigation for seismic microzonation in terms of average shear wave velocity at 30 m depth, fundamental frequency and amplification factor. The main challenge was permission to conduct measurement in private land and restricted area like security agencies, airport etc. It was really hard to make understand people on the work Geo Engineering Consult is doing and seismic microzonation. However, the proper orientation to the landowner and authorization letter from the municipality made it possible to conduct measurements in those areas smoothly.
3. The COVID-19 pandemic was another challenge in the implementation of the project. There were health issues of the staffs and expert as they were tested positive with COVID-19 as a result the stipulated time duration was not enough to accomplish the proposed activities. This challenge was overcome by mutual understanding with Tayar Nepal project/USAID with the provision of no-cost-extension for the required time duration.
4. This grant program requires significant participation of stakeholders and community people. Due to COVID-19 pandemic, there was difficulty in organizing orientation training, workshop and other community oriented programs. The implementing agency was compelled to reduce the number of participants and merged the similar kind of activities to achieve the goals.

LESSON LEARNED

1. Since the project was an innovative and aimed to introduce new technology in seismic hazard and risk assessment along with multi hazard assessment. In such specialized techniques, it is difficult to find women experts to contribute to the project as a result GESI requirement were not fulfilled in the expected level. It is, therefore, better to add a component to build up capacity through hands-on training during the project implementation for developing human resources in the specialized theme.
2. According to the program objectives, there were fixed participants therefore, it was difficult to achieve the meaningful participation in the project activities. For example, there was a DM sensitization workshop for local government representatives. However, there are very limited women in local government, therefore, it was difficult to maintain meaningful participation of women and marginalized people, janajati, people with disability etc. It is learned that while formulating project activities, it is better to conduct a preliminary survey and proposed stakeholder and nature of participants.
3. While framing the time schedule, it is better to envision the possibility of disasters and their mitigation plans for effective implementation of the project.

16. ANNEXES

ANNEX 1: GESI PLAN REPORTING FRAMEWORK

PROJECT ACTIVITY	GESI GAPS/ ISSUES IDENTIFIED	ACTIONS TAKEN TO MITIGATE/ ADDRESS THE GAPS	RESULTS OF THE ACTIONS (ACHIEVEMENTS/NON-ACHIEVEMENTS)
Co-ordination Meeting	• Underrepresentation of women, persons with disability,Dalits and Janajatis. • GESI related agenda and discussion were not given priority.	• Request was submitted to the municipal government to ensure inclusive participation ensuring representation of women and other excluded groups.	Non-Achievements • Underrepresentation of women and other excluded groups as our participants of co-ordination meeting were only municipal officials.
Consultation workshop	• Underrepresentation of persons with disabilities and elderly population. • GESI related agenda and discussion were not given priority.	• Special emphasis was given to invite women,persons with disability,Dalits and Janajatis.	Achievements There were forty-five participants including Mayor, Mr. Dev Kumar Subedi and Deputy Mayor, Mrs. Mohan Maya Dhakal in the consultation workshop. Similarly, Mr. Teeka Ram Dhakal, Chief Administrative Officer and Mr. Prakash Poudel, Disaster Risk Reduction (DRR) focal person along with other municipal officers were also present at the workshop. Out of forty five participants thirty two were male and thirteen were female making male and female participation 72% and 28% respectively. Four participants were linked to Dalit community among which one was female. Similarly, four participants belonged to Janajati community. One male representative from Newar community,too joined the workshop. A total of thirty four participants from Brahmin/Chhetri community were present at the workshop out of which twenty two were male and twelve were female.The maximum number of participants belonged to 30+ years age group. Thirty male and nine female participants were above thirty years of age while two young girls of (15-19) years age group also demonstrated their participation in the workshop. The number of female in the age group (25-29)years is two while male is one.One male participant with

			physical disability belonging to 30+years age group also took part in the workshop. There was an active participation of ward chairs as well. Eleven out of sixteen ward chairs were present at the workshop. Representatives from Nepal Red Cross Society, I/NGOs also joined the workshop. Sixteen participants belonged to social organization among which six were female. <u>Non-Achievements</u> • Meeting could not be conducted in user friendly venue due to lack of availability of venue. • Meaningful participation of women and other excluded group could not be experienced. Thus in coming programs we will to encourage them to be proactive and express their views.
Geological/Engineering geological mapping	• Limited women expert and from other excluded groups for field work.	• Women participation was practiced in data verification, analysis and mapping.	<u>Achievements</u> • Further human resource has been created in geological mapping.