LANDSLIDE RISK ASSESSMENT OF CHEPE RIVER CORRIDOR, GANDAKI RIVER BASIN, NEPAL

A Dissertation Submitted to

CENTRAL DEPARTMENT OF ENVIRONMENTAL SCIENCE

Institute of Science and Technology
Tribhuvan University
Kirtipur, Kathmandu, Nepal

In Partial Fulfilment of the Requirements for the Award of Degree of M.Sc. in Environmental Science

By
Kripa Shrestha

June, 2018

Landslide Risk Assessment of Chepe River Corridor, Gandaki River Basin, Nepal.

–Shrestha, K.

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By
Kripa Shrestha
TU Registration no.: 5-2-453-203-2011
TU Exam Roll no: 518

June, 2018

DECLARATION

I hereby declare that the work presented in this dissertation is a genuine work done originally by me and has not been submitted anywhere for the award of any degree. All the sources of information have been specifically acknowledgement by reference to the author(s) or institution(s).

……………………………………

Kripa Shrestha

Date: 29th June, 2018

TRIBHUVAN UNIVERSITY
Central Department of Environmental Science

Tel No: 4-332147
4-332711

Date: 29th June, 2018

RECOMMENDATION

This is to certify that Ms. Kripa Shrestha has completed this dissertation work entitled **"Landslide Risk Assessment of Chepe River Corridor, Gandaki River Basin, Nepal"** as a partial fulfilment of the requirements of M.Sc. in Environmental Science under our supervision and guidance. To our knowledge, this research has not been submitted for any other degree, anywhere else.

We therefore, recommend the dissertation for acceptance and approval.

Supervisors:

……………………………………
Udhab Raj Khadka, PhD
Central Department of Environmental Science,
Tribhuvan University
Kirtipur, Kathmandu, Nepal

…………………………………….
Mandira Singh Shrestha, PhD
Program Co-ordinator-Hi-RISK
River Basins and Cryosphere
ICIMOD

TRIBHUVAN UNIVERSITY
Central Department of Environmental Science
Kirtipur, Kathmandu, Nepal

Tel No: 4-332147
4-332711

Date: 29th June, 2018

LETTER OF APPROVAL

On the recommendation of supervisors "Dr. Udhab Raj Khadka" and "Dr. Mandira Singh Shrestha" this dissertation submitted by **"Ms. Kripa Shrestha"** entitled **"Landslide Risk Assessment of Chepe River Corridor, Gandaki River Basin, Nepal"** has been approved for the examination and submitted to the Tribhuvan University in partial fulfilment of the requirements of M.Sc. in Environmental Science.

…………………………………….
Rejina Maskey, PhD
Professor and Head

TRIBHUVAN UNIVERSITY
Central Department of Environmental Science
Kirtipur, Kathmandu, Nepal

Tel No: 4-332147
4-332711

Date: 13th September, 2018

CERTIFICATE OF ACCEPTANCE

This dissertation entitled **"Landslide Risk Assessment of Chepe River Corridor, Gandaki River Basin, Nepal"** submitted by **"Ms. Kripa Shrestha"** has been examined and accepted as a partial fulfilment of the requirements of M.Sc. in Environmental Science.

Evaluation Committee

……………………………………..
Udhab Raj Khadka, PhD
Supervisor
Central Department of Environmental Science,
Tribhuvan University
Kirtipur, Kathmandu, Nepal

……………………………………..
External Examiner
Vishwas Chitale, PhD

……………………………………….
Mandira Singh Shrestha, PhD
Supervisor
Program Co-ordinator-Hi-RISK
River Basins and Cryosphere
ICIMOD

……………………………………..
Internal Examiner
Asst. Prof. Man Kumar Dhamala, PhD
Central Department of Environmental Science
Tribhuvan University
Kirtipur, Kathmandu, Nepal

....
Prof. Rejina Maskey, PhD
Internal Examiner
Head
CDES, TU
Kirtipur, Kathmandu,

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Kripa Shrestha

June, 2018

ABSTRACT

Landslide is one of the major type of natural disaster that causes loss of life and property in Nepal. The landslide risk assessment using GIS and remote sensing tools identifying hazard, vulnerability and risk are very useful for disaster risk reduction and management. The study was carried out in the Chepe river corridor using two landslide hazard models which were compared for the evaluation of the performance of the hazard model in the small area like a river corridor. In this study, the Statistical Index Model and Logistic Regression Model were applied, within a geographical information system (GIS), to derive landslide hazard map of the Chepe river corridor. Eleven factors were considered as possible triggering factors for the hazard assessment. In order to validate both the models, Receiver Operating Characteristic (ROC) was used which shows that logistic regression has 82% prediction accuracy whereas Statistical Index model has 63% prediction accuracy. The logistic regression model seems to have extensive applicability in river corridor of Nepal than statistical index method using eleven causative factors. For the vulnerability assessment, the analysis of fourteen indicators were done to obtain the vulnerability score following the Local Disaster and Climate Resilience Planning (LDCRP) guideline. 10 wards were found to be low vulnerable whereas 8 wards were observed to be medium vulnerable. No wards were found to be highly vulnerable to landslide till date. Similarly, most of the area lies in medium risk zone i.e. 16.59 km^2 followed by high, very high and low risk area in the Chepe river corridor.

Keywords: *Corridor, logistic regression, risk, river, statistical index, vulnerability*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

ACRONYMS AND ABBREVIATIONS

ADPC	Asian Disaster Preparedness Center
AKDN	Aga Khan Development Network
AUC	Area Under Curve
DEM	Digital Elevation Model
DHM	Department of Hydrology and Meteorology
GEE	Google Earth Engine
Arc GIS	Aeronautical Reconnaissance Coverage Geographical Information System
GoN	Government of Nepal
GPS	Global Positioning System
HI-AWARE	Himalayan Adaptation, Water and Resilience
HRRP	Housing Recovery and Reconstruction Platform
ICIMOD	International Centre for Integrated Mountain Development
ILC	Irrigation Line of Credit
ILO	International Labor Organization
IRDR	Integrated Research on Disaster Risk Programme
Kml	Keyhole Markup Language
LDCRP	Local Disaster and Climate Resilience Planning
LHI	Landslide Hazard Index
LHMs	Landslide Hazard Models
LSMs	Landslide Susceptibility Models
MoFE	Ministry of Forest and Environment
MoHA	Ministry of Home Affairs

MoLRM	Ministry of Land Reform and Management
NARC	National Agriculture Research Centre
ROC	Receiver Operating Characteristic
SRTM	Shuttle Radar Topography Mission
UNISDR	United Nations International Strategy for Disaster Reduction
VA	Vulnerability Assessment
VDC	Village Development Committee
WB	World Bank

CHAPTER 1: INTRODUCTION

1.1 Background

Nepal's varied topography makes it susceptible to climate-related disasters and it experiences a range of natural hazards, some of which occur yearly e.g., floods and landslides whereas others occur less frequently (earthquakes) (UNDP, 2009). Disasters triggered by natural hazards cause heavy loss of lives, properties and also the unparalleled threat to sustainable development. Nepal ranks 23rd in terms of total natural hazard related deaths globally for the year 1988-2007 with more than 7000 deaths (Baruwal, 2014). Nepal ranks 11th in the world in terms of vulnerability to earthquakes and 30th in terms of water-induced hazards such as flood and landslides (UNDP, 2009) and the country falls in the top 20th list of the most multi-hazard prone countries in the world (Dangal, 2011). The effects of climate change and extremes have further aggravated the disaster vulnerability in Nepal. In this way, Nepal is one of the most disaster-prone countries in the world. Despite of some good practices and disaster risk reduction (DRR) initiatives, the frequency and intensity of disasters are observed to be in increasing trend. MoHA and DpNet-Nepal (2015) stated that the various studies and reports over the last 33 years have shown that each year, floods, landslides, fires, avalanches and epidemics kill hundreds of people and destroy property worth billions of rupees and the extreme weather events associated with heavy rainfalls are the principal cause of cascading natural disasters in Nepal.

Landslides are recognized as the third type of natural disaster in terms of worldwide importance. Most of the damages and a considerable proportion of the human losses associated with earthquakes and meteorological events are caused by landslides (Guzzetti et al., 1999). Due to the unique combination of active tectonic setting, high rates of weathering and abundant rainfall, human interference in the form of rapid urbanization and infrastructure development, it is considered to be a major natural hazard in Nepal. Landslides in Nepal are the country's costliest and deadliest type of natural disaster, but their management is still seen as low priority (IRIN, 2013). Landslide susceptibility, vulnerability and risk maps are vital for disaster management and for planning development activities in the mountainous country like Nepal. The new tools like remote sensing and GIS will help to improve the quality of landslide maps, with positive effects on all derivative products and analyses, including erosion studies and landscape modeling, susceptibility and hazard assessments, and risk evaluation (Guzzetti, 2012).

Landslide hazard zonation techniques can be subdivided into direct and indirect methods. The direct mapping of the geomorphologies is based on the experience and knowledge of terrain conditions determining the degree of susceptibility directly whereas in the case of indirect mapping, it basically uses either statistical models or deterministic models to predict landslide prone areas, based on information obtained from the interrelations between landslide conditioning factors and the landslides distribution (Khanh, 2009). GIS is appropriate for indirect susceptibility mapping, in which all possible landslide contributing terrain factors are combined with landslide inventory map, using data-integration techniques (Chung et al., 1995). Modeling is important method for the studying of many aspects of physical geography which allows the use of mathematical expressions to represent the behavior of particular geographical systems. Available information and basic knowledge of landslides have been applied in the process of model creation and defining of places with the highest landslide risk and all the created models are very powerful tools for describing and assess not only landslides but natural phenomena as well (Vozenilek, 2000).

Risk assessment is the final goal of many landslide investigations which lays at the fuzzy boundary between science, technology, economy and politics, including planning and policy making. The assessment of landslide risk is a complex and uncertain operation which requires the combination of different techniques, methods and tools, and the interplay of various expertise such as geology and geomorphology, engineering and environmental sciences, meteorology, climatology, mathematics, information technology, economics, social sciences and history. Though there is the indisputable importance of landslide risk evaluation for decision making, comparatively very less efforts have been made to establish and systematically test methods for landslide risk assessment and as well as to determine their advantages and limitations (Guzzetti, 2012). The study in Chure area also recommended that the area identified as the most susceptible for landslides should be given first priority for the prevention and mitigation measure through structural and nonstructural interventions (CDES, 2014).

1.2 Rationale

MoFE (2010) stated that the overall vulnerability of Lamjung district is very high with the index ranging from 0.100 to 0.787. The district is considered highly vulnerable to landslide, rainfall, temperature and glacial lake outburst flood (GLOF). Landslide occurrence was noted highest in the year 2001 when it occurred 17 times and comprised 16% of total human death, 6% of houses destruction and 4 % were affected. During 2001 to 2011, landslide is calculated as the most vulnerable cause causing the loss of life and property (DCEP, 2014). Similarly, Gorkha is also the another district which is prone to landslides and the earthquake of 25th April, 2015 and its aftershocks triggered many new landslides, often in locations not previously affected (Shrestha et al., 2016). The varieties of hazards have been increased and especially landslide is calculated as the most vulnerable cause in case of Nepal. The major purpose of this study is to assess the landslide hazard and risk along the Chepe river corridor touching the boundary of Lamjung and Gorkha district. Since this area is unexplored in term of landslide risk assessments, this study will provide the information about the landslide hazard, vulnerability and risk area along the river corridor. Landslide causing the loss of life and property is not new in the history of Nepal. The study of landslide in the river corridor should not be underestimated as it can cause a huge destruction. The major motive of doing this study is to observe the number and condition of landslide and assessing the causative factors. This study will contribute towards the methodological approach of landslide risk assessment in similar river corridor as well. Additionally, this study will identify the landslide risk which can be helpful in mitigating the impact of landslide towards life, property and development within Chepe River corridor.

1.3 Research Questions

- **i.** What are the characteristics (type and number) of landslide in the Chepe River corridor?
- **ii.** What are the significant triggering factors of landslide in the river corridor?
- **iii.** Which is the relevant model for the hazard assessment of landslide in the river corridor?
- **iv.** What is the risk associated with the landslides in this river corridor?

1.4 Objectives

General Objective

To assess the landslide hazard, vulnerability and risk along the Chepe River corridor.

Specific Objectives

i. To prepare the inventory of landslides with their spatial distribution in Chepe River corridor.

ii. To assess the significant factors responsible for the landslide along the corridor.

iii. To validate and compare Landslide Hazard Index models.

iv. To analyze hazard, vulnerability and risk of the river corridor.

1.5 Limitations

i. The factors like soil type, soil depth, vegetation density, stream power index etc. that trigger the landslide aren't considered in this study due to the time constrain.

ii. Crack version of Arc GIS 10.2 is used.

CHAPTER 2: LITERATURE REVIEW

Nepal is exposed to a variety of natural hazards and human induced disasters. More than 80 percent of the total population of Nepal is at risk of natural hazards such as floods, landslides, windstorms, hailstorms, fires, earthquakes and Glacial Lake Outburst Floods (GLOFs) (MoHA & DpNet-Nepal, 2017). A massive landslide took place in Jure, Sindhupalchowk district during 2014 which killed 33 people, 123 people have been missing and 478 families were affected from that unfortunate event. In the year 2014, about 113 people died in the whole country due to landslides (MoHA & DpNet-Nepal, 2015). The Hill region, including the Siwaliks (or the Churia Range) experiences regular landslides, debris flow along creeks and steep slopes, flooding in the lower stages of river terraces and erosion of river banks during the monsoon (ISDR, 2009). According to the study by Bhattarai et al. (2002), a total of about 12,000 small and large-scale landslides occur in Nepal every year, most of which often remain unnoticed and unreported mainly because of an inadequate information system, little economic impact, or little harm to humans and national infrastructure. Several scientific studies have reported the basics of landslide mechanisms and processes in the Nepal Himalaya (Dhital et al., 1991; Yagi & Nakamura, 1995; Dahal & Hasegawa, 2008; Dahal et al., 2008; Poudyal et al., 2010; Ghimire et al., 2011).

Landslide susceptibility maps (LSMs) are the likelihood of a landslide occurring in an area on the basis of local terrain conditions which is vital for disaster management and for planning development activities in the mountainous country like Nepal (Brabb, 1993). Hazard assessment is the process of studying nature/manmade hazards determining its essential features (ADPC, 2016). Various factors are responsible for the occurrence of the landslide. Slope is the measure of an angle between a location in the ground surface and the horizon (Ohlmacher, 2006) which is the important factors that control the amount of material available for landslides, size and resultant landslides (Chen et al., 2015). Aspect is defined as the direction of the slope and in some cases of landslide cases, researchers have agreed that the slope aspect is one of the main reasons for the occurrences of landslides (Tian et al., 2010). Plan curvature controls the convergence or divergence of landslide material and water in the direction of landslide motion (Carson & Kirk, 1972). Profile curvature is the curvature in the downslope direction along a line formed by the intersection of an imaginary vertical plane with the ground surface (Ohlamacher, 2007). Profile curvature affects the driving and resisting stresses within a landslide in the direction of motion (Meten et al., 2015). Altitude is also a significant landslide conditioning factor because it is controlled by several geologic and geomorphological processes (Gritzner et al., 2001; Dai & Lee, 2002; Ayalew et al., 2005; Pourghasemi, 2008). The vegetation covers or land use characteristics are important for the stability of slopes, and considered vegetation cover to assess the conditioning factors of landslides (Ocakoglu et al., 2002). A road constructed results an increase in stress on the back of the slope, because of changes in topography and decrease of load on toe, some tension cracks may develop (Pourghasemi et al., 2012).

There are dozens of numerical models that were devised for the zoning of the relative risk of the slope instability with weight, rate, computational logic and different scale agents and modified in a variety of conditions based on land evidences (Sakar & Kanungo, 1995). According to Van Westen et al. (1994) the bivariate methods are a modified form of the qualitative map combined with the exception that weights are assigned based upon statistical relationships between past landslides and various factor maps and along with this these statistics can be used to develop decision rules. Individual factor maps (independent variables) or combinations of factor maps (e.g. unique condition units) are overlaid with a landslide map (dependent variable) to develop cross tabulations for each factor and subclass. Similarly, the multivariate methods have been used for slope instability zonation where the techniques used are: multiple linear regression analysis (Carrara, 1983), discriminate analysis (Carrara, 1983; Guzzetti et al., 2005), and logistic regression analysis (Dai et al., 2001; Suzen & Doyuran, 2004; Lee et al., 2004). Multivariate analysis is based on the presence or absence of stability phenomena within the units (Van Westen, 1993). Logistic regression and discriminant analysis are the most frequently used models (Brenning, 2005) and have been developed using the geographic information system (GIS) for landslide susceptibility mapping (Lee et al., 2010). The multivariate logistic regression approach (Yesilnacar & Topal, 2005; Lee & Pradhan, 2007; Nandi & Shakoor, 2009; Yilmaz, 2010; Oh & Lee, 2010; Felicisimo et al., 2013, Akgun, 2012) and bivariate (Bednarik et al. 2010; Pradhan & Lee, 2010; Pourghasemi et al. 2013) were used by various researchers worldwide for the landslide susceptibility mapping.

In the study of landslide hazard assessment between Besi Sahar and Tal area in Marsyangdi River Basin, West Nepal, it was found that the high hazard zone was lying along the Marsyangdi River and its tributaries where logistic regression was applied (Acharya & Pathak, 2017). Statistical Index Model (SIM) is a bivariate statistical analysis introduced by Van Westen (1997) for landslide susceptibility analysis. A weight value for a parameter class (e.g., a certain lithological unit or a certain slope class) is defined as the natural logarithm of the landslide density in the class divided by the landslide density in the entire map. SIM are generally considered the most appropriate method for landslide susceptibility mapping at regional scales because they are objective, reproducible and easily updatable (He & Beighley, 2008). The LSI model is a data-driven bivariate statistical approach in which each parameter is analyzed individually and the calculation and application are easy and fast (Suzen & Doyuran, 2004). For the validation of models, many recent studies (Nandi & Shakoor, 2010; Akgun, 2012; Pourghasemi et al., 2012; Zare et al., 2012; Pourghasemi et al., 2013; Conforti et al., 2014; Youssef et al., 2016; Wang et al., 2017) have utilized ROC curve to demonstrate and compare the reliability of their created LSMs.

Vulnerability refers to the conditions, as determined by physical, social, economic and environmental factors or processes, which make a community susceptible to the impact of hazards (UNISDR, 2004). For the United Nations, the term "vulnerability" refers to the conditions which make a community susceptible to the impact of hazards, the conditions being determined by physical, social, economic and environmental factors or processes (UNISDR, 2009). Vulnerability is a fundamental component in the evaluation of landslide risk (Leone et al., 1996) and in the present context, it can be defined as the level of potential damage, or degree of loss, of a given element (expressed on a scale of 0 to 1) subjected to a landslide of a given intensity (Fell, 1994; Leone et al., 1996; Wong et al., 1997). Vulnerability assessment (VA) serve various purposes such as to identify the impacts and prioritizing adaptation options in the initial planning phase. Birkmann (2007) also studied about the risk and vulnerability indicators at different scales: applicability, usefulness and policy implications which was basically focused on four attempts to measure risk and vulnerability by applying indicators. All the approaches presented in his paper were based on a common theory that disaster risk is a product of three major elements i.e. exposure to hazards, the frequency or severity of hazard and vulnerability. Therefore, in actual landslide risk assessment, the most common method is to set the landslide vulnerability of different elements at risk to a constant 1, that is, to believe that the elements at risk will be completely damaged and lost, or to assign the vulnerability on the basis of expert knowledge and experience (Van Westen et al., 2009). There are several scholars that had studied the vulnerability of building, road, and land use to landslide by the methods of vulnerability curve, vulnerability matrix, and vulnerability indicators (Silva & Pereira, 2014; Quan Luna et al., 2011; Galli & Guzzetti, 2007). Societal vulnerability is related to factors such as demographics, preparedness levels, memory of past events, and institutional and non-institutional capacity for handling natural hazards which can be quantified by means of questionnaire, poverty level, literacy rate and decentralization (UNISDR, 2009). The physical dimension of vulnerability links extreme physical or natural phenomenon with a vulnerable human group (Westgate & O'Keefe, 1976). It is important to find out how different kinds of natural environment cope with and recover from different hazards (TU-CDES & UNDP, 2014).

Vulnerability Assessment describes who and what is exposed to threat (hazard identification), and the differential susceptibility and impacts of the exposure. In other word, it doesn't only identify the risk factors (who and what is vulnerable) but also the driving forces that shape vulnerability in a particular place (Birkmann, 2006). According to Glade (2003), although vulnerability estimation is an important part within in landslide assessment, a literature review demonstrates a lack of vulnerability studies in landslide risk research with regard to both social and natural science approaches. Landslide vulnerability assessment is still considered a difficult process because of its dependency on several factors like landslide type and the way its impact may generate different degree of impacts. Douglas (2007) explained why vulnerability should not be modelled while Van Western et al. (2006) explained why it is too difficult to model. At present, there is no uniform methodology to quantitatively assess the vulnerability of various elements at risk to different types and magnitudes of landslides (Glade & Crozier, 2005).

The elements at risk are the population, property, economic activities, including public services, or any other defined entities exposed to hazards in a given area (UNISDR, 2004). Risk analysis uses available information to estimate the risk to individuals, population, property or the environment from hazards which generally contains the following steps like hazard identification, hazard assessment, inventory of elements at risk and exposure, vulnerability assessment and risk estimation. Since all of these steps have an important spatial component, risk analysis often requires the management of a set of spatial data and the use of geographic information systems. Risk evaluation is the stage at which values and judgments enter the decision process, explicitly or implicitly, including considerations of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks (Corominas et al., 2014). Multiple risk can be defined as the risk to more than one specific element from a single specific hazardous factor affecting landslide, or the risk to one specific element from more than one specific hazardous factors affecting the landslide. Multiple partial risk, multiple specific risk, and multiple specific value risk can also be estimated by applying standard probability concepts (Vandine et al., 2004). The devastating earthquake of 25th April, 2015 A.D. and aftershocks have increased the exposure of the humans and resources towards the vulnerable situation. Therefore, only guided activities are allowed to be operated and the responsibility of probabilities of newly created hazards among natural disasters should be taken into account in such hazard prone or vulnerable areas of natural disasters (MoLRM, 2015). The major objective of Land Use Policy (2015) is to ensure the hygienic, beautiful, well-facilitated and safe human settlement, sustainable and planned urbanization of the country as well as to maintain a balance between physical infrastructure development and environment (MoLRM, 2015).

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

The study area is the Chepe River, which lies in the border between the Gorkha and Lamjung districts. The river originates from the Dudhpokhari at an elevation of about 5300 m. The name of Chepe river is historically linked to Nepal's politics and the formation of the nation state, which offer a rich context for the study of institutional responses to landslides. In the 18th century and before, it was a political boundary between the two princely states-Rainaskot in the west and Ligligkot in the east. The size of the river thus acts more as a symbolic divider of the boundary and at the same time, a connector among communities on either side. It has the total catchment area of 308 km^2 at the confluence of Marshyangdi River. The total area of the river corridor taken for the study is 47.301 km^2 considering the buffer of 1km along the river. There are five precipitation stations around Chepe river catchment with only one station inside the catchment. The terrain is very rugged, precipitation distribution pattern seems to be very much influenced by the spotty convective activities, so the pattern from one station to the other nearby station is also different and complex (Pokhrel, 2003). The Chepe river corridor touches five municipalities i.e. two from Lamjung district (Rainas and Dudhpokhari) and three from Gorkha district (Palungtar, Siranchowk and Ajirkot).

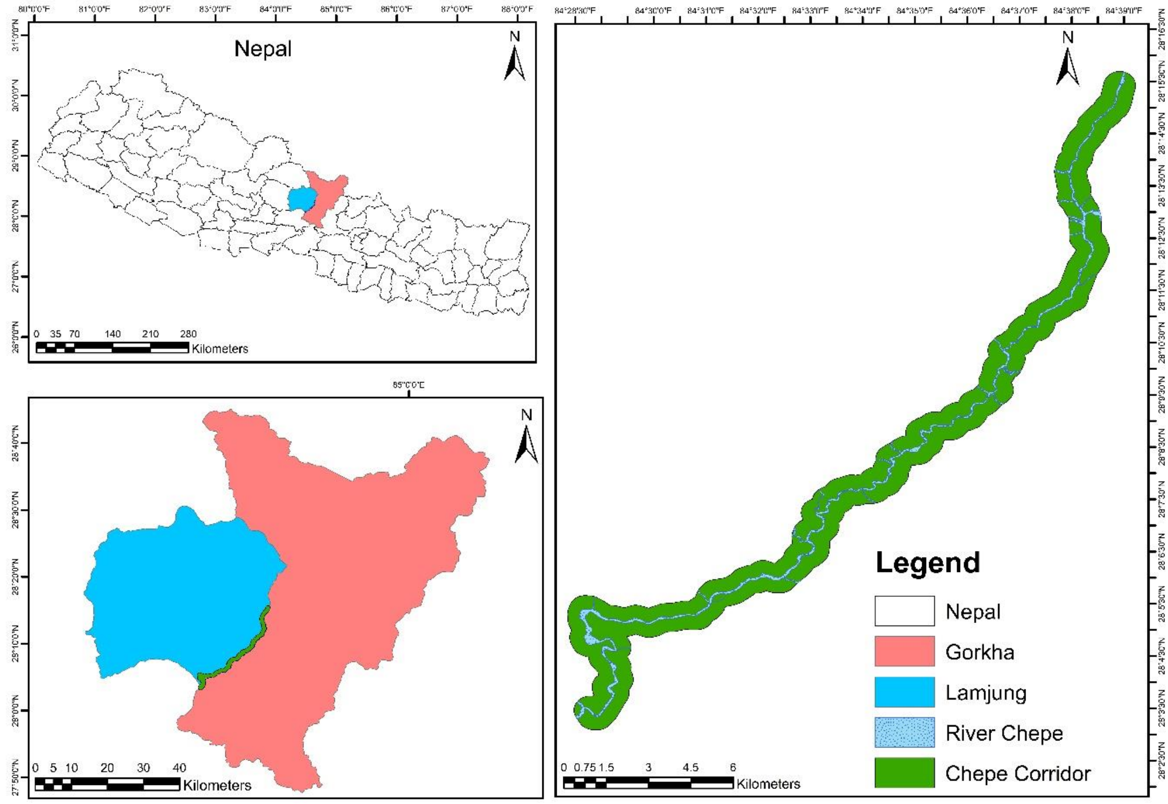


Figure 1: Location of study area showing Chepe River corridor

- (*Source: Data from Department of Survey)*

3.2 Data Collection

3.2.1 Field work

The fieldwork (15th-27th Jan, 2018) was carried out for the mapping of landslide and infrastructures with the help of Global Positioning System (GPS). Along with landslides location their few features and characteristics were also studied. After field visit, the GPS locations that were recorded in the field were entered in the google earth image for the landslide verification and inventory map preparation. The Keyhole Markup Language (kml) file was then imported to Arc GIS 10.2 for the preparation of inventory and factor maps. For the vulnerability assessment the field work was carried out from 5th -13th June, 2018.

3.2.2 Software used for data analysis

- Arc GIS 10.2
- R studio
- JMP (pronounced as jump) software (Trial version)
- Google Earth Engine (GEE)

Table 1: Different landslide triggering factors and it's sources

S.N	Factors	Source
1	Slope	Extracted from the DEM (SRTM 1 Arc-Second Global) of cell size 30 m x 30 m
2	Distance to Road	Open street map further cleaned by the World Bank Group and stored in the raster format of cell size of 30 m x 30 m
3	Geology	Extracted from geological survey department and stored in ArcGIS in raster format of cell size 30 m x 30 m
4	Land use	Manual digitization using base map in Arc GIS and validating using Google Earth Engine (GEE)
5	Rainfall	Extracted data from DHM from the year 1987-2016 from 8 meteorological stations which were neighboring station to study area
6	Elevation	SRTM 1 Arc-Second Global of cell size 30 m x 30 m
7	Plan curvature	Extracted from the DEM and stored in the raster format of cell size of 30 m x 30 m
8	Relief	Extracted from the DEM and stored in the raster format of cell size of 30 m x 30 m
9	Profile curvature	Extracted from the DEM and stored in the raster format of cell size of 30 m x 30 m
10	Drainage density	Extracted from DEM; stream feature and stored in the raster format of cell size 30 m x 30 m
11	Aspect	Extracted from the DEM and stored in the raster format of cell size of 30 m x 30 m

3.3 Landslide modelling

Total landslides were divided into training data (70%) and validation data (30%) using random selection in Arc GIS, in which training data were used for running the model and rest 30% were used for the model comparison and validation purpose (Dou et al., 2015; Kalantar et al., 2018; Fayez et al., 2018).

3.3.1 Remote sensing and GIS based landslide inventory by Bivariate Analysis

Landslide were identified by visual inspection and expert suggestion. Google earth and GIS were used for the preparation of landslide inventory map of Chepe river corridor.

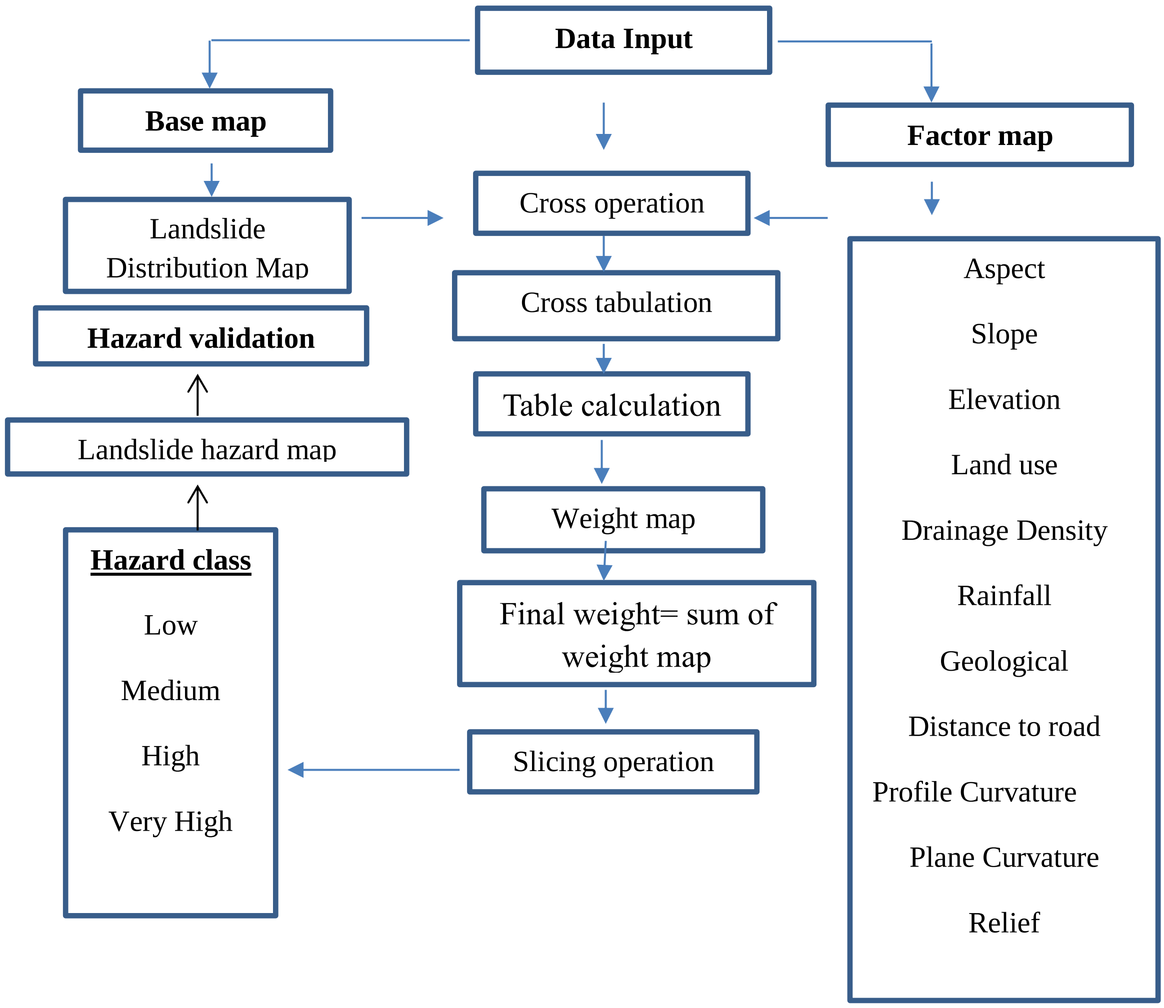


Figure 2: Flow Chart of Landslide Hazard Map Preparation by Statistical Index Model

It is based on assumption that causative factors of landslide can be quantified by calculating areas of each class. The model calculation and map preparation is done by using Arc GIS 10.2 and hazard class is differentiated into 4 classes by using R studio.

- **Statistical-Index Model (Van Westen, 1997)**

  $W_{ij} = \ln(f_{ij}/f) = \ln((A^*_{ij}/A_{ij}) \times (A/A^*)) = \ln((A_{ij}^*/A^*) \times (A/A_{ij}))$

  Where,

  W_{ij} = weight given to class I of parameter j

  F_{ij} = landslide density within class I of parameter j

  F = Landslide density within entire map

  A_{ij}^* = area of landslide in class I of parameter J

  A_{ij} = area of a class I of parameter j

A* = totalarea of landslide in entire map

A = total area of entire map

- **Landslide Hazard Index (LHI)**

LHI= $\sum_{j=1}^{n} Wij$

Where,

Wij = weight of class i of parameter j

n = number of parameter

- **Drainage Density**

The drainage distance map was prepared by using the stream feature and line density tool in Arc GIS. The drainage density i.e.

$$\text{Drainage Density} = \frac{Total\ length\ of\ stream}{Total\ area\ of\ studyarea}$$

3.3.2 Multivariate Analysis Model

Logistic regression model (Cox, 1958)

Considering p independent variables, $x_1, x_2, \ldots, x_p$, affecting landslide occurrences, we define the vector $X = (x_1, x_2, \ldots, x_p)$. In this study, the independent variables will be with values of 1 (presence) or 0 (absence).

The conditional probability that a landslide occurs is represented by

$P(y = 1/X)$.

The logit of the multiple logistic regression model (Hosmer & Lemeshow, 2000) is:

$$\text{Logit}(y) = b_0 + b_1x_1 + b_2x_2 + \ldots\ldots + b_px_p$$

where b_0 is the constant of the equation, and $b_1, b_2, \ldots, b_p$ are the coefficients of variables $x_1, x_2, \ldots, x_p$.

The probability $P(y = 1/X)$ can be expressed in the logistic regression model:

$$P(y = 1/X) = \frac{1}{1 + e^{-(b_0 + b_1x_1 + b_2x_2 + \ldots\ldots + b_px_p)}}$$

Where, 'e' is the constant 2.718.

Higher the value of coefficient, higher will be the weightage.

For hazard mapping, both the model was used and lastly, the model that gave the accurate result was considered for the risk assessment.

3.3.3 Landslide Hazard Index Classification (Lee & Pradhan, 2007)

For the differentiation of different hazardous class, hazard index classification was done using R studio. Both the landslide and non-landslide points are taken for the landslide hazard index classification. The hazard index having 25% of landslide was classified as low hazard, 25%-50% as medium hazard, 50%-75% as high hazard, and 75%-100% as very high hazard. By this method both the percentage cumulative of landslide distribution and hazard index were used for the classification purpose of hazard index class. Both landslide and non-landslide points are considered for the preparation of % cumulative of landslide versus hazard index graph from which the differentiation of low, medium, high and very high hazardous area was done.

3.3.4 ROC index (Pontius & Schneider, 2001)

It is very important to check the efficiency or the validation of the landslide hazard model and similarly ROC (relative operating characteristic) index has been used in this study for the validation. ROC curve is a diagram in which the pixel ratio that correctly predicts the occurrence or nonoccurrence of landslides (True Positive) is plotted against the supplement amount that is the pixel ratio that is wrongly predicted. The hazard model computes the change in likelihood in each pixel in a continuous range of zero and one. By determining a threshold (e.g. 0.5) the model's output can be converted to a discrete scale of zero and one e.g. the pixels, in which that the change likelihood is more than their threshold, it takes the value 1 and pixels in which the change likelihood is less than their threshold, it takes the value 0. After this the output is presented as a map. By comparing this with the landslide inventory, the pixel ratio can be plotted in ROC diagram. The ROC index equals to the area under the curve (Pontius & Schneider, 2001). In ROC curve, the sensitivity of model (the percentage of existing landslide pixels correctly predicted by the model) is plotted against the 1-specificity (the percentage of predicted landslide pixels over the total study area). The quality of the probabilistic model to reliably predict of the occurrence or non-occurrence of landslides is predicted by the area under the curve of ROC. A good fit model has AUC values that range from 0.5 to 1, while values below 0.5 represent a random fit (Youssef et al., 2016). The ROC of Statistical Index Model and Logistic Regression Model using 30% (18) of landslides were obtained to check the accuracy and reliability of the model.

3.4 Vulnerability Assessment

For the vulnerability assessment, four major factors i.e. physical, social, environmental and economic were considered (UNISDR, 2009). Exposure and susceptibility along with the adaptive capacity were included in this vulnerability assessment. Data were collected on the basis of 18 Key Informant Interview (KII) (1 in each ward), 5 FGDs (1 in each municipality), 36 schedule surveys (2 in each ward) and the data published in their reports. Local Disaster and Climate Resilience Planning Guideline (LDCRP) by GoN (2017) was followed for the vulnerability assessment. The indicators taken for the vulnerability analysis and score which incorporates environmental, social, physical and economic factors prescribed by LDCRP guideline are as follows:

- Death
- Impacted households
- Damaged houses
- Economic loss
- Impacted agricultural and forest area
- Social impact
- Possible impact of landslide
- Trends of landslide occurrence
- Change is seasonal calendar
- Change in temperature
- Access to source
- Population analysis
- Education, awareness, skills
- Organizational help

3.5 Risk Assessment

By overlaying hazard and vulnerability map, the risk map was prepared where the area with very high, high, medium and low risk was separated. Risk map is the product of hazard and vulnerability (UNISDR, 2004) and the risk map was prepared incorporating both the hazard as well as vulnerability of the study area.

Risk = Hazard x Vulnerability

3.6 Standardized map

The hazard, vulnerability and risk map formed was then standardized from 0 to 1. For standardization, minimum-maximum standardization method (Briguglio et al., 2009) was used.

$$\text{Standardized map} = \frac{(Prepared\ map - Maximum\ value)}{(Maximum\ value - Minimum\ value)}$$

CHAPTER 4: RESULTS

4.1 Landslide Inventory Map

A total of 73 landslides were observed during field visit and inspection of the Google Earth. The landslides with the area ranging from 3.87 m^2 to 30600.79 m^2 are heterogeneously distributed over the area. Some landslides are located near the confluence with Marshyangdi River, some on the middle section of river and some close to the river source. The 70% (55) of total landslides were used as training data for the analysis purpose and remaining 30% (18) of landslides were used as validation data for validation purpose (Figure 3).

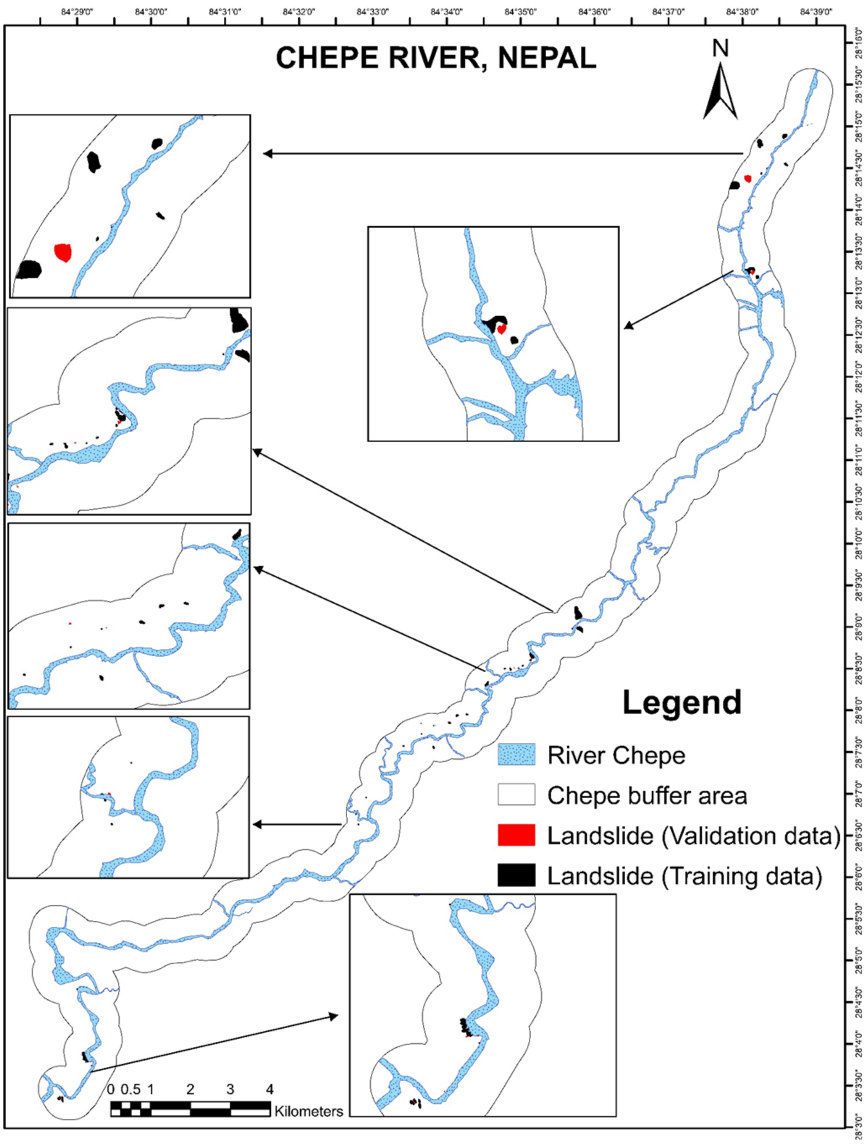


Figure 3: Landslide inventory map showing the distribution of landslides in the Chepe River corridor

4.2 Factor maps for Bivariate Statistical Index Model

The landslide triggering factors used in this study include slope, elevation, geology, land use, aspect, plan and profile curvatures, distance to road, line density and relief as intrinsic factors of the landslides and rainfall was taken as extrinsic factors that trigger landslide.

4.2.1 Slope

Slope were divided into seven different classes ranges from <10°, 10-20°, 20-30°, 30-40°, 40-50°, 50-60°, 60-70° respectively. Most of the landslide in the study area falls into the classes 40-50°. Whereas the slope class of 30-40°, 40-50°, 50-60° and 60-70° have the positive weightage value (Table 2).

Table 2: Weightage values of each slope class in Chepe River corridor

Value	**Slope (Degree)**	**Area of Slope (m^2)**	**Area of Landslide (m^2)**	**Weightage (Wij)**
1	<10	11766600	6300	-1.736
2	10-20	14140800	27000	-0.4645
3	20-30	11758500	27900	-0.2472
4	30-40	6904800	30600	0.3775
5	40-50	2431800	36000	1.5836
6	50-60	367200	13500	2.4933
7	60-70	27000	2700	3.4939
Total		47396700	144000	5.5006

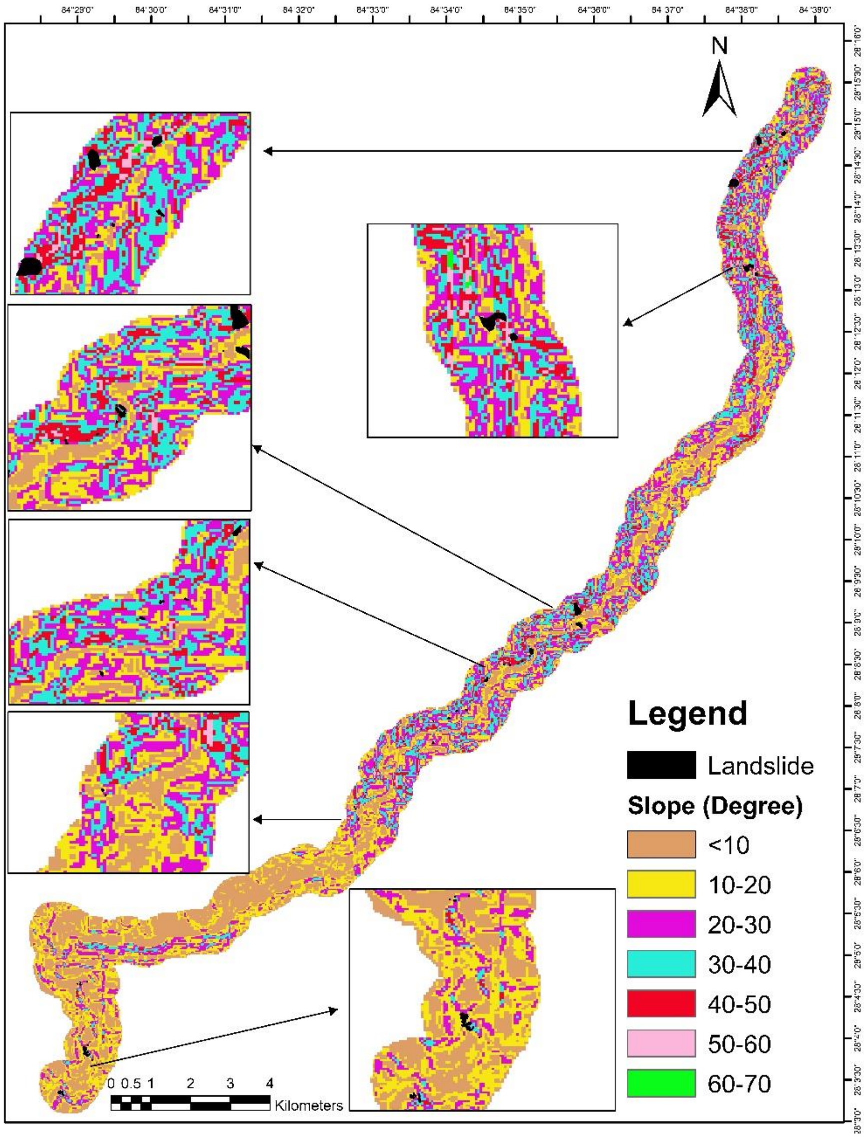


Figure 4: Distribution of landslides in the different slopes of Chepe River corridor

4.2.2 Aspect

Aspect class was classified into nine different classes: Flat, North, Northeast, East, Southeast, South, Southwest, West and Northwest. The most of the study area lies in Southeast and west aspect, whereas most of the landslides lies in southeast aspect covering relatively large area (Table 3). Positive weightage values were found in northeast, southeast and south, whereas negative weightage value were found in north, east, southwest, west and northwest**.**

Table 3: Weightage values of each aspect in Chepe River corridor

Value	**Aspect**	**Area of Aspect (m^2)**	**Area of Landslide (m^2)**	**Weightage (Wij)**
1	Flat	42300	0	0
2	North	5288400	1800	-2.189
3	Northeast	3159000	10800	0.118
4	East	5742900	15300	-0.1314
5	Southeast	7514100	56700	0.9097
6	South	6327900	35100	0.602
7	Southwest	5180400	11700	-0.2965
8	West	7363800	9000	-0.9106
9	Northwest	6777900	3600	-1.744
	Total			- 3.6418

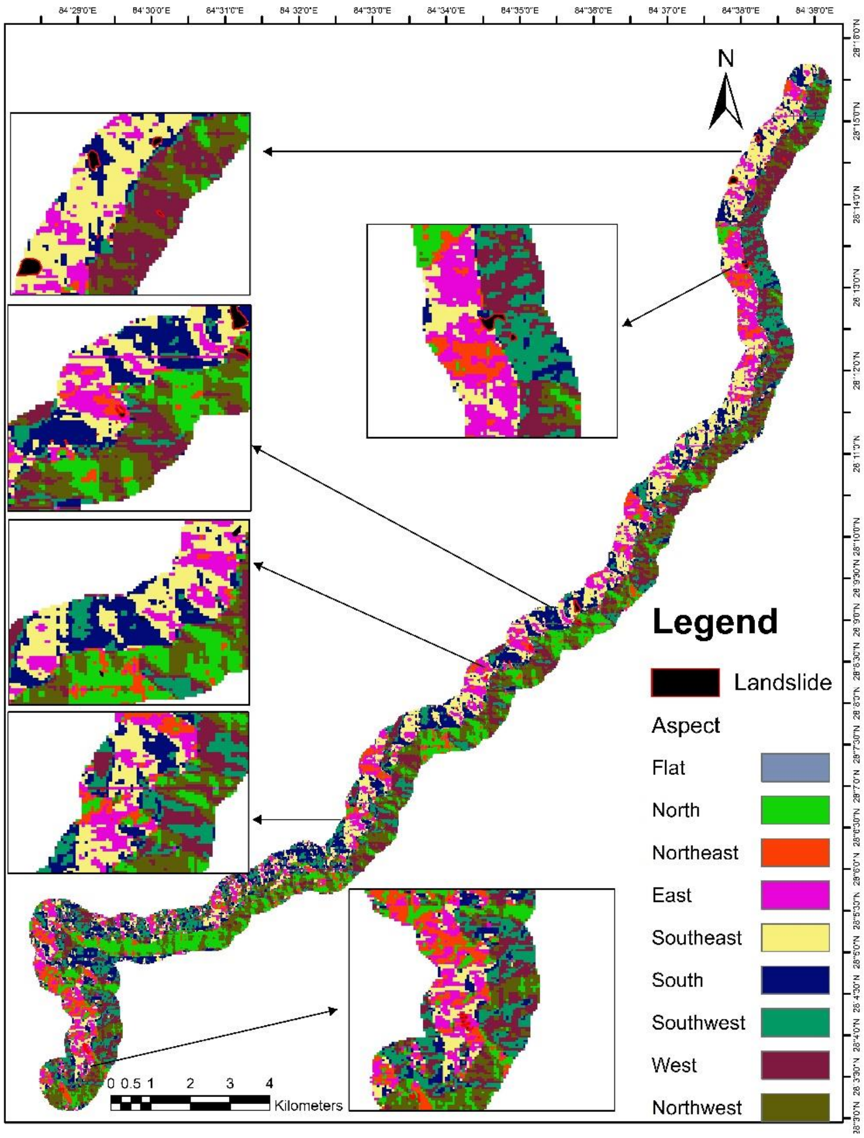


Figure 5: Distribution of landslides in the different aspects of Chepe River corridor

4.2.3 Distance to road

By using the Euclidean distance, the distance of the road to landslide was calculated. More landslides were observed in the areas nearer to the road i.e. less than 500 m (Table 4). The total weightage of the road was calculated to be 5.1733 which states that the road is a very strong triggering factor of the landslide in the Chepe River corridor.

Table 4: Weightage values of distance from road in Chepe River corridor

Value	Road Distance (m)	Area of Road Distance (m^2)	Area of Landslide (m^2)	Weightage (Wij)
0	<500	24497100	36000	-0.7372
1	500-1000	5670000	0	0
2	1000-1500	2346300	28800	1.3854
3	1500-2000	1687500	28800	1.7149
4	2000-2500	841500	15300	1.7782
5	2500-3000	522000	4500	1.032
6	3000-3500	522900	0	0
7	3500-4000	522000	0	0
8	4000-4500	310500	0	0
		Total		5.1733

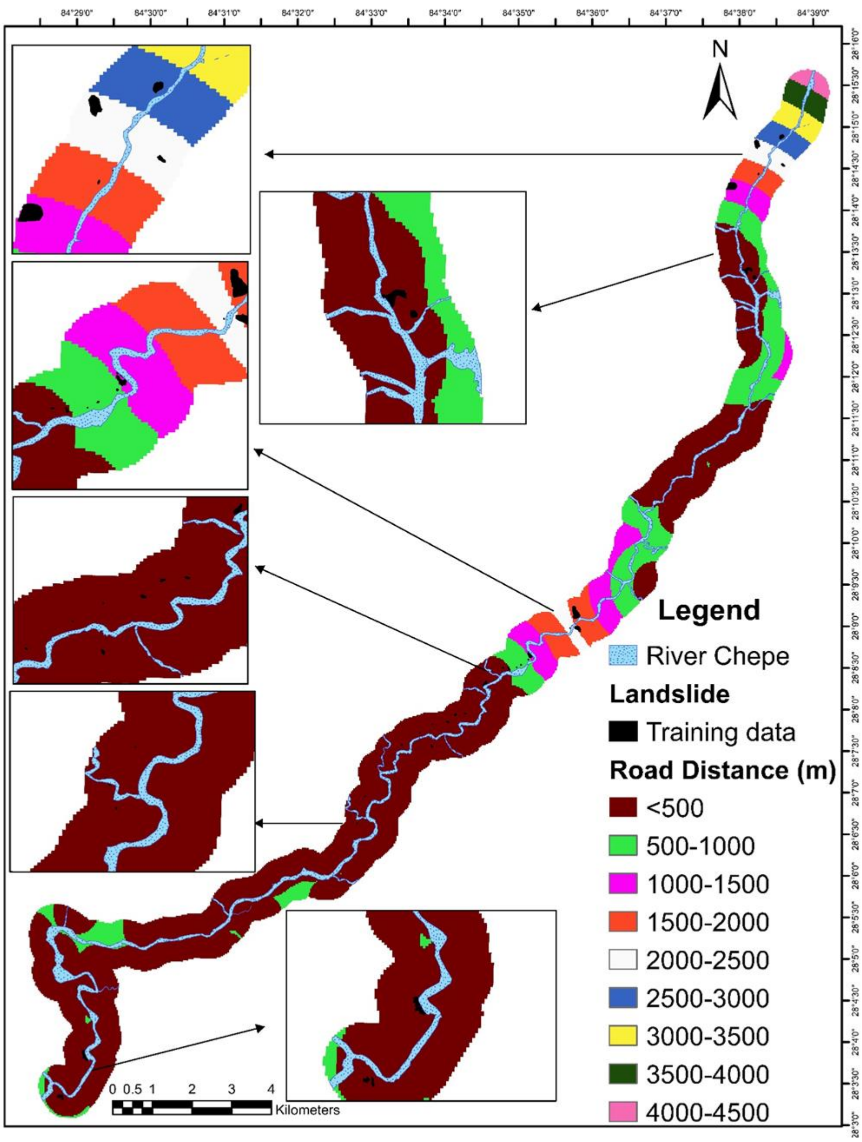


Figure 6: Distribution of landslides along the distance from road in the Chepe River corridor

4.2.4 Relief

The relief is the variation in height of land surface or the local difference in height within a unit area. Basically, the different reliefs have different climatic conditions. The study area has the maximum area of landslide in the relief of less than 30 m (Table 5). With the increase of the variation in the height of the land surface the area of landslide is decreasing. Lesser the variation greater is the probability of landslide. The sum weightage of the relief is a positive value which states that the relief is one of the triggering factor of the landslide in the study area.

Table 5: Weightage values of each relief class in Chepe River corridor

Value	**Relief (m)**	**Area of Relief (m^2)**	**Area of Landslide (m^2)**	**Weightage (Wij)**
1	<30	1302300	35100	2.1544
2	30-60	1706400	18900	1.2651
3	60-90	2795400	17100	0.6714
4	90-120	3913200	23400	0.6487
5	120-150	5305500	14400	-0.1412
6	150-180	9058500	14400	-0.6761
7	180-210	10118700	9900	-1.1615
8	210-240	8546400	5400	-1.5987
9	240-270	1595700	0	0
Total		44342100	138600	1.1621

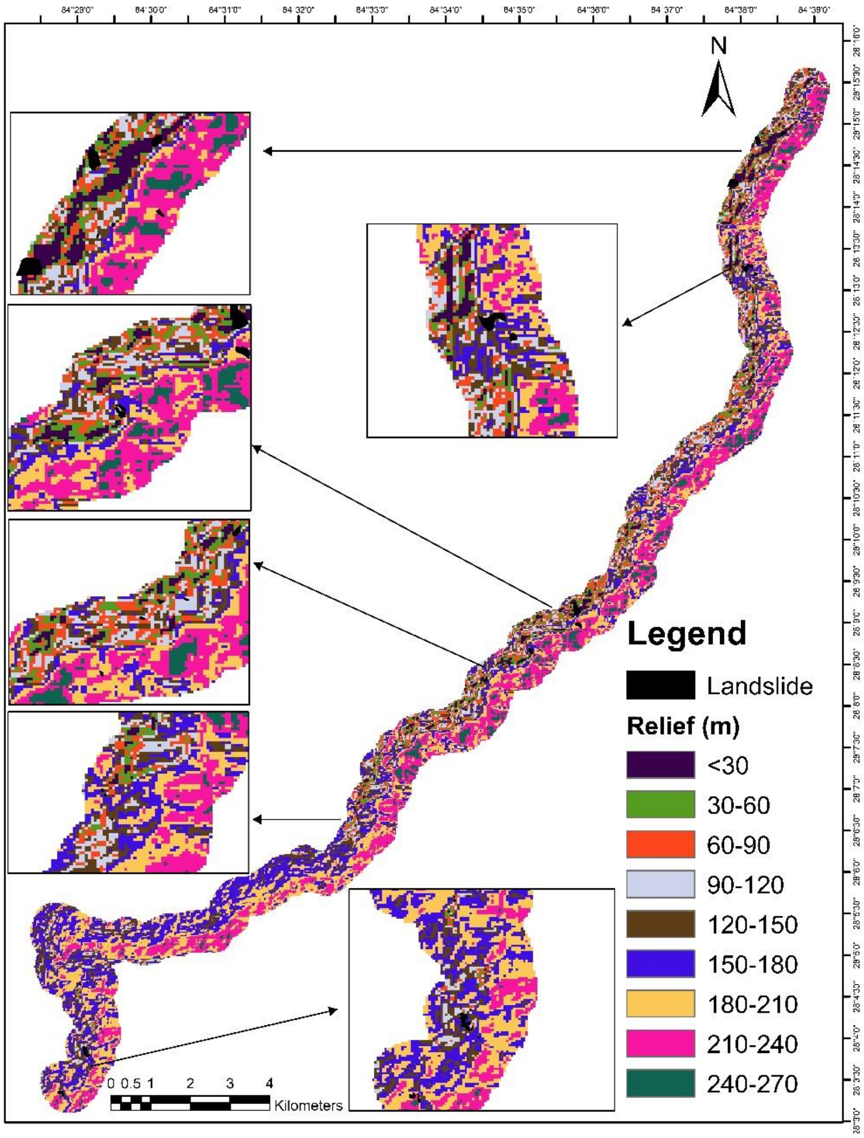


Figure 7: Distribution of landslides with the relief in the Chepe River corridor

4.2.5 Profile curvature

A hill shade of profile curvature is classified into three categories i.e. convex, concave and planar. Negative (< -6.8179) indicates that the surface is upwardly convex and positive (1-7.6562) profile indicates that the surface is upwardly concave. The planar surface has the value range from -6.8179 to 1 (Table 6). In this study area, hill slope with planar profile has a greater area covered by landslide followed by concave and convex. The weightage is positive in concave and convex surface whereas negative in planar surface.

Table 6: Weightage values of each category of profile curvature in Chepe River corridor

Value	Profile Curvature (Value)	Profile Curvature	Area of Profile Curvature (m^2)	Area of Landslide (m^2)	Weightage (Wij)
1	<-6.8179	Convex	6417000	40500	0.7311
2	-6.8179-1	Planar	34599600	60300	-0.5558
3	1-7.6562	Concave	6380100	43200	0.8014
Total			47396700	144000	0.9767

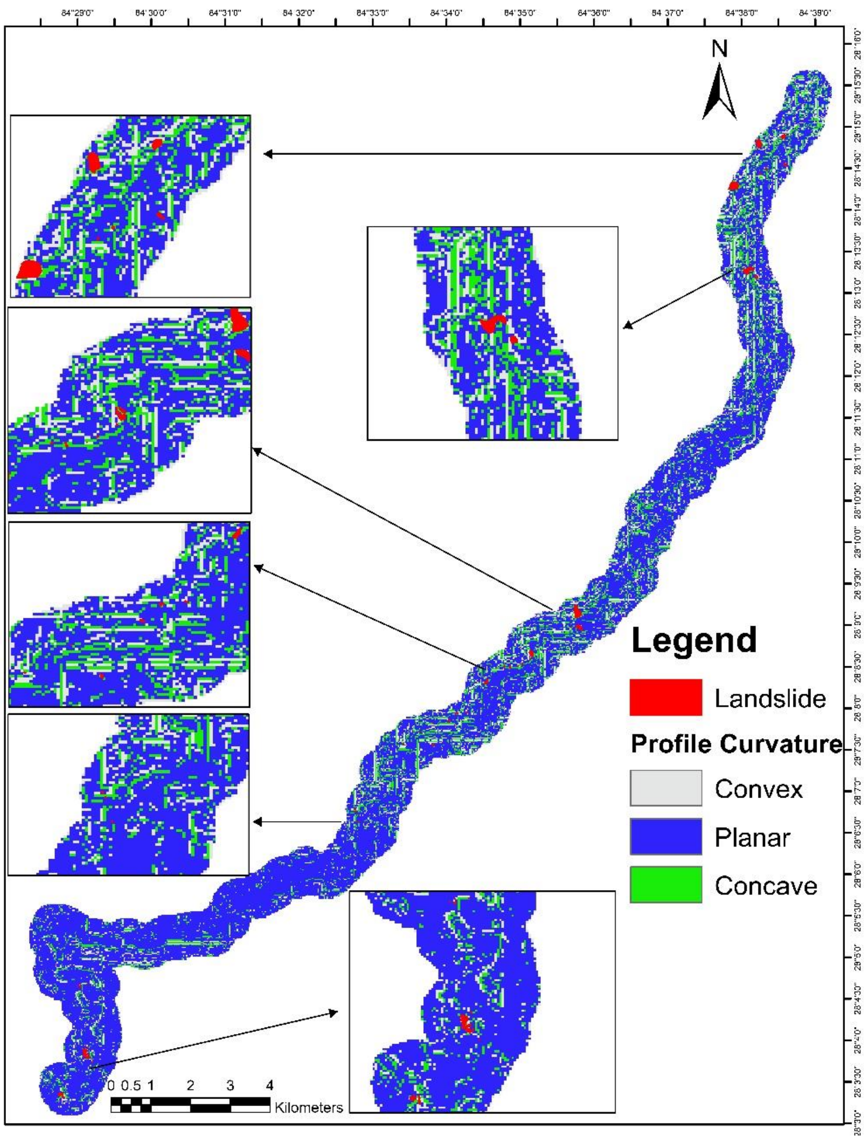


Figure 8: Distribution of landslides with the profile curvature in Chepe River corridor

4.2.6 Plan curvature

The plan curvature of study area is classified into three categories i.e. concave, planar and convex. The concave has its range from > -6.8179, planar has its range from -6.8179 to 1 and convex ranges from 1 to 6.8179. Planar surface comprises maximum area of landslide followed by concave and convex. The positive weightage value is observed in concave and convex whereas the negative value was observed in planar surface (Table 7).

Table 7: Weightage values of each category of plan curvature in Chepe River corridor

Value	Plan Curvature (Value)	Plan Curvature	Area of Plan Curvature	Area of Landslide	Weightage (Wij)
1	-6.8179	Concave	3698100	33300	1.0865
2	-6.8179-1	Planar	39724200	82800	-0.3768
3	1-6.8179	Convex	3973500	27900	0.8377
Total			47395800	144000	1.5474

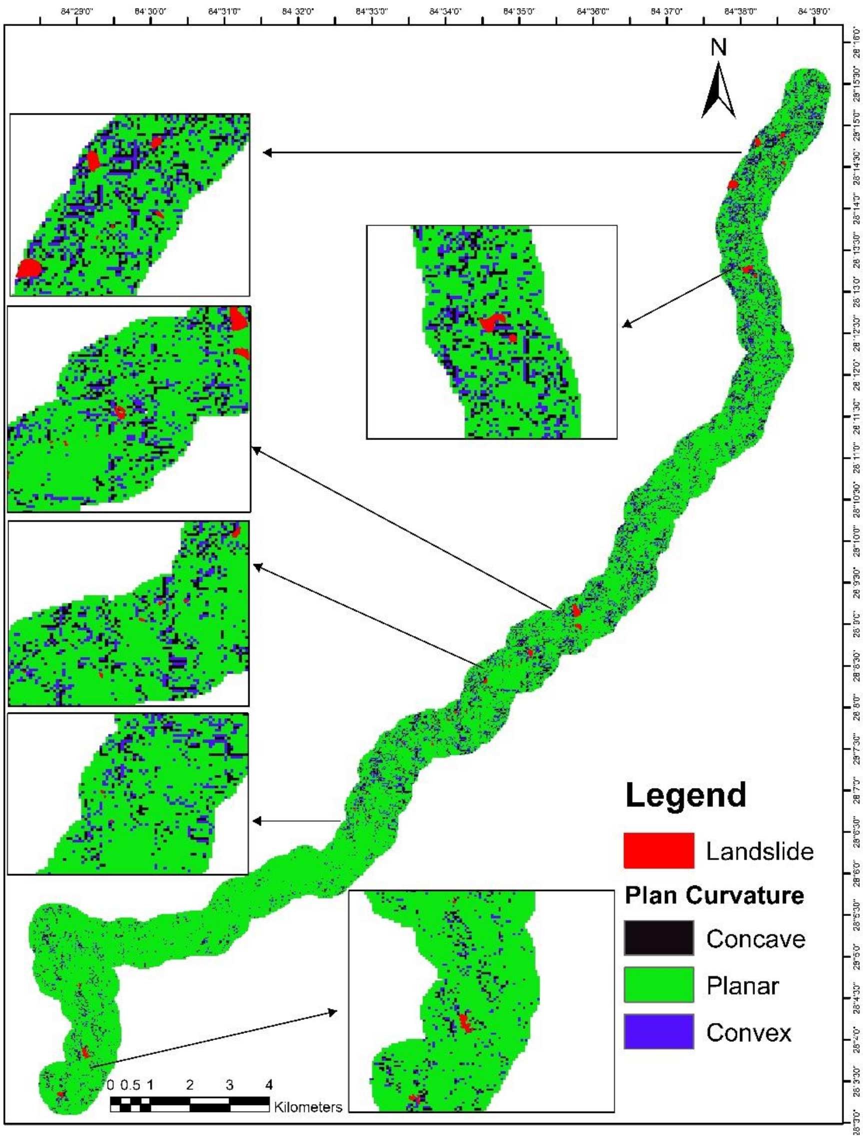


Figure 9: Distribution of landslides with the plan curvature in the Chepe River corridor

4.2.7 Geology

Geology of the area is also considered as one of the causative factors for the landslide hazard analysis. The geology of the study area consists of Himal group, Ghanapokhara formation, Corallian (Cr), Ranimatta formation, Ulleri formation and Basic rocks. Most of the study area comprises Ranimatta formation and Ghanapokhara formation. Whereas most of the area where the landslide has occurred comprises Himal group of geology. There is no landslide in Ghanapokhara and Corallian (Cr) class of geology (Table 8).

Table 8: Weightage values of each type of geological formation in Chepe River corridor

Value	**Geology**	**Area of Geology (m^2)**	**Area of Landslide (m^2)**	**Weightage (Wij)**
1	Himal group	7452900	77400	1.2208
2	Ghanapokhara formation	9406800	0	0
3	Corallian (Cr)	1578600	0	0
4	Ranimatta formation	27189900	39600	-0.7436
5	Ulleri formation	1512900	27900	1.795
6	Basic rocks	154800	0	0
Total		47295900	144900	2.2722

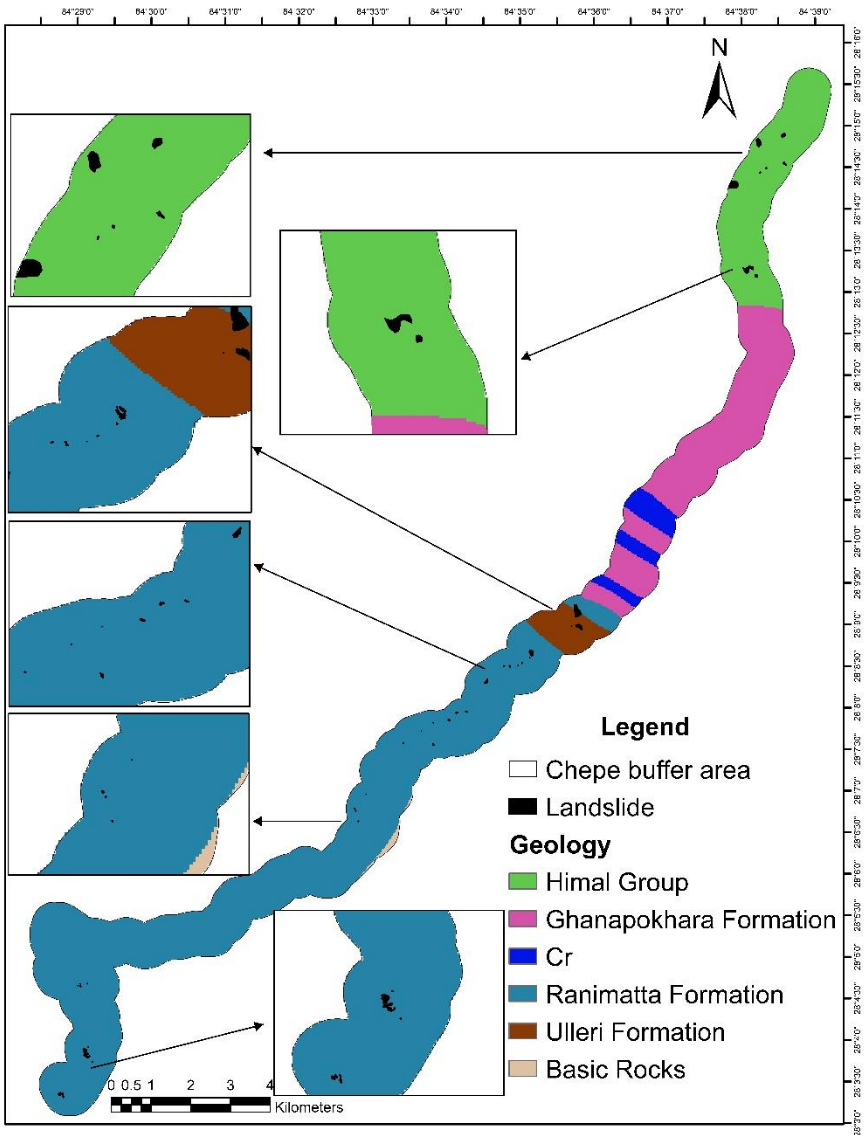


Figure 10: Distribution of landslides with the geological formation in Chepe River corridor

4.2.8 Elevation

Elevation is one of the important intrinsic factors which contribute the landslides, its size and volume. The elevation of area ranges up to 2400 m. The maximum area comprises the elevation of 400-800 m whereas the area of landslide is maximum in 800-1200 m elevation. No landslide was observed below the elevation of 400 m (Table 9).

Table 9: Weightage values of each elevation class in Chepe River corridor

Value	Elevation (m)	Area of Elevation (m^2)	Area of Landslide (m^2)	Weightage (Wij)
1	<400	19800	0	0
2	400-800	23101200	25200	-1.0243
3	800-1200	14104800	42300	-0.013
4	1200-1600	4860000	21600	0.3804
5	1600-2000	3466800	38700	1.3013
6	2000-2400	1844100	16200	1.0617
Total		47396700	144000	1.7061

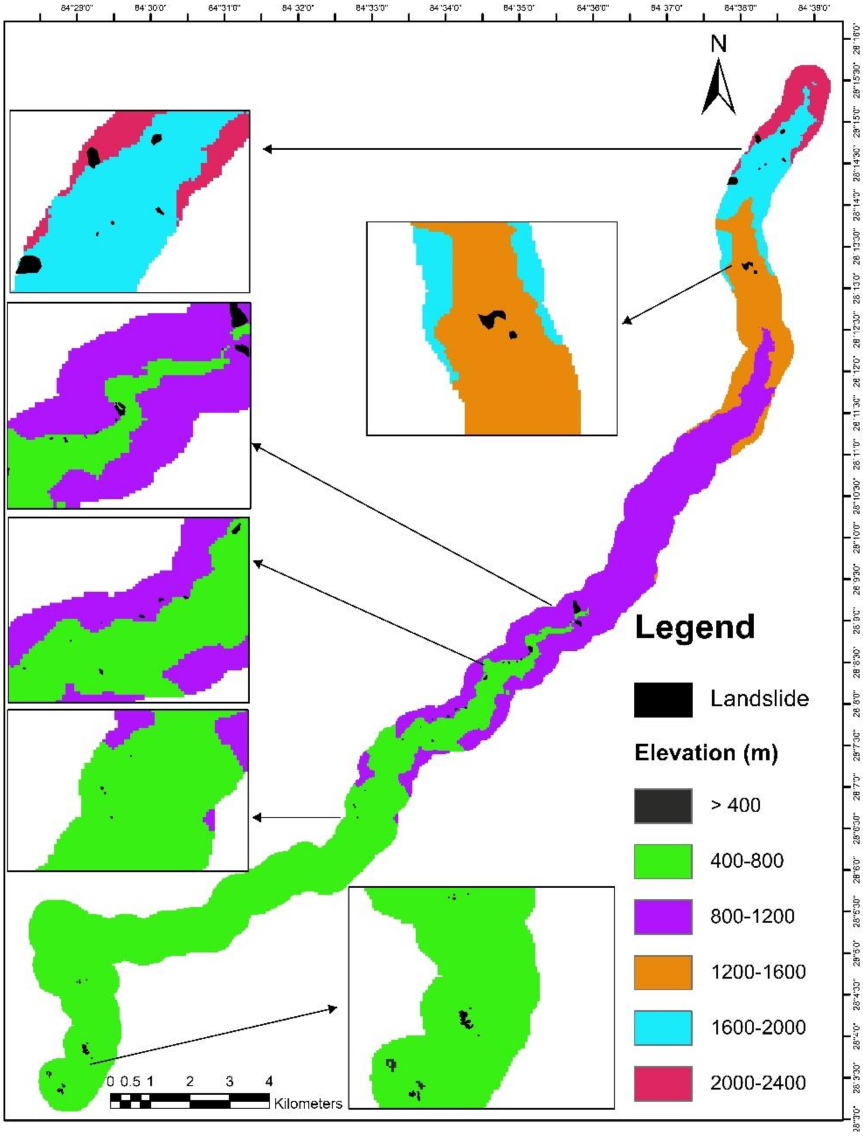


Figure 11: Distribution of landslides with the different elevation in Chepe River corridor

4.2.9 Drainage density

The drainage density of overall study area is 0.00305 m/m^2. The maximum area covered by the landslide is within the line density of <0.502875 m^2 and the sum weightage of line density is negative i.e. -1.840117.

Table 10: Weightage values of drainage density in Chepe River corridor

Value	Line density (m/m^2)	Area of line density (m^2)	Area of landslide (m^2)	Weightage (Wij)
1	<0.502879	14864400	77400	0.530398
2	0.502879-0.978691	11997900	36900	0.00386
3	0.978691-1.430713	10513800	15300	-0.74446
4	1.430713-2.073061	7430400	2700	-2.13195
5	2.073061-3.036581	2489400	12600	0.502035
Total				-1.840117

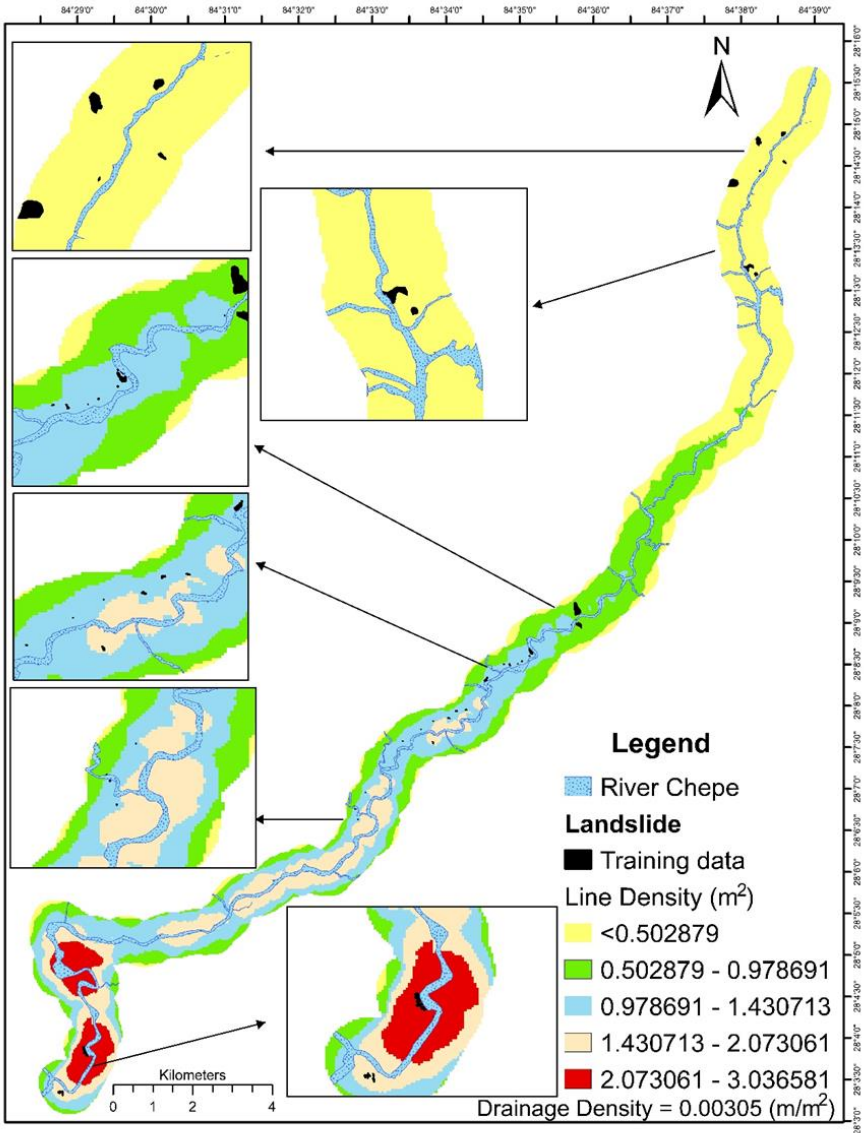


Figure 12: Distribution of landslides with the drainage density in the Chepe River corridor

4.2.10 Land use

The land use of the study area is divided into six different classes i.e. agriculture, river, shrub and bushes, settlement, forest and barren land. The result shows that the area is mostly covered by forest followed by the agricultural area. Landslide wasn't found exactly in the settlement area but few were found very nearer to the settlement area. Most of the landslides were found to be in the forested areas followed by barren land (Table 11).

Table 11: Weightage values of each category of land use in Chepe River corridor

Value	Land use	Area of land use (m^2)	Area of landslide (m^2)	Weightage (Wij)
0	Agriculture	13617900	13500	-1.0503
1	River	3001500	6300	-0.3002
2	Shrubs and Bushes	4812300	16200	0.1722
3	Settlement	433800	0	0
4	Forest	14566500	49500	0.1816
5	Barren Land	407700	18900	2.7947
	Total			1.798

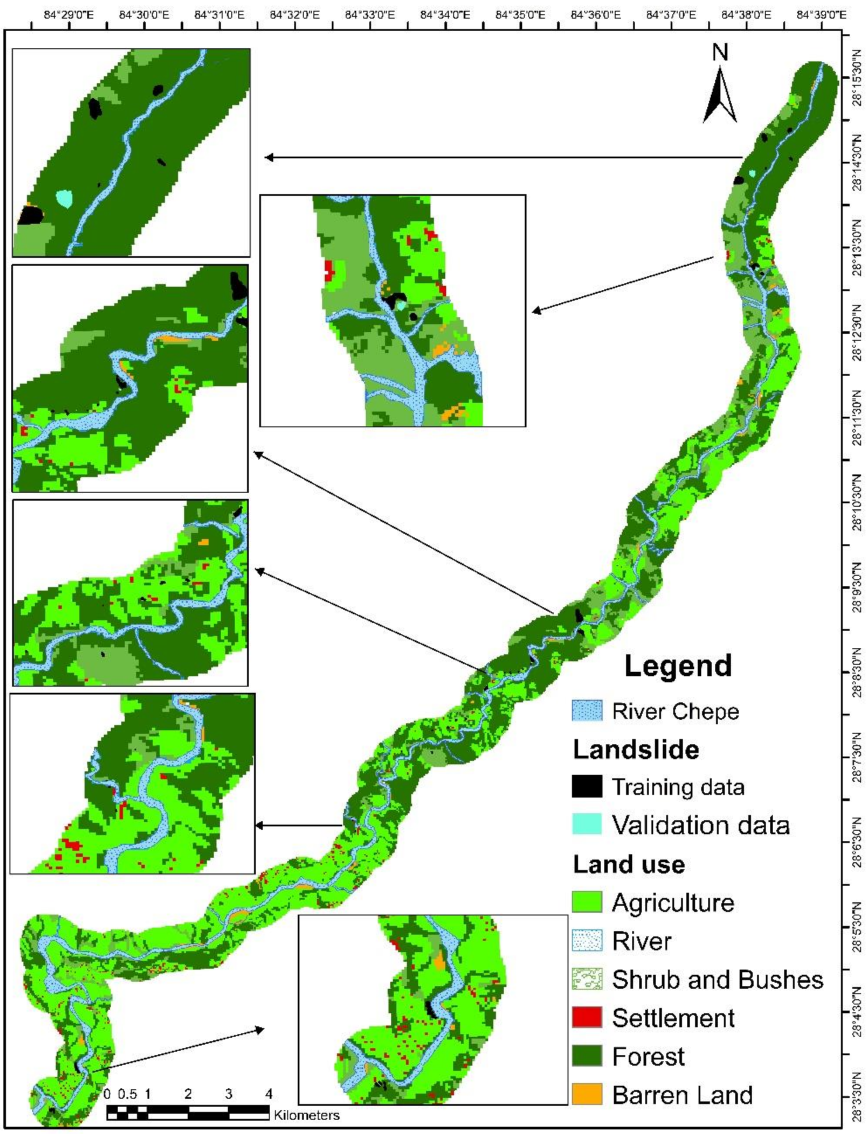


Figure 13: Distribution of landslides with the land use in the Chepe River corridor

4.2.11 Rainfall

The rainfall data taken from eight stations (Annex 6) ranges from 2000 mm to 2900 mm. Rainfall of study area fall into nine classes with the minimum rainfall 2000 mm and the maximum rainfall about 2900 mm. The landslide is basically found to be occurring in the area having the rainfall of 2800-2900 mm. With the increasing intensity of rainfall, the area covered by the landslide is also maximum (Table 12).

Table 12: Weightage values of rainfall in Chepe River corridor

Value	**Rainfall (mm)**	**Area of rainfall (m^2)**	**Area of landslide (m^2)**	**Weightage (Wij)**
0	<2100	213300	0	0
1	2100-2200	2445300	10800	0.4446
2	2200-2300	5112000	0	0
3	2300-2400	5904000	0	0
4	2400-2500	2271600	0	0
5	2500-2600	3672900	5400	-0.6554
6	2600-2700	5031000	30600	0.7646
7	2700-2800	9031500	20700	-0.2114
8	2800-2900	3188700	36900	1.4078
	Total			1.7502

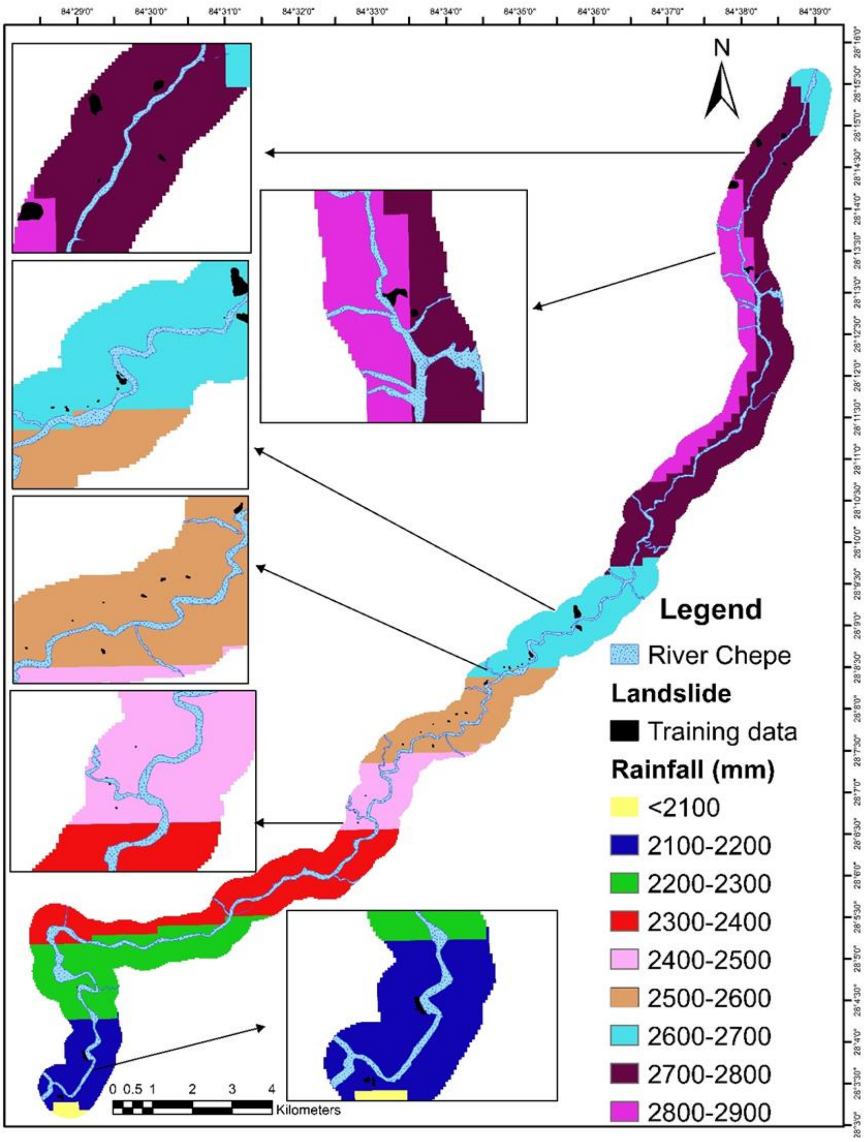


Figure 14: Distribution of landslides with the rainfall in the Chepe River corridor

On the basis of the bivariate model i.e. Statistical Index Model, the major triggering factor was observed to be slope and distance to road followed by geology, land use, elevation, plan curvature, relief, profile curvature, drainage distance and aspect (Table 13).

Table 13: Weightage Values for the triggering factors of landslide

S.N	Landslide triggering factors	Weightage
1.	Slope	5.5006
2.	Distance to Road	5.1733
3.	Geology	2.2722

4.	Land use	1.798
5.	Rainfall	1.7502
6.	Elevation	1.7061
7.	Plan curvature	1.5474
8.	Relief	1.1621
9.	Profile curvature	0.9767
10	Drainage density	-1.8401
11.	Aspect	-3.6418

4.3 Landslide Hazard Index (LHI) for Statistical Index Model

The result from the landslide hazard index classification showed the maximum value of 1 and the minimum value of 0.1 for hazard index value. By this method both the landslide distribution and hazard index are used for the classification purpose of hazard index class. The result obtained showed that about 25% of the landslide has the landslide hazard index below 0.1, about 50% of landslide is in the range of 0.1 to 0.19, about 75% of landslide is at the range of 0.19 to 0.2 and 100% of landslide are in the range of 0.2 to 1 (Table 14).

Table 14: Landslide Hazard Index Classification

S.N	**Landslide Hazard Index**	**Hazard class**
1.	<0.1	Low hazard
2.	0.1-0.19	Medium hazard
3.	0.19-0.2	High hazard
4	0.2-1	Very high hazard

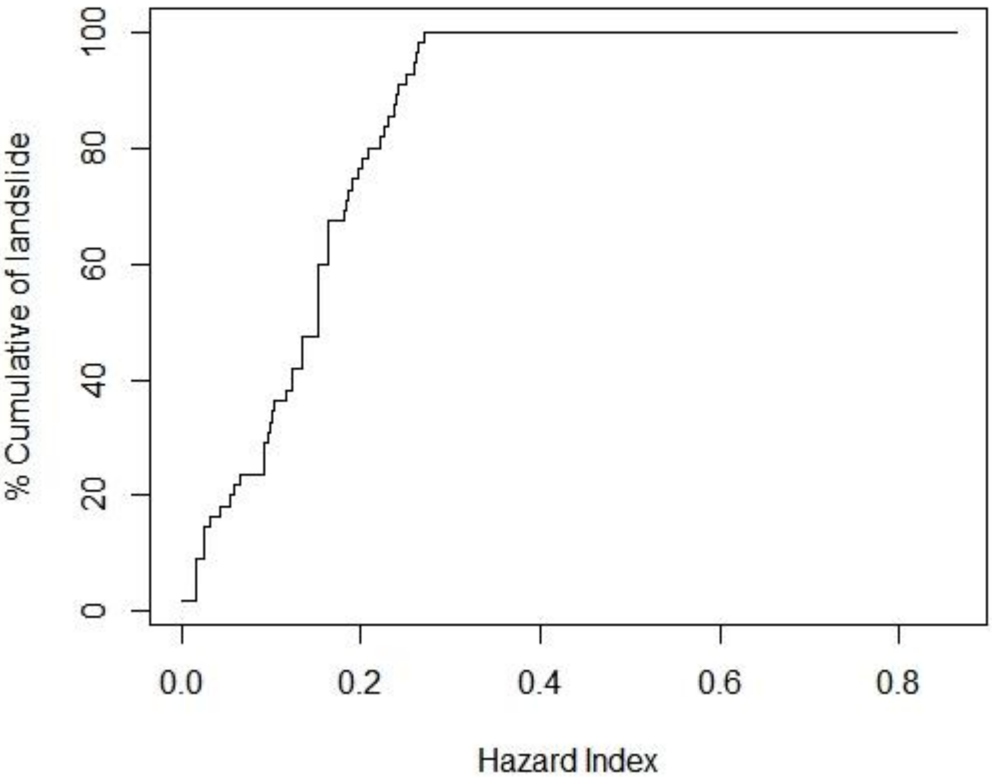


Figure 15: Percentage cumulative of landslide with their corresponding hazard index

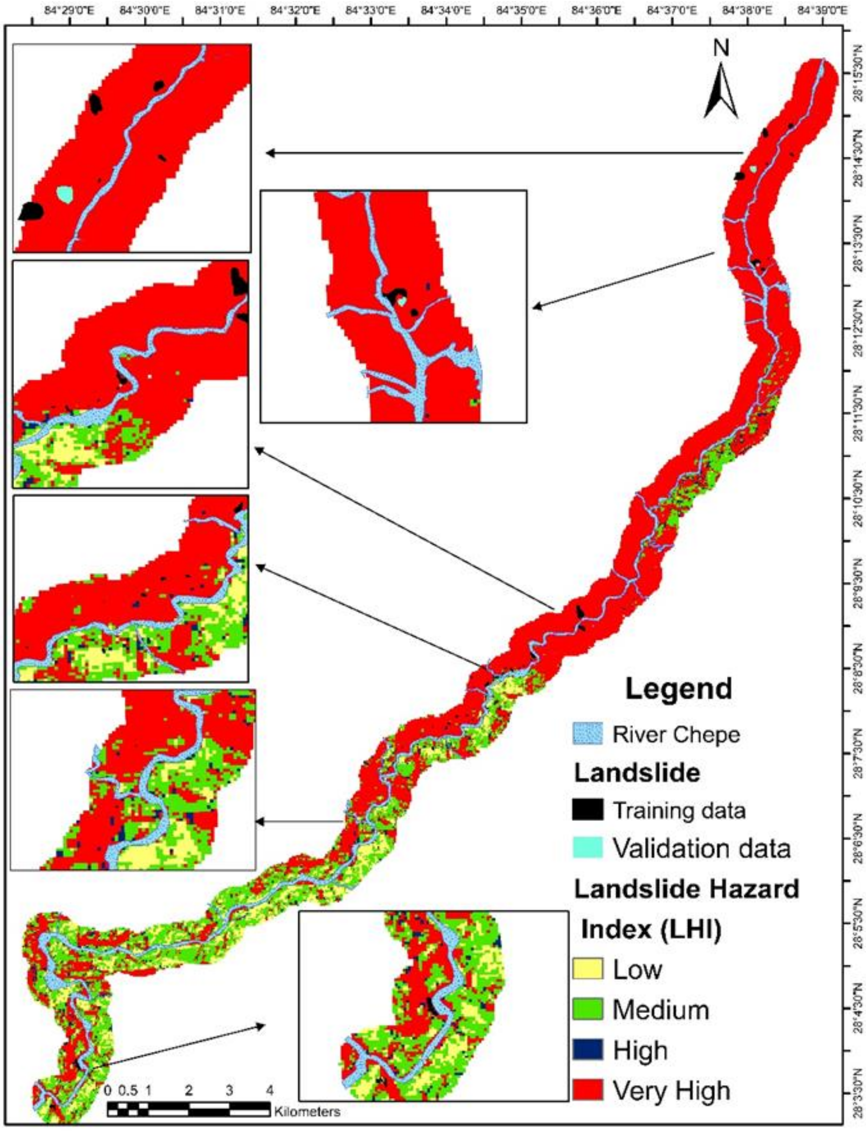


Figure 16: Landslide hazard map prepared by Statistical Index Model

4.3 Multivariate Logistic Regression Model

The multivariate logistic regression was done by using R studio, Arc GIS and JMP i.e. R studio and JMP for data calculation and formation of equation and Arc GIS for the preparation of multivariate hazard map. The resultant beta (β) coefficients for each independent variable in the logistic regression equation are given in Table 15.

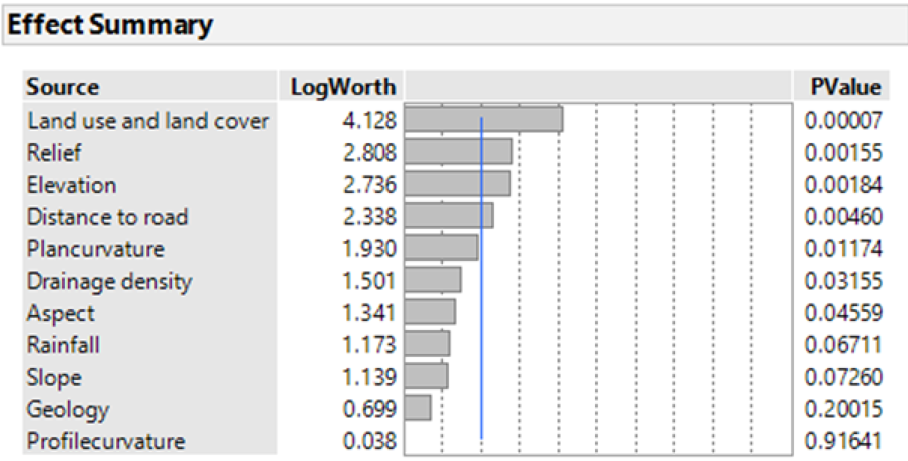
Table 15: Coefficient value of factors in Logistic Regression Model

S.N	Factors	β
1	Slope	0.0967
2	Distance to Road	- 0.0028

3	Geology	
	Ghanapokhara formation	-13.5925
	Cr	-10.4906
	Ranimatta formation	11.6915
	Ulleri formation	12.3917
4	Land use	
	Agriculture	-3.2927
	River	1.079
	Shrubland	2.3956
	Forest	-0.1821
5	Rainfall	0.0092
6	Elevation	- 0.0190
7	Plan curvature	1.1295
8	Relief	- 0.0335
9	Profile curvature	0.0631
10	Drainage density	2.2773
11	Aspect	0.0069

Using both landslide and non-landslide points, the following equation was obtained from JMP software.

Z = Float (-20.4030 - 0.0190 x Elevation + 2.2773 x Drainage - 0.0028 x Road + 0.0631 x Profile Curvature + 1.1295 x Plan Curvature - 0.0335 x Relief + 0.0092 x Rainfall + 0.0069 x Aspect + 0.0967 x Slope + Con (“Landuse” == 1, -3.2927, Con (“Landuse” == 2, 1.079, Con (“Landuse” ==3, 2.3956, Con (“Landuse” ==5, -0.1821, 0)))) + Con ("Geology" == 2, -13.5925, Con ("Geology" == 4, -10.4906, Con ("Geology" == 5, 11.6915, Con ("Geology" == 8, 12.3917, 0)))))



Effect Summary

Source	LogWorth	PValue
Land use and land cover	4.128	0.00007
Relief	2.808	0.00155
Elevation	2.736	0.00184
Distance to road	2.338	0.00460
Plancurvature	1.930	0.01174
Drainage density	1.501	0.03155
Aspect	1.341	0.04559
Rainfall	1.173	0.06711
Slope	1.139	0.07260
Geology	0.699	0.20015
Profilecurvature	0.038	0.91641

Figure 17: Probability value for each triggering factors of landslide.

Table 16: Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	38.025046	15	76.05009	<.0001*
Full	30.591474			
Reduced	68.616520			

RSquare (U)	0.5542
AICc	99.8171
BIC	134.705
Observations (or Sum Wgts)	99

Map prepared was converted into the log expression:

$$P(y = 1/X) = \frac{1}{(1+Power(2.718, -rastermap)}$$

4.4 Landslide Hazard Index for Logistic Regression Model

The result of landslide hazard index classification showed the maximum value of 0.7309 and the minimum value of 0.62. The result obtained showed that about 25% of the landslide has the LHI less than 0.62, about 50% of landslides is in the range of 0.62-0.64, about 75% of landslides had at the range of 0.64 to 0.645 and 100% of landslides had the range of 0.645 to 0.7309.

Table 17: Landslide Hazard Index Classification

S.N	Landslide Hazard Index	Hazard class
1.	<0.62	Low hazard
2.	0.62-0.64	Medium hazard
3.	0.64-0.645	High hazard
4	0.645-0.7309	Very high hazard

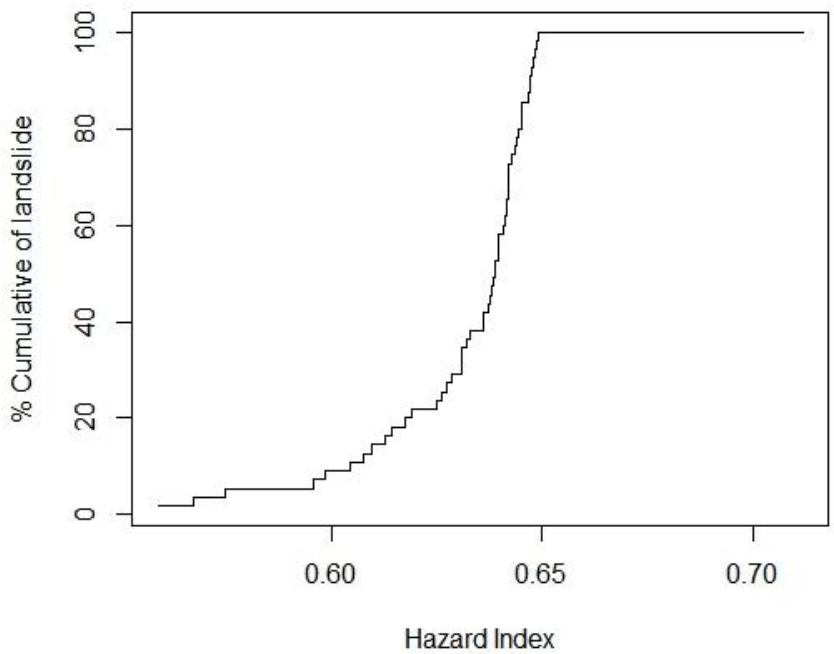


Figure 18: Percentage cumulative of landslide with the hazard index

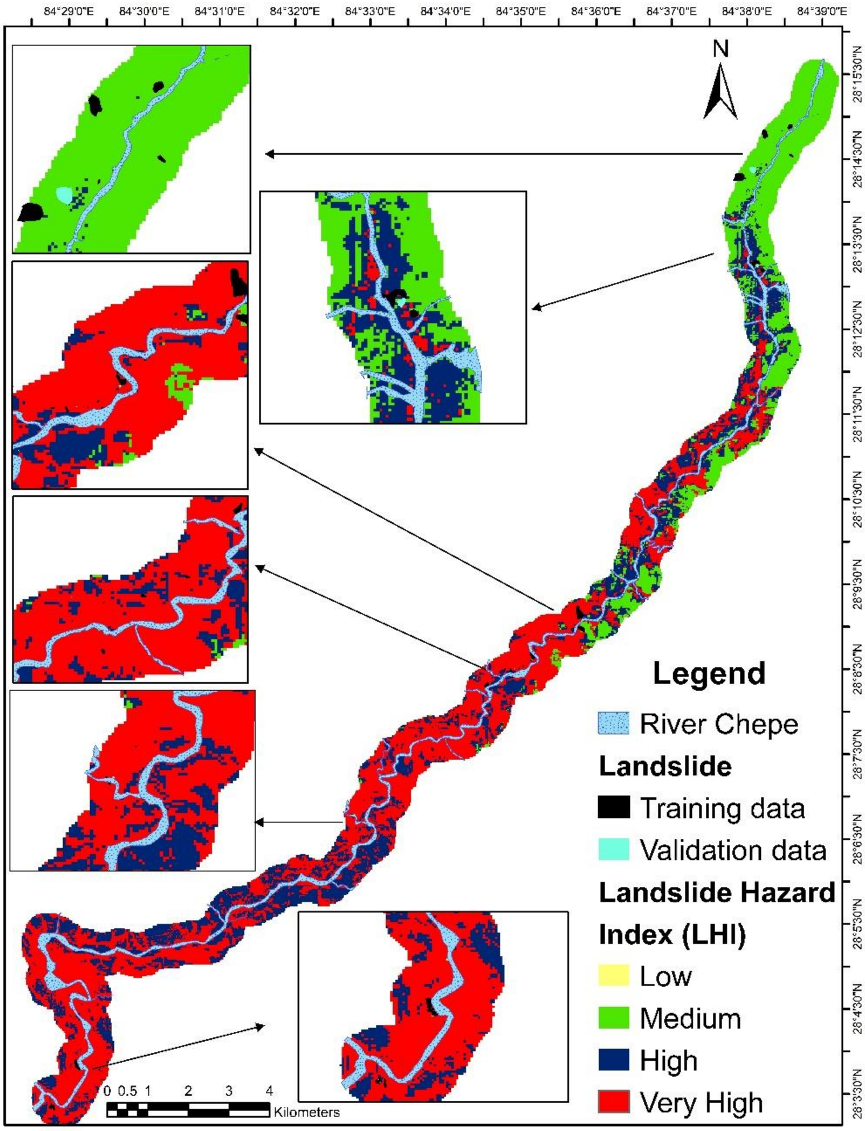


Figure 19: Landslide hazard map prepared by Logistic Regression Model

4.5 Receiver Operating Characteristic (ROC)

The landslide hazard assessment was carried out using two different models i.e. Statistical Index Model (bi-variate model) and Logistic Regression (multi-variate model). Furthermore, the analysis results were validated using the receiver operating characteristic (ROC) analysis to evaluate the correlation between the landslide hazard maps and landslide inventory points as well as to compare the effectiveness of model in landslide hazard mapping of Chepe River corridor. 30% of total 73 landslides (18 landslide) had been employed for validation purpose. The results obtained shows that a value of area under curve (AUC) for Statistical Index model was 0.6296 and the prediction accuracy was about 63%. Similarly, AUC for logistic regression model was 0.8209 and the prediction accuracy was 82%. This results obtained from ROC indicate that the logistic model looks to be more accurate in terms of the performance of landslide hazard mapping and has better prediction accuracy than the Statistical Index Model in the study area.

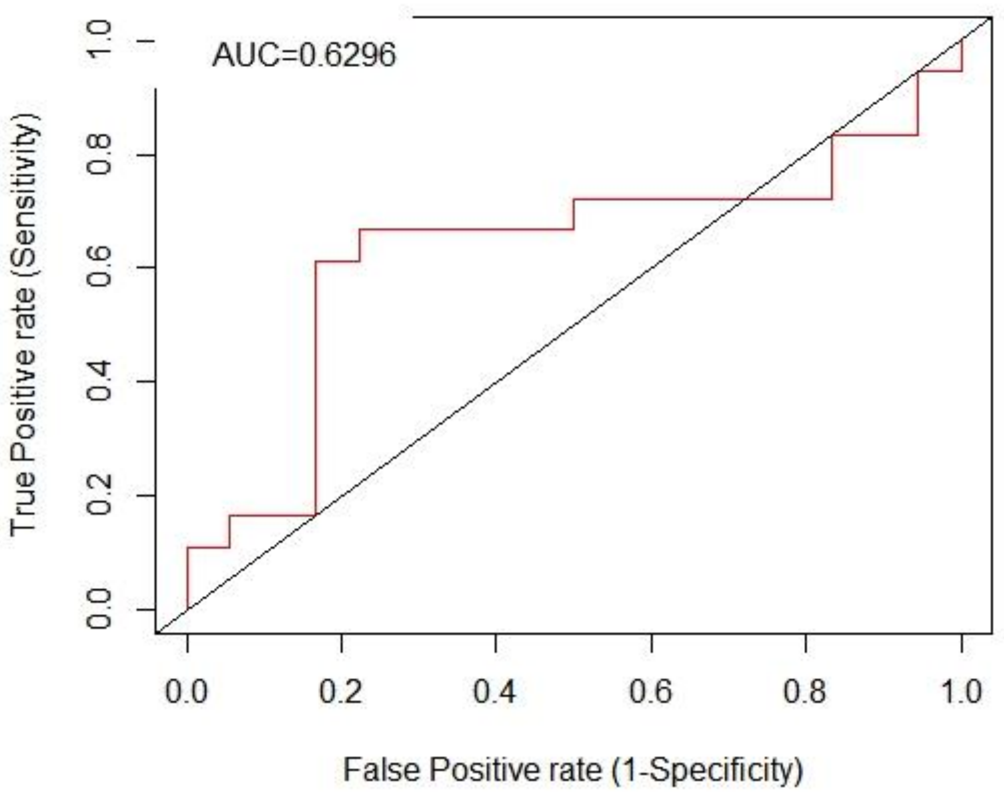


Figure 20: ROC for Statistical Index Model

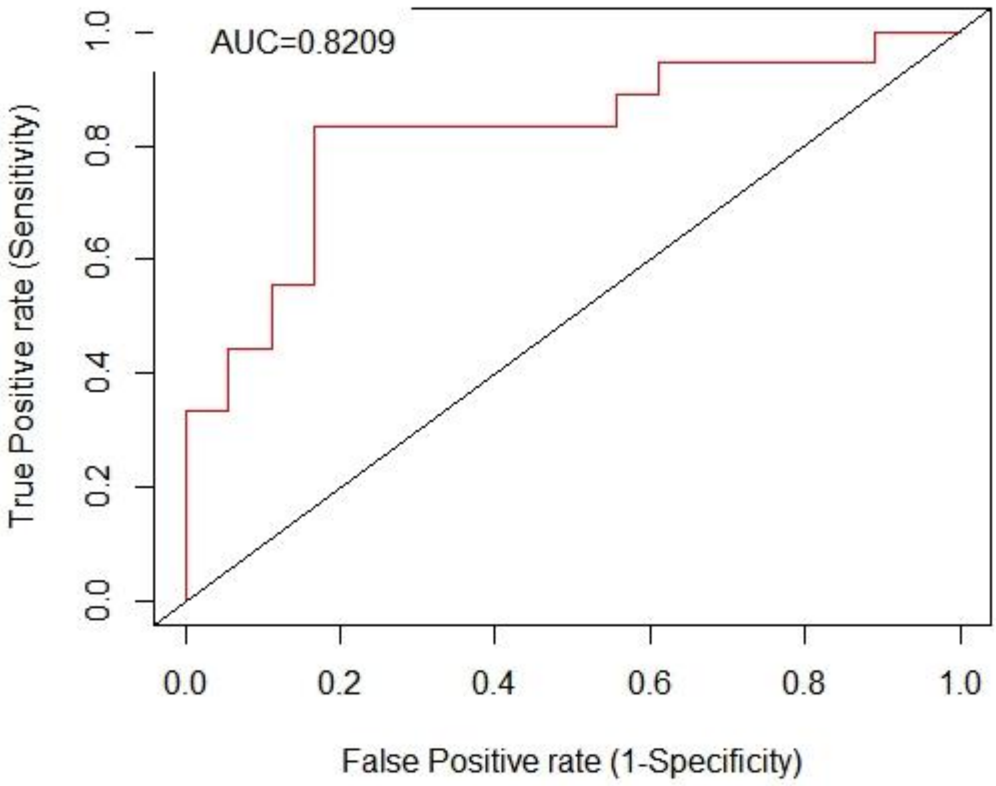


Figure 21: ROC for Logistic Regression Model

4.6 Vulnerability Assessment

For the vulnerability assessment a total of five municipalities and eighteen wards were taken that falls within the boundary of river corridor (Table 18). Local Disaster and Climate Resilient Planning guideline (2017) by Government of Nepal was followed for the analysis of vulnerability of the Chepe River corridor.

Table 18: List of wards and municipality in the study area

S.N	District	Municipality	Wards	Area covered (km^2)
1	Gorkha	Ajirkot	2, 3	4.1698
2	Gorkha	Siranchok	1, 2, 3	5.3201
3	Gorkha	Palungtar	3, 5	3.3780
4	Lamjung	Rainas	1, 2, 3, 4, 5, 6, 7	9.7069
5	Lamjung	Dudhpokhari	1, 2, 4, 5	13.9777

Though landslides were found in the seven wards, all the eighteen wards were taken into analysis for vulnerability assessment because people own property like house and land on the other ward apart from that they were residing (Table 18). Landslides were found to occur more in the forest area with none in the settlements (Table 19).

Table 19: Landslide occurring areas (m^2)

S.N	Municipality	Wards	Agriculture (m^2)	River (m^2)	Shrub and bushes (m^2)	Forest (m^2)	Barren land (m^2)
1	Ajirkot	2	0	0	0	900	0
2	Palungtar	5	900	0	0	1800	0
3	Rainas	1	2700	1800	4500	4500	1800
4	Dudhpokhari	1	0	0	9900	14400	17100
5	Dudhpokhari	4	5400	900	0	25200	0
6	Dudhpokhari	5	3600	0	1800	0	0
7	Rainas	7	900	3600	0	3600	0

The result obtained from the KII and FGD was converted into the vulnerability scores (Annex 5) for each indicators and the vulnerability map of the Chepe River corridor was prepared (Figure 22). Out of eighteen wards considered for the vulnerability assessment, ten wards were observed to have low vulnerability to landslide while eight wards were observed to have medium vulnerability (Table 20). Rainas Municipality (Ward-7) and Dudhpokhari Municipality (Ward-4) have the maximum vulnerability score in comparison to the other wards. Single death was found in the Dudhpokhari (ward-4) due to Mughe landslide. Based on the field survey, people living in the Chepe River corridor reported that many houses have possibility of getting impacted due to the landslide in the near future as there is no proper management of spring source of water that creates gullies and haphazard road construction. Houses of Rainas-1, 4, 6, Dudhpokhari-4, Palungtar-3 and Siranchowk-2 were found to be highly affected due to the landslide (Annex 5).

Table 20: Vulnerability score of each wards falling within the study area

S.N	Municipality	Ward	Vulnerability score
1	Ajirkot	2	22
2	Ajirkot	3	23
3	Siranchowk	1	23
4	Siranchowk	2	25
5	Siranchowk	3	27
6	Palungtar	3	27

7	Palungtar	5	22
8	Rainas	1	25
9	Rainas	2	23
10	Rainas	3	29
11	Rainas	4	23
12	Rainas	5	22
13	Rainas	6	26
14	Rainas	7	33
15	Dudhpokhari	1	23
16	Dudhpokhari	2	23
17	Dudhpokhari	4	29
18	Dudhpokhari	5	23

Table 21: Differential vulnerability classes on the basis of vulnerability scores (GoN, 2017)

S.N	**Vulnerability score**	**Vulnerability class**
1	< 23	Low
2	24-38	Medium
3	>38	High

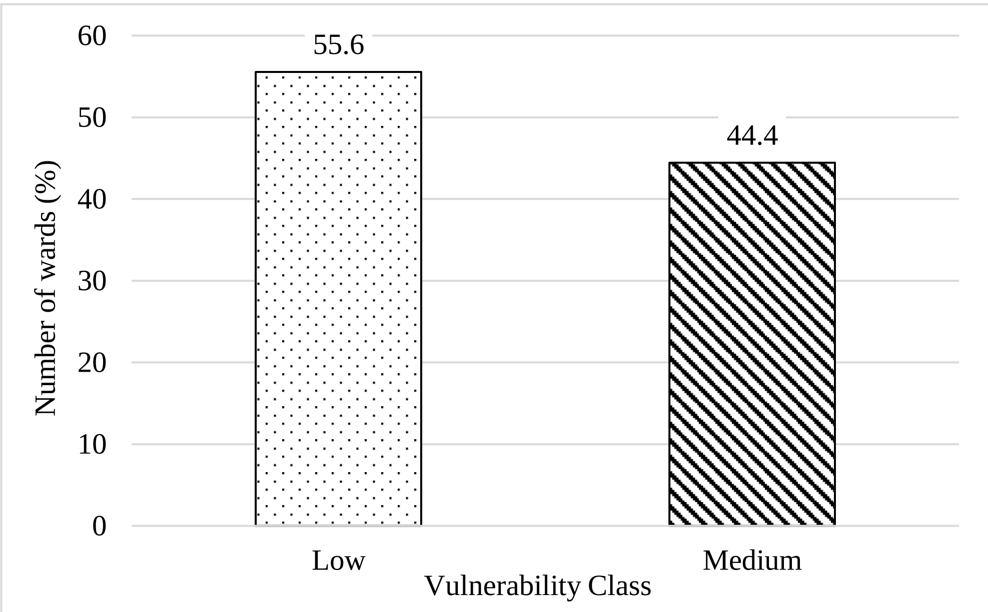


Figure 22: Vulnerable wards in the Chepe River corridor

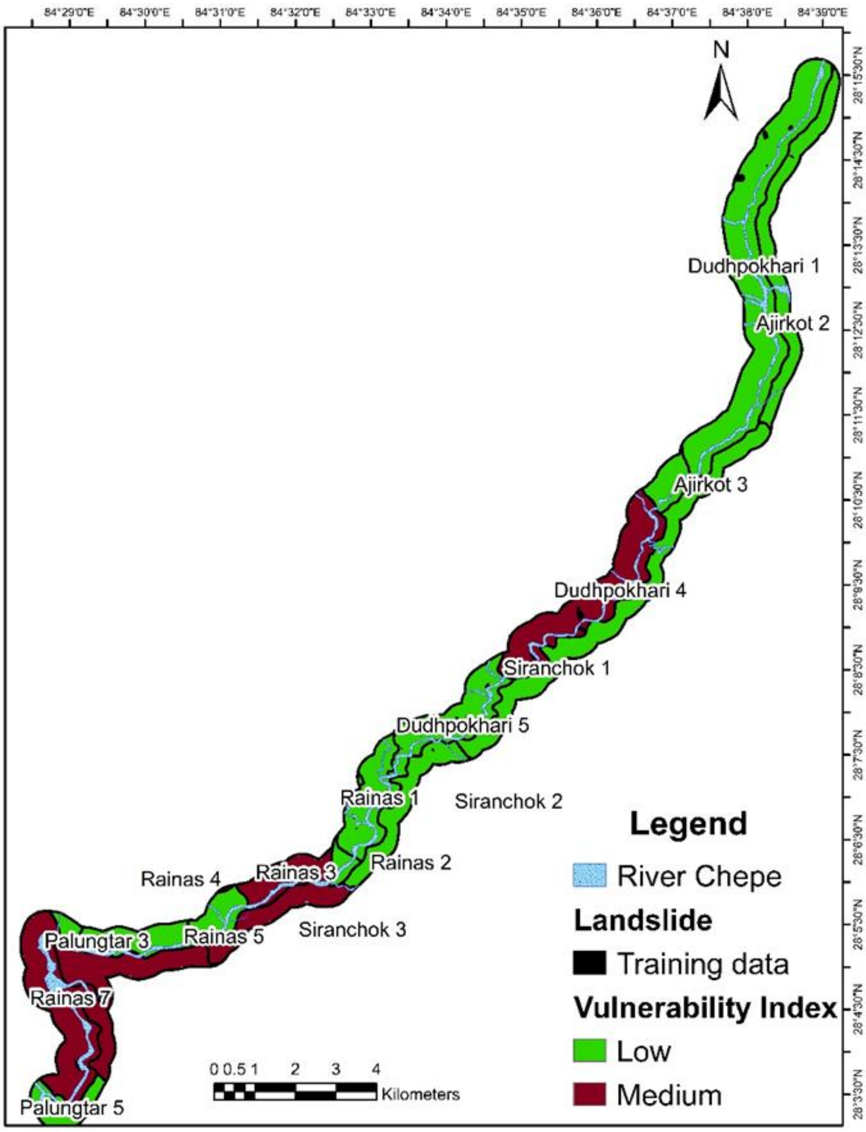


Figure 23: Ward-wise landslide vulnerability in the Chepe River corridor

4.6 Risk Assessment

As the logistic regression model was found to be more reliable in terms of landslide hazard assessment, the model was multiplied with the vulnerability model to get landslide risk map. The risk level was classified into 4 level i.e. low, medium, high and very high. 16.59 (34.54%) km^2 area lies in the medium risk followed by 12.13 (27.46%) km^2 in high risk, 7.75 (17.54 %) km^2 in very high risk and 7.72 (17.46 %) km^2 in low risk respectively (Figure 23).

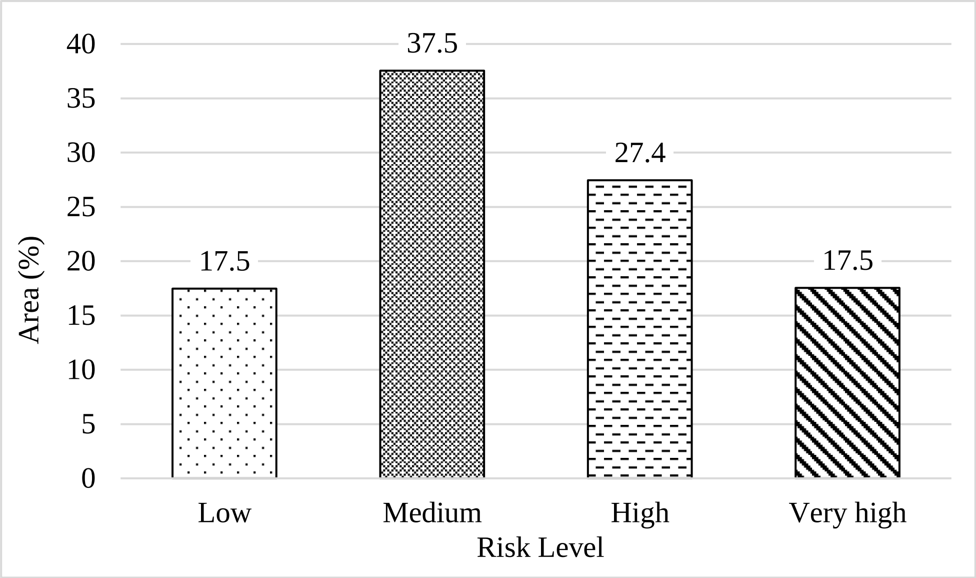


Figure 24: Area covered by each risk level in the study area

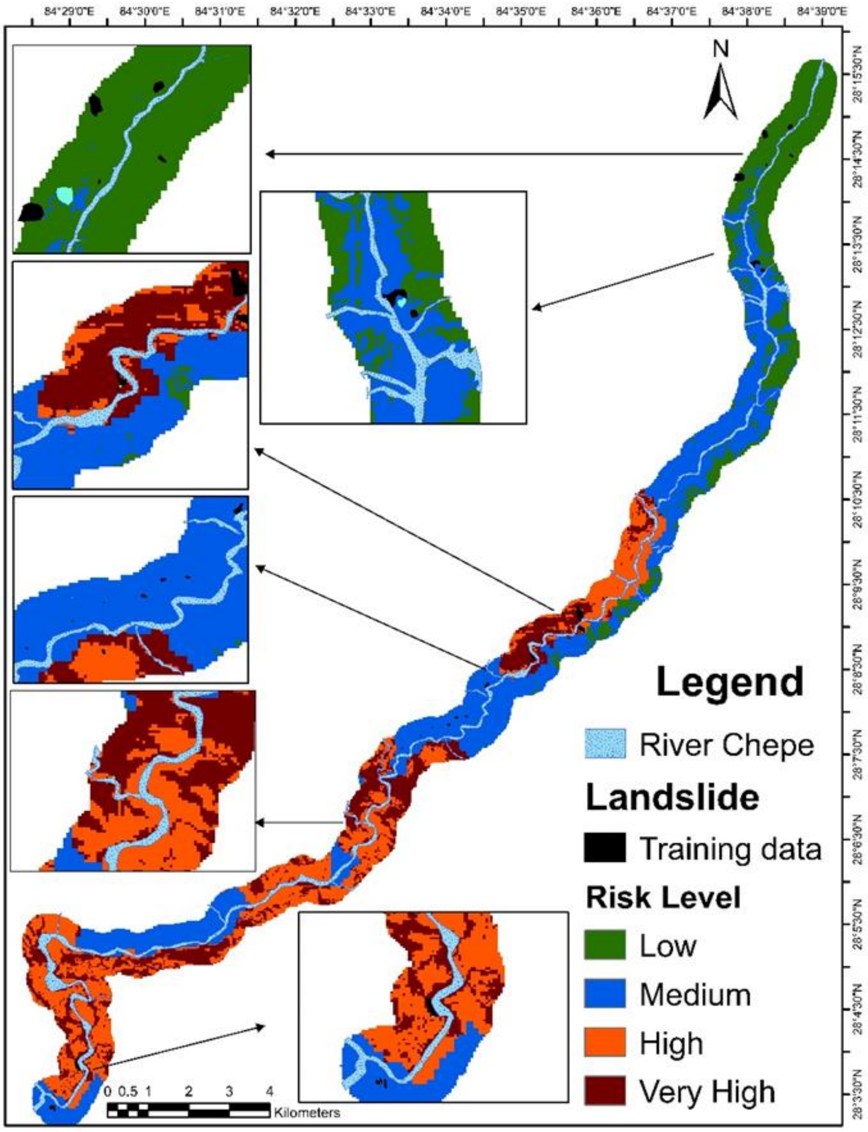


Figure 25: Spatial distribution of landslides risk areas in Chepe River corridor

CHAPTER 5: DISCUSSION

5.1 Inventory and historical analysis of landslides

In the present study, a total of 73 landslides were observed. Most of the landslides observed were debris flow and very few were rock flow and were found to be active. According to the people living on the corridor the major reason for the landslide are the road construction, irrigation canal construction, spring source and rainfall. A series of landslides in Dhamilikuwa VDC had occurred in the slopes along the Chepe River. There are about 7-10 landslides at the same place which had displaced Bharati family from that area and the landslide is also called Bharati veer (personal communication with local people). According to Ojha et al. (2015), Patapati (first started in 1984), Simpani (first started in 2001) which is still active covering the area about 200m x 150m, Chepe Sangu (first started in 2011), and Bagar/Tamang tole (first started in 2012) are some of the landslides. An irrigation canal popularly known as Rainastar Sinchai Nahar was initiated by the Government of Nepal (GoN) in 1984 with the technical and financial support from the Irrigation Line of Credit (ILC), World Bank (WB) and the International Labor Organization (ILO), which was completed in 1996 (Ojha et al., 2015). The people of Borangkhola believe that the landslide is caused due to this canal too along with the other spring sources and rainfall. Another most popular landslide in the Chepe River corridor is Chunpaharo landslide in Bangechaur. The landslide occurred about 10 year ago and is still active slowing taking away the land of the people living nearby. Around 5 houses are highly vulnerable to that landslide which has covered a broad area in the river corridor. Mughe landslide is the another huge landslide which is basically the rock flow that may cause loss of life and property if it occurs frequently. During 2015 (September) a massive Mughe landslide killed one disable person who wasn't able to run during that landslide. Most of the landslide were found to have occurred due to road construction whereas others are found to be older one occurred 5-10 years before which is still active.

5.2 Landslide triggering factors

Many factors are responsible for the landslide occurrence. In this study a total of 11 factors were considered for the analysis of landslide hazard and risk. The slope class from 10° to 50° showed an increasing trend of landslide whereas from 50° to 70°, it is decreasing (Table 2). Generally, as slope increases, the probability of landslide occurrence also increases (Meten et al., 2015). Chen et al. (2001) state that there is no appropriate relationship between the steepness of a slope and the probability of occurrence of landslides. Landslides are prone to occur on slopes having a particular range of steepness. The finding of this study agrees to Chen et al. (2001).

Aspect (slope orientation) affects the exposure to sun-light, wind and precipitation thereby indirectly affecting other factors such as soil moisture, vegetation cover and soil thickness that contribute to landslides (Clerici et al., 2006). In the present study, aspect towards the southeast and south is found mostly to contributes towards landslides (Table 3). This may be because most of rivers flows from east-west and most of landslides appear on the south slopes towards the river (Caiyan, 2006). The south facing slopes are generally steep and anti-dipping slopes and many south facing facets are on the windward side of the summer monsoon rain which agrees with Ghimire (2011).

The land use has also the significant role in the stability of soil slope. Landslide was found to occur more in the forested area than in the barren lands (Table 11) which is similar to the findings in Chure area (TU-CDES, 2016). Based on the field survey the maximum area covered by landslides in the forest is may be due to factors like haphazard road construction, broader girth of older trees, spring source creating gullies etc. There are numerous factors responsible for the occurrence of landslide. Statistical Index Model has also stated that slope (40-50°), distance to road (less than 500 m), geology (Himal group, Ranimatta and Ulleri formation) and rainfall (2800-2900 mm) are mostly responsible for the occurrence of landslide in the study area which might be the reason for the observation of maximum landslide in the forest areas. Most of the area of the corridor falls in the forest which might be the another reason of maximum landslide observed in forest. Trees and forests can make a positive contribution in various situations however it also increase landslide risk by imposing load on unstable slopes and via wind-related effects; they are unlikely to prevent or minimize deep landslides or slides on very steep slopes. However, they can (FAO, 2018).

The surface relief is the variation in height of land surface and the different reliefs have different climatic conditions. According to Bhattarai and Pradhan (2011) the construction activities like roads are preferentially built along the same relief and are therefore landslide hazards in an area are observed more or less on the same relief. The study area has the maximum area of landslide in the relief of less than 30 m (Table 5).

Most of the area of Chepe River falls within the elevation of 400-800 m where the area of occurrence of landslide is maximum in the elevation of 800-1200 m. According to

Ghimire (2011), there is no exact relation between occurrence of landslide and elevation and therefore elevation alone cannot explain about the occurrence of landslides. Elevation along with other linked parameters like aspect, slope is interlinked for causing landslides in any place.

The roads built on the slopes cause the loss of toe support. The change of the topography and loss of support lead to increase in strain behind the slope and development of cracks. It leads to the instabilities occurring in the slope because of the negative effects such as water infiltration (Devkota et al., 2013) and with that the road segment may act as a barrier, a net source, a net sink or a corridor for water flow, and depending on its location in the area, it usually serves as a source of landslides (Pradhan & Lee, 2010). In the study area, maximum landslides were found to be near to the road i.e. < 500 m. With the increasing distance of the road the landslide is also less which shows that the landslide is triggered due to the haphazard road construction (table 4). The similar result was reported by Devkota et al. (2013) in the Mugling-Narayanghat road section which stated that road construction is one of the reason behind the landslide occurrence. Implementation of improved standards for road construction needs to be undertaken immediately to reduce landslide risk.

Plan curvature is the curvature of the hillside in a horizontal plane or the curvature of the contours on a topographic map. Hillsides can be subdivided into regions of concave outward, convex outward, and straight contours called planar regions (Ohlmacher, 2007). It was observed that slope in the case of curvature, the planar curvature is the most susceptible to landslides, in both plan as well as profile curvature and the finding of this study is similar to Ohlmacher (2007) in which the statistical analysis of plan-curvature and landslide datasets also indicate that hillsides with planar plan curvature have the highest probability for landslides in regions dominated by earth flows and earth slides in clayey soils (CH and CL). The curvature values represent the morphology of the topography (Lee et al., 2004; Erener & Duzgun, 2010). Devkota et al. (2013) concluded that the concave curvature is most susceptible to the landslide whereas Lee and Pradhan (2007) observed that convex curvature is more susceptible to landslide which indicates there are other factors like rainfall, slope, geology, land use etc. along with curvature type responsible for the landslide.

Geology plays an important role in the causes of landslide failure. Most of the landslide in the study area is found to contain Himal group and Ranimatta formation. Himal group consists of rocks like marble, gneiss, magmatite whereas Ranimatta formation consists of phyllite, quartzite, metasandstone and conglomerate (Ojha, 2009). Thin beds of phyllite between quartzite beds is one of the cause of landslide. Phyllite has less friction angle and higher weathering rate which gets weathered during long environmental exposure. Due to that the landslides are active. Himal group consists gneiss which contains more amount of feldspar and weathering rate of feldspar is higher which undergoes chemical weathering with water. Due to which land sliding is common in gneiss (Gasim et al., 2015).

Drainage density is the important factor in deciding the degree of dissection and has been observed that in the low dissected hill the drainage density is low, while in the highly dissected hills the drainage density is high. It is important factor for slope instability as higher the drainage density, lower is the infiltration and faster is movement of the surface flow (Pachauri et al., 1998). In the area close to the drainages, the high drainage density can cause accelerated surface erosion resulting into intense superficial mass wasting (Barredo et al., 2000). Many landslides in hilly areas occur due to the erosional activity associated with drainage. The result of this present study showed that landslide area is maximum in the area having less drainage density, which shows more infiltration causing the more landslide to occur.

Rainfall plays an important role in landslide triggering effects. Rainfall triggered landslides are reported every year in different countries. The findings of this study also shows rainfall as one of the significant triggering factor. The area of landslide is increasing with the increase in the intensity of rainfall in the Chepe River corridor. Although rainfall is one of the main landslides triggering factors in Nepal and throughout the Himalaya, the relationship between landslide occurrence and rainfall characteristics, either in empirical equations, or in known physical interactions of slope materials, is still unclear. In the Himalaya, the empirical relationship between rainfall and landslide occurrence, such as minimum or maximum amount of rainfall necessary for triggering landslides, is yet to be established (Dahal & Hasegawa, 2008).

5.3 Landslide modelling and model comparison

Statistical Index Model (SIM) is a polygon (area) based analysis and the result showed that slope and road are the major triggering factor of landslide in the study area. Most of the area of the corridor lies to the very high hazard area. Dudhpokhari municipality of Lamjung district and Ajirkot municipality of Gorkha district lying in the river corridor are observed to be very high hazardous in terms of landslide. Logistic regression model, one of the proposed favorable model to deal with the problem of combination of heterogeneous data, has been widely used for mapping landslide susceptibility. It is based on the point based analysis of landslide. In the present study, logistic regression model shows that there is greater significance of landuse and landcover in the occurrence of the landslides whereas geology and profile curvature has very less significance. There is a general consensus that geological information is one of the most decisive parameters regarding landslide manifestation and thus included in landslide hazard models (LHMs) (Rossi et al., 2010; Pourghasemi et al., 2012). However, the study by Paudel (2016) revealed that the necessity of using geological information in additional to topographical parameters is not always high. The whole model test (table 15) shows that the-loglikelihood has dropped to 30.59 (from 68.62) and the difference in model by including the variable is significant with Prob>ChiSq (<.0001) and chi square statistics (76.05009). This means models are compared and hypothesis is tested which showed model improvement has been achieved. On the basis of landslide hazard map, Rainas and few areas of Dudhpokhari municipality and Palungtar and Siranchowk municipality of Gorkha district are observed to be high hazard areas.

Landslide Hazard Models (LHMs) after the preparation should be validated before using to ascertain their reliability. According to Vakhshoori and Zare (2018), the validity of LSMs had simply been presented by simple statistics such as landslide percentage per susceptible zones and model efficiency. Owing to the inefficiency of these simple statistics (Provost & Fawcett, 1997; Provost et al., 1998), threshold-independent methods, like receiver operating characteristic (ROC), have been recommended for validation (Fielding & Bell, 1997; Begueria, 2006; Akgun, 2012; Corominas et al., 2014). The area under curve (AUC) value of SIM was 0.6296 and the prediction accuracy was 63%. Similarly, AUC for logistic regression model was 0.8209 with the prediction accuracy of 82% which shows that comparatively logistic regression is better in performance than statistical index model for landslide hazard assessment. Various results from different studies has shown the logistic regression models to be more reliable than the statistical Index models: Pourghasem et al. (2013) prepared the landslide susceptibility mapping by binary logistic regression, analytical hierarchy process, and statistical index models along with this they also compared the performances of model which also shows logistic regression model is better than SIMs; Similar result have been observed by Lim et al. (2011) where landslide hazard maps were produced using the probabilistic methods like frequency ratio, statistical index, certainty factor and landslide susceptibility analysis, logistic regression (80.05%) accuracy represented the best result followed by frequency ratio (79.68%), landslide susceptibility analysis (79.6%), statistical index (79.38%) and certainty factor (79.37%); logistic regression was found to be more reliable than SIMs in the study of landslide susceptibility in Japan (Dou et al., 2015). The result of logistic regression showed that geology has very less impact in the landslide occurrence in this study area and the similar result was obtained in the study of Khanh (2009). Vakhshoori and Zare (2018) also stated that ROC curve could merely estimate a general validity for the produced LSMs and therefore, it is by no means certain that a map with a ROC-AUC a few percent lower than that of the other maps is less reliable in predicting the future landslides.

5.4 Vulnerability and risk assessment

Vulnerability assessment is a challenging work to be done as different studies uses different indicators for the analysis. In this study the LDCRP guideline provided by the GoN (2017) was used. A total of 14 indictors were used for the analysis. Ajirkot-2,3, Siranchowk-1,2, Palungtar-5, Rainas-2, 4,5, and Dudhpokhari-1,2,5 were observed to be low vulnerable to the landslides whereas Siranchowk-3, Palungtar-3, Rainas-1,3,6,7 and Dudhpokhari-4 were found to have medium vulnerability. Landslide has caused the economic loss by means of damaged house and loss of agricultural land. Maize, wheat, millet, paddy and buckwheat are some of the major agricultural production in the study area. These crops were also considered during the vulnerability analysis of economical aspect (Appendix 5). Most of the area was found to be less vulnerable to the landslide because of less impact of landslide in the settlement area and good economic stability of people. None of the area is found to be highly vulnerable to the landslide till date but according to the people there is a high possibility of increment of the impact from the increment in the landslide number because of the external factors like road construction in the study area. Most of the area of landslide lies in the medium risk zone followed by high, very high and low risk zone. Areas like Rainas-1,3,7, Siranchowk-3, Palungtar-3 and Dudhpokhari-4 were observed to be at high and very high risk in terms of landslide. The early paradigms within social science emphasized the reaction and perceptions of communities during and after emergencies and did not explicitly focus on issues of risk, or mitigating the risk of physical harm and social disruption before an event occurred (Kreps,1973; Cardona, 2003).

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

A total of 73 landslides were found in the Chepe River corridor which was divided into training data (70%) and validation data (30%). The hazard, vulnerability and risk assessment of Chepe River corridor comprising 5 municipalities and 18 wards was studied. Two models i.e. bivariate statistical index model and multivariate logistic regression model were used for the landslide hazard assessment. According to the statistical index model slope, distance to road, geology, land use and rainfall are the major triggering factors of landslides whereas the logistic regression model states that land use, relief, elevation, drainage density, slope and plan curvature are the major triggering factors in the study area. The comparison and validation of the model was done by using ROC which states the prediction accuracy of logistic regression model is 82% whereas the statistical index model is only 63%. The logistic regression model is found to be a better model for the landslide hazard assessment in the smaller area like river corridor. Therefore, the prioritization should be given to the proper land use management to control the landslide of the area. The vulnerability assessment done in the study area indicates 10 wards falling within the river corridor to be low vulnerable to the landslide whereas 8 wards were found to be medium vulnerable to the landslide. None of the wards were highly vulnerable to the landslide. But due to the haphazard road construction, the likelihood of occurrence of landslide and increment of its negative impact is maximum in upcoming days. Most of the area (34.54%) lies in the medium risk followed by high risk (27.46%), very high risk (17.54%) and low risk (17.46%).

6.2 Recommendations

Based on the findings of the present study following recommendations have been put forward:

- This study has identified the risk prone areas in terms of landslide therefore the information and awareness about the risk should be provided to the people living in such areas for their preparedness towards mitigation.
- Proper Land Use planning (according to Land Use policy, 2015) and its implementation should be done in order to use the land sustainably.

- Proper baseline study on the hazard and risk zonation should be done prior to the construction of roads, houses and the other infrastructures.
- Government (Federal, Provincial and Local) should prevent the people living in the risk prone area where the landslide is cutting the land mass slowly.
- As the present study incorporates eleven factors, further studies can be carried out incorporating the other triggering factors like vegetation index, soil type etc.

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APPENDICES

Appendix 1: Letter from Palungtar municipality, Gorkha for the completion of fieldwork at the site

Website: www.Palungtarmun.gov.np

☎064-400002

पालुङटार नगरपालिका

PALUNGTAR MUNICIPALITY

नगर कार्यपालिकाको कार्यालय

Office of The Municipal, Executive

पालुङटार, गोरखा

Palungtar, Gorkha

4 No. Province, Nepal

प.सं./Ref.No. :- ०७८/०७९

च.नं./Des.No.:- १२२८

मिति/Date:- २०७८।१०।१८

श्री जो जससँग सम्बन्धित छ ।

विषयः सिफारिस गरिएको बारे

प्रस्तुत विषयमा वातावरण विज्ञान विभाग, त्रि.वि. किर्तिपुरमा स्नातकोत्तर दोस्रो वर्ष चौंथो सेमेस्टरमा अध्यायनरत कृपा श्रेष्ठले गोरखा जिल्ला पालुङटार न.पा. वडा नं. ३, ५ मा " Risk Assessment of landslide in Chepe River Corrider,West Nepal" शीर्षकमा अध्यायन अवलोकन सम्बन्धि कार्य सम्पन्न गरेको व्यहोरा सिफारिस गरिन्छ ।

०७८।१०।१८

नि. प्रमुख प्रशासकीय अधिकृत

Appendix 2: Letter from Rainas municipality, Lamjung for the completion of fieldwork at the site

राइनास नगरपालिका
नगर कार्यपालिका कार्यालय
वडा नं. १ को कार्यालय
बोराङखोला, लमजुङ
४ नं. प्रदेश, नेपाल

Website: www.rainasmun.gov.np

च.न. : ०७४/०७५

मिति : २०७४।१०।१४

बिषयः सिफारिस सम्बन्धमा ।

श्री विज्ञान तथा प्रविधि अध्ययन संस्थान

वातावरण विज्ञान केन्द्रिय विभाग

त्रि.वि.क्याम्पस, कीर्तिपुर-काठमाडौं ।

प्रस्तुत विषयका सम्बन्धमा विज्ञान तथा प्रविधि अध्ययन संस्थान, वातावरण विज्ञान केन्द्रिय विभागका M.Sc. दोस्रो वर्ष चौथो सेमेस्टरमा अध्ययनरत छात्रा श्री **कृपा श्रेष्ठले** लमजुङ जिल्ला राइनास न.पा.- १ नं. वडा कार्यालयमा उपस्थित भई **"Risk Assessment Of Landslide in Chepe River Corridor, West Nepal"** शिर्षकमा आफ्नो शोधकार्य गर्नुभएको व्यहोरा अनुरोध छ ।

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रमेश न्यौपाने

वडा अध्यक्ष

Appendix 3: Questionnaire for Key Informant Interview

1. Date of Survey:
2. Name of Interviewee: ………………………………………………
3. Name of Village/settlements: ……………………………
4. GPS Location: ……………………………………………………
5. Landslide event in the past (you observed)

S.N	Date /Year	Description of the event (timing, causes)	Loss/damages

6. Landslides that caused your loss/damage

S.N	Loss/damages	Description of the event (amount)	Date/Year
1.	Human Death		
2.	House Damaged		
3.	Economic Loss		
4.	Agriculture and forest area		
5.	Social Impact (human lost, robbery, etc.)		

7. Do you have any idea on the cause of landslide in this area?
   ☐ Yes ☐ No
   If yes. What may be the causes of landslide?
   i. ……………………………
   ii. ……………………………
   iii. …………………………….

8. Do you still feel that you are vulnerable to landslide? ☐ Yes ☐ No
   If yes, why do you think so?
   ……………………………………………………………………………….

9. Have you ever experienced the changes in the event in this area since last 10 years?

 Yes No

If yes:

 Increasing Decreasing

10. What do you feel about the trend of landslide occurrence in this area?
    a. Stable
    b. Decreasing
    c. Increasing
    d. Rapidly Increasing

11. What do you think the impact of landslide would be in the future and why?
    a. Stable
    b. Medium
    c. High
    d. No idea

12. Access to information:
    i. TV
    ii. Radio
    iii. Newspaper
    iv. Friends
    v. Others specify………………………………

13. Do you get any information/hints prior to landslide event and if yes, from where?

     Yes, I know Yes, somewhat
     No No response

14. Do you have any traditional/indigenous knowledge to mitigate the landslide?

    ………………………………………………………………………………..

15. What is the percentage of population group which includes pregnant woman, old people, population group less than 25 and greater than 60 years in this area?
    a. 0-20
    b. 20-40
    c. 40-60
    d. 60-80

16. Has your household taken any coping strategies or action to cope up with the impact of landslide?

     Yes No

    If yes:

    …………………………………………………………………………………
    …

17. Do you think the local knowledge, skills, capacity and technical approaches are not used for the control of landslide in the area?

a. No idea
b. Strongly agree
c. Moderately agree
d. Disagree

18. Is there any watershed management approach?
 Yes No
If yes. What?
…………………………………………………………………………………………

19. Is there any evacuation center identified?
 Yes No
If yes. Where is it?
……………………………………………………………………….

20. Resources availability and access:
i. Both available and accessible
ii. Available but not accessible
iii. Limited resources

21. Is there any private or government agencies working in landslides?
 Yes No
If yes. Can you name the organization and the work done by them?

Organization	Work done

Appendix 4: List of Key Informant Interviewed

S.N	Name of Key Informant	Ward Chairperson/Senior Officers
1	Ramesh Neupane	Rainas-1
2	Ram Chandra Adhikari	Rainas-2
3	Swotantra Hamal	Rainas-3
4	Jaiman Gurung	Rainas-4
5	Nanda Bahadur Kumal	Rainas-5
6	Rup Bahadur Tamang	Rainas-6
7	Madhav Prasad Parajuli	Rainas-7
8	Man Singh Gurung	Dudhpokhari-1
9	Govinda Dawadi	Dudhpokhari-2
10	Dhan Prasad Gurung	Dudhpokari-4
11	Saroj Gurung	Dudhpokhari-5
12	Bhim Lal Gurung	Ajirkot-1
13	Toya Raj Gurung	Ajirkot-3
14	Ramesh Adhikari	Palungtar-3
15	Dipak Pandey	Palungtar-5
16	Suk Man Gurung	Siranchowk-1
17	Gyanendra Gurung	Siranchowk-2
18	Bir Bahadur Thapa	Siranchowk-3

Appendix 5: Ward level vulnerability Scores of each indicators

S.N	Municipality	Wards	Indicators	Vulnerability scores	Total vulnerability
1	Ajirkot	2	Death	2	22
			Impacted households	1	
			Damaged houses	1	
			Economic loss	1	
			Impacted agricultural and forest area	1	
			Social Impact	2	
			Trends of landslide occurrence	2	
			Possible impact of landslide	2	
			Change is seasonal calendar	1	
			Change in temperature	1	
			Access to source	2	
			Population analysis	2	
			Education, awareness, skills	2	
			Organizational help	2	
2	Ajirkot	3	Death	2	
			Impacted households	1	23
			Damaged houses	1	
			Economic loss	1	

			Impacted agricultural and forest area	1	
			Social Impact	1	
			Trends of landslide occurrence	2	
			Possible impact of landslide	3	
			Access to source	3	
			Population analysis	2	
			Change is seasonal calendar	1	
			Change in temperature	1	
			Education, awareness, skills	2	
			Organizational help	2	
3	Siranchok	1	Death	2	23
			Impacted households	1	
			Damaged houses	1	
			Economic loss	1	
			Impacted agricultural and forest area	1	
			Social Impact	2	
			Trends of landslide occurrence	2	
			Possible impact of landslide	3	

			Change is seasonal calendar	1	
			Change in temperature	1	
			Access to source	2	
			Population analysis	2	
			Education, awareness, skills	2	
			Organizational help	2	
4	Siranchok	2	Death	2	25
			Impacted households	1	
			Damaged houses	1	
			Economic loss	3	
			Impacted agricultural and forest area	1	
			Social Impact	2	
			Trends of landslide occurrence	2	
			Possible impact of landslide	2	
			Change is seasonal calendar	2	
			Change in temperature	1	
			Access to source	2	
			Population analysis	2	
			Education, awareness, skills	2	

			Organizational help	2	
5	Siranchok	3	Death	2	27
			Impacted households	1	
			Damaged houses	1	
			Economic loss	1	
			Impacted agricultural and forest area	3	
			Social Impact	2	
			Trends of landslide occurrence	2	
			Possible impact of landslide	2	
			Change is seasonal calendar	1	
			Change in temperature	2	
			Access to source	3	
			Population analysis	3	
			Education, awareness, skills	2	
			Organizational help	2	
6	Palungtar	3	Death	2	27
			Impacted households	1	
			Damaged houses	2	
			Economic loss	3	
			Impacted agricultural and forest area	1	

			Social Impact	2	
			Trends of landslide occurrence	2	
			Possible impact of landslide	2	
			Change is seasonal calendar	1	
			Change in temperature	2	
			Access to source	3	
			Population analysis	2	
			Education, awareness, skills	2	
			Organizational help	2	
7	Palungtar	5	Death	2	
			Impacted households	1	
			Damaged houses	1	
			Economic loss	1	
			Impacted agricultural and forest area	1	
			Social Impact	2	22
			Trends of landslide occurrence	2	
			Possible impact of landslide	2	
			Change is seasonal calendar	1	

			Change in temperature	1	
			Access to source	2	
			Population analysis	2	
			Education, awareness, skills	2	
			Organizational help	2	
8	Rainas	1	Death	2	25
			Impacted households	1	
			Damaged houses	1	
			Economic loss	3	
			Impacted agricultural and forest area	1	
			Social Impact	1	
			Trends of landslide occurrence	2	
			Possible impact of landslide	2	
			Change is seasonal calendar	1	
			Change in temperature	1	
			Access to source	3	
			Population analysis	2	
			Education, awareness, skills	2	
			Organizational help	3	
9	Rainas	2	Death	2	23

			Impacted households	1	
			Damaged houses	1	
			Economic loss	1	
			Impacted agricultural and forest area	1	
			Social Impact	2	
			Trends of landslide occurrence	2	
			Possible impact of landslide	2	
			Change is seasonal calendar	1	
			Change in temperature	2	
			Access to source	2	
			Population analysis	2	
			Education, awareness, skills	2	
			Organizational help	2	
10	Rainas	3	Death	2	29
			Impacted households	1	
			Damaged houses	1	
			Economic loss	2	
			Impacted agricultural and forest area	2	
			Social Impact	2	
			Trends of landslide occurrence	3	

			Possible impact of landslide	3	
			Change is seasonal calendar	2	
			Change in temperature	2	
			Access to source	3	
			Population analysis	2	
			Education, awareness, skills	2	
			Organizational help	2	
11	Rainas	4	Death	2	23
			Impacted households	1	
			Damaged houses	1	
			Economic loss	2	
			Impacted agricultural and forest area	1	
			Social Impact	2	
			Trends of landslide occurrence	2	
			Possible impact of landslide	2	
			Change is seasonal calendar	1	
			Change in temperature	1	
			Access to source	2	
			Population analysis	2	

			Education, awareness, skills	2	
			Organizational help	2	
12	Rainas	5	Death	2	22
			Impacted households	1	
			Damaged houses	1	
			Economic loss	1	
			Impacted agricultural and forest area	1	
			Social Impact	2	
			Trends of landslide occurrence	2	
			Possible impact of landslide	2	
			Change is seasonal calendar	1	
			Change in temperature	1	
			Access to source	2	
			Population analysis	2	
			Education, awareness, skills	2	
			Organizational help	2	
13	Rainas	6	Death	2	26
			Impacted households	2	
			Damaged houses	3	
			Economic loss	1	

			Impacted agricultural and forest area	2	
			Social Impact	2	
			Trends of landslide occurrence	2	
			Possible impact of landslide	2	
			Change is seasonal calendar	1	
			Change in temperature	1	
			Access to source	2	
			Population analysis	2	
			Education, awareness, skills	2	
			Organizational help	2	
14	Rainas	7	Death	2	33
			Impacted households	3	
			Damaged houses	3	
			Economic loss	2	
			Impacted agricultural and forest area	3	
			Social Impact	2	
			Trends of landslide occurrence	2	
			Possible impact of landslide	2	

			Change is seasonal calendar	2	
			Change in temperature	2	
			Access to source	2	
			Population analysis	3	
			Education, awareness, skills	3	
			Organizational help	2	
15	Dudhpokhari	1	Death	2	
			Impacted households	1	
			Damaged houses	1	
			Economic loss	1	
			Impacted agricultural and forest area	1	
			Social Impact	2	
			Trends of landslide occurrence	2	
			Possible impact of landslide	2	23
			Change is seasonal calendar	1	
			Change in temperature	1	
			Access to source	2	
			Population analysis	2	
			Education, awareness, skills	2	

			Organizational help	3	
16	Dudhpokhari	2	Death	2	
			Impacted households	1	
			Damaged houses	1	
			Economic loss	1	
			Impacted agricultural and forest area	1	
			Social Impact	1	
			Trends of landslide occurrence	1	
			Possible impact of landslide	3	23
			Change is seasonal calendar	1	
			Change in temperature	1	
			Access to source	3	
			Population analysis	2	
			Education, awareness, skills	2	
			Organizational help	3	
17	Dudhpokhari	4	Death	2	29
			Impacted households	2	
			Damaged houses	2	
			Economic loss	3	
			Impacted agricultural and forest area	1	

			Social Impact	2	
			Trends of landslide occurrence	2	
			Possible impact of landslide	2	
			Change is seasonal calendar	1	
			Change in temperature	2	
			Access to source	3	
			Population analysis	2	
			Education, awareness, skills	2	
			Organizational help	3	
18	Dudhpokhari	5	Death	2	23
			Impacted households	1	
			Damaged houses	1	
			Economic loss	1	
			Impacted agricultural and forest area	1	
			Social Impact	2	
			Trends of landslide occurrence	2	
			Possible impact of landslide	2	
			Change is seasonal calendar	1	

	Change in temperature	1
	Access to source	2
	Population analysis	3
	Education, awareness, skills	2
	Organizational help	2

Appendix 6: Rainfall stations in Chepe vicinity

S.N	Station number	Name of station	Latitude	Longitude	Average rainfall (mm)
1	808	Bandipur	27.93333333	84.416667	1678.847
2	817	Damauli	27.966667	84.283333	1719.187
3	823	Gharedhunga	28.2	84.616667	2920.9
4	809	Gorkha	28	84.616667	1566.95
5	802	Khudibazar	28.283333	84.366667	3174.38
6	807	Kunchha	28.133333	84.35	2598.737
7	801	Jagat	28.366666	84.9	1310.367
8	815	Khairenitar	28.033333	84.1	2218.41

PHOTOGRAPHS

Photograph 1: View of Chepe River

Photograph 2: Study of landslide in the river corridor


Photograph 3: Landslide in the study area


Photograph 4: Landslide in the study area

Photograph 5: Questionnaire with the local residents

Photograph 6: Questionnaire with the local residents

Photograph 7: KII with Mr. Ramesh Neupane (Ward Chairperson, Rainas-1)

Photograph 8: Created gully resulting the landslide (Rainas, Lamjung)

Photograph 9: Rainas Irrigation Canal

Photograph 10: Unmanaged road construction causing downfall of the slope area

Photograph 11: Gabion wall as control measure of landslide

Photograph 12: Landslide caused due to the river cut-off