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INSTITUTE OF ENGINEERING
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# Remote Sensing and GIS Application for the study of Chure Degradation of Lal Bakaiya Watershed

by

Ravi Kumar Gupta

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Head of the Department
Department of Civil Engineering
Central Campus, Pulchowk, Institute of Engineering,
Lalitpur, Nepal

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The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance, a thesis entitled **Remote Sensing and GIS Application for the study of Chure Degradation of Lal Bakaiya Watershed** submitted by Ravi Kumar Gupta in partial fulfillment of the requirements for the degree of Master of Science in Geo-Technical Engineering.

…………………………………….
External Examiner, Dr. Danda Pani Adhikari
Associate Professor
Department of Environmental Science
Trichandra Campus, Tribhuvan University
Ghantaghar, Kathmandu Nepal

……………………………………..
Supervisor, Dr. Dinesh Pathak
Associate Professor
Central Department of Geology
Geodisaster Research Center
Tribhuvan University, Kirtipur, Nepal.

……………………………………..
Supervisor, Dr. Indra Prasad Acharya
Lecturer, Program Co-ordinator
Msc Program in Geotechnical Engineering
Department of Civil Engineering

Date:-

# ABSTRACT

This report deals with the Remote Sensing and GIS Application for the study of Chure Degradation of Lal Bakaiya Watershed. The degradation could leads to become a cause of hazard of this area.

This study is intended to develop a methodology for preparation and analysis of hazard map of Lal-Bakaiya Watershed with GIS as a main tool for the data input and analysis. The location of the study area is Lal Bakaiya Watershed in central southern part of Nepal. The eight causative factors considered for the preparation of hazard map are precipitation, soil, land use, distance to road, stream density, geology, slope and slope aspect. For the preparation of the hazard map three steps: desk study, field investigation, data analysis and interpretation were carried out. In the initial phase of the research, collection of secondary data and review of the literature were done. Different thematic layers are then prepared from collected datas. From the field investigation, all information and maps prepared earlier were verified in the field. Analytical Hierarchy process (AHP) is used for the decision making and hazard map preparation. The data prepared and verified data were then analyzed for hazard mapping. This study also shows how the land cover and land use pattern is changing in four different decades of Lal Bakaiya watershed.

Validation of the hazard map is done with the landslide inventory map prepared from the past landslide records. The results and hazard map shows that most of the landslides falls near the agricultural areas and barren land areas of the study area. These indicate that human activities play an important role in the hazard areas. Hence it is recommended to control the causes of degradation of the Lal Bakaiya Watershed.

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Ravi Kumar Gupta
070/MSG/813
M. Sc. Geotechnical Engineering
Department of Civil Engineering
IOE Central Campus, Pulchowk

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# ABBREVIATIONS

AHP - Analytic Hierarchy Process
CED - Continuing Education Division
CI - Consistency Index
CR - Consistency ratio
DEM - Digital Elevation
DHM - Department of Hydrology and Meteorology
DOLIDAR - Department of Local Infrastructure Development and Agricultural Road
DoR - Department of Road
DoS - Department of survey
FIG - Figure
FR - Frequency ratio
GIS - Geographical Information Systems
ILWIS - Integrated Land and Water Information System
KM - Kilometer
M - Meter
MBT - Main Boundary Thrust
MCT - Main Central Thrust
MFT - Main Frontal Thrust
MM - Millimeter
MRE - Mountain Risk Engineering
NDVI - Normalized Difference Vegetation Index
OBIA - Object Based Image Analysis
STDS - South Tibetan Detachment
TM - Multi Temporal
VDC - Village Development Committee
U.S - United States

# CHAPTER ONE

## 1. Introduction

### 1.1 Background

Nepal is a small country located between China in the north and India in the south, east and west with an area of 147,181 sq. km (Fig 1.1) It occupies about 850 km long central part of the Himalayan arc which has been formed by the collision of Indian and Eurasian plates. Nepal is mainly characterized by rugged topography, very high relief, variable climatic conditions, complex geological structures affected by active tectonic process and seismic activities. Topographic elevation changes from 60 m at the southern plains to 8,848 m at the Mt. Everest in the north within a horizontal distance of less than 200 km. This kind of topography is prone to landslide and erosion in Nepal. The mountainous and hilly regions of the country occupy nearly 83% of the total area.

Siwaliks, commonly referred as Churia, is the range gradually elevated from Terai plains up to 1,800 m from the sea level, stretched almost the entire length of the country from east to west. The Churia range cross cuts the 33 districts of the country. Varied in height and breadth across the length, Churia range, however, shares common morphological features: coarse-grained, loose rocks and thin layer of soil, resulting into a fragile topography and, therefore, unsuitable for farming. Gradually declined slope and forming a flat plain area to the southern lap of the Churia is known as Bhabar. Though possessing a different morphological feature, Bhabar shares a common fate with Churia in many senses. Therefore, conservation/degradation of Churia is directly interlinked with the future of Bhabar.

The Churia hills are young and composed of unconsolidated loose materials originated from soft rocks such as mudstone, sandstone, silt stone, shale. The Churia region is unique, biologically, hydrologically and ecologically, and needs special attention and treatment. Until the early ’90s, the region was treated like any other hilly region and was not given any special consideration. Later, from the early’90s onwards, it started receiving a little attention. A couple of projects were implemented in some parts of the region, but with limited coverage and focus. The conservation of the Churia region is directly linked with the production potential of the Tarai and dun regions. Its fragility is an all-time challenge for the welfare of the grain basket, and, therefore, it deserves better conservation, with due consideration to poverty alleviation. As it provides various environmental services to other regions of the Churia area (Dun, Bhabar and Tarai), it should be treated differentially and with priority. Every year, the Tarai region suffers from floods, which originate in the upstream areas of the Churia hills. Most of the Tarai population suffering from floods have yet to understand the underlying causes of floods. Therefore, for the betterment of the people of the Tarai, there is a need to invest in conservation and development programmes in the Churia region. This has to be well understood by the people of the Tarai and they will have to support initiatives accordingly.

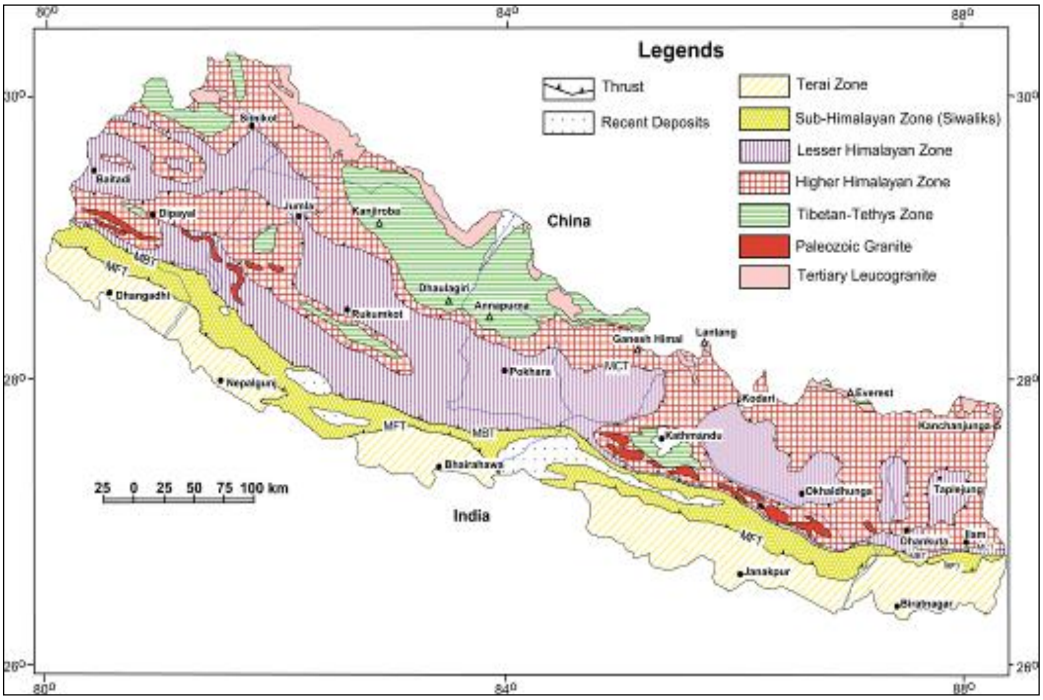

Figure 1.1 Simplified geological map of Nepal (Amatya and Jnawali 1994 and Dahal 2006)

The Lal Bakaiya watershed is located in the central southern part of Nepal. Geologically, the watershed can be divided into three major units – the Terai and Bhabar in the south; Chure including Dun Valley in the middle; and the Mahabharat range in the north.

This study is intended to prepare the hazard map of the study area using GIS as a tool. For the preparation of the hazard map of the Lal Bakaiya Watershed three steeps: desk study, field investigation, data analysis and interpretation were carried out. In the initial phase of the research, collection of secondary data and review of the literature were done. The base map was then prepared from digital topographic map. From the field investigation, all information and maps prepared earlier in the desk study were verified in the field. The data prepared and verified data were then analyzed for hazard mapping.

## 1.2 The Study Area

In Nepal, factors such as the excessive rainfall and human intervention are the main triggering agents of landslide. The factors such as groundwater condition, river under cuttings and deforestation on slopes are also facilitating landslides. The Siwaliks (Churia) Range is made up of geologically very young sedimentary rocks such as mudstones, shale, sandstones, siltstones and conglomerates. These rocks are soft, unconsolidated and easily disintegrable. The Upper Siwaliks contains thick beds of conglomerates and they are loose and fragile. Similarly, Lower Siwaliks and Middle Siwaliks have problem from alternating beds of mudstones and sandstone. In such alternating bands, mudstone can flow when saturated with water, which results overhanging sandstone beds. Such overhang jointed sandstone beds easily are disintegrated into blocks. Similarly, throughout Nepal, the rainfall within the Churia Range is normally in the range of 1400 to 2500 mm per year. As a result, geological conditions and the climate render the Churia Range highly susceptible for landslides processes.

The study area Lal Bakaiya watershed is located in Bara and Makawanpur district of central part of Nepal. Geologically, the watershed comprises of five types of formations namely Recent, Upper Siwalik, Middle Siwalik (Ms2), Middle Siwalik

(Ms1). Geographically, the watershed is located between 85°3'14.37"E to 85°17'26.63"E longitudinal and 27°21'53.14"N to 27°10'45.74"N latitude, covers an area of 384 Sq. Km. The elevation ranges from 160 m to 1700 m. The average precipitation is about 1470 mm. Mean annual precipitation seems to increase with altitude. The maximum rainfall is received during the month of June to September.

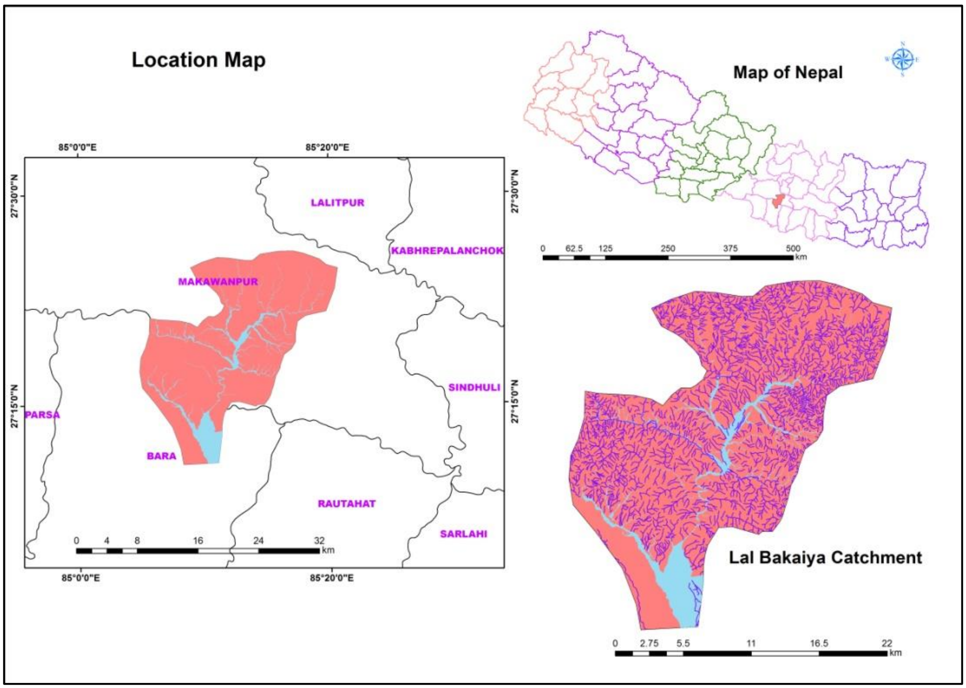

Figure 1.2 Location Map of the Study area.

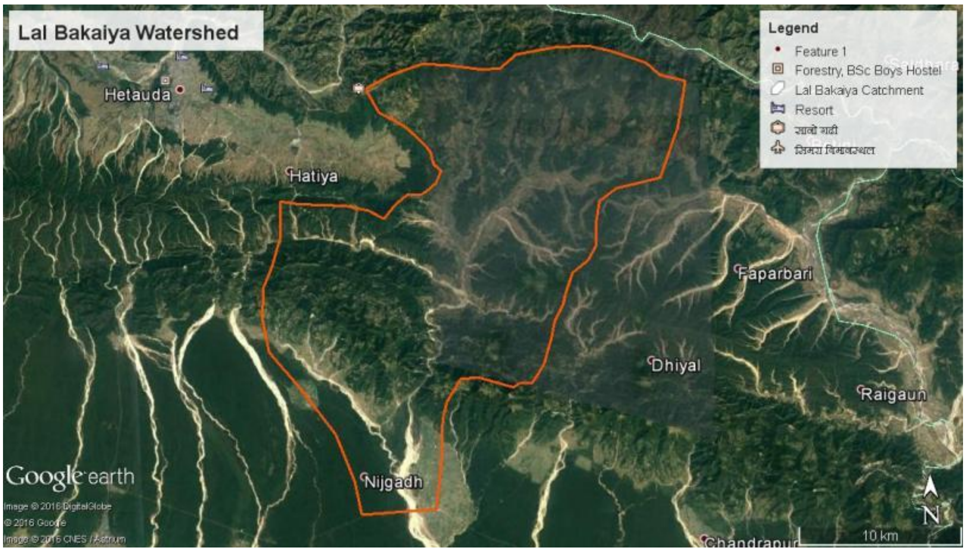

Figure 1.3 Overall view of the study area (Source: Google Earth)

## General Geology of the Study Area

The study area lies in the Siwalik Group of the central Nepal Himalaya. The study section is demarcated by the Main Frontal Thrust (MFT) in the south and by the active Main Boundary Thrust (MBT) in the north. Lying in the southern belt, the study site represents the rock of Middle Siwalik in which consist of predominately coarse-grained, loose rocks and thin layer of soil, resulting into a fragile topography and, therefore, unsuitable for farming.

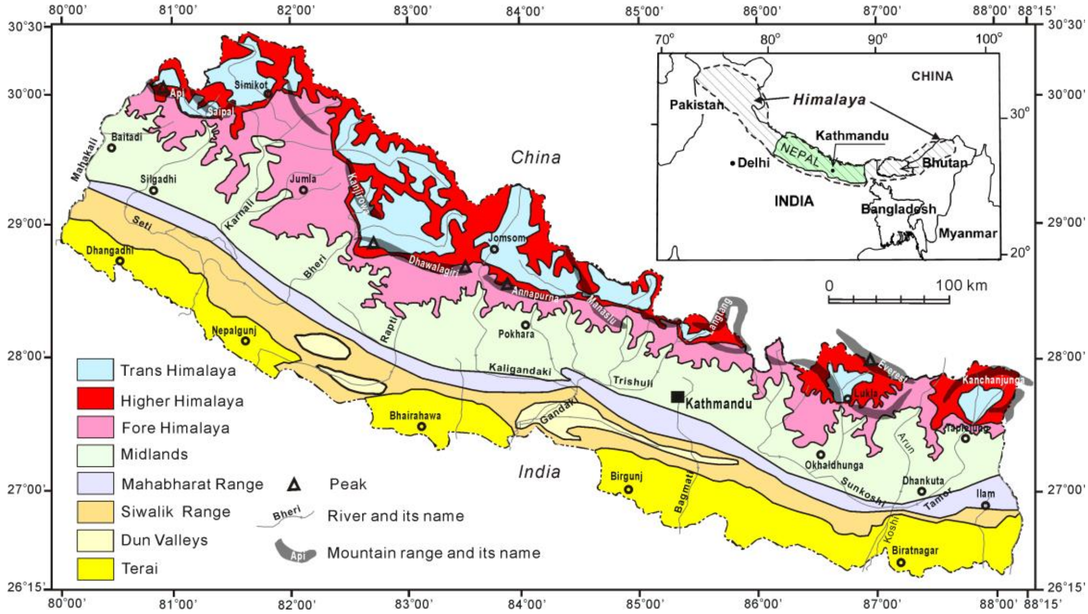

Figure 1.4 Digital elevation model (DEM) based regional geomorphic map of Nepal; inset illustrates Location of Nepal in the Himalaya Dahal and Hasegawa 2008)

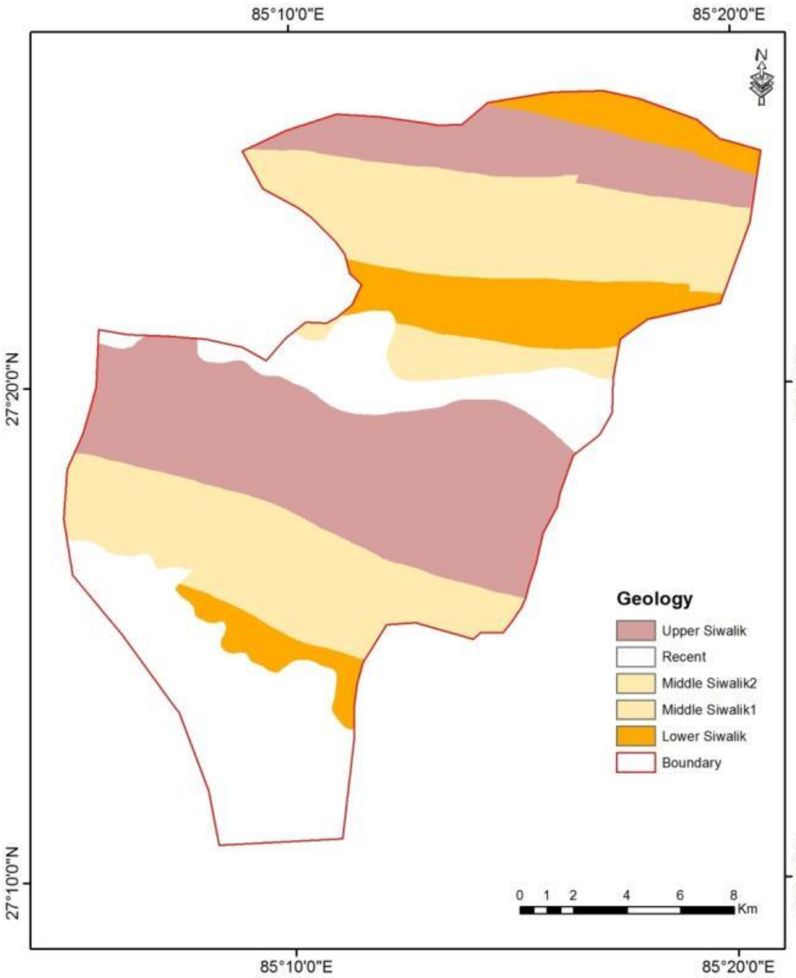

Figure 1.5 Geologic map of the study area (DMG/GoN, 1994)

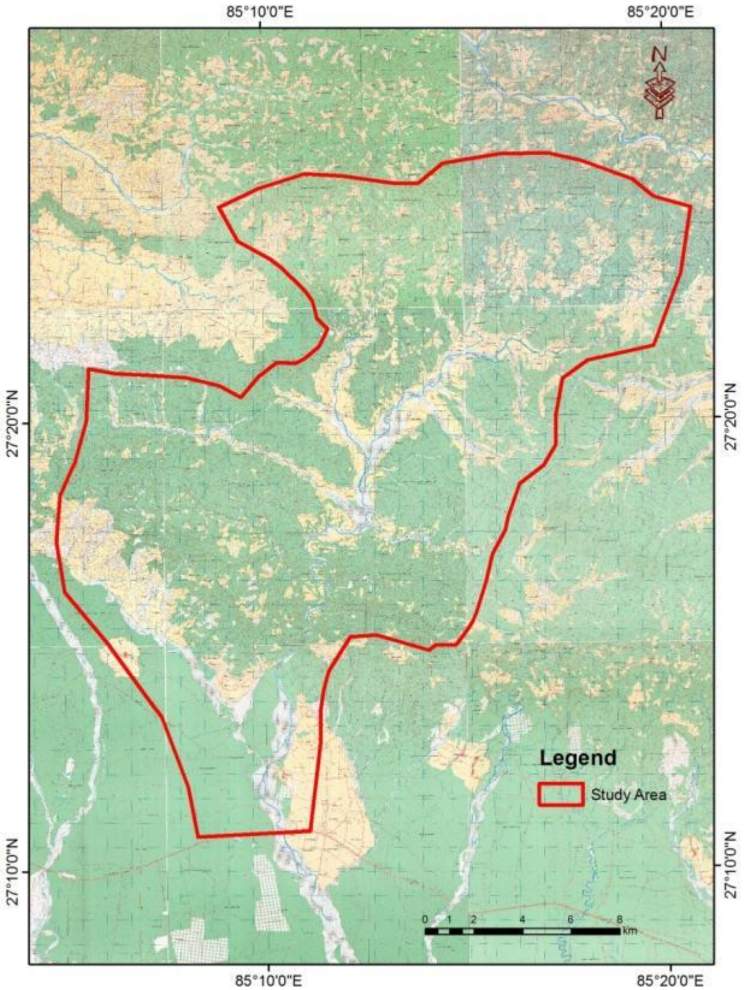

Figure 1.6 Topographic map of the study area. (Survey Department 1983)

## 1.3 Problem Statement

The Churia hills are young and composed of unconsolidated loose materials originated from soft rocks such as mudstone, sandstone, silt stone, shale. The Churia region is unique, biologically, hydrologically and ecologically, and needs special attention and treatment.

### 1.3.1 Key Problems and Issues concerning Degradation of Area

#### Damage/degradation to agricultural land

Large tracts of fertile agricultural land are either damaged by floods and river bank cutting in downstream areas, specifically in the Bhabar, Dun and Tarai regions. Agricultural land is also degrading through unscientific use of chemical fertilizers in farmlands. It is especially acute in Chitwan valley, narrow river valleys and in the Tarai. Water-logging and wind erosion are confined to some parts. Water scarcity is high in both dun and Bhabar. Surface erosion and decreasing use of forest leaf litter in agricultural land are also degrading the soil fertility.

#### Flooding

Flooding and heavy erosion occur whenever there are incessant rains in upstream areas, which might be due to geo-morphological factors or faulty land use practices. In both cases, human settlement and interventions without appropriate land use planning and conservation measures have led to siltation in rivers. This has in turn raised the riverbed level, resulting in floods and riverbank-cutting, mainly due to the weak embankment of riverbanks. Grazing on the banks of the major rivers is a common practice in the Churia, Bhabar and Tarai regions.

#### Encroachment of Forest

Encroachment of forest is a common occurrence all over the Churia region. Poor people occupy open forest areas in the hope that they will get land title someday based on past precedents when many such encroachers were granted land entitlements by various resettlement commissions. Political motivation and vote buying during elections have also contributed to forest encroachment. Landlessness, unemployment and an ever-growing poor population also encourage encroachment. Victims of landslides, floods and other natural disasters have also taken refuge in the forest or other public land.

### Inadequate institutional commitment towards law enforcement

The enforcement of laws relating to the conservation and protection of forests is weak. The support and cooperation of the local people and institutions is vital for the enforcement of law. Political interferences are common to resolve social conflicts and disturbances. The law enforcement agencies do not have adequate human and other necessary resources. The allocated resources are also inadequate. Ineffective monitoring has compounded the problem, not only affecting the work of the agencies concerned, but also weakening them. There has not been enough encouragement and reward for the actions required for law enforcement. The contradictions between the various legislation and policies related to forest conservation and utilization have also acted as a constraint on effective law enforcement. As the involvement of the major stakeholders in drafting and preparing legislation and policies was almost lacking, they lack ownership of new policies, Acts and legislation.

## 1.3.2 Main Causes of Problems

### Lack of a comprehensive policy for Churia issues

So far, there is no specific or comprehensive policy on the issues of the Churia. There are certain policy documents and references that highlight the issue of conservation in the Churia region, such as the Ninth and Tenth Plans and the concept paper on Churia 2000. However, these references have not adopted a holistic approach to planning by covering more than the forestry sector.

### Unscientific land use

Land use practices are basically dictated by traditions and age-old knowledge and practices that have evolved from generation to generation. However, a growing population and an ever-increasing demand for food, fodder and firewood often force people to modify their traditional land use practices. Such practices are often highly detrimental to the environment, and negatively affect the local livelihood concerns, including security. Some of such practices include slope cultivation, non-existent or very poor water management; open grazing of large numbers of livestock and cultivation of inappropriate crops that require more intensive land tillage, resulting in erosion.

### Unawareness of the importance of Churia conservation

The people living in the southern areas of the Churia (in Bhabar and Tarai) have yet to realize the magnitude of the threat to their safety and security from the degradation of the Churia hills. They depend on and use significant amounts of natural resources from the Churia, but seldom contribute towards their conservation. Furthermore, the much-needed conservation and development efforts have not been directed at the Churia hills. Generally, the people from the Tarai are in decision-making positions, and govern development and conservation activities in the district. If the Tarai people could realize the importance of conservation and investment in the Churia region, they would pay greater attention to the protection and development of the region.

### Ineffective operation of resettlement commissions

Although several Sukumbasi (resettlement) commissions have been formed to resolve the land encroachment problem and resettle the victims of natural disasters, they have seldom considered the issue of illegal settlers in the Churia hills. None of the commissions had clear-cut responsibility and accountability in respect of the land issues, which has delayed decision-making and, consequently, resolution of problems. Amicable resettlement of such people needs coordination between several ministries such as the MFSC, Ministry of Land Reforms (MoLR), Ministry of Home Affairs (MoHA) and Ministry of Finance (MoF).

## 1.4 Objectives of the Study

### 1.4.1 Main Objectives of the Study

The main objective of the study is to develop a methodology for preparation and analysis of hazard map of Lal-Bakaiya Watershed with GIS.

### 1.4.2 Specific Objectives of the Study

The specific objectives of the study are as follows:

- To assess land use & land use change of different time periods.
- To prepare different thematic layers considering the different factors causing landslide to the study area.
- To use the AHP method for the weight distribution to different factors and decision making.
- To prepare the hazard map of Lal Bakaiya Watershed originating from churia.
- To validate the landslide hazard map with the help of the landslide inventory map prepared with the past landslide records.

## 1.5 Limitations of the Study

Following limitations apply to the scope of the present study:

- Detailed geological map is not available, which is required to prepare lithological map.
- In depth knowledge of soil-water interaction is not available for the study area, which is site specific.
- Detailed soil map for the study area is not available.

# CHAPTER TWO

## 2. Literature Review

The Churia range (also called Siwaliks) rises steeply from the Terai plains along the whole of its northern border. It is extended as a contiguous landscape from east to west in 33 districts. The Churia hills are young and composed of unconsolidated loose materials originated from soft rocks such as mudstone, sandstone, silt stone, shale. The Churia region is unique, biologically, hydrologically and ecologically, and needs special attention and treatment. Until the early ’90s, the region was treated like any other hilly region and was not given any special consideration. Later, from the early’90s onwards, it started receiving a little attention. A couple of projects were implemented in some parts of the region, but with limited coverage and focus. The conservation of the Churia region is directly linked with the production potential of the Tarai and dun regions. Its fragility is an all-time challenge for the welfare of the grain basket, and, therefore, it deserves better conservation, with due consideration to poverty alleviation. As it provides various environmental services to other regions of the Churia area (Dun, Bhabar and Tarai), it should be treated differentially and with priority. Every year, the Tarai region suffers from floods, which originate in the upstream areas of the Churia hills. Most of the Tarai population suffering from flood shaves yet to understand the underlying causes of floods. Therefore, for the betterment of the people of the Tarai, there is a need to invest in conservation and development programmes in the Churia region. This has to be well understood by the people of the Tarai and they will have to support initiatives accordingly (Source: www.rccp.gov.np).

## 2.1 Geological setting

Geomorphologically, Nepal is divided into eight units running east–west, namely, Terai, Churia Range, Dun Valley, Mahabharat Range, Midland, Fore Himalaya, Higher Himalaya, Inner and Trans Himalaya (Hagen 1969; Upreti 1999). Likewise, geologically and tectonically, Nepal is divided into five major tectonic zones from south to north, namely, Terai, Sub-Himalaya (Siwaliks), Lesser Himalaya, Higher Himalaya and Tibetan-Tethys Himalaya (Ganser 1964; Upreti 1999). These tectonic zones are separated by major thrusts and faults of the Himalaya, namely from north to south, South Tibetan Detachment System (STDS), Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Main Frontal Thrust.

According to Bilham et al. (1997), the Indian Plate is moving northwards with an average rate of 1.5–5 cm per year and nearly half of this horizontal slip is being accommodated within the Himalaya. As a result, the rocks of the Himalaya are moving upwards as well as horizontally towards south along the major thrusts.

The Himalayan mountain system developed in a series of stages 30 to 50 million years ago and they are still active and continue to rise today. Himalaya is considered as a tectonically very active and vulnerable mountain system in the world. (Gansser, 1964) provided the first comprehensive picture of the Himalaya and he had transversely divided the whole Himalayan range into five major groups namely The Punjab Himalaya, Kumaon Himalaya, Nepal Himalaya, Sikkim-Bhutan Himalaya and NEFA Himalaya.

### 2.1.1 Transverse Division of Himalaya

**The Punjab Himalaya**

It has the Himalayan range that is in between the Satluj (east) and the Indus Rivers in the west. Its extension is about 550 km.

**Kumaon Himalaya**

Its extension is about 820 km. This is the Himalayan range bordered easterly by the Mahakali River and westerly by the Sutlej River.

**Nepal Himalaya**

Nepal has the longest division of the Himalaya. Its extension is about 800 km and starts from west at the Mahakali River and ends at the east at the Tista River.

**Sikkim-Bhutan Himalaya**

Its length is about 400 km and extends between Sikkim and Bhutan.

**NEFA Himalaya**

It stretches about 440 km from the eastern boarder of Bhutan to the Tsangpo River in the east. Longitudinally, Himalayan Range is also divided into five tectonic zones (Gansser 1964) namely: Gangetic Plain, Sub-Himalayan Zone, Lesser Himalayan Zone, Higher Himalayan Zone and Tibetan-Tethys Himalayan Zone.

### 2.1.2 Longitudinal Division of Himalaya

**The Gangetic Plain**

The Gangetic Plain is also called as Terai Zone and it is the Nepalese portion of the Gangetic Plain that extends from the Indian Shield in the South to the Sub-Himalayan (Siwalik) Zone to the North. The plain is in less than 200 meters above sea level and usually has thick (nearly 1500 m) alluvial sediments. The alluvial sediments contain mainly boulder, gravel, silt and clay.

The width of Terai Zone varies from 10 to 50 km and forms a nearly continuous belt from east to west. Exceptionally at two place Chitwan and Rapti valleys, the Terai Zone is interrupted by Siwalik for 70 km and 80 km respectively.

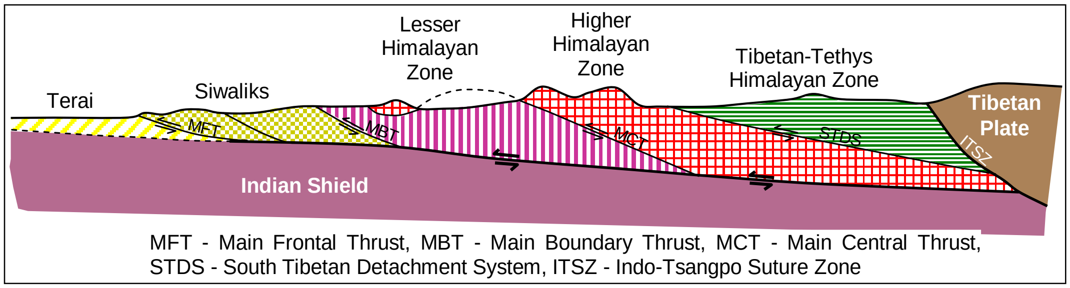

Figure 2.1 Generalized cross section of Himalaya (Dahal 2006)

Terai Zone is a foreland basin and has sediment originated from peaks of Northern part. To the north, this zone is separated by an active thrust system called as the Main Frontal Thrust (MFT) with Siwalik. At some places along MFT, the Siwalik rocks are observed to rest over the recent sediments of the Terai. It further helps to classify the Terai into Northern Terai or Bhabhar Zone, Middle Terai and Southern Terai.

### a. Northern Terai (Bhawar Zone)

The Northern Terai is adjoining to the foothills of Siwaliks and continues southward to a maximum width of 12 km. This part of Terai is also known as Bhawar Zone. This zone is mainly composed of boulders, pebbles, cobbles and coarse sand derived from the rocks of the Siwaliks and Lesser Himalayan zones. These boulders, pebbles, and cobbles are mostly made up of sandstones and the rocks from the immediate northern vicinity.

### b. Middle Terai (Marshy) Zone

This is a narrow zone of about 10-12 km wide and lying between the Northern Terai Zone and the Southern Terai Zone. This zone is characterized by pebbly and brown to grey colored unconsolidated sandy sediments with few clay layers. Clay is mostly dark grey colored and intercalated with brown colored sandy layers.

### c. Southern Terai Zone

Southern Terai Zone is southernmost part of Terai up to Nepal-India border and continues into India. This zone consists of main sediments of Gangetic Plain. Basically, sand, silt and clay are the main sediments of this zone. This zone is composed of finer sediments than the Middle Terai Zone.

### The Siwaliks

This zone situated between the Main Frontal Thrust (MFT) and the active main boundary thrust (MBT). The Siwaliks are formed from debris derived from the erosion of the rising Himalayas to the north. They mostly consist of rocks of alternating beds of sandstone, mudstone, siltstone, shale and conglomerate. The Dun Valleys occur at intervals within the Siwalik chain and form enclosed alluvial basins surrounded by Hills. The conglomerates of beds of the Upper Siwaliks are fairly stable if they are not alternating with thin claystone and sandstone. The Inner bedded mudstone and sandstone rocks of the Middle Siwalik are stable, and the lower Siwaliks which are composed predominately of green gray sandstone with a minor amount of clays stone, are moderately stable (MRE III, 1991)

Siwalik can be classified as follow:

- Lower Siwalik
- Middle Siwalik and
- Upper Siwalik

### a. Lower Siwalik

The Lower Siwalik consists of irregularly laminated beds of fine grained greenish sandstone and siltstone with mudstone. The alternating mudstone beds are thickly bedded and are variegated, red, purple, and brown colored. The best exposures of Lower Siwalik are found in Surainaka, Amlekhgunj, Arun Khola, Barahchhetra and Rato Khola area of Nepal.

### b. Middle Siwalik

The Middle Siwalik is comprised of medium to coarse grained salt-and-pepper (looks like mixture of salt and black pepper) sandstones interbedded with mudstone. This is differentiated from the Lower Siwalik in lacking variegated mudstone and sandstone. In upper part of the Middle Siwalik, pebbly sandstone beds are also found. In Middle Siwalik the sandstone beds have thickness mostly ranges from 1 m to 45 m. The exposures of Middle Siwalik are found mainly in Surkhet, Surai Khola, Hetauda, and Butwal.

### c. Upper Siwalik

The Upper Siwalik is comprised of conglomerate and boulder beds and subordinately sand and silt beds. The mudstone beds of the Upper Siwalik are massive and irregularly bedded and contain many invertebrate fossils including Brachiopods and Gastropods. The upper part of this sequence contains conglomerate beds, which have mostly boulder and cobble size rounded to sub angular fragments of Lesser Himalayan rocks. In Bardibas, Hetauda, Bhalubang, and Chitwan the good exposure of Upper Siwalik can be seen.

### The Lesser Himalaya

The Lesser Himalayan Zone is bounded to the north by the Main Central Thrust (MCT) and to the south by Main Boundary Thrust (MBT), and it is most complicated zone to folding, faulting and thrusting. This region is tectonically very active and weathering of the rock is very high.

Morphologically the lesser Himalayas can be divided into the Mahabharat Range and the more depress Midland zone in the north. Both zones consist of a thick sequence of metamorphosed rock with a wide variation in properties. These are slates, phyllite, schist, quartzite, limestone, dolomite and some granite.

### The Higher Himalaya

Geologically, the Higher Himalayan Zone includes the rocks lying north of the Main Central Thrust (MCT) and below the highly fossiliferous Tibetan-Tethys Zone. This zone is separated with Tibetan-Tethys Zone by normal fault system called as South Tibetan Detachment System (STDS). Higher Himalayan Zone consists of an approximately 10 km thick succession of strongly metamorphosed coarse grained rocks. It extends continuously along the entire length of the country as in whole Himalaya, and its width varies from place to place.

### The Tibetan-Tethys Zone

The Tibetan-Tethys Zone lies in northern part of the country. It begins from the top of the STDS and extends to the north in Tibet. In Nepal, the fossiliferous rocks of the Tibetan-Tethys Zone are well-developed in Mustang, Manang and Dolpa area. In eastern part, amount of exposure of the Tibetan Tethys Zone is almost negligible and found only in top of the Mount Everest. Most of the other Great Himalayan peaks of Nepal such as Manaslu, Annapurna, and Dhaulagiri have rocks of Tibetan-Tethys Zone. This zone is composed of sedimentary rocks, such as shale, limestone, and sandstone.

## 2.2 Mass Wasting and Landslides

Mass wasting refers to the down slope movement of earth materials such as regolith or solid rock under the influence of gravity. Regolith is a term used to refer to all of the materials lying between unweathered rock below and the Earth's surface above. It therefore includes weathered rock, soils, and unconsolidated deposits derived from flowing water, ice (glaciers), and wind. When such material rests on horizontal surfaces, then it is relatively stable. However, if it rests on an inclined or sloped surface, then the degree to which the inclined or sloped surface varies from the horizontal, determines its stability. In such setting the resistance of the regolith to down slope motion is dependent upon its cohesiveness and its frictional resistance to motion.

Landslide according to Varnes (1958) defined as the downward and outward movement of slope forming materials composed of natural rock, soils, artificial fills, or combinations of these materials. The moving mass proceeds down slope by falling, sliding spreading, flowing, or some combination of these processes. The movement of falls, slides, spreads, and most flows are perceptible to the human eye, while creep and solifluction occur so slowly that the human eye can't detect the down slope motion characteristic of these two processes.

## Classification of landslide

Landslide is classified on the basis of 1.the type of the material that existed prior to the landslide and 2. The type of movement that dominates during the landslide. The types of material that might exist prior to a landslide are rock, soil, earth, mud, and debris.

Rock is defined as any intact, hard, and firm mass that existed in its natural place prior to the landslide. Examples include igneous, metamorphic, and lithified sedimentary rocks. At the other end of the spectrum is Soil an aggregate of minerals and rock fragments plus or minus organic material that formed from the in situ weathering of rocks or sediments. In soil, pores or open voids between the minerals and rock fragments are often filled with gases or water.

Material defined as earth is composed 80% or more particles smaller than 20mm (the upper limit of sand) while mud is composed of 80% or more particles smaller than about .06mm (the upper limit of silt). Finally, debris contains 20% to 80% particles larger than 2mm, while the remainder is generally less than 2mm.

The four classes of movement during any given landslide are fall, slide, spread, and flow. Hence, to classify a landslide we first determine the material that existed prior to the landslide and then attach to that name the class of movement. Using such a scheme, a rock fall is a landslide that involved intact, hard, and firm material down slope.

A complex landslide commonly involves two or more of the classes fall, slide, spread, or flow. For example, in its lower parts, a rotational slide commonly transforms into an earth flow. Hence, such a landslide would be classified as a complex rotational slide-earth flow.

### Landslides in Churia

In Nepal, factors such as excessive rainfall and human intervention are the main triggering agents of landslide. The factors such as groundwater condition, river under cuttings and deforestation on slopes are also facilitating landslides. The churia (siwaliks) range is made up of geologically very young sedimentary rocks such as mudstones, shale, sandstones, siltstones and conglomerates. These rocks are soft, unconsolidated and easily disintegrable. The upper siwaliks contain thick beds of conglomerates and they are loose and fragile. Similarly, Lower siwaliks and middle siwaliks have problem from alternating beds of mudstone and sandstone (Burbank et al. 1996). In such alternating bands, mudstone can flow when saturated with water, which results overhanging sandstone beds. Such overhang jointed sandstone beds are easily disintegrated in to blocks. Similarly, throughout Nepal, the rainfall within the churia range is normally in the range of 2000 to 2500mm per year. As a result, geological conditions and the climate render the churia range highly susceptible to landslides process.

## 2.3 Hazard Map

A Hazard map is a map that highlights areas that are affected or vulnerable to a particular hazard. They are typically created for natural hazards, such as earthquakes, volcanoes, landslides, flooding and tsunamis. The functions of a hazard map are to know the phenomenon and to make it known to residents. Su Wu, a famous Chinese strategist, says “If you know your enemy and yourself, you will not be in danger even in 100 combats.” The hazard maps cannot stop a disastrous phenomenon. But the effective use of hazard maps can decrease the magnitude of disasters. Within this framework, earth sciences, and geomorphology in particular, may play a relevant role in assessing areas at high hazard and in helping to mitigate the associated risk, providing a valuable aid to a sustainable progress. Tools for handling and analyzing spatial data (i.e. GIS) may facilitate the application of quantitative techniques in hazard assessment and mapping.

All hazard maps are not unconditionally acceptable to residents. Landowners and land developers may fear about the fall of land prices and oppose to the public release of the maps. In addition, Government administrators may oppose to the public release of the maps, fearing the criticism of residents that the administrators are neglecting preventive works even though they have a good understanding of the likelihood and consequences of potential disasters.

Hazard maps are very compatible with GIS. First, the GIS is very useful in arranging a high volume of data necessary to produce a hazard map. Then, it can be used for analysis of places of refuge. Three-dimensional representations are available. Digital cartography is also available. So, it is possible to test a method of creating an easy to read hazard map. Recently, there have been cases where maps are publicly released using the Internet GIS technology.

### 2.3.1 Landslide Susceptibility Map

Spatial prediction of landslide is termed as landslide susceptibility, which is a function of landslide and landslide related internal factors. The aim is to identify places of landslide occurrence over a region on the basis of a set of internal causative factors. This is specifically known as landslide susceptibility zonation (LSZ), which can formally be defined as the division of land surface into near homogeneous zones and then ranking these according to the degrees of actual or potential hazard due to landslides.

### 2.4. Methods for Landslide Assessment

Review of the previous works (e.g. Varnes 1984; Soeters and van Westen 1996; van Westen et al. 1997; Aleotti and Chowdhury 1999; Guzzetti et al. 1999) depicts that methods for ranking landslide factors and assigning different susceptibility levels can be generally grouped either (a) direct or indirect method or (b) qualitative, quantitative, methods or a combination of them (semi-quantitative). Nowadays, all approaches such as qualitative, quantitative and semi-quantitative methods are friendly working with GIS environment.

#### 2.4.1 Qualitative Method

Qualitative method is subjective and demonstrate the hazard zoning in descriptive (qualitative) terms (Validnia et al. 2009); such techniques depend highly on experience, knowledge and previous works on the study area. In this method, information is analyzed and evaluated on logical and judgement based argument.

**Heuristic approach**: This method is one of the qualitative based methods used in landslide susceptibility assessment. This method is proposed for the first time by Amatesi (1977) for the identification of geo-environmental and anthropogenic factors that determine the landslide or slope instability. According to him the environmental factors are divided into passive and active. The passive factors (e.g. geological and geomorphological factors) are relatively constant over short time while the active ones (e.g. climate, land use) are subject to considerable variations in short term. According to this method the causative factors of the landslide for the study area are first selected, and each causative factor is considered as parameter map. Then the relative importance of each parameter map for slope instability is evaluated depending upon the experience of the expert knowledge and previous works on the study area (Anbalagan, 1992), or statistics of landslide distribution and analysis (Dai et al. 2001; Lee et al. 2004; Lee 2005). In this approach, information is generally analyzed and evaluated on logical and judgement based argument. After the weight is assigned to each factors, the various maps are summed based on their corresponding attribute using ArcGIS to get the final landslide susceptibility zoned maps of the study area. The landslide susceptibility zoning is provided in descriptive (qualitative) terms (Validnia et al. 2009). The limitation of this method is its subjectivity in weighting the factors.

### 2.4.2 Quantitative Method

This method produces numerical estimates (probabilities) for the occurrence of landslide phenomenon in any hazard zone (Guzzeti et al. 1999, 2005) and such approach is based on mathematically objective structures (Neaupane and Piantanakulchai 2006). It includes the various statistically and probabilistic based models, physical based models or deterministic or geotechnical approach.

#### Statistical and probabilistic methods

The statistical analysis approaches and technique for landslide analysis is introduced by Carrara (1983), which nowadays has been widely used for landslide prone area zonation due to its feasibility, high efficiency, low cost and a better understanding upon spatial factors influencing slope instability. Landslide susceptibility mapping using either multivariate or bivariate statistical approaches analyses the historical link between landslide-controlling factors and the distribution of landslides (Guzzetti, et al., 1999)

**Bivariate Statistical Analyses (BSA)** involves the idea of comparing a landslide inventory map with maps of landslide influencing parameters in order to rank the corresponding classes according to their role in landslide formation. The main idea of this analysis is to determine the densities of landslide occurrences within each parameter map and its parameter map classes, and to derive data driven weights based on the class distribution and the landslide density (Suzen and Doyuran 2004). With these weights, causative factors maps can be combined to obtain a landslide susceptibility map.

**Multivariate Statistical Analyses-** Multivariate statistical analysis of causal factors controlling landslide occurrence may indicate the relative contribution of each of these factors to the degree of susceptibility within a defined land unit. These analyses are based on the presence or absence of stability phenomena within the units (Van Westen, 1993).

Several researches suggested that statistical analysis are more appropriate for susceptibility zoning at medium scales (1:50,000 to 1: 25,000) because of their potential to minimize expert subjectivity (van Westen et al. 2006). However, if we didn't do adequate consideration with the mechanics of the physical process involved, and correlation of the causative factors and landslide susceptibility, statistical methods are liable to result in very coarse and even misleading regression. With this in mind, some cross check procedures were proposed to minimize these drawbacks and increase the quality of landslide susceptibility assessments with the statistical approaches through: a) proper validation and reduction of simulation uncertainty, and b) introduction of expert knowledge to the statistical models used (van Westen, et al. 2006)

**Weight of evidence** is a data-driven process that uses known landslide occurrences (training points) as model training sites to produce predictive probability maps from multiple weighted evidences (Raines 1999). Training points (Landslide occurrences) are used in Weight of evidence to calculate prior probability, weights of each of the evidential thematic classes, and posterior probabilities of the predictive factors.

Prior probabilities and posterior probabilities are the most important concepts in the Bayesian approach. Prior probability is the probability that a terrain unit contains the response variable (e.g. landslide) before taking landslide predictive factors (B) (e.g.

causative factors) into account and its estimation is based on the response variable (landslide occurrences) density for the study area.

The prior probability that an event (landslide, LS) occurs per unit area is calculated as the total number of events over total area. This initial estimate can be modified (i.e. increased or decreased) by the introduction of other available class of the predictive variables.

**Frequency ratio (FR) probability model** is a quantitative method, which comprises the analysis of the relationship between landslide occurrence and factors causing the failure. When evaluating the probability of occurrence of a landslide within a certain area and in a specific period of time, it is crucial to recognize the conditions that can favor the landslide and the process that could trigger the failure. The application of the FR probabilistic model is based on the assumption that future landslides will occur under the circumstances similar to those of past landslides (Lee, et al. 2004). FR approach is based on the observed relationships between distribution of landslides and each landslides-related factor to reveal the correlation between landslide locations and the factors in the study area (Lee and Pradhan 2006)

The use of GIS is very important to apply the FR method in that it helps: (1) to prepare all the necessary input thematic maps, (2) to apply the map overlay technique of the various thematic maps (3) to calculate all the areas of landslide and non-landslide for each class of each factor.

**Deterministic Method** are other quantitative method that depends on engineering principles of slope instability expressed in terms of the factor of safety. They depend on classical slope stability theory and principles such as infinite slope; limit equilibrium and finite element techniques and require standard soil parameter inputs such as soil thickness, soil strength, ground water pressures, slope geometry (Fell R, et al. 2008).

Recent studies have shown that the best approach for spatial prediction of landslides is the application of deterministic slope stability models, combined with steady state or transient models for hill slope hydrology. In this regard deterministic models provide the best quantitative information on landslide hazard that can be used directly in the design of engineering works or in the quantification of risk.

However, their application is restricted to over small areas at large scale (van Westen, 2004) due to (1) their requirement of large amount and detailed input data, (2) their substantial degree of simplification of the landslide types and depths (3) the over simplification of the geological and geotechnical model, and difficulties in predicting groundwater pore pressures and their relationship to rainfall (Fell R, et al. 2008).

**Limit equilibrium theory** is often used to analyze the stability of natural slopes. A number of methods and procedures based on limit equilibrium principles have been developed for this purpose. The aim of limit equilibrium studies is to analyze the stability of any mass of soil or rock assuming incipient failure along a potential slip surface. This approach often enables the solution of many problems by simple statics provided some simplifying assumptions are made (Chowdhury 2010).

**The infinite slope stability model** has been widely applied to the determination of natural slope stability, particularly where the thickness of soil mantle is small compared with the slope length and where landslides are due to failure of a mantle that overlies a sloping drainage barrier (Amantii et al. 2002). The drainage barrier may be bedrock or a denser soil mass. In this case, soil depth is obviously the depth due the drainage barrier. However, a translational failure plane may develop at any hydraulic conductivity contrast where positive pore water pressure can develop. Therefore, the depth to the failure plane may be much less than the depth to competent bedrock. The infinite slope model generally relies on several simplifying assumptions which may cause some limitation to its application (Ritter 2004).

### 2.4.3 Semi Quantitative Methods

Qualitative methods depend critically on expert opinions and demonstrate the hazard zoning in descriptive (qualitative) terms. Some qualitative approaches, however, incorporate the idea of ranking and weighting, and may evolve to be semi-quantitative in nature. The semi quantitative estimation for landslide risk assessment is found useful in the following situations (AGSI 2000): i) as an initial screening process to identify susceptible/hazards; ii) where the possibility of obtaining numerical data is limited. Semi-quantitative approaches consider explicitly a number of factors influencing on stability (Chowdhury and Flentje 2003). A range of scores and setting for each factor may be used to assess the extent to which that factor is favorable or unfavorable to the occurrence of instability. The application of the Analytical Hierarchy Process (AHP) method developed by Saaty (1980), is one of the best examples for such semi quantitative methods of landslide susceptibility mapping. Being partly subjective, results of these approaches vary depending on the knowledge of experts. This approach may be applicable to any scale or level of analysis, but more reasonably it is used in medium scales. Nowadays, such a semi-quantitative approach can efficiently use spatial multi-criteria techniques implemented in GIS that facilitate standardization, weighting and data integration in single set of tools.

## 2.5 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process builds a hierarchy of decision elements (factors) and renders comparisons possible between pairs of factors in form of matrix. The results are weights for each factor and also a consistency ratio which quantifies the unambiguity of the pairwise weighting. It is based on three principles namely decomposition, comparative judgement and synthesis of priorities (Malczewski 1999; Feizizadeh et al. 2013). AHP is a multiple criteria decision making technique that allows subjective as well as objective factors to be considered in the decision making process. It allows the active participation of decision-makers and gives managers a rational basis on which to make decisions. In MCDM the AHP method is widely used to obtain the required weightings for the criteria, AHP has been successfully employed in GIS-based MCDM since early 1990s (Feizizadeh et al. 2013). It calculates the required weights associated with criterion map layers with the help of a preference matrix in which all relevant criteria identified are compared against each other on the basis of preference factors. The weights can then be aggregated. GIS-based AHP has gained popularity because of its capacity to integrate a large quantity of heterogeneous data, and because obtaining the required weights can be relatively straightforward, even for large number of criteria. It has been applied to a variety of decision making problems (Tiwari et al. 1999; Nekhay et al. 2008; Hossain and Das 2009, Feizizadeh et al. 2013). Finally, AHP as a multi objective, multi criteria decision-making approach enables the user to specify preferences drawn from a set of alternatives. AHP gained wide applications in site selection, suitability analysis and regional planning.

### 2.5.1 Parameter Weight Assignment

To apply AHP, it is necessary to break a complex unstructured problem down into its component factors, arrange these factors in a hierarchic order, assign numerical values to subjective judgments on the relative importance of each factor and synthesize the judgements to determine the priorities to be assigned to these factors (Saaty and Vargas 2001, Feizizadeh et al. 2013). The AHP requires the criterion of a reciprocal pairwise comparison between each layer based on a 9-point rating scale as developed by Saaty (1977) (Table2.1), where value of 1 is given to imply the criteria under comparison are of equal importance to the final solution and 9 expresses extreme importance of one criterion over another. Values in between are used for expressing moderate importance of one criterion over another (3), strong importance (5) and very strong importance (7). In the case of the criteria being compared are deemed to be closer than indicated by this scale, one can use values in between (Robinson et al., 2010, Feizizadeh et al. 2013). Comparisons are made by comparing the row criterion to the column criterion. If the row criterion is of less importance to the column criterion the reciprocal is used (e.g. very strongly less important would be expressed as 1/7). By definition the diagonal entries are all equal to 1 (criteria are equally important when compared to themselves) and the rating in any position i, j will be reciprocal of that in position j, i (Robinson et al. 2010, Feizizadeh et al. 2013). The principal eigenvector of this matrix yields the weights applicable to each layer. Scales for pairwise comparisons

Table 2.1 Scales for pairwise comparisons

| **Intensity of importance** | **Description** |
|---|---|
| 1 | Equal importance |
| 3 | Moderate Importance |
| 5 | Strong or essential importance |
| 7 | Very Strong or demonstrated importance |
| 9 | Extreme importance |
| 2,4,6,8 | Intermediate values |
| Reciprocals | Values for inverse comparision |

### 2.5.2 Pairwise Comparison of the causative factors

The pairwise comparison method is used to determine the preference of the triggering factors. For pairwise comparison, the factors identified as the causative factors are arranged in the form of matrix as shown in table 2.2, and the factors are subjectively compared with each other as a pair and their preferences are expressed in the numeric values in the adjacent cells i.e. the factors preferences are quantified.

Once the preferences of the factors have been determined using pairwise comparison method, the alternative weight of the couple comparison is calculated using arithmetic mean method. In this method, at first, the values of each column of pairwise comparison matrix are summed up. Then the values in each cell of the matrix is divided by the summed value of the same factor column, and at last, the factor mean values are derived in each row as mean of the values in each row. These mean values of each row are the weight values of each factor (Bhatt et al. 2013). The example can be shown as:

Table 2.2 Pairwise Comparison Sample Matrix

| | Soil | Rainfall | Slope | Aspect | Geology | Land use |
|---|---|---|---|---|---|---|
| Soil | a | b | c | d | e | f |
| Rainfall | 1/b | a | g | h | i | j |
| Slope | 1/c | 1/g | a | k | l | m |
| Aspect | 1/d | 1/h | 1/k | a | n | o |
| Geology | 1/e | 1/i | 1/l | 1/n | a | p |
| Land use | 1/f | 1/j | 1/m | 1/o | 1/p | a |

Each parameter is again classified into a number of significant classes based on their relative influence on mass movements. Weighting values will be subsequently assigned to each class. The relative importance of each terrain parameter as a determining factor of slope instability is quantitatively determined by pairwise comparison using analytical hierarchy process (AHP). The integration of the various factors in a single hazard index has been accomplished by a procedure based on their weighted linear sum (Barredo et al., 2000). as follows:

$$H = \sum_{j=1}^{n} \left( W_j X_{ij} \right)$$

Where:

H=landslide hazard

$W_i$=weight parameter j

$X_{ij}$= weight of class i in parameter j

The continuous landslide hazard raster map thus generated will be eventually into five hazard classes i.e. high, moderate to high, moderate, moderate, moderate to low, low. In multi criteria evaluation techniques the weighted linear sum is considered a compensatory procedure. The derived value of each alternative is primarily a function of the weight assigned to the parameters and secondarily, of the weight of each parameter class (Barredo et al., 2000). In this approach, however, subjectivity is involved both in the assignment of weight values to classes and, although quantitatively less significantly, in pair wise comparison of the parameters relevance.

In AHP, for checking consistency of matrix, consistency ratio will be used, which depends on the number of parameters. The consistency ratio (CR) will be obtained by comparing the consistency index (CI) with average random consistency index (RI). The consistency ratio is defined. The consistency ratio (Rahman 2014) is defined as

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}$$

The value of random consistency index RI for different order of matrix is given as below:

Table 2.3 Table Random Consistency Index

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

Where, CI is the consistency index which is expressed as:

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n-1}$$

Where $\lambda_{max}$ is the major principal Eigen value of the matrix and it is computed from the matrix and n is the order of the matrix. And the average random consistency index (RI) is derived from a sample of randomly generated reciprocal matrices using scales 1/9, 1/8……8 and 9.

The final result shall consist of the derived factor weights and class weights, and a calculated consistency ratio (CR). In AHP, the consistency used to build a matrix would be checked by a consistency ratio, which depends on the number of parameters. The CR must be less than 0.1 to accept the computed weights. The models with a CR greater than 0.1 shall be automatically rejected, while a CR less than 0.1 shall be acceptable.

## CHAPTER THREE

## 3. Methodology and Data analysis

This study is intended to prepare the hazard map of the study area using GIS as a tool. For the preparation of the hazard map of the Lal Bakaiya Watershed three steeps: desk study, field investigation, data analysis and interpretation were carried out. In the initial phase of the research, collection of secondary data and review of the literature were done. The base map was then prepared from digital topographic map and satellite images. From the field investigation, all information and maps prepared earlier in the desk study were verified in the field. The data prepared and verified data were then analyzed for hazard mapping.

### 3.1 Desk Study

In this phase of work collection and preparation of available data are the main job. It is based on published literature covering a range of topics regarding the study area, topographical maps, geological map and land use maps. The objective of the desk study is to develop the preliminary concept of the study area about the nature of the slope, geology, soil, rainfall, settlement, stream and watershed boundaries.

### 3.2 Field Work and Data Collection

The field work was carried out and the objective of the field work was to record the nature of the slope, general geology, geomorphology and discontinuity data of the study area. In this study, field works cover the geological observation, geological mapping, geomorphologic mapping and topographical study and data collection. The detailed field visit was done after the preparation of different thematic layers for the verification of the output.

For the preparation of landslide hazard map, the factors considered will be slope aspect, slope, distance from road, stream density, soil, rainfall, land use and geology. Elevation, slope aspect, slope angle, will be derived from Digital Elevation Model

(DEM) and 20m contour, while land use and land cover will be derived from Landsat satellite images. Other base layer like streams, road, contour, will be extracted from the digital topographic map and soil type from geological map collected from DoS.

The data of RS and GIS data were downloaded from the earthexplorer.usgs.gov a website of U.S geological survey and rainfall data of the station lying in the watershed area were collected from the DHM.

### 3.2.2 Satellite Image and GIS data

For the preparation of land use and land use change pattern and hazard mapping will be conducted by Geographical Information system (GIS) and Remote Sensing Analysis. Time series data of 1987, 1997, 2007 and 2015 will be used for preparation of land use and hazard map and quantification of land cover of Lal Bakaiya watershed. All the landsat images are collected from earthexplorer.usgs.gov a website of U.S geological survey which comprised of landsat TM of 30m spatial resolution and will be classified by object based image analysis (OBIA) technique. The classification of the OBIA is based on the information from a set of similar pixels called objects or image objects. More specifically, image objects are groups of pixels that are similar to one another based on a measure of spectral properties i.e. color, size, shape, and texture, as well as context from neighborhood surrounding pixels.

Table 3.1 Landsat satellite sensor specification (GLCF 2004)

| Satellite | Sensor | Swath (km) | Scene Size (km) | Altitude (km) | Revisit (days) |
|---|---|---|---|---|---|
| L 1-5 | MSS | 180 | 180 x 170 | 917 | 18 |
| L 4-5 | TM | 185 | 170 x 183 | 705 | 18 |
| L 7 | ETM+ | 185 | 170 x 183 | 705 | 16 |
| L 8 | OLI | 185 | 170 x 185 | 705 | 16 |

Landsat imagery is relatively high resolution earth observation data that is acquired through sensors on one of the NASA Landsat satellites. The satellite sensors acquire high integrity images of the planet surface in a systematic fashion. User stake this imagery and use it to determine the health and type of vegetation, amount of built surfaces, success of agriculture, or apply it for a myriad other uses.

**Limitation of Landsat TM**

Some of the limitations of the landsat images are:

i. Since resolution of data from Landsat image is 30m, the linear strips of forest cover along roads, canals, bunds and rails of width less than the resolution are generally not captured.
ii. Young plantations and species having less chlorophyll contents in their crown do not give proper reflectance and as a result are difficult to be interpreted correctly.
iii. Considerable details on ground may be obscured in areas having cloud sand shadows. It is difficult to interpret such areas without the help of collateral data.
iv. Variation in spectral reflectance during leafless period poses problem in interpretation.
v. Gregarious occurrence of bushy vegetation and certain agricultural crops such as lantana, sugarcane, cotton, etc. often pose problems in delineation of forest cover as their reflectance is similar to that of tree canopy.
vi. There is drastic difference in texture (Color pattern) in 1987,1997, 2007and 2015 downloaded from U.S geological survey website.

### 3.2.3 Geological Map, Topographical & Rainfall data

#### Geological Map

The geological map of Nepal is collected from the Department of Mines and Geology, Kathmandu. Then the geology map of the study area is prepared by digitizing the image of geological map of Nepal in Arc GIS 10.2.2.

### Topographical data

The digital topographical datas of the study area are collected from the Department of Survey (DoS), Kathmandu. These data include built-up areas, hydro (poly & line), topo data, Landslide inventory, different utility data & boundaries. Elevation, slope aspect, slope angle, is derived from Digital Elevation Model (DEM) prepared from the 20m contour provided in these topographical data.

### Rainfall data

The daily rainfall data from year 1987 to present time period of different stations situated in the watershed and around the watershed were collected from Department of Hydrology and Meteorology (DHM) Kathmandu. The stations used for the analysis of the rainfall data are Hetauda N. F.I, Amlekhganj, Simara Airport, Nijgadh, Parwanipur, Ramoloi Bairiya, Makwanpur Gadhi, Kalaiya & Chyuntaha.

Table 3.2 Rainfall Staitions used for analysis (Department of Hydrology and Meteorology)

| S.N. | Stations | Place | Lat | Long |
|---|---|---|---|---|
| 1 | Hetauda(906) | Makwanpur | 3033605.08 | 603809.75 |
| 2 | Amlekhgunj (907) | Bara | 3018828.34 | 598984.30 |
| 3 | Simara Airport (909 | Bara | 3005962.78 | 597402.36 |
| 4 | Nijgadh(910) | Bara | 3007891.76 | 615619.21 |
| 5 | Parwanipur (911) | Bara | 2994871.16 | 595902.12 |
| 6 | Ramoli Bairiya (912) | Rautahat | 2989716.17 | 637223.70 |
| 7 | Makawanpurgadhi (919) | Makwanpur | 3033818.95 | 615376.97 |
| 8 | Kalaiya (921) | Bara | 2991129.78 | 599204.99 |
| 9 | Chyutaha (924) | Bara | 2982045.48 | 612482.75 |

### 3.2.4 Other Data Collection

#### Drainage Density

The drainage density map was prepared by using the DEM and the hydro data from the topographical map of the study area and with aid of density tool of ArcGIS. The density map is classified in to low, Medium and High stream density classes.

#### Road Network

The road network data are collected from respective departments. The Strategic road network data was collected from Department of Roads (DoR) & the district road core network data is collected from DOLIDAR.

#### Soil Map

Soil map is prepared using the satellite image of the study area as the base map. This study area is mainly classified into four groups namely Rock, Alluvial, Colluvium & Residual soil.

#### Landslide Inventory Map

As delineation of past landslide occurrences is useful for the prediction of future patterns of instability, landslide inventory of the study area has been executed through the direct field survey supported by the interpretation and extraction of the landslide areas with the use of satellite images, Google Earth and the data of landslide areas from the topographical data.

### 3.3 Data Analysis

In data analysis, both qualitative and quantitative data analysis and preparation of the GIS layers are the main task. The detail data analysis is presented below:

### 3.3.1 GIS Based Data Analysis

A GIS is a special case of information systems where the database consists of observations on spatially distributed features, activities and events, which are definable in space as points, lines and areas to retrieve data for analyses. GIS is an information system that is designed to work with data referenced by spatial or geographic co-ordinates. In other words, GIS is both a database system with specific capabilities for spatially referenced data as well as a set of operations for working with the data.

GIS is the effective tool to deal with the widely scattered and the enormous number of data. Various factors affecting on the slope stability analysis were considered as the input parameters for GIS.

### 3.3.2 Land Cover Classification

Digital Land use/ land cover classification through supervised classification method, based on the field knowledge is employed to perform the classification. Arc GIS platform provides very effective platform for extracting the land use, land cover layer from satellite imageries (Tiwari and Khanduri 2011; Prakasam 2010). The collected data in Landsat of 1987, 1997, 2007 and 2015 were OBIA classified raster data. These were converted to vector (ESRI shape file) on Arc GIS 10.2 by using raster to vector conversion tool. With the help of previously selected watershed area, a shape file was prepared and the watershed area was extracted from all four maps of 1987, 1997, 2007 and 2015 by using clipping tool. These vector shape file were classified into five classes i.e., forest land, sand plain, water bodies, agriculture land and barren land to observe the changes in the land use and land cover of Lal Bakaiya watershed by different contrast colors. Colors like green, brown, light pink, white and blue color were used to distinguish forest, barren land, agriculture, and sand plain and water bodies respectively. Change on Land Use and Land Cover of Lal Bakaiya watershed in four different periods of 1987, 1997, 2007 and 2015 were calculated by using geometric calculator. The analysis and interpretation of different aspects of the numeric data of land use dynamic was performed on Microsoft Excel. The result was presented easily in understandable tabular form by area and percentage. In this study land cover is classified into different groups with the help of Landsat Images. The major five classified groups are:

1. Forest Cover
2. Sand Plain
3. Water Bodies
4. Agricultural Land
5. Barren Land

The descriptions of above classified land cover group are given below:

1. **Forest Cover:** Forest cover is defined as an area more than 1ha in extent and having tree canopy density of 10 percent and above. All species of trees (including bamboos, fruits or palms, etc.) and all types of lands (forest, private, community or institutional) satisfying the basic criteria of canopy density of more than 10 percent have been delineated as forest cover while interpreting satellite data. The minimum area of 1ha for forest cover has been kept because this is the smallest area that can be delineated on a map at 1:50,000 scale.
2. **Sand Plain:** The land of bank of the river covered with sand are classified as sand plain.
3. **Water Bodies:** The space covered with water are classified as water bodies.
4. **Agricultural Land:** The land primarily used for food and fibre are classified as agricultural land.
5. **Barren Land:** The fallow land without vegetation cover as well as gravel covered stream bank were classified as barren Land.

### 3.3.3 Preparation of Landslide hazard map

Firstly, a database of the terrain parameters considered the most important determining factors of the slope instability in the area has been compiled. Relevant data have been collected by means of aerial photo interpretation, field surveys, satellite image processing and digitizing base maps.

Next, each parameter has been classified into a number of significant classes based on their relative influence on mass movements. Weighting values have been subsequently assigned to each class. The relative importance of each terrain parameter as a determining factor of slope instability has been quantitatively determined by pairwise comparison using the so called analytical hierarchy process (AHP) (Barredo et al. 2000).

In multi criteria evaluation techniques the weighted linear sum is considered a compensatory procedure. The derived value of each alternative is primarily a function of the weight assigned to the parameters and secondarily, of the weight of each parameter class (Barredo et al. 2000). In this approach, however, subjectivity is involved both in the assignment of weight values to classes and, although quantitatively less significantly, in pair wise comparison of the parameters relevance.

### 3.3.4 Parameters used for the Landslide Hazard Map

#### 1. Precipitation

The daily rainfall data collected from Department of Hydrology and Meteorology (DHM), Kathmandu from year 1987 to present time period of Hetauda N. F.I, Amlekhganj, Simara Airport, Nijgadh, Parwanipur, Ramoloi Bairiya, Makwanpur Gadhi, Kalaiya & Chyuntaha stations situated in the watershed and around the watershed were used to calculate the average monsoon rainfall, which is used for preparation of landslide hazard map of the study area. Average monsoon (June to September) rainfall is used because the rainfall is very high compared to rest of the months of the year. Rainfall in the study area is in the range of 1400 to 2100 mm. So the precipitation map is classified into four classes as 1400-1600, 1600-1800, 1800-2000, 2000-2103 mm.

### 2. Stream Density

The stream density map was prepared by using the DEM and the hydro data from the topographical map of the study area and with aid of density tool of ArcGIS. The density map is classified in to low, Medium and High stream density classes.

### 3. Land use

Land use change map was derived from classification of multi-temporal Landsat TM data. Highest weighting was given to the areas covered by irrigated terraces, recently abandoned agricultural land and the water bodies. Lower weights were assigned progressively to permanent soil cover with mixed vegetation to permanent soil cover, new and permanent soil cover with mixed vegetation.

### 4. Geology

The geological map of Nepal collected from the Department of Mines and Geology, Kathmandu is used to digitize the geological map of the study area in Arc GIS 10.2.2. The study area comprises of five types of formations. These are:

i. Recent: - Alluvium boulders gravels sands and clays.
ii. Upper Siwalik: - Consist of Coarse boulder, conglomerates with irregular bands and lenses of sandstones and thin intercalations of yellow, brown, grey sandy clays.
iii. Middle Siwalik (Ms2): - Medium to coarse grained, arkosic, pebbly sandstones with grey clays and occasionally silty sandstones and conglomerates.
iv. Middle Siwalik(Ms1): - Fine to medium grained friable arkosic sandstones and hard, compact massive sandstones intercalated with green to greenish grey clays, thin bands of pseudo-conglomerates and mudstones, Plant and animal fossils are present in clays.
v. Lower Siwalik: - Fine Grained, hard, grey sandstones interbedded with purple and chocolate colored shales, nodular maroon clays, pseudo-conglomerates.

### 5. Slope Map

Slope map of the study area was derived from a digital elevation model (DEM) following of digitized topographic maps. A raster layer of continuous angle values was generated as slope map. The slope values are divided into five classes 0-10, 10-20, 20-30, 30-45, 45-60 and above 60.

### 6. Slope Aspect

An aspect map shows to which side a slope is directed. An aspect value of 0° and 360° means that the slope is facing the north. Similarly, 90°, 180° & 270° means the slope is facing is east, south and west respectively. Slope aspect map of the study area was also derived from a digital elevation model (DEM) following of digitized topographic maps. Slope Aspect is the direction of the slope of the terrain. Generally, there are nine types of the aspect created by the tool used in Arc GIS 10.2.2, which are Flat, North, Northeast, Northwest, East, West, South, Southeast and South west. For the study North, Northeast, Northwest were taken as North and South, Southeast and southwest were taken as South. Hence the slope aspect map is finally divided in five classes namely Flat, North, East, West & South.

### 7. Soil

Satellite image of the study area is used as the base map for the preparation of soil map. Different layers are digitized using the base layer and then the study area is mainly classified into four groups namely Rock, Alluvial soil, Colluvium soil & Residual soil.

### 8. Distance from Road

Road network of the study area obtained from different sources are firstly merged into one layer. Then this layer is used to create the multiple buffer zones. These buffer zones indicate distance from the road. These buffer zones are used to analyze the impact of road construction on the surrounding soil. For the study of area four classes are defined 50m, 200m, 400m & above 400m.

**Parameter of weight assignment**

Although there exists a variety of procedures for establishing parameter weights, the AHP permits to evaluate the consistency of the parameter pairwise comparison. In this procedure a value comprised between 9 (extremely more important than), 1 (equally important as) and 1/9 (extremely less important than) will be assigned to each pair of parameters in square reciprocal matrix by rating rows relative to columns.

In AHP, for checking consistency of matrix, consistency ratio will be used, which depends on the number of parameters. The consistency ratio (CR) will be obtained by comparing the consistency index (CI) with average random consistency index (RI).

The final result shall consist of the derived factor weights and class weights, and a calculated consistency ratio (CR). In AHP, the consistency used to build a matrix would be checked by a consistency ratio, which depends on the number of parameters. For 10x10 matrix, the CR must be less than 0.1 to accept the computed weights. The models with a CR greater than 0.1 shall be automatically rejected, while a CR less than 0.1 shall be acceptable.

Table 3.3 Pairwise Comparison matrix

| **S.N.** | | **Precipitation** | **Stream Density** | **Land use** | **Geology** | **Slope** | **Slope Aspect** | **Soil** | **Road network** |
|---|---|---|---|---|---|---|---|---|---|
| 1 | **Precipitation** | 1 | 3 | 1/2 | 2 | 1/2 | 1 | 1/3 | 1 |
| 2 | **Stream Density** | 1/3 | 1 | 1/4 | 1/2 | 1/4 | 1/3 | 1/5 | 1/3 |
| 3 | **Land use** | 2 | 4 | 1 | 2 | 1 | 2 | 1/2 | 2 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 4 | **Geology** | 1/2 | 2 | 1/2 | 1 | 1/4 | 1/2 | 1/3 | 1/2 |
| 5 | **Slope** | 2 | 4 | 1 | 4 | 1 | 3 | 1/2 | 2 |
| 6 | **Slope Aspect** | 1 | 3 | 1/2 | 2 | 1/3 | 1 | 1/3 | 1 |
| 7 | **Soil** | 3 | 5 | 2 | 3 | 2 | 3 | 1 | 3 |
| 8 | **Road network** | 1 | 3 | 1/2 | 2 | 1/2 | 1 | 1/3 | 1 |

Table 3.4 Factors with Weight, Class, Rating and CR

| **SN** | **Factor** | **Weight** | **Class** | **Rating** | **CR** |
|---|---|---|---|---|---|
| 1 | Precipitation | 0.0962 | 1400-1600 | 0.0742 | 0.0251 |
| | | | 1600-1800 | 0.1947 | |
| | | | 1800-2000 | 0.2941 | |
| | | | 2000-2103 | 0.4368 | |
| 2 | Stream Density | 0.0374 | Low | 0.1061 | 0.0477 |
| | | | Medium | 0.2604 | |
| | | | High | 0.6333 | |
| 3 | Land use | 0.1615 | Forest cover | 0.1252 | 0.0481 |
| | | | Barren land | 0.4996 | |
| | | | Agriculture | 0.2364 | |
| | | | Water bodies | 0.0859 | |
| | | | Sand | 0.0526 | |
| 4 | Geology | 0.0615 | Recent Deposit | 0.0566 | 0.007 |
| | | | Upper Siwalik | 0.3781 | |
| | | | Middle Siwalik2 | 0.2187 | |
| | | | Middle Siwalik1 | 0.2187 | |
| | | | Lower Siwalik | 0.1277 | |
| 5 | Slope | 0.1872 | 0-10 | 0.0678 | 0.0187 |
| | | | 10-20 | 0.1586 | |
| | | | 20-30 | 0.2532 | |
| | | | 30-45 | 0.3473 | |
| | | | 45-60 | 0.1301 | |
| | | | >60 | 0.0426 | |
| 6 | Aspect | 0.0927 | Flat | 0.0546 | 0.0548 |
| | | | North | 0.0585 | |
| | | | East | 0.1399 | |
| | | | West | 0.1471 | |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
|  |  |  | South | 0.5997 |  |
| 7 | Soil | 0.2668 | Rock | 0.4092 | 0.0579 |
|  |  |  | Alluvium | 0.1103 |  |
|  |  |  | Colluvium | 0.2653 |  |
|  |  |  | Residual | 0.215 |  |
| 8 | Road Alignment | 0.0962 | 50m | 0.4949 | 0.0681 |
|  |  |  | 200m | 0.2423 |  |
|  |  |  | 400m | 0.1769 |  |
|  |  |  | > 400m | 0.0857 |  |

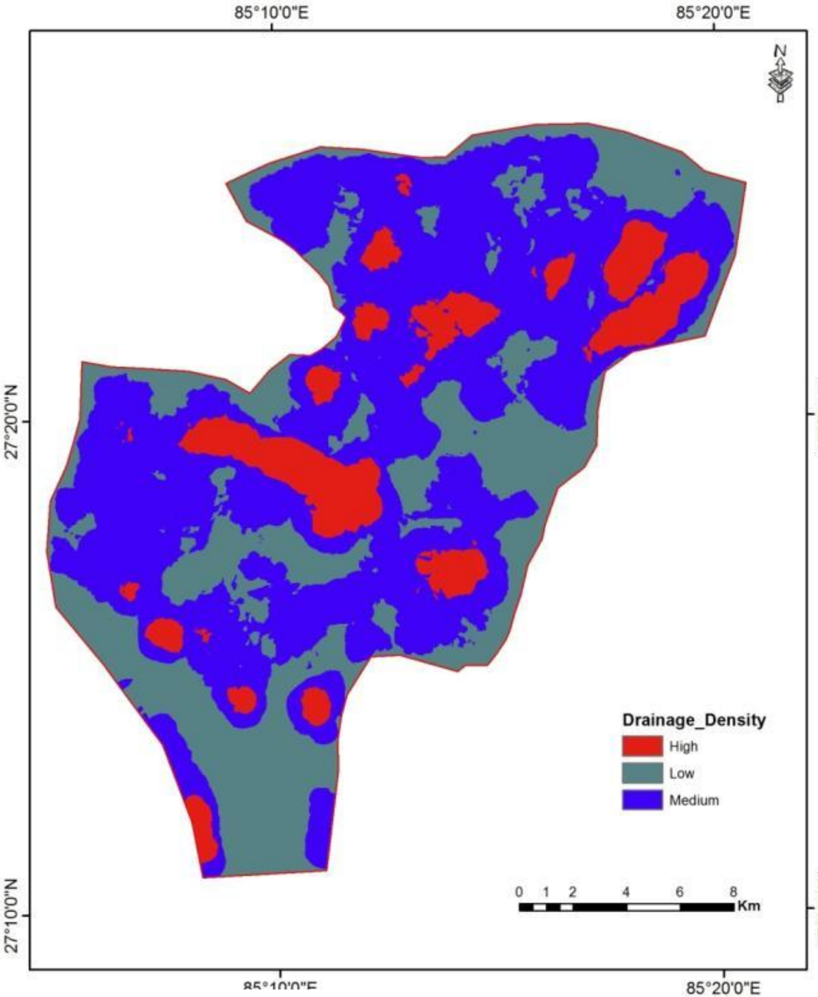

Figure 3.2 Drainage Density Map

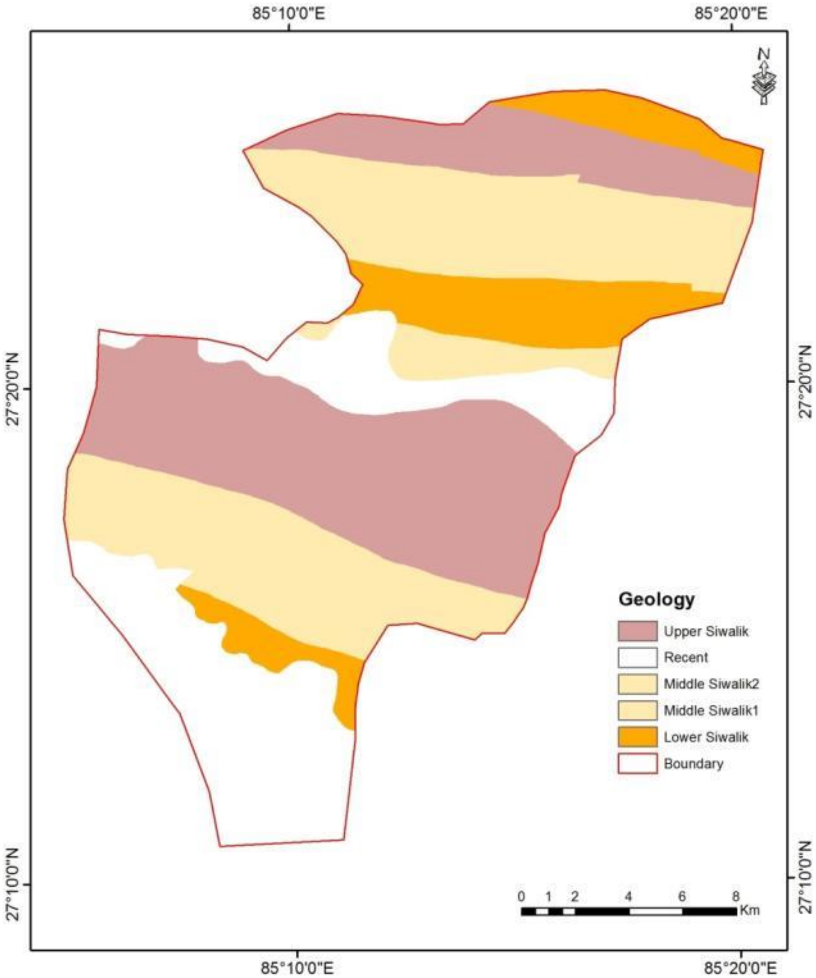

Figure 3.1 Geological Map

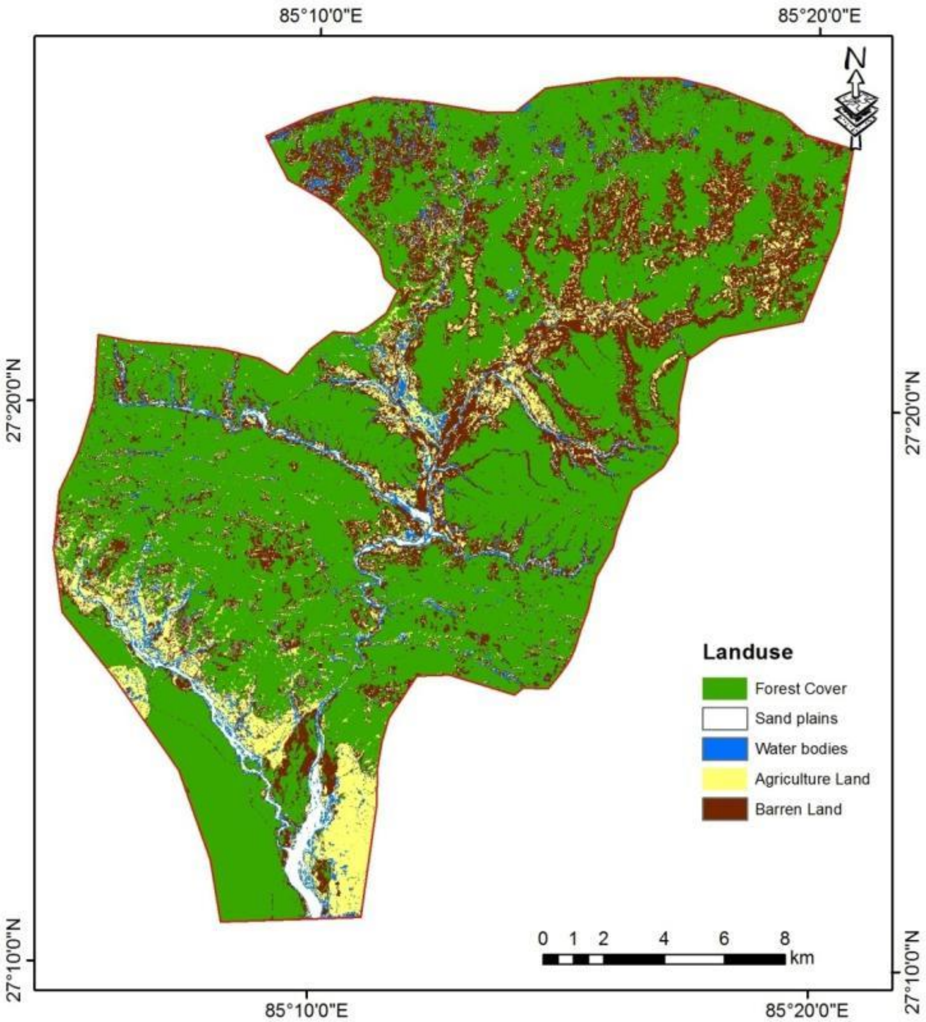

Figure 3.4 Land use Map

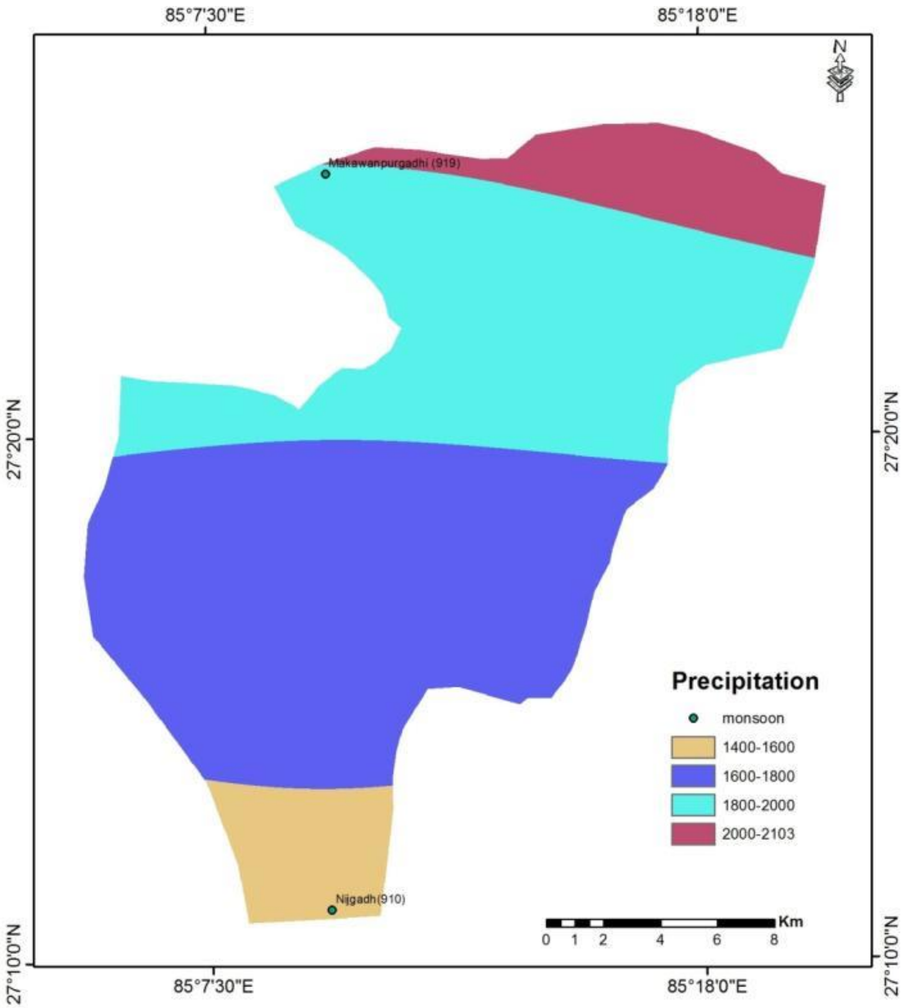

Figure 3.3 Precipitation Map

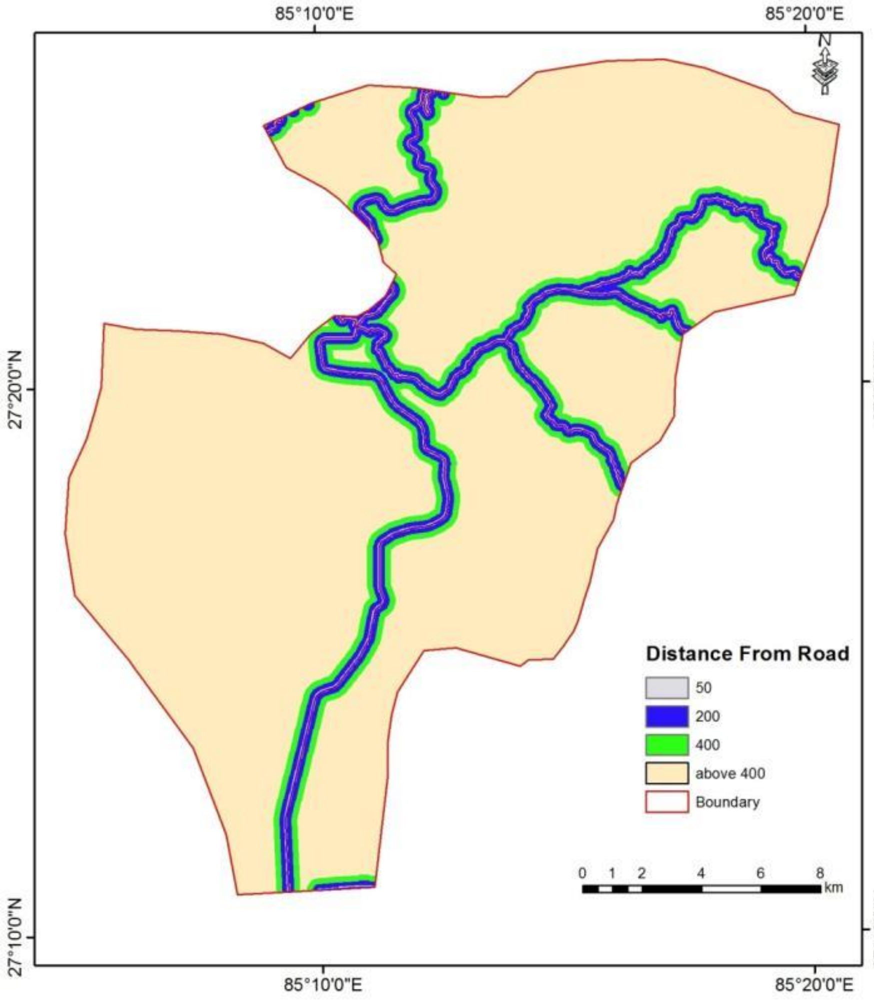

Figure 3.6 Distance from Road

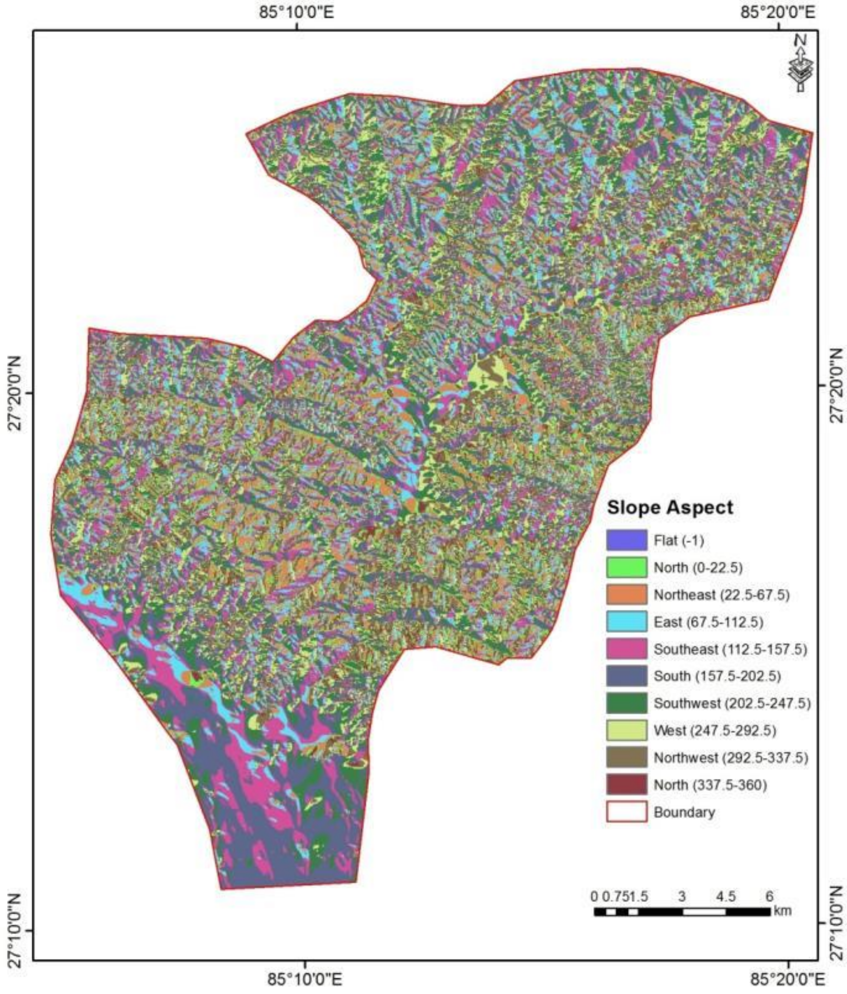

Figure 3.5 Slope Aspect Map

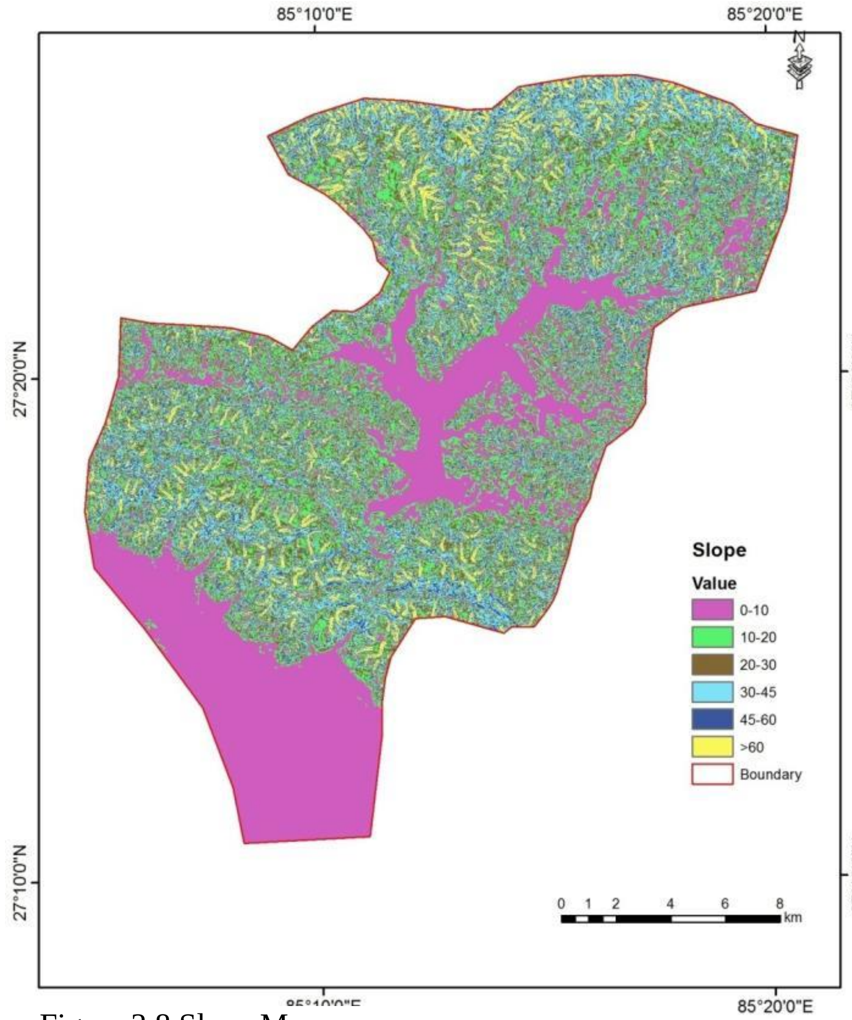

Figure 3.8 Slope Map

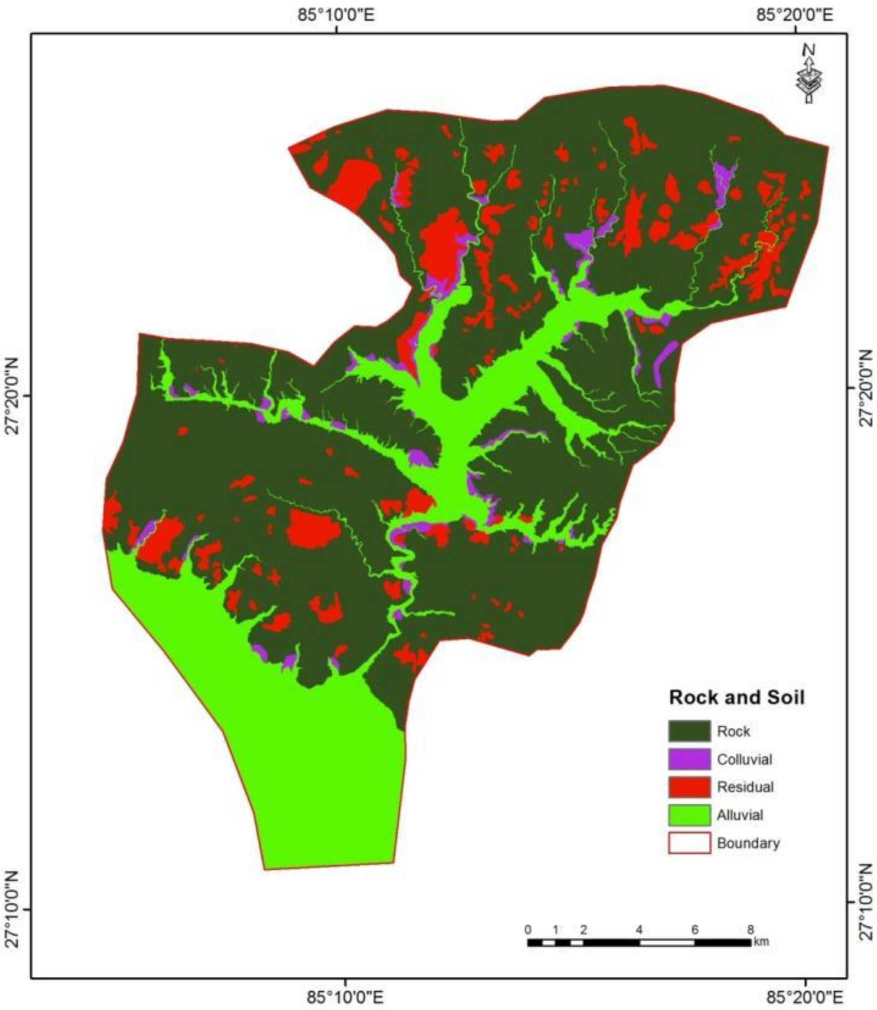

Figure 3.7 Rock and Soil Map

# CHAPTER FOUR

## 4. Result and Discussion

This chapter deals with the results of the applied method to develop the Land use maps of different decades and the landslide hazard map of the study area and interpretation of the results.

### 4.1 Land Use Map

The result of OBIA classification of change on Land Use and Land Cover of Lal Bakaiya watershed in four different periods of 1987, 1997, 2007 and 2015 was presented in understandable tabular form by area and percentage below:

Table 4.1 Land Cover changes of different decades

| **Year** | **1987** | | **1997** | | **2007** | | **2015** | |
|---|---|---|---|---|---|---|---|---|
| **Land Cover Groups** | Area (km2) | Land Cover (%) | Area (km2) | Land Cover (%) | Area (km2) | Land Cover (%) | Area (km2) | Land Cover (%) |
| **Forest Cover** | 219.78 | 57.24 | 198.67 | 51.74 | 201.80 | 52.56 | 226.05 | 58.86 |
| **Sand Plains** | 13.23 | 3.44 | 11.02 | 2.87 | 7.79 | 2.03 | 10.55 | 2.75 |
| **Water Bodies** | 7.42 | 1.93 | 8.59 | 2.24 | 21.09 | 5.49 | 12.20 | 3.18 |
| **Agricultural land** | 29.49 | 7.68 | 45.36 | 11.81 | 45.92 | 11.96 | 74.49 | 19.40 |
| **Barren Land** | 114.06 | 29.70 | 120.34 | 31.34 | 107.38 | 27.97 | 60.72 | 15.81 |

The above result of change on Land Use and Land Cover of Lal Bakaiya watershed in four different periods of 1987, 1997, 2007 and 2015 shows that the Forest cover decreases from the year 1987 to 1997 and then from 1997 to 2007 forest cover again increases. From the year 2007 to 2015 increase in forest cover continues. Also the above table shows that the agricultural land is increasing in all the decades in the study area. The detailed Land use maps of different decades are shown in figures below.

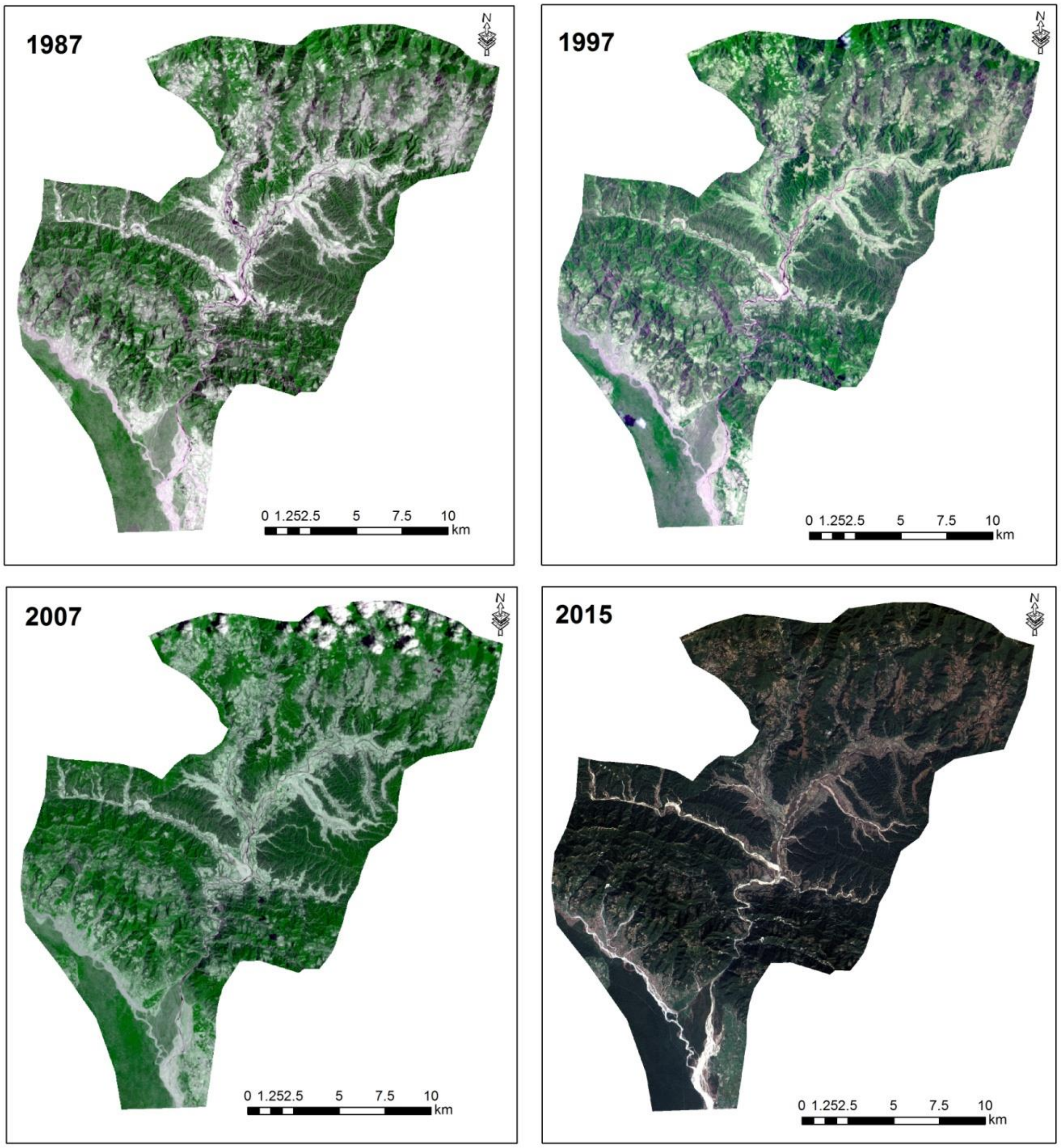

Figure 4.1 Landsat Images of 1987, 1997, 2007 and 2015

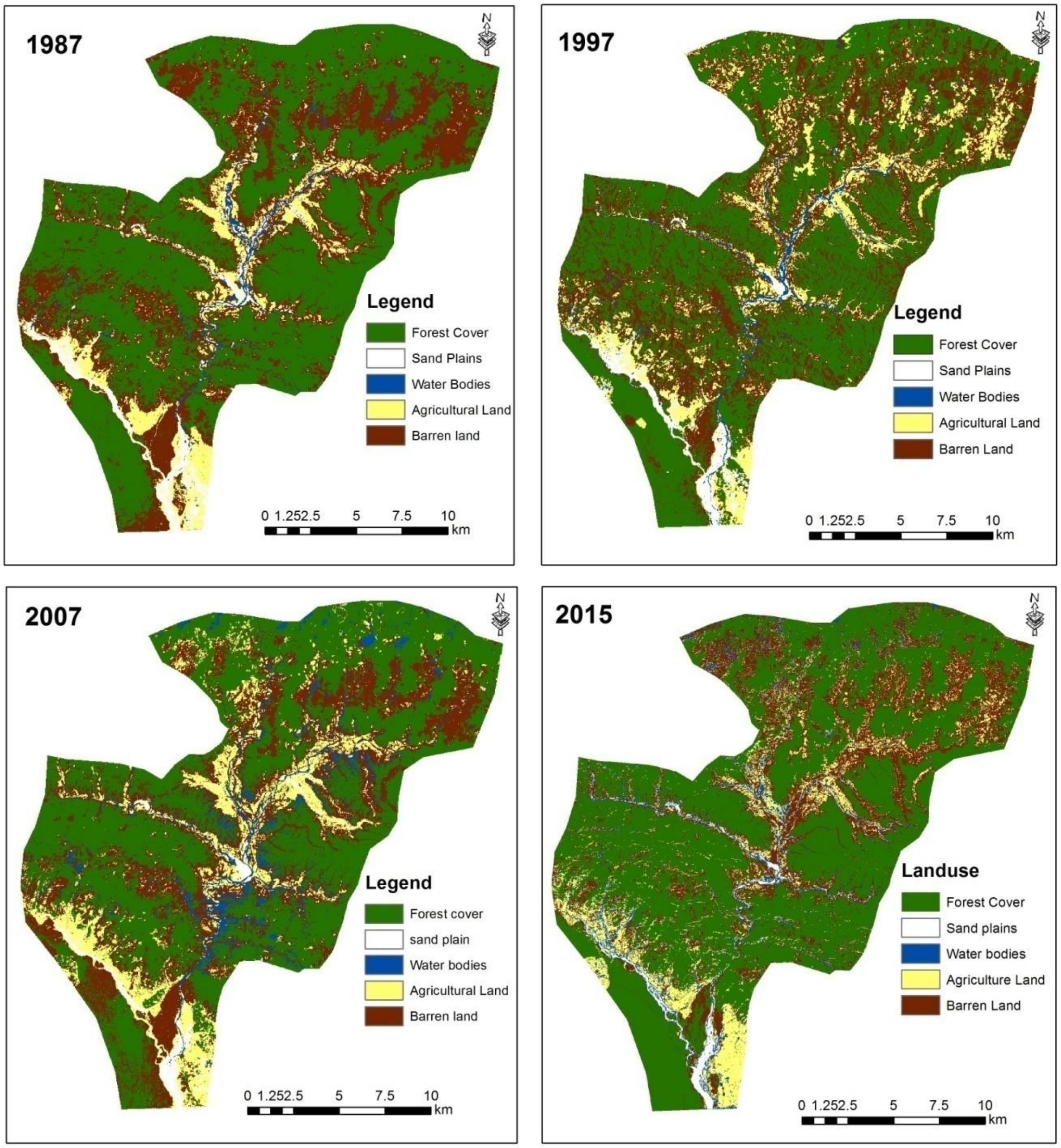

Figure 4.2 Land Use Maps of 1987, 1997, 2007 and 2015

## 4.2 Landslide Hazard Map

After the compilation of a database of the terrain parameters considered the most important determining factors of the slope instability in the area, different thematic layers are prepared with the help of data collected. The relative importance of each terrain parameter as a determining factor of slope instability has been quantitatively determined by pairwise comparison using the so called analytical hierarchy process (AHP). Then all the thematic layers are combined as per the weighting assigned based on their relative importance in the study area, which gives the landslide hazard map as shown below.

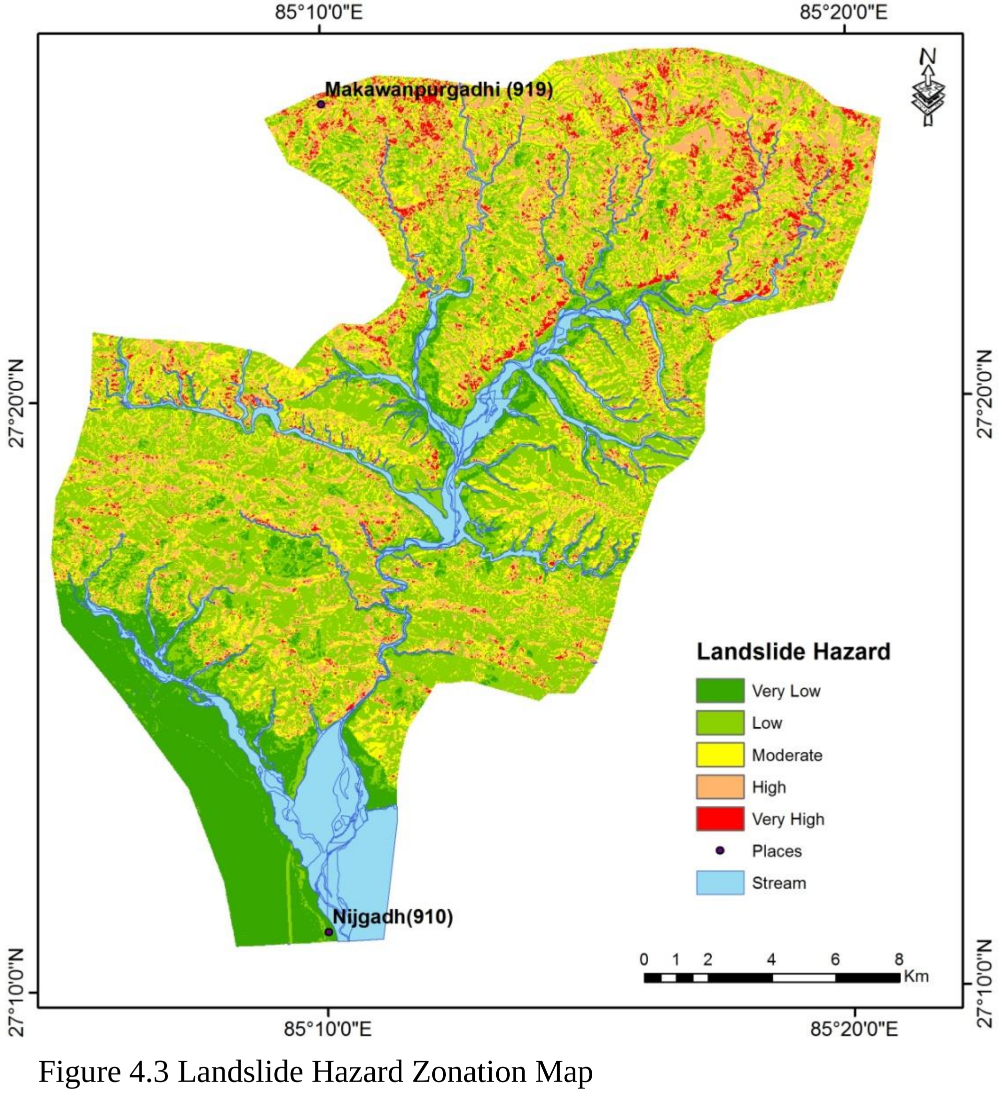

Figure 4.3 Landslide Hazard Zonation Map

Table 4.2 Hazard Zones with Area and Percentage

| Hazard Zone | Area (Sq. Km.) | Percentage |
|---|---|---|
| Very Low | 69.95 | 18.24 |
| Low | 156.13 | 40.70 |
| Moderate | 78.65 | 20.50 |
| High | 64.02 | 16.69 |
| Very High | 14.82 | 3.86 |

The above table shows the categorized five zones namely Very low, Low, Moderate, High, very high with the area covered by each zone and percentage of area covered. The table shows that the area covered by the very high hazard zone is the least having the percentage of 3.86 % of the total area of the study area. Similarly, the area covered by the high hazard zone, moderate hazard zone, low hazard zone and very low hazard zone are 16.69 %, 20.50 %, 40.70 % and 18.24 % of the total area of the study area respectively.

## 4.3 Validation of Hazard Map

For the validation of Hazard map prepared above, the landslide inventory map of the study area has been prepared through the direct field survey supported by the interpretation and extraction of the landslide areas with the use of satellite images, Google Earth and the data of landslide areas from the topographical data. This landslide inventory map is used for the validation of the hazard map. The number of small and large landslide of the study area used for the validation is 120 in total.

Table 4.3 Validation of Hazard Map

| Hazard Zone | Area (Sq. Km.) | Percent |
|---|---|---|
| Very Low | 0.003 | 0.63 |
| Low | 0.044 | 10.68 |
| Moderate | 0.061 | 14.77 |
| High | 0.144 | 34.50 |
| Very High | 0.164 | 39.43 |

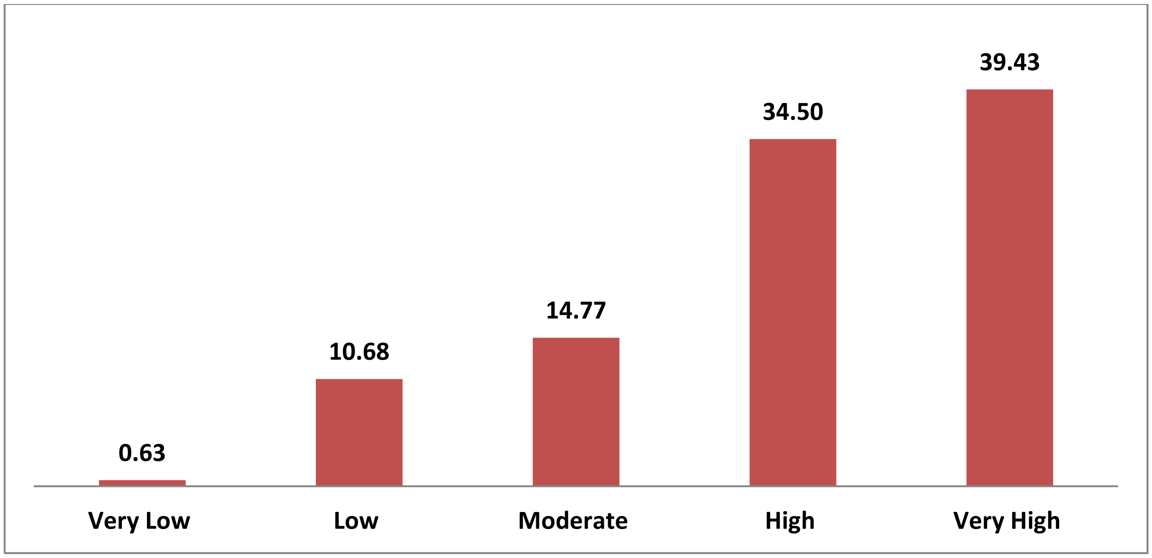

Figure 4.4 Validation of Hazard Zonation Map

Above figure shows that out of 0.4160 Sq. Km of existing landslide area 39.43 % of total landslides falls under very high hazard zone and 34.50 % of the total area of the past landslide areas falls under high hazard zone of the landslide hazard map prepared. Similarly, Moderate, Low and very low hazard zones cover 14.77, 10.68 and 0.63 percent of the landslide areas respectively.

# CHAPTER FIVE

## 5. Conclusions

This chapter deals with the conclusion and recommendations based on the results of the Land use maps of different decades and the landslide hazard map of the study area and interpretation of the results.

### 5.1 Land use Map

Land use change study shows that Forest cover decreases from the year 1987 to 1997 and then from 1997 to 2007 forest cover again increases. From the year 2007 to 2015 increase in forest cover continues. Also the above table shows that the agricultural land is increasing in all the decades in the study area. The change in land use and land cover is basically forest to agricultural land or shrub/degraded forest, however, it is not only in unidirectional, but also in reverse and multiple directions dictated by poverty, landlessness and unemployment, natural disaster, policy, state of governance, and the natural factors like river activity, erosion and landslides. High incidence of landless people and marginal landholders and heavy dependency on agriculture mostly the subsistent traditional crop and growing livestock pressure, heavy dependency on fuel wood make the region vulnerable to deforestation, natural hazards and land degradation, which recycle the poverty and ecosystem degradation in vicious circle. In addition, the lack of good governance and policy instability has further encouraged for indiscriminate and illegal exploitation of forest resources in the region.

### 5.2 Landslide Hazard Map

The main aim of landslide hazard map is to identify places of landslide occurrence over a region on the basis of a set of causative factors. For this AHP method is used with eight causative factors with different weightings depending upon the site condition of the study area. The eight causative factors used for the analysis are precipitation, soil, slope, aspect, geology, stream density, land use and distance from the road. The weighting to the soil is highest (0.2668) and the least to the stream density (0.0374). The final hazard map shows that area covered by the very high hazard zone, high hazard zone, moderate hazard zone, low hazard zone and very low hazard zone are 3.86 %, 16.69 %, 20.50 %, 40.70 % and 18.24 % of the total area of the study area respectively. Also validation of the hazard map with previous landslides (120 Nos.) shows that very high, high, moderate, low and very low hazard zones cover 39.43, 34.50, 14.77, 10.68 and 0.63 percent of the landslide areas respectively. Above results and hazard map shows that most of the landslides falls near the agricultural areas and barren land areas of the study area. These indicate that human activities play an important role in the hazard areas. Hence it is recommended to control the causes of degradation of the Lal Bakaiya Watershed.

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# APPENDICES

## APPENDIX – I PHOTOGRAPHS

Photograph 1. A view of the Lal Bakaiya Watershed

Photograph 2. Settlment Area (Nijgadh) near Lal Bakaiya Watershed

Photograph 3. A view near Lal Bakaiya Bridge.

Photograph 4. Field visit of Lal Bakaiya study area.

Photograph 5. Landslide observed near Gundu in the watershed.

Photograph 6. Landslide observed near Shreepur Chhatiwan in the watershed.

Photograph 7. Landslide observed near Shikharpur in the watershed.

Photograph 8. Landslide observed near Shikharpur in the watershed.

# APPENDIX – II TABLES

## Pairwise Comparison Tables of Eight Causative Factors

| **Precipitation (mm)** | **1400-1600** | **1600-1800** | **1800-2000** | **2000-2103** |
|---|---|---|---|---|
| 1400-1600 | 1 | 1/3 | 1/4 | 1/5 |
| 1600-1800 | 3 | 1 | 1/2 | 1/2 |
| 1800-2000 | 4 | 2 | 1 | 1/2 |
| 2000-2103 | 5 | 2 | 2 | 1 |

| **Stream Density** | **Low** | **Medium** | **High** |
|---|---|---|---|
| Low | 1 | 1/3 | 1/5 |
| Medium | 3 | 1 | 1/3 |
| High | 5 | 3 | 1 |

| **Land use** | **Forest cover** | **Barren land** | **Agriculture** | **Water bodies** | **Sand** |
|---|---|---|---|---|---|
| Forest cover | 1 | 1/5 | 1/3 | 2 | 3 |
| Barren land | 5 | 1 | 3 | 5 | 7 |
| Agriculture | 3 | 1/3 | 1 | 3 | 4 |
| Water bodies | 1/2 | 1/5 | 1/3 | 1 | 2 |
| Sand | 1/3 | 1/7 | 1/4 | 1/2 | 1 |

| **Geology** | **Recent Deposit** | **Upper Siwalik** | **Middle Siwalik2** | **Middle Siwalik1** | **Lower Siwalik** |
|---|---|---|---|---|---|
| Recent Deposit | 1 | 1/5 | 1/4 | 1/4 | 1/3 |
| Upper Siwalik | 5 | 1 | 2 | 2 | 3 |
| Middle Siwalik2 | 4 | 1/2 | 1 | 1 | 2 |
| Middle Siwalik1 | 4 | 1/2 | 1 | 1 | 2 |
| Lower Siwalik | 3 | 1/3 | 1/2 | 1/2 | 1 |

| **Slope (deg.)** | **0-10** | **10-20** | **20-30** | **30-45** | **45-60** | **>60** |
|---|---|---|---|---|---|---|
| 0-10 | 1 | 1/3 | 1/5 | 1/4 | 1/2 | 2 |
| 10-20 | 3 | 1 | 1/2 | 1/2 | 1 | 4 |
| 20-30 | 5 | 2 | 1 | 1/2 | 2 | 5 |
| 30-45 | 4 | 2 | 2 | 1 | 3 | 7 |
| 45-60 | 2 | 1 | 1/2 | 1/3 | 1 | 3 |
| >60 | 1/2 | 1/4 | 1/5 | 1/7 | 1/3 | 1 |

| **Slope Aspect** | **Flat** | **North** | **East** | **West** | **South** |
|---|---|---|---|---|---|
| Flat | 1 | 1 | 1/3 | 1/3 | 1/9 |
| North | 1 | 1 | 1/3 | 1/3 | 1/7 |
| East | 3 | 3 | 1 | 1 | 1/7 |
| West | 3 | 3 | 1 | 1 | 1/5 |
| South | 9 | 7 | 7 | 5 | 1 |

| **Rock & Soil** | **Rock** | **Alluvium** | **Colluvium** | **Residual** |
|---|---|---|---|---|
| Rock | 1 | 3 | 2 | 2 |
| Alluvium | 1/3 | 1 | 1/2 | 1/3 |
| Colluvium | 1/2 | 2 | 1 | 2 |
| Residual | 1/2 | 3 | 1/2 | 1 |

| **Distance from Road** | **50m** | **200m** | **400m** | **> 400m** |
|---|---|---|---|---|
| 50m | 1 | 3 | 3 | 4 |
| 200m | 1/3 | 1 | 2 | 3 |
| 400m | 1/3 | 1/2 | 1 | 3 |
| > 400m | 1/4 | 1/3 | 1/3 | 1 |