Landslide Hazard Assessment and Distribution Mapping of Mountain Region of Nepal: A Case from Triveni Rural Municipality

Tej Raj Oli
Tribhuvan University, Institute of Forestry
Hari Prasad Pandey (pandeyhp123@gmail.com)
Ministry of Forests and Environment https://orcid.org/0000-0002-9448-7395
Shiv Kumar Manjan
Tribhuvan University, Institute of Forestry, Hetauda

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Abstract

An application of GIS for landslide hazard assessment using multivariate statistical analysis, mapping, and the evaluation of the hazard maps is crucial for disaster risk reduction. Landslides are the rapid downward movement of a mass of rock, earth or artificial fill to the slope. The study was conducted the Khara of Triveni Rural Municipality of Rukum West district of Karnali Province of where the pressure of rural road constructions seems relatively higher. Primary data were collected and used to construct the landslide distribution map and hazard assessments those were obtained from the direct ground-truthing and mapping using GIS. To determine the factors and classes influencing land sliding, the layers of topographic factors derived from a digital elevation model (DEM), geology, and land use/land covers were analyzed. The results are presented in landslide distribution mapping and hazard analyses. From the landslide inventory of more than 200 landslides that were occurred since 2015, the landslide distribution maps, landslide-size distribution maps and hazard level of sliding graphics were presented. Hazard map of the study area shows 4.34% area lies in the high hazard level, 53.64% on moderate hazard level and 42.02% in low hazard level in the study area. The results would give insights to the landslide distribution in the area that could support rural municipality for shaping disaster risk reduction policies and strategies. The result could be reference for landslide distribution mapping and hazard zonation.

1. Introduction

Landslides are common in mountainous terrains globally. Nepal is one of the mountainous, geologically young country that straddles the boundary between the Indian and Himalayan tectonic plates. The country is geologically young and still evolving. Landslides are very common occurrences in Nepal and are also one of the main natural hazards (Kayastha et al. 2013). Many hill slopes in the country are situated on or adjacent to unstable slopes and old landslides, which are reactivated from time to time (Pandey 2017; Aydin et al. 2018). One of the case is in Rolpa district, the adjacent district to the study area where series of landslides occurred in later decades (Pandey 2017). In Nepal, on an average 260 people lost their lives every year and about 300000 families have affected annually due to landslides (Terlien et al. 1995) and huge amount of soil including soil fertility is lost throughout the country (Pandey 2003). Moreover, during monsoon season, the main heading of the newspapers cover with the casualties and damage caused by landslides in various parts of country where more than 80% terrain is sloppy and fragile (Li et al. 2002). Landslide is a natural process and its occurrence is controlled by the geologic, geomorphologic, hydrologic and climatic and vegetation conditions (Aydin et al. 2018). Anthropogenic activities may also reactivate pre-existing landslide or may also initiate entirely new landslides (Regmi et al. 2014). Landslides claims infrastructure, property, human lives and livestock apart from natural resources (Regmi et al. 2014; Pandey 2017).

Hazard mapping is the process by which the probability of occurrence of any damaging phenomena can be predicted in any given area (Gnyawali et al. 2020). To conduct landslide hazard mapping, it is necessary to identify the elements at risk such as population, infrastructures, economic activities, environment that are exposed to the known hazard and that are likely to be adversely affected by the impact of the hazard (Dahal and Hasegawa 2008). A landslide hazard map indicates the possibility of a landslide occurring in a given area, potential instability, or as complex as a quantitative map incorporating probabilities based on variables such as rainfall thresholds, slope angle, soil type, and level of earthquake shaking (Kopackova and Sebesta 2007). In the hazard map, the area is divided into low, medium and high hazard zones. The low hazard zone is considered to be more stable whereas medium hazard zone may have a possibility of landslide disaster. Very dangerous and active landslide area represents the high hazard zone. The sign of instabilities occurs in the high hazard zone, which has a high possibility of failure in the future (Bhattarai and Pradhan 2013). So hazard mapping is an important tool in predicting the probability of occurrence of any damaging phenomena within any given area. Thus, if the prediction is significant, the damage to lives property and ecosystem can be minimized to large extent. This study mainly focuses on the making hazard zonation mapping such that preliminary measures can be applied to before large type of hazard occurs.

Landslide presents a threat to life and livelihood throughout the world, ranging from minor social disruption to huge economic catastrophe. Most work on landslide hazard assessment has been site-based and driven by development projects and engineering concerns (Crozier and Glade 2005). The study of landslides has drawn worldwide attention mainly due to increasing awareness of the socio-economic impact of landslides, as well as the increasing pressure of the urbanization on the mountain environment. The local geology and slope of the area also have a significant effect on landslides. To minimize the loss due to landslide, landslide-prone areas should be identified. Regional and local scale landslide hazard analysis and risk management are essential. Landslide hazard map (LHM) can be useful in estimating, managing and mitigating landslide hazards. A region with terrain condition similar to the region where a landslide has occurred is considered to be susceptible to landslides (Malik 2013). Hence, LHM is a fundamental tool for disaster management activities in fragile mountainous terrains. Despite the study is focus in relatively small area, this will provide a glimpse of site-specific landslide mapping for designing cost-effective method for disaster management in mountainous and growing economy county like Nepal. The result would be a reference for proper land-use management and effective and integrated watershed management in the verge of changing national and global context in disaster risk reduction.

2. Study Area

The study area lies in Triveni Rural Municipality of Rukum West district of Nepal and is situated at the south part of district and extends between 28.55˚ N 82.43˚ E. The Triveni Rural Municipality (TRM) is bordered by Rolpa and Salyan district at south; Salyan district, Chaurjahari Municipality and Saniveri Rural Municipality of Rukum at the west, Musikot Municipality of Rukum West at north and Rolpa district and Musikot Municipality at east (FRTC 2019). The study area lies inside the Triveni rural municipality and Khara contains three wards (3, 4, and 5) of TRM, the former Khara Village Development Committee of Rukum district. The study area covering the total area of about 33.52 km^2 where this study is focused in (Fig. 1).

The Rapti highway is passing from study area which connects other parts of Rukum West, Rukum East district and Jajarkot district with lower land Terai district like Dang, Nepalgunj. Southern face of Khara area is covering with forest areas where many small streams are originated and passing to Triveni stream. Khara stream is the main watershed area of this reason which includes more than 15 streams that passing from here and finally mix with Triveni stream and which ultimately meets with the Sano Bheri river of Rukum West district.

3. Materials And Methods

3.1. Research Design

The research is focused on the study on landslide distribution and their Hazard assessment of the Khara of TRM, Rukum West district, Nepal. The methodological framework is presented in Fig. 2.

The research is primarily based on field inventory. Google map (Google 2020a), Google Earth data (Google 2020b), geological maps, topographic maps (DOS 2020) and reports, articles were used as secondary source of information for the study. Data collection was done using a GPS instrument to locate the landslides, co-ordinates of landslides were recorded and the boundaries were surveyed for every landslides, causative factors were identified by direct visualization and in a participatory interaction with local people.

3.2 Data Collection

Primary data were collected through reconnaissance survey, questionnaire survey, focus group discussion and direct observation.

Reconnaissance survey

A reconnaissance survey was carried out to identify general features and existing situation of the study area and also for resources allocation. Rapport building with government officers, students, farmers, teachers, other concerned personnel and individuals was made and they were informed about the research to build the trust and to create a friendly environment for the study.

Questionnaire Survey

The questionnaires were pre-tested in some households during the preliminary survey and were finalized by incorporating the feedback from local people. A structured questionnaire survey was carried out to gather the required information needed to fulfil objectives. About 4% (120) households, proportionally from each ethnic group or caste were interviewed to gather the basic data using questionnaire following a simple random sampling method. The survey represents *Brahmin/ Chettri (B/C)*, Janajati*/Adhibasi and Dalits* and male-female respondents. Head of the family and elderly individuals were interviewed. Information on the total number of landslide occurred, the damage was done by it and the mitigation practice adopted by people themselves and other concerned authority all-round the year was also noted.

Focused Group Discussion

Discussions were held with poor, men and women and disadvantaged groups to discuss the issues related to study background and also to triangulate the information obtained from the household survey.

Direct Observation

Direct observation was made to analyze the actual field situation. A systematic sampling method was used with 4% sampling intensity to select household, representative to the study area. Total number of landslide occurred to the area was observed with the help of local people and supported by the local government of Triveni Rural Municipality. The landslides over five years that occurred in 2015, 2016, 2017, 2018, 2019 and 2020 were observed and geocodes were noted for their mapping. Total damage done by landslides in various field like in the agricultural field, in human settlement, human property, damage to domestic animals and injury or death to men, damage to the forest area and environment and damage to infrastructure were analyzed and noted. The precaution measures, landslide hazard risk reduction measures and mitigation practices adopted by local people themselves in cooperation with the local government were also analyzed. The role of local people, students, local government and other NGOs, INGOs and relevant authority in the landslide hazard risk reduction and its mitigation was also analyzed and noted. The secondary data were obtained from secondary sources.

3.2. Data Analysis

The data were coded, categorized and fed in the computer and analyzed using computer software packages MS Excel and GIS 10.2.2. The data collected during the field works were categorized into separate variables as required by the study objectives. Reconnaissance survey for the identification and location of different landslides within the study area was carried out and the topographical map was also referenced (Department of Survey, Nepal) (DOS 2020). The landslides were also marked in the satellite image in Google Earth and then exported as appropriate file types. The Google earth image with landslide inventory was verified during the field survey. The verified landslide inventory map is digitized and produced. Different factor maps such as elevation map, Slope map and Aspect map, Curvature, Geology and Land use, road network and stream map has been prepared and classified under appropriate classes

4. Results And Discussions

4.1. Landslide Inventory and Causative Factor Analysis

4.1.1. Landslide Inventory

In the study area, more than 200 landslides were recognized by field visit and using the Google earth imageries. Landslides are distributed heterogeneously throughout the area. The distributed landslides are separately shown in the map as a landslide in the road network area, landslide in protected parts (protected parts: parts covering of forest area, bush area and other vegetative parts) and other parts (other parts: parts covering of settlement area and agricultural areas) as shown in Fig. 3. The hazard level of each landslide is also calculated in the map. Landslides co-ordinate points and the size of them was taken from field visit and Google earth pro for triangulation. Finally, an Arc GIS is used for mapping. Landslides mapping is carried out according to their size as shown in Fig. 4. Total landslides that were occurred during the last five years have been classified into three classes according to their sizes:- Small-sized landslide: area < 15 m^2; Medium-sized landslide: area between 16–50 m^2; and Large-sized landslide: area > 50 m^2.

Landslide size also plays a great role in its hazard level. Simply, the study consider that the hazard level of landslide increases with an increase in its size and vice-versa. There will be more risk of disaster with an increase in its size. Similar finding observed in most of the area in Nepal (Bhattarai and Pradhan 2013; Pandey 2017; Gnyawali et al. 2020).

4.1.2. Landslide Causative Factor Analysis

The influencing factors of landslide hazard, for this particular study, as represented by the slope map, aspect map, geology map, relief map, and land use map are archived to integrate the hazard level. The precipitation is included in this study. Geology of the region has also a great deal of control over the process of mass wasting in the region, but because the study area is not large, the difference in geology does not look apparent (Fig. 5). The maximum landslides in Khara of Triveni rural municipality are due to the cause of intensive precipitation during monsoon. Steep slope land, unmanaged agricultural system and settlement make an increase in soil instability and thus, makes soil layer more susceptible to erosion during intensive precipitation. From the direct field observation over five years period and local people perception, about 29% of the landslides of Khara is because of heavy rainfall. In contrast, rampant developmental construction and other anthropogenic disturbances were the main cause of increasing intensity of landslides in Rolpa district of Nepal (Pandey 2017). Agriculture practicing without due considering conservation measures was the second influential causative factor of landslide in the study area (Fig. 5). Other factor that foster for landslide triggering is degree of slope (Fig. 6 and Fig. 7).

The natural slopes are the primary factor to dictate the stability of the terrain. The slope condition includes the slope angle and the slope aspect. In general, the stability of the slope is the interplay of slope angle with, material properties such as permeability, friction angle, and cohesion of the material. The slope is divided into the range of: <15˚, 15˚ -30˚, 30˚-45˚ and > 45˚. In the study area, most of the area is occupied by the high slope area followed by the sloping (medium slope). However, the was not the case in Rolpa (Pandey 2017), in Himalaya region (Gnyawali et al. 2020) and in Kathmandu valley (Bhattarai and Pradhan 2013) of Nepal .

The slope map shows that the total area under different slope category and total area occupied by various slope classes as shown in Fig. 7.

The landslide distribution map was superimposed on the slope map and the areas of a landslide in each slope categories were calculated. The percentages of a landslide in different slope categories were also estimated. High slope type (30˚-45°) has the dominant landslide occurrence (60%) which is the earthflow type and the cliff sloping type (> 45°) has 25% followed by the medium sloping type (15°-30°) having 11% and gentle slope have about 4% of landslides as presented in Fig. 8.

The windward and leeward faces as well as the northern and southern slope of a mountain differ in their climatic conditions. It is because of the difference in the amount of rainfall and sunshine received which in turn controls the diversity, density and the distribution of vegetation in the area. All these factors control the soil type, drainage type and a susceptibility to mass wasting over an area. An aspect map (Fig. 9) shows to which side a slope is directed. An aspect value of zero means that the slope is facing the north. The distribution of the different aspect categories in the area shows that the study area is found to be predominately facing North-West (Nw) (20%) and East (E) (19.5%) followed by the west (12%), North-East (11.5%), North (11%), South-East (11%), South (8%) and South-West (7%) (see Fig. 9). The landslide distribution map was superimposed on the aspect map and area of a landslide in each aspect was calculated.

Slope facing North-East is found to be the highest share of landslide occurrence, followed by north facing North-West. The percentage of landslides in different aspects level is shown in Fig. 9.

Deforestation has a great impact on landslides. Forest area is situated in the south part of the study area and has high slope land. The population is increasing rapidly and hence, it needs more natural resources for the livelihood improvement. Road construction, encroachment in forest area and grazing activity make soil unstable and results in increase in landslides. Deforestation activity is increasing at a high level. To reduce the landslides, deforestation, grazing, infrastructure construction activities should be reduced and plantation activity should be increased. There are many streams in the study area. Streams are flowing from the upper high slope hill to lower parts and thus, the water flowing speed is very high and more enough to cut lands situated near side of stream channel and landslide becomes resulted. The stream channel of Khara of TRM is shown in Fig. 10.

In the study area, road construction is increasing rapidly. The Rapti Highway is passing from Khara and roads are constructed and still constructing in the study area as shown in Fig. 11. Construction of roads in the hilly region causes more landslides. The roads in hilly regions become unstable until about 3–4 years because the land having week geology and thus, landslides occur in the rainy season. Road construction in the hilly region makes more damage to land and increase landslide hazard. Consistence findings are in many places for Nepal (Pandey 2003; Kopackova and Sebesta 2007; Regmi et al. 2014; Pandey 2017; Aydin et al. 2018). Previously, the development activities in the landslide controlling perspective were regulated by District Soil Conservation Offices (Pandey 2011a), employed almost every district of Nepal. But, with the synchronizing of these officers in federal Nepal rampant increase in the road construction leading to large scale and intensity of landslides in the country. This is a case in TRM in Khara region of Nepal.

Topographic relief is the variation in height of the land surface. Different reliefs have different climatic conditions. Another important aspect relating relief and landslide hazard is that construction activities like roads are preferentially built along with the same relief. It is therefore that the landslide hazards in an area are observed more or less on the same relief. The distribution of land in the study area in various relief groups is shown in Fig. 12.

The land use has also a significant role in the stability of soil slope. The land covered by forest regulates continuous water flow and an infiltration regularly whereas the cultivated land affects the soil slope stability due to saturation of covered soil. In the study area, the area covered by settlement area, bush, cultivation land, construction, forest and water body cover the area of 11%, 13%, 35%, 7%, 30% and 4% respectively. The area covered by the various land-use system is shown in Fig. 13 and Fig. 14.

From the distribution of different land use and land cover categories in the area, the largest share of the study area is covered by cultivation (35% i.e 11.73 sq.km) followed by the forest area (30% i.e 10.056 sq.km) while the least is covered by water body (4% i.e 1.34 sq km). The land cover in the study area is used in various ways. They are settlement, bush, cultivation, forest and waterbody. The landslide map is superimposed on the land use map and the area of a landslide in the different land-use group is calculated. The prominent occurrence of the landslide is found on cultivation area (32%) followed by construction site (26%). Land under the construction site is comparatively low as compared to the cultivation area. The cultivation area bears more landslides because of improper and unmanaged cultivation system and traditional crops and lack of knowledge in crops cultivation and crop cultivation system. There is less landslide occurrence in the settlement area (7%) followed by waterbody site (10%). In some areas, farmers used their traditioal knowledge to balance the topography and in somewhere student also involves to maintain their surrounding against sliding the lands (Pandey 2011b). In many areas, designated government organization would have responsibility to manage the landslide (Pandey 2011a). But, vanishing these activities from all side trigring landslides severly in many areas of the mountainous region like in Khara of Nepal (Pandey 2003) and unsustainable management of available resources leads to the conflict (Pandey 2011c).

An internal relief map shows the local relief that is the local difference in height within a unit area. It indicates the potential energy for erosion and a mass movement. Internal relief shows the major breaks in the slope of the study area. Four categories of internal relief in meter have been chosen for hazard evaluation as presented in Fig. 16.

Other causative factors of landslide include the earthquake, mining activity, volcanic eruption and so on. These factors are not considered here because there was no effect of these events during the last five years. The earthquake which was appeared in April 2015 has no significant effect in Rukum in term of landslide fostering. Beside earthquake, there was no appearance of volcanic eruption, there was no mining activity.

4.2 Hazard Map

The landslide hazard map with the serverity (degree of hazard) is presented in Fig. 17. In the study area, the landslides have been taken as the indicator of slope instability process. The slope instability is an outcome of a complex interaction among a large number of interrelated terrain factors (Saha et al. 2005a). To evaluate the contribution of each factor towards landslides, distribution data layer were compared to various thematic data layers separately. The resulting total weight directly indicates the importance of total weights is positive the factor is favourable for landslide and if it is negative, it is unfavourable. Based on the clustering of total weights, as well as the concentration of instabilities, the area under study was divided into the low, moderate and high hazard categories (Fig. 18).

The percentage of landslides at various hazards level can be concluded. Three hazard level of landslides is taken i.e high hazard level, medium hazard level and low hazard level. About 9% of landslides are under high hazard level, about 23% of landslides are under medium hazard level and the remaining 68% of landslides are under low hazard level as shown in Fig. 19.

The landslides that were occurred during the last 5 years have been classified into three categories as presented in Fig. 19. The level of hazard is classified according to its level of damage to the environment, human resources and the entire ecosystem (Fig. 20).

The hazard map generated has displayed a degree of reliability as an overwhelming number of active and old landslides scars occur on high and very hazard zone. The hazard assessment shows that almost 53.64% of the study area lies in the moderate hazard, 42.02% of the area lies in the low hazard zone and 4.34% of study area lies in high hazard zone of hazard map prepared after detail investigation of the factor that might be responsible causes for the onset of the landslide (Fig. 19 and Fig. 20). This agrees with the fact that weak geological formations of the slope of the lesser Himalayas are greatly susceptible to landslide hazards (Crozier and Glade 2005; Saha et al. 2005b; Pandey 2017; Gnyawali et al. 2020). Moreover, such weaker formation in our study area is disturbed by the construction of roads and buildings (Pandey 2017; Aydin et al. 2018). Construction of roads and construction of buildings or other heavy structure development in slopes land makes it vulnerable to a mass wasting phenomenon which in turn increase the driving force of slope area. From the field observation, it indicates that the majority of the landslides in the area where human interference is more as observed in adjacent district, Rolpa of Nepal (Pandey 2017).

Anthropogenic disturbances like construction of roads, building and other activity like agricultural activity is relatively high in moderate and lower slope area. As a result huge amount of soil is lost every year from the country (Pandey 2003). The other parameters like land use also showed the effects of human activity on the stability of the land. This requires all level of awareness and action for plantation including students (Pandey 2011b) and conservation measures (Pandey 2011a) for sustainable resource management including landslide hazard reduction (Pandey 2011c). From the land use map analysis, 35% of landslide observed in the cultivation area, has the highest percentage of landslide whereas, the construction site has an area covering of 7% and it has the second-highest percentage of the landslide. The study area is characterized by a steep slope, steeper channel course and fragile geology. These factors have contributed to frequent slope movement and intense erosion processes during the heavy rainfall in monsoon. This is obvious by widespread landslide scars, gully development in the study area. The topographic and geomorphic features reflect the marginality and susceptibility of the environment in terms of productivity and human habitat (Kayastha et al. 2013). The growing population pressure has been pressurizing the marginal ecosystem of the area. The

expansion of the cultivation land on the steep slope either encroaching the forest area or shrub or bushes is evident to this. The study only cover a small area (less than 50 km^2). However, findings will provide a glimpse of site-specific landslide mapping and landslide hazard analyses for designing cost-effective conservation measures in mountainous and growing economy country like Nepal. The result would be a reference for proper land-use management and effective and integrated watershed management in the verge of changing national and global context in disaster risk reduction.

5. Conclusion

The study focused mainly on the identification and the distribution mapping of landslides in Triveni Rural Municipality, Rukum West of Nepal. The results in the classification of the hazardous zone as well as the identification of the causes of the slope instability will facilitate to divert the preventive work to the area of high susceptibility. Hazard map of the study area shows 4.34% area lies in the high hazard level, 53.64% on moderate hazard level and 42.02% in low hazard level in the study area. The results would give insights to the landslide distribution in the area that could support rural municipality for shaping disaster risk reduction policies and strategies. The result also could be reference for landslide distribution mapping and hazard zonation. The results indicate as high hazard region on the hazard zonation map study area and prioritized work can be assigned. To minimize the implication of natural hazards by methods such as bio-engineering technique or immediate mechanical intrusion can be applied.

Declarations

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Data Availability:

The data will be available upon request with the corresponding author.

Author Contributions:

The first author conceive the idea, methodology designed, data collected, data analyzed, and original draft prepared. The second author involve in data editing, refining the sections, English checking, discussion writing. Third author critically reviewed the manuscript and guided overall process.

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Figures

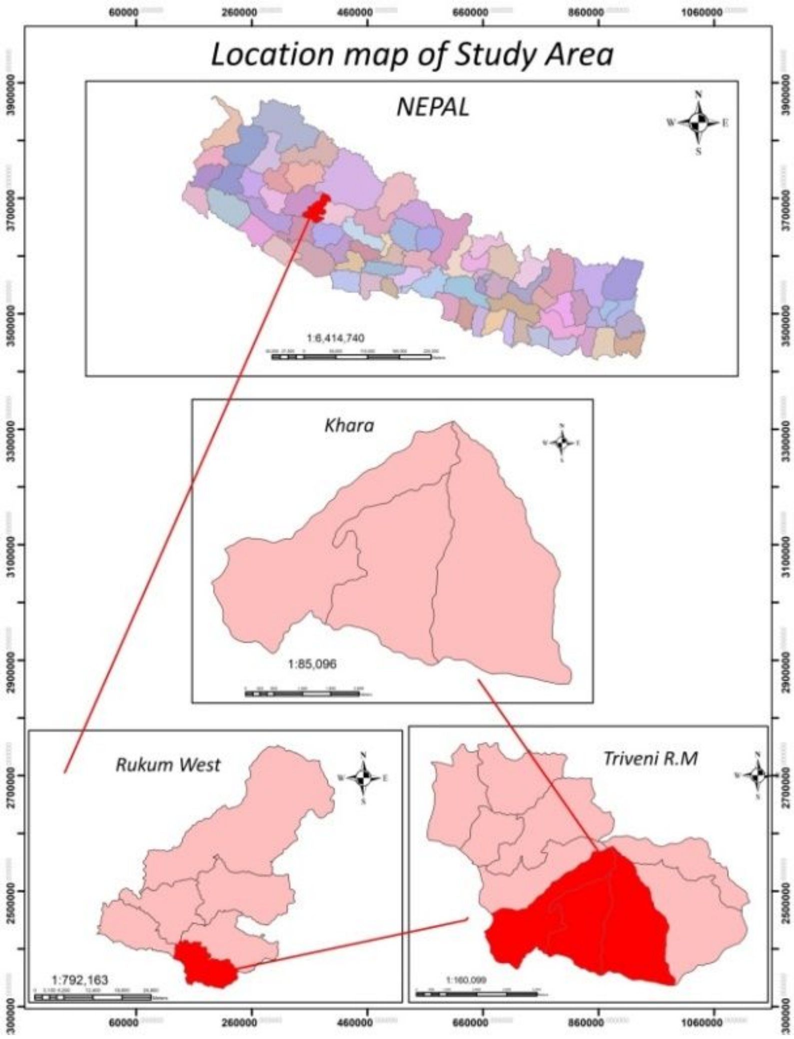

Figure 1

Map showing the study area (Base map source: dos.gov.np). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

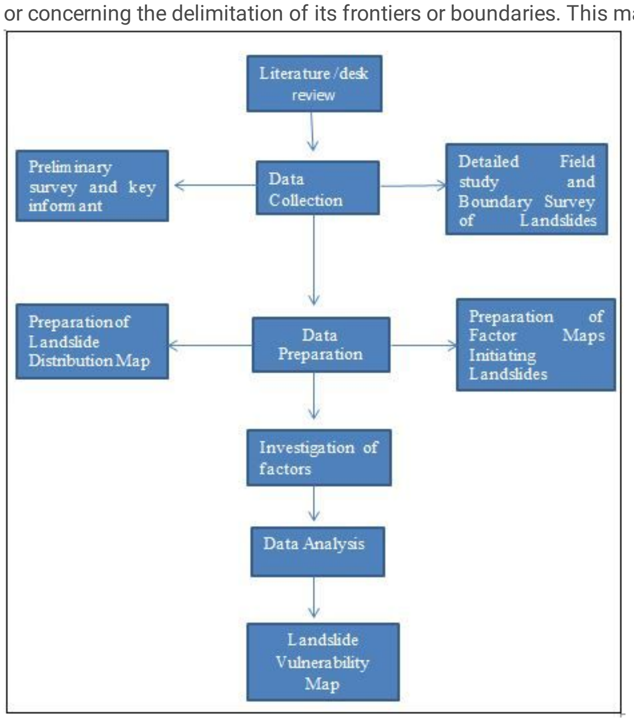

Figure 2

Methodological framework of the study

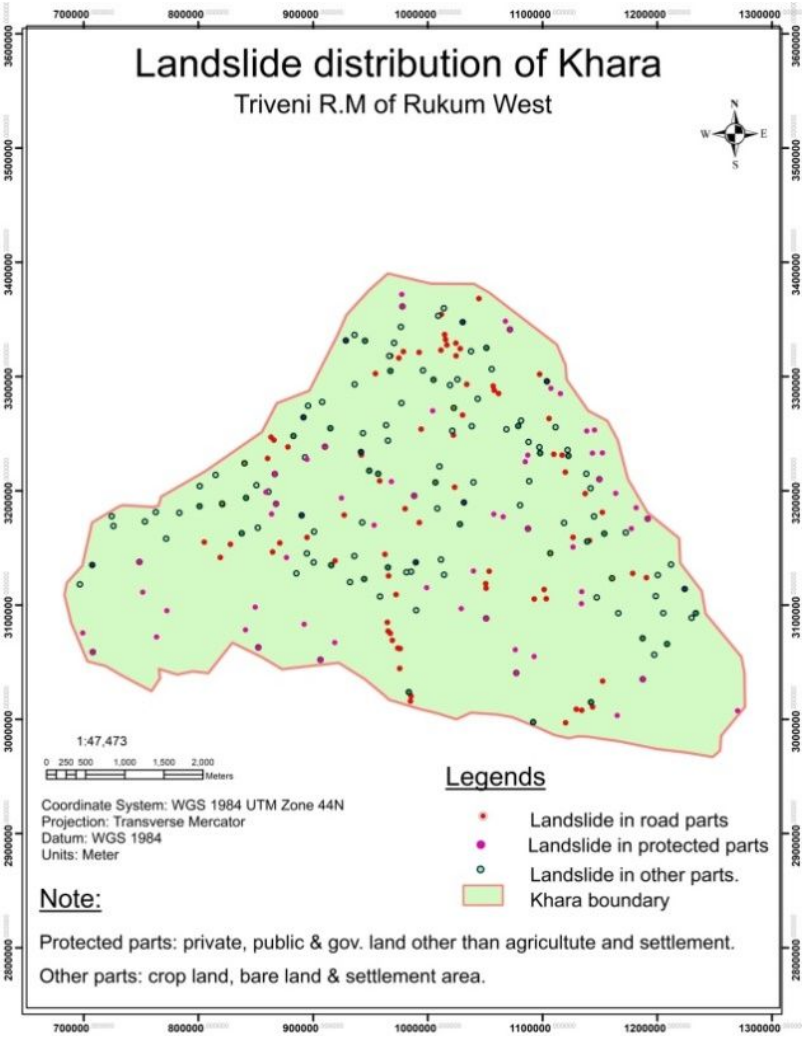

Figure 3

Landslide distribution mapping (Base map source: dos.gov.np)

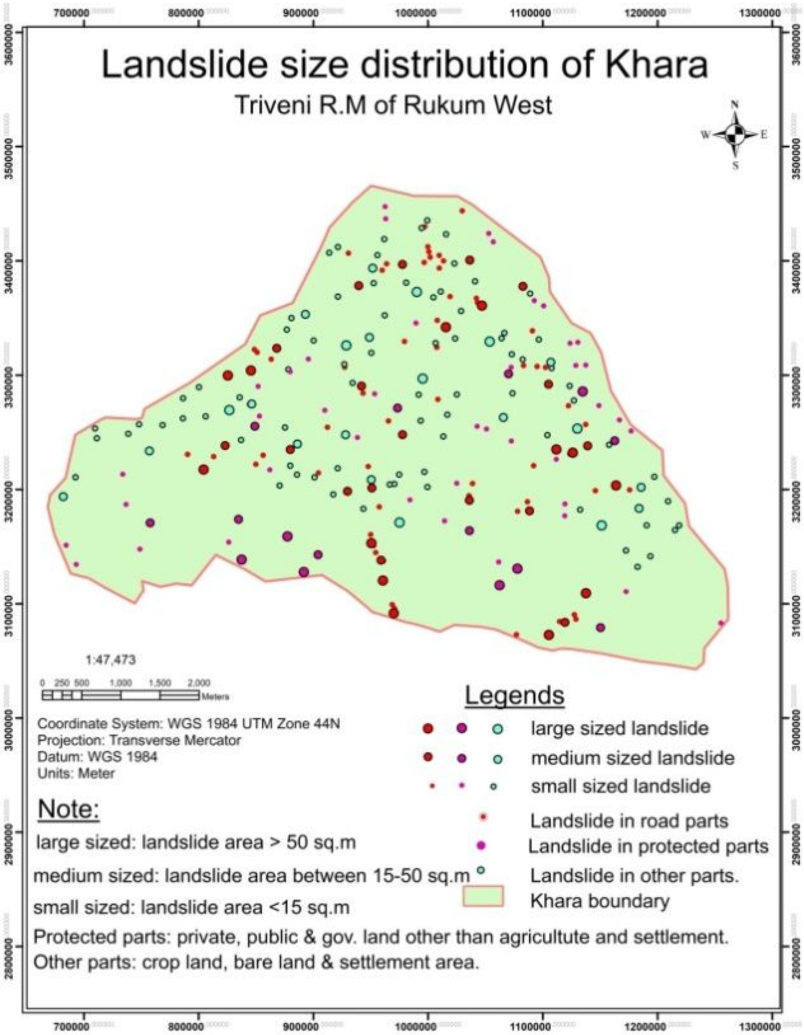

Figure 4

Landslide size distribution mapping (Base map source: dos.gov.np)

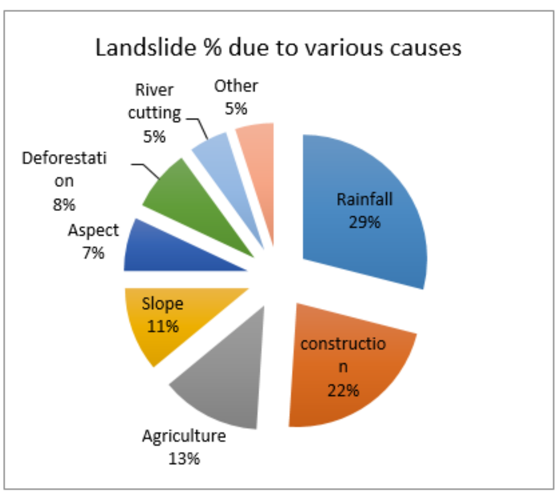

Figure 5

Landslide causative factors and their proportion in the study area

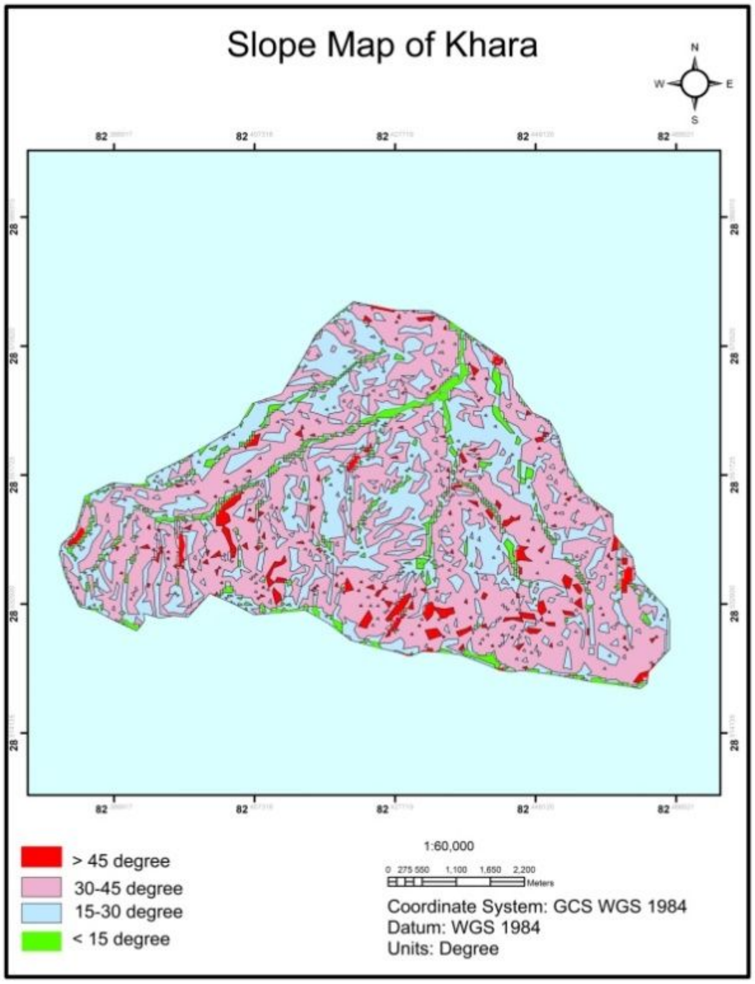

Figure 6

Different category of slopes in the study area (Base map source: dos.gov.np)

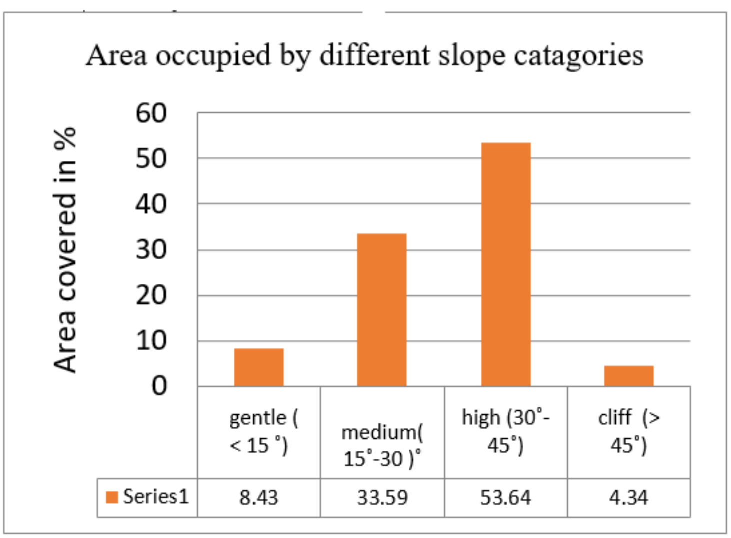

Figure 7

The area occupied by different slope level in study site

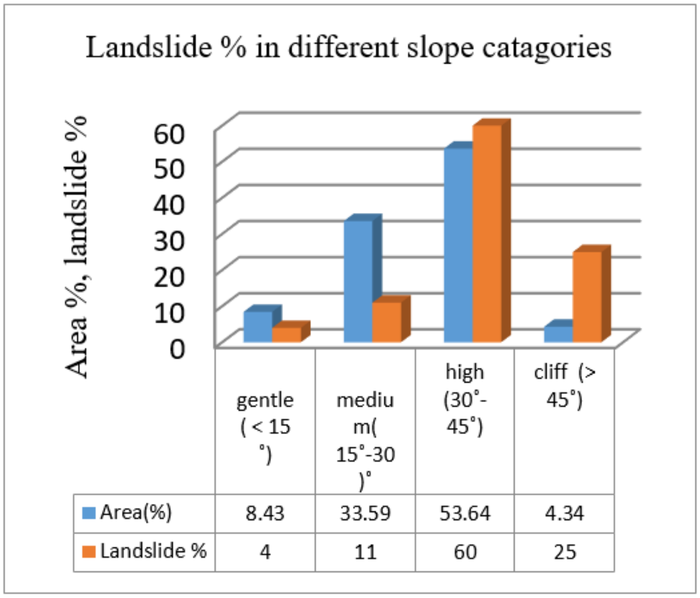

Figure 8

Landslides percentage due to different slope level in the study area

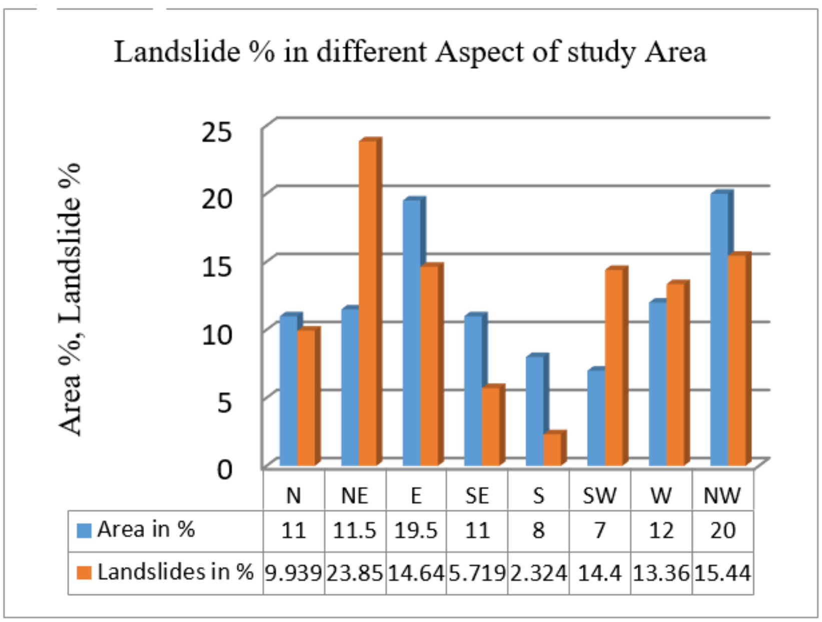

Figure 9

Land area proportion and Landslide percentage in different aspect in the study area

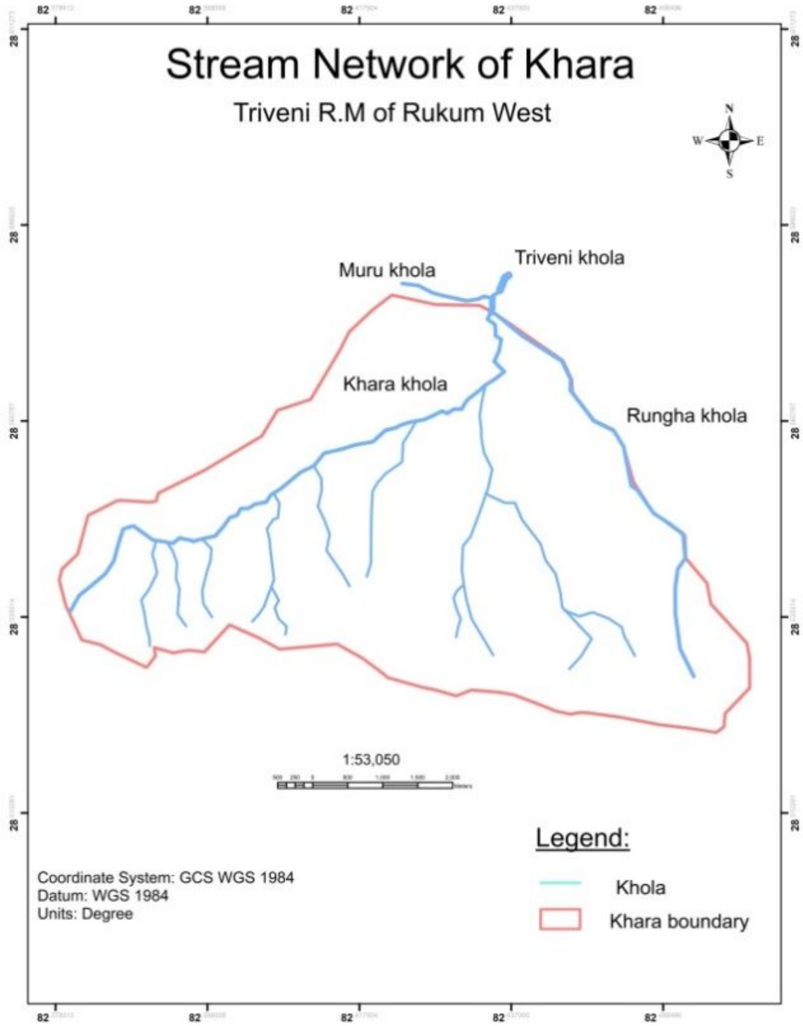

Figure 10

Major drainage system of the study area (Base map source: dos.gov.np)

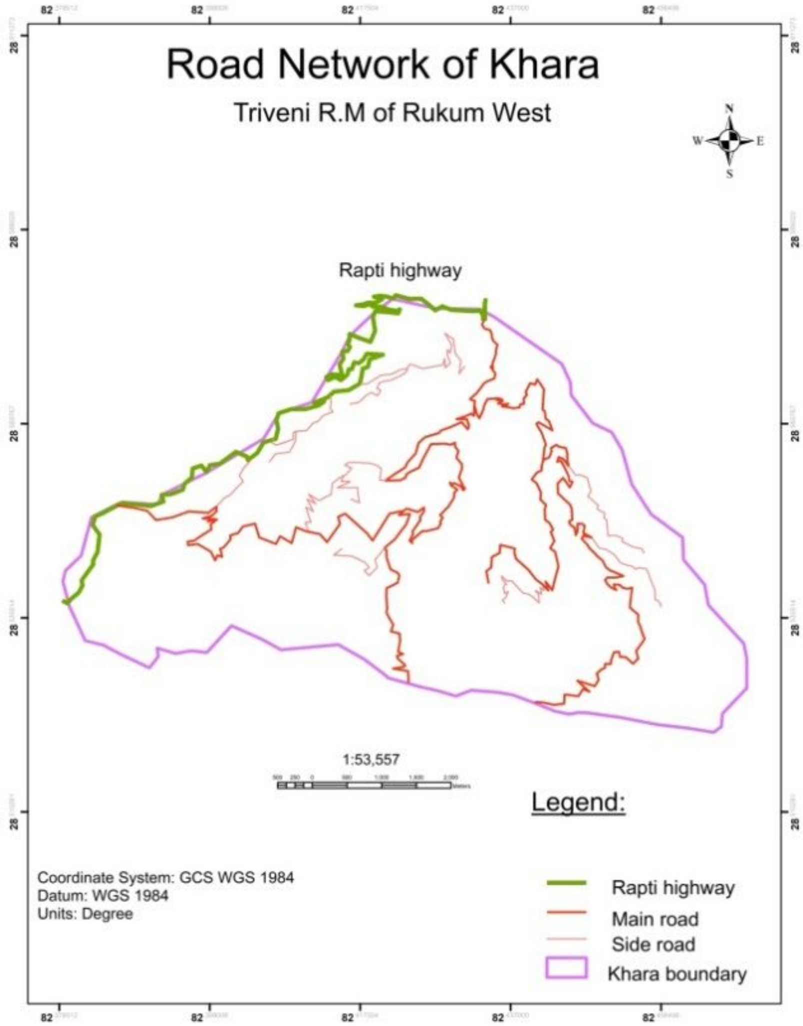

Figure 11

Road network of Khara region which is relatively dense as compared to population and the topographic fragility (Base map source: dos.gov.np)

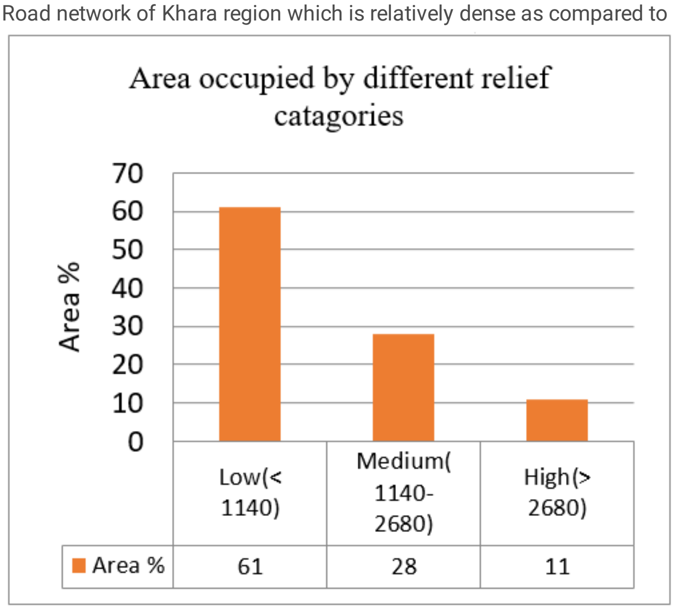

Figure 12

Landslide percentage with respect to topographic relief in the study area

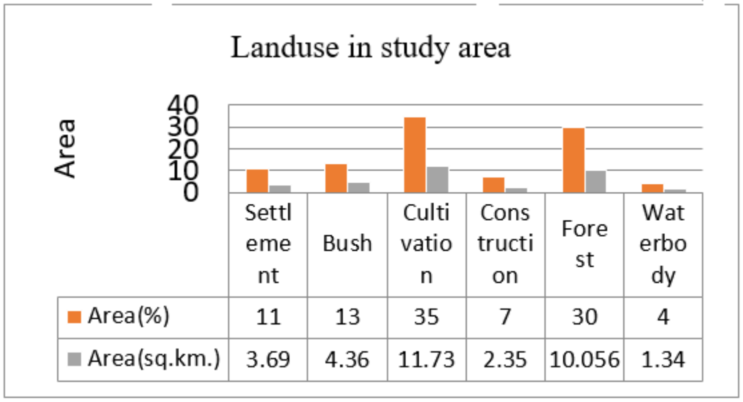

Figure 13

The area occupied by different land use type in the study area

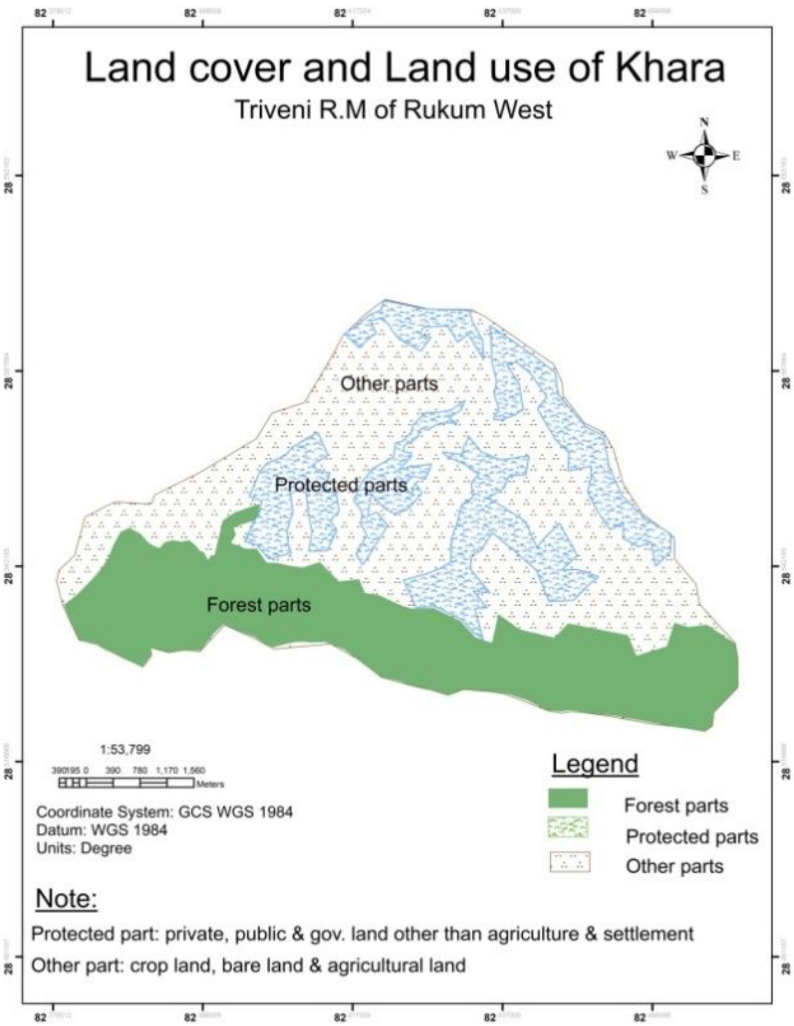

Figure 14

Land use and land cover map of Khara region of Triveni Rural Municipality (Base map source: dos.gov.np)

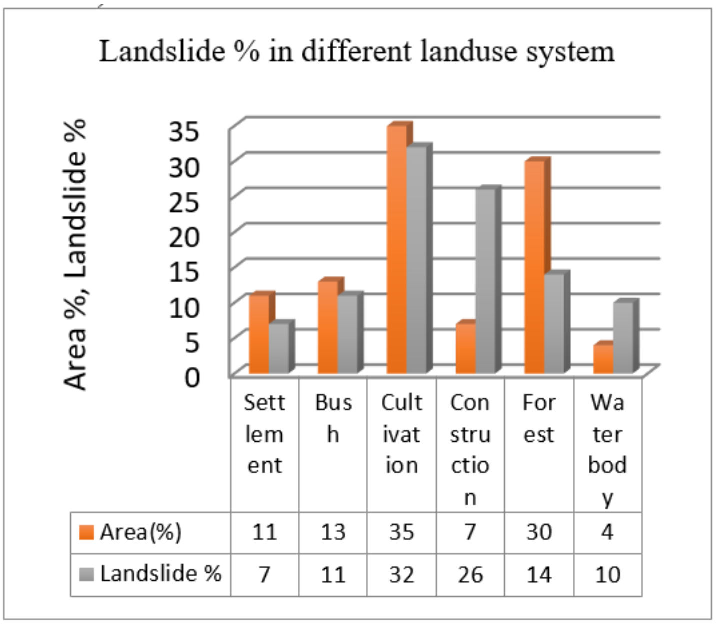

Figure 15

Landslide distribution proportion at the different land-use and land cover system in the study area

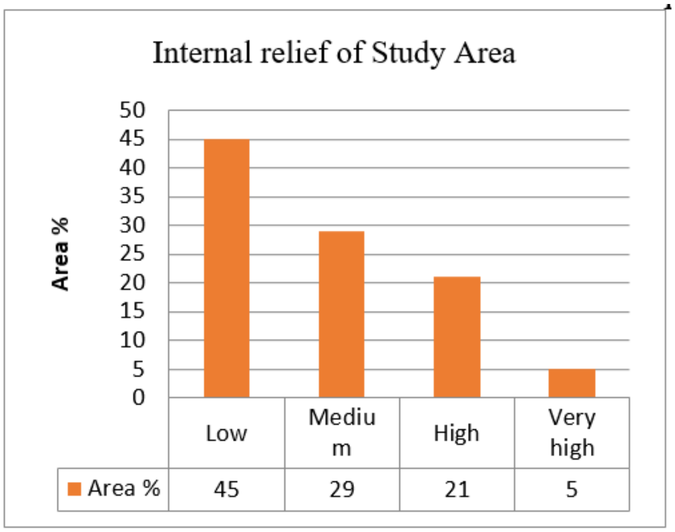

Figure 16

The area occupied by different internal relief in the study area

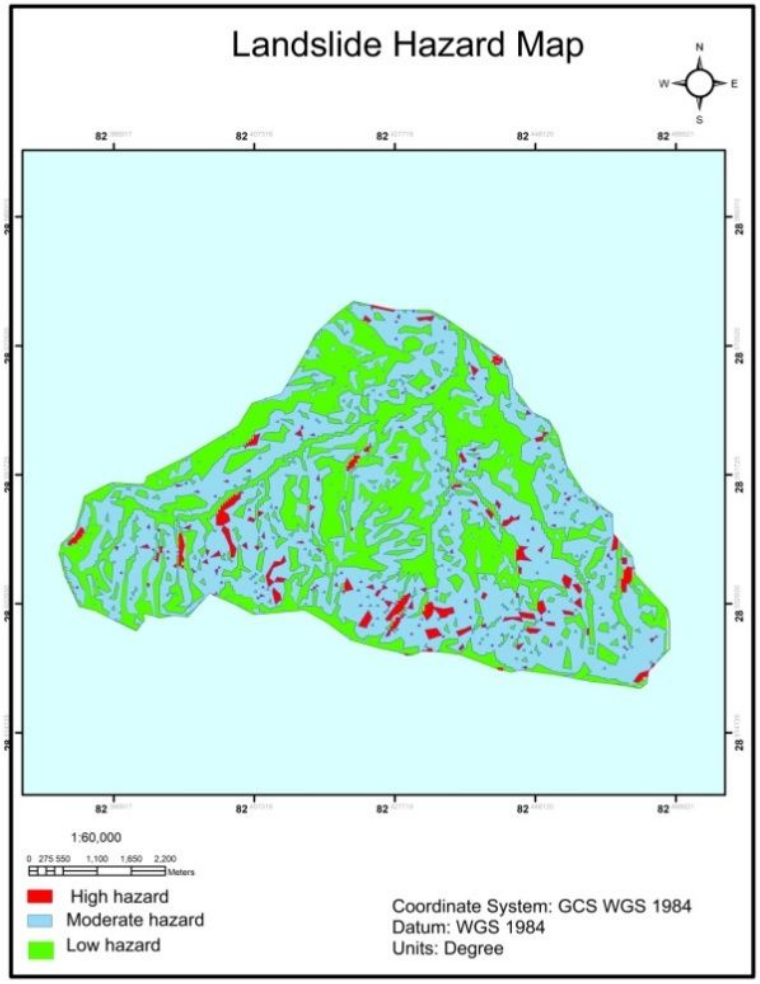

Figure 17

Landslide slope hazard map of study area (Base map source: dos.gov.np)

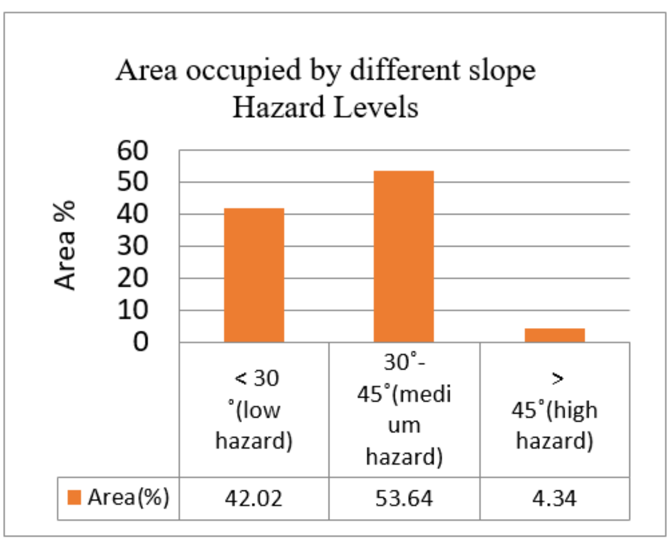

Figure 18

Proprotional area of different hazard level in different slope category of the study area

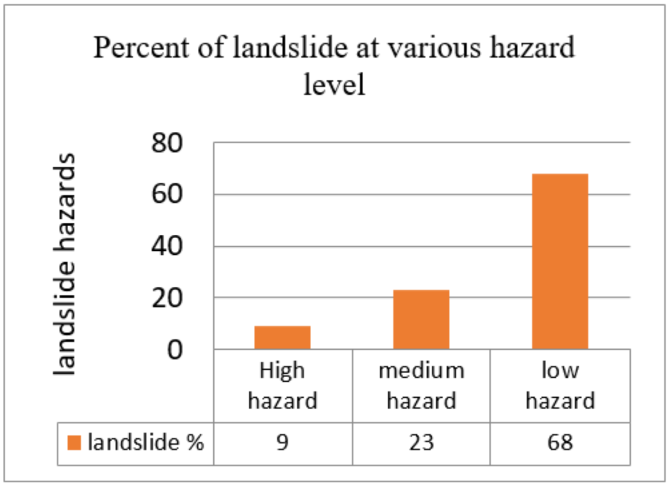

Figure 19

Landslide proportion at various hazard level in the study area

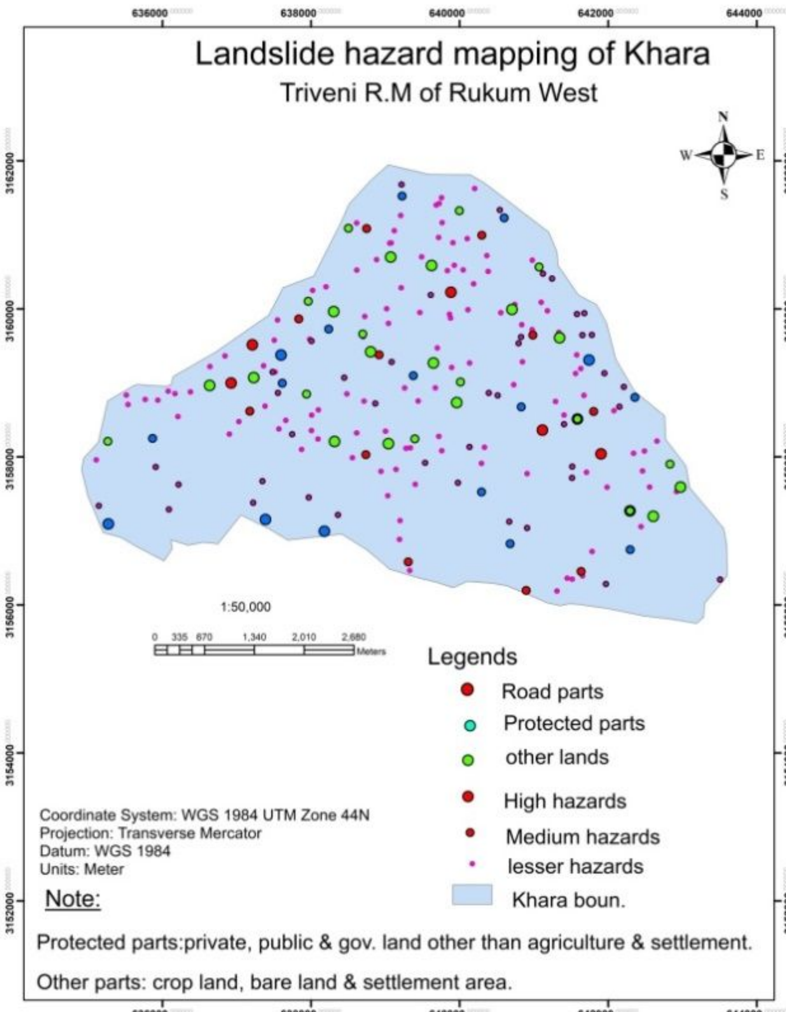

Figure 20

Landslide hazard level in the study area (Base map source: dos.gov.np)