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Landslide Hazard Assessment and Distribution Mapping: A Case from Triveni Rural Municipality, Nepal

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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 and it covers three wards (3, 4 & 5) of rural municipality covering the total area of about 33.52 square kilometres located in the Karnali province of Nepal which is under the pressure of high road construction activities. Data used to construct the landslide distribution map and hazard assessments were obtained from the direct field, and mapping using GIS. More data sources and verifications were made from the rural municipality, published articles and journals, topographical and geological maps, google images and aerial photographs and other digital sources. To determine the factors and classes influencing land sliding, the layers of topographic factors derived from a digital elevation model, geology, and land use/land covers were analyzed and the results were used for landslide distribution mapping and hazard analyses. From the landslide inventory of more than 200 landslides that were occurred during the last five years since 2015, the landslide distribution map, landslide-size distribution map 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.

INTRODUCTION

Nepal is a 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 (Dikshit, 1983). Many hill slopes in Nepal are situated on or adjacent to unstable slopes and old landslides, which are reactivated from time to time (Johs Howell, 2002). In Nepal, on an average 260 people lost their lives every year and about 30000 families have affected annually (UNDP, 2002).

Landslide is a natural process and its occurrence is controlled by the geologic, geomorphologic, hydrologic and climatic and vegetation conditions (Khanal Keshi Raj, 1998). Anthropogenic activities may also reactivate pre-existing landslide or may also initiate entirely new landslides. Landslides have been identified as a source of hazard which results in environmental, social or economic loss such as human lives, houses, vehicles, passengers, cultivated land, community forests and development infrastructures like an electric power station, road, and irrigation channel. Hazard is the probability of occurrence of a particularly damaging phenomenon whining a specified period and area because of a set of existing or predicted conditions (Deoja et al., 1991).

Hazard mapping is the process by which the probability of occurrence of any damaging phenomena can be predicted in any given area (Markus, 1985) To conduct landslide hazard mapping, it is necessary to identify the elements at risk such as population, infrastructures, economic activities, environment etc. that are exposed to the known hazard and that are likely to be adversely affected by the impact of the hazard (Pradhan, 2003).

A landslide hazard map indicates the possibility of a landslide occurring in a given area. A hazard map may be as simple as a map which uses the location of old landslides to indicates 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 (Varnes, 1984). 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 (Ghimire, 1993). 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.

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LITERATURE REVIEW

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 et al., 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 (van Westen, 1997). Hence, LHM is a fundamental tool for disaster management activities in fragile mountainous terrains. I think that LHM is a cost-effective method for disaster management in the context of the county like ours. It leads to proper land-use practices and effective watershed management which could result in mitigating climate-induced disaster.

STUDY AREA

District description

Formally Western Rukum district was part of Rukum district, which divided into two districts, they are: Western Rukum and Eastern Rukum after the state reconstruction of administrative division as of 20 September 2015. Rukum west district is located in Karnali province (6) of Nepal having coordinates of 28.63˚N 82.49˚E. The district is covering the total area of 1,213.49 square k.m (465.53 square miles) and a total population of this district as of 2011 Nepal census was 154,272 individuals. Located in the western hill, western Rukum is mostly composed of hilly terrain with some basin and valley. It is neighbored with five districts; they area: Eastern Rukum in east, Jajarkot district in the west, Dolpa in north and Salyan and Rolpa in the south. It has six local levels.

Study Area Description

The study area lies in Triveni rural municipality of Rukum West district of Nepal and is located at the south part of district and south part of local level too at coordinates of 28.55˚N 82.43˚E. Triveni rural municipality 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. The study area lies inside the Triveni rural municipality and Khara contains three wards of Triveni R.M i.e ward no. 3, 4 and 5 lies in this study area (old Khara VDC of Rukum district) and covering the total area of about 33.52 square kilometres.

Border of the study area:

- North: Simrutu bazar, Rungha Rukum.
- South: Rolpa district.
- East: Rungha, Dangchung boarder.
- West: Rapti high way.

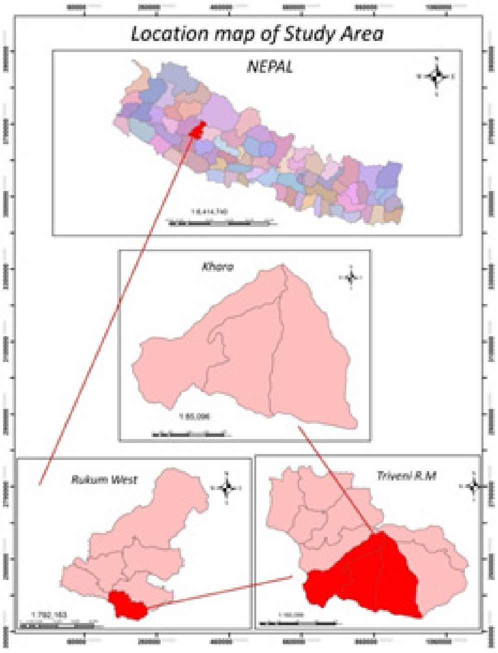

Figure 1: Location map of the study area.

The Rapti highway is passing from this study area which connects the other parts of Rukum and Jajarkot district with lower terai district like Dang, Nepalgunj etc. Many small to large streams are originated and passing from here. Southern face of Khara is covering by forest lands where many small streams are originated and passing from there to Triveni Khola, Khara Khola is the main watershed of this reason which includes more than 15 streams that passing from here and finally mix with Triveni Khola and which ultimately meets with the Sanoveri river of Rukum West.

MATERIALS AND METHODS

Research Design

The research is focused on the study on landslide distribution and their Hazard assessment of the Khara of Triveni R.M, Rukum West district, Nepal. The procedure of research is shown below in Figure 2.

The research is based upon the field data collection together with secondary data collection. Geological maps and reports, articles were also reviewed. Data collection was done using a GPS machine, taking samples and other materials. Co-ordinates of landslides were taken and their boundary survey was done, causative factors were also analyzed by direct visualization and interaction with local people. A field survey was focusing on data collection for landslide inventory and their distribution using inventory forms and mapping of various factors that are mostly responsible for triggering landslides.

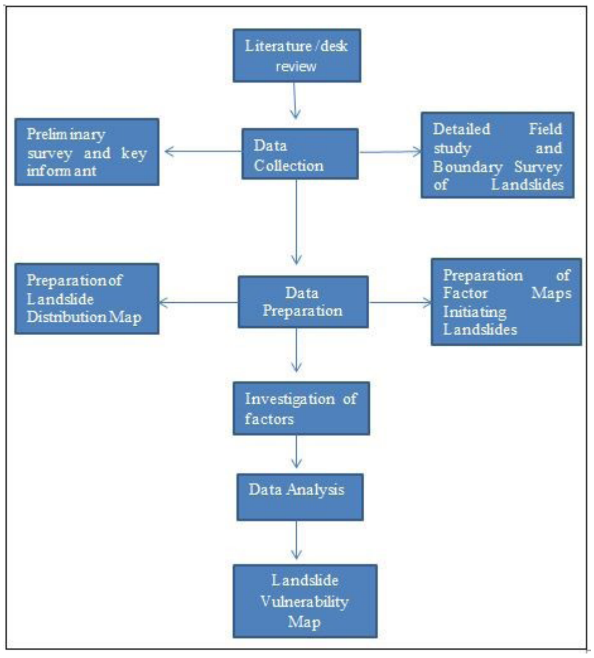

Figure 2: Research design.

Methodology

Both the primary and secondary data were collected during the research. Primary data were collected through a Focus group discussion and Self-observation & Figure Questionnaire survey while secondary data were collected through relevant sources.

Primary 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, CDG members, 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. 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 no. 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 no. of landslide occurred to the area was observed with the help of local people and supported by the local government of Triveni R.M of Rukum West. A landslide over five years i.e landslide that was occurred in 2016, 2017, 2018, 2019 and 2020 was observed and geocode was noted for their mapping. Total damage done by a landslide 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 local government was analyzed. The role of local people, students, local government and other NGOs, INGOs in the landslide hazard risk reduction and its mitigation was also analyzed and noted.

Secondary data collection

Secondary data were collected from the various sources and records like- reports published by related project, District Agriculture Development Office, municipality, Division Forest Office and District Soil Conservation Office. Maps, journals, publications, reports of other line agencies, published or unpublished and relevant literature were also consulted in the library and the relevant websites to make better understanding, interpretation and analysis of the research.

Method of 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. The data of the study were analyzed using both quantitative and qualitative methods. Quantitative data were analyzed using descriptive statistics such as percentage, mean, frequency distribution, maps and use of graphics whereas the qualitative data was presented by illustrations such as simple tables, charts, and graphs and in other pictorial forms.

RESULTS

Reconnaissance survey for the location of different landslides within the study area was carried out and landslides were located on the topographical map (Department of Survey, Nepal). The landslides were also marked in the satellite image in Google Earth and then exported as *.kml files. 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.

LANDSLIDE INVENTORY AND CAUSATIVE FACTOR ANALYSIS

Landslide inventory map

In the study area, more than 200 landslides were recognized by field visit and also using the Google earth imageries. Landslides are distributed heterogeneously over the area. The distributed landslides are separated 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 Figure 3.

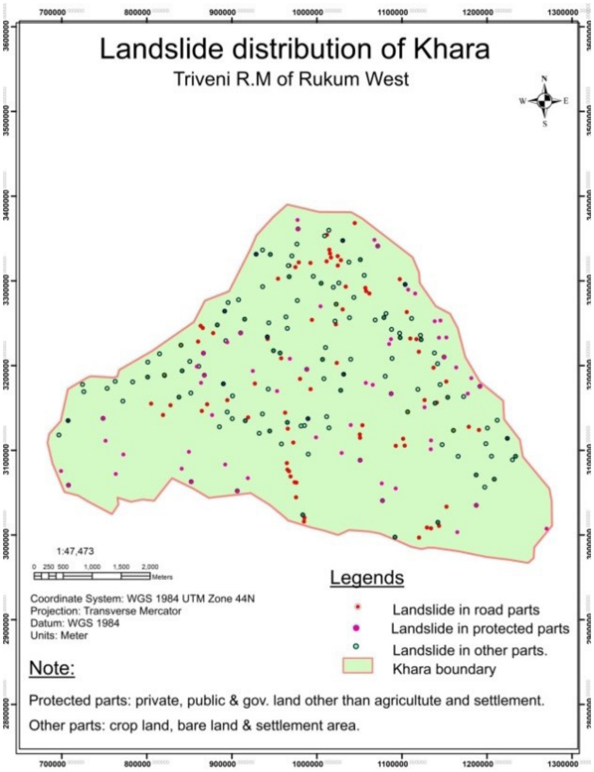

Figure 3: Landslide distribution mapping.

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 too. Finally, an Arc GIS 10.2.2 is used for inventory mapping. Landslides are also shown in the map according to their sizes. 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 square m.
- •Medium-sized landslide: area between 15-50 square m.
- •Large-sized landslide: area >50 square m.

Landslide size also plays a great role in its hazard mapping. Simply, we can consider that the hazard level of landslide increases with an increase in its size. There will be more risk of disaster with an increase in its size.

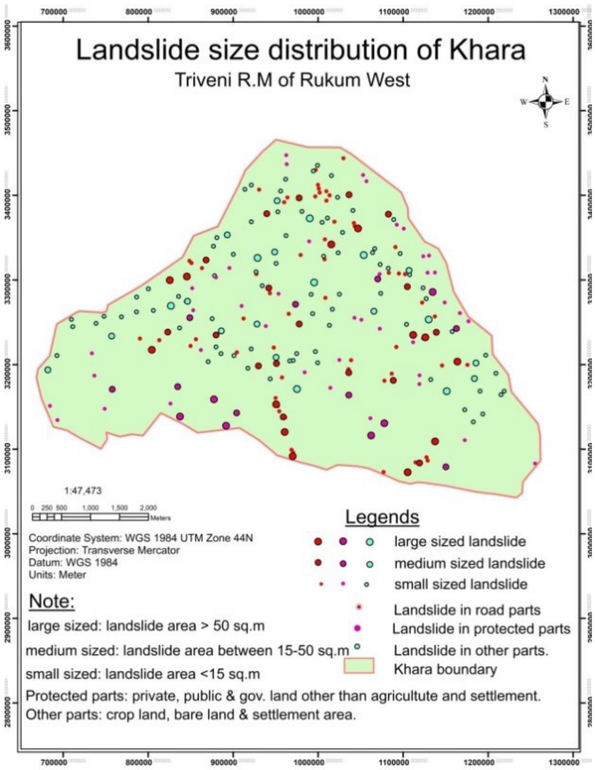

Figure 4: Landslide size distribution mapping.

Landslide causative factors 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 factor is also 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. The major components for landslide hazards in this study area are shown as above.

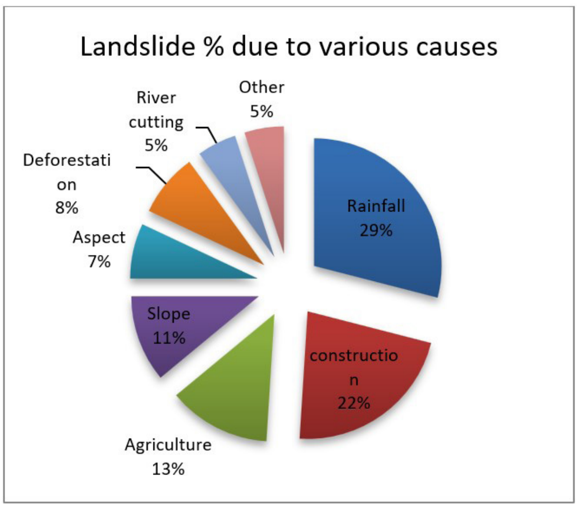

Figure 5: Landslide causative factors.

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 factor is also 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. The major components for landslide hazards in this study area are shown as above.

The main landslide causative factors of the study area are described as follows:

a) Rainfall:

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. About 29% of the landslides of Khara is because of heavy rainfall.

b) Agricultural system:

The traditional, unmanaged and without planning agricultural system is also the main cause of landslides. People in the study area are not highly educated and local government has not long term vision in the agricultural part yet. People make terrace for planting crops but the crops are traditional. Traditional agriculture system requires more efforts, more time but production becomes less in both qualitative as well as in a quantitative manner. Due to the lack of modern agricultural knowledge, modern agricultural techniques and crops suitable to a local place and soil type cannot be grown. Young people are in abroad for employment. Women, old men and children are unable for better education production. This unmanaged agricultural system is also enhanced by landslides hazards.

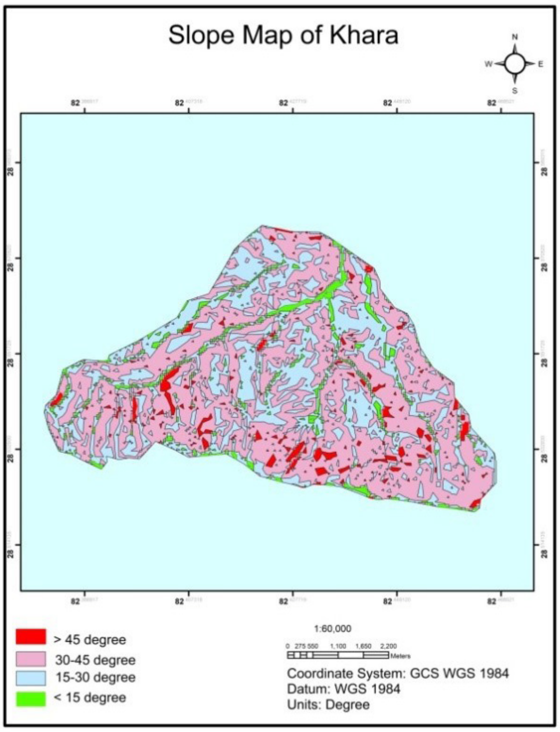

Figure 6: Slope map.

c) Slope:

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.

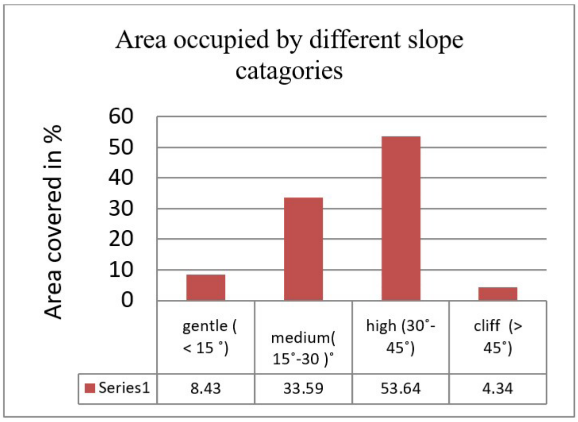

Figure 7: The area occupied by different slope level.

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. 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 only 11% and gentle slope have only 4% of landslides.

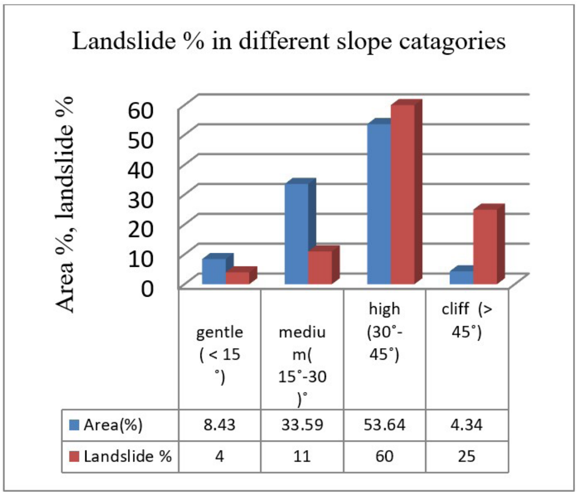

Figure 8: Landslide % due to different slope level.

d) Aspect:

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.

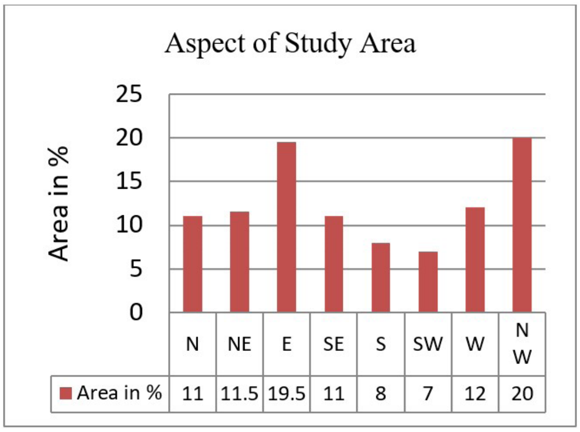

Figure 9: The area occupied by different aspect.

An aspect map 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%). 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 Figure 10.

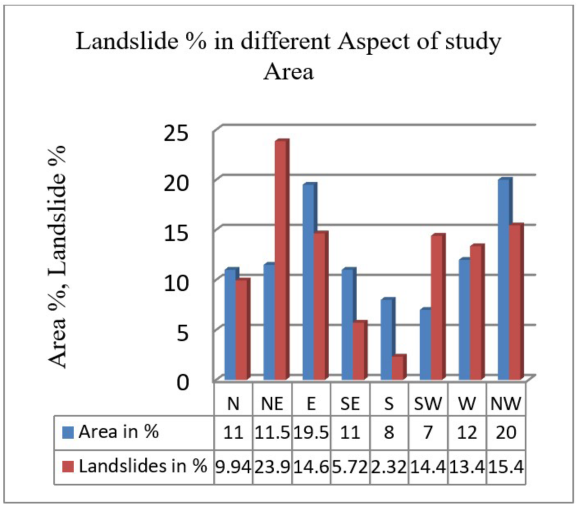

Figure 10: Landslide % due to different aspect level.

e) Deforestation:

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 in forest area make soil unstable and results in landslides. It is increasing at a high level. To reduce the landslides, deforestation, grazing, infrastructure construction activities should be reduced and plantation activity should be increased.

f) River cutting:

There are many streams in the study area. Streams are flowing from the upper 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 Triveni R.M is shown in Figure 11.

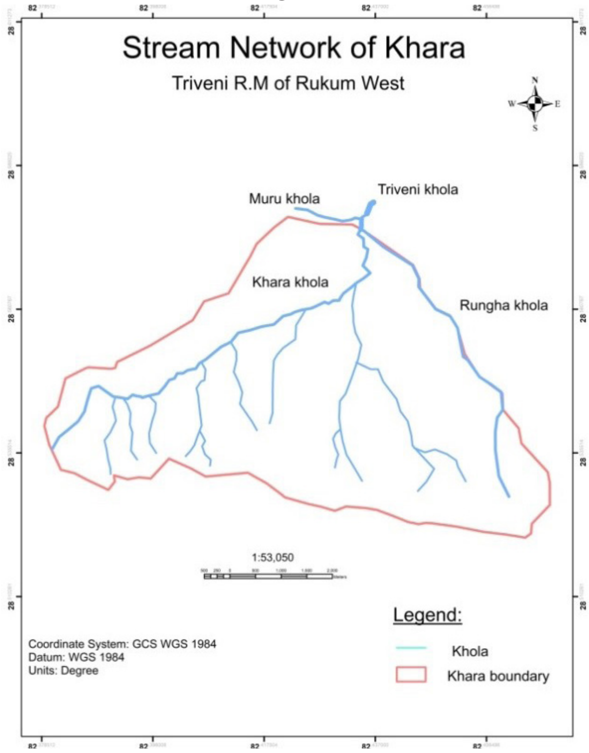

Figure 11: Stream network map of Khara.

g) Road construction:

In the study area, road construction is increasing rapidly. The Rapti High way is passing from Khara and road networks are constructed and still constructing in the study area as shown in Figure 12.

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 is a week and landslides occur in the rainy season. Road construction in the hilly region makes more damage to land and increase landslide hazard.

h) Relief:

The surface 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 Figure 13.

i) Landuse and land cover:

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 Figure 14 and Figure 15.

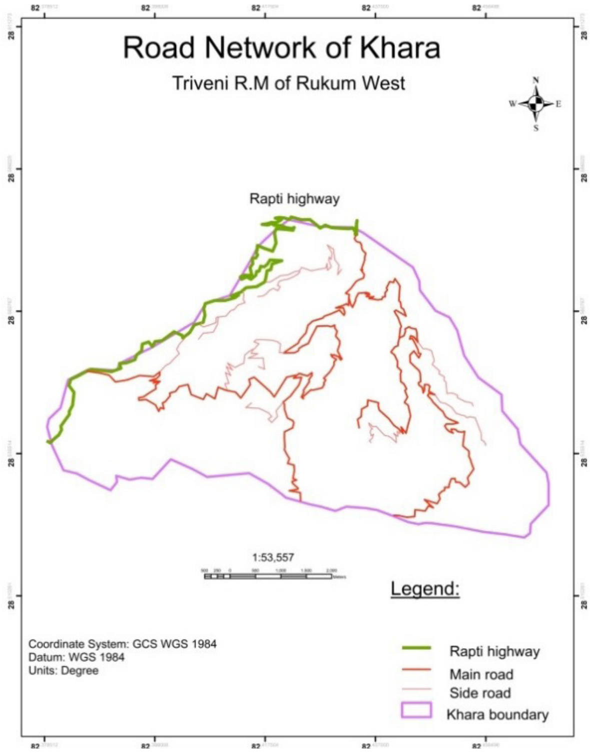

Figure 12: Road network of Khara.

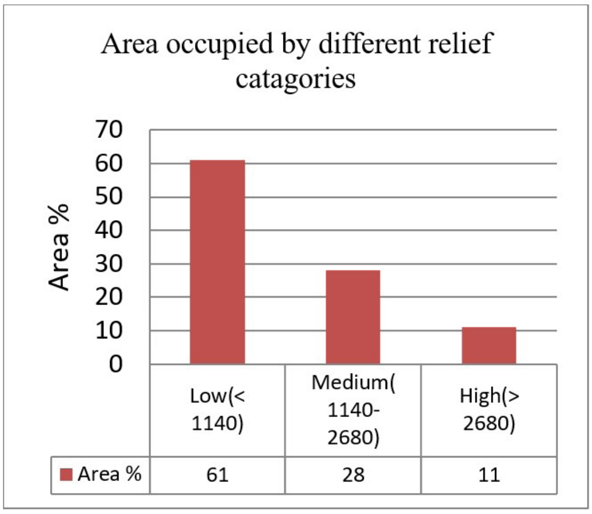

Figure 13: Landslide % in different relief level.

From the distribution of different land use 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%).

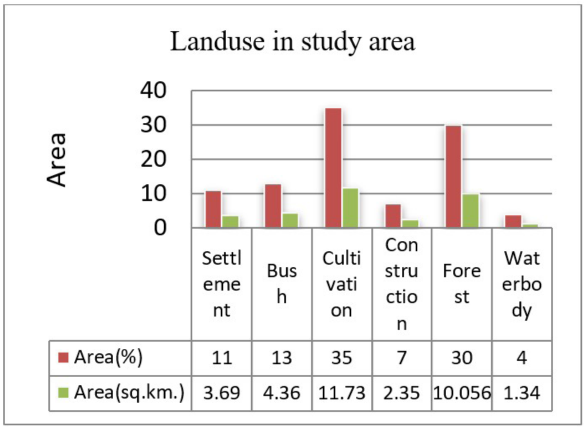

Figure 14: The area occupied by different land use. Land under the construction site is comparatively low as compared to the cultivation area. The cultivation area bears more landslides because of improper and unmanaged cultivation system and traditional crops and lack of knowledge in crops cultivation and crop cultivation system. There is less landslide occurrence in the settlement area (7%) followed by waterbody site (10%).

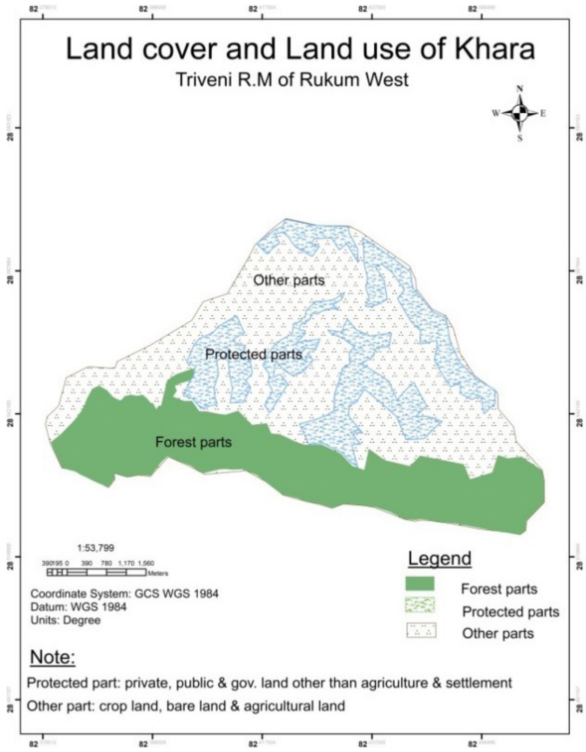

Figure 15: Land use map of Khara.

j) Internal relief:

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. They are:

- Low internal relief
- Medium internal relief
- High internal relief and,
- Very high internal relief.

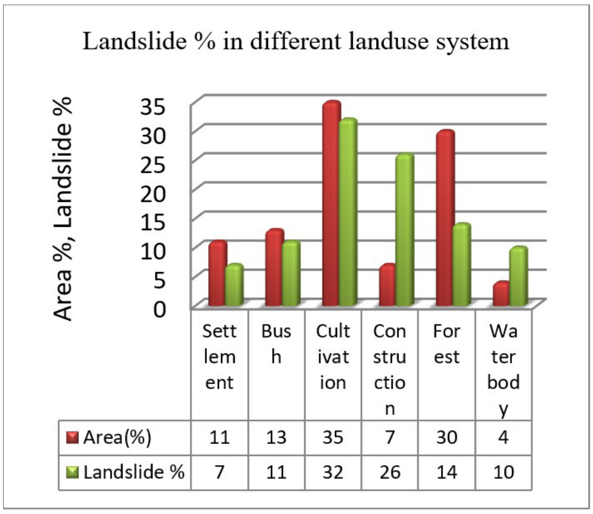

Figure 16: Landslide % at the different land-use system.

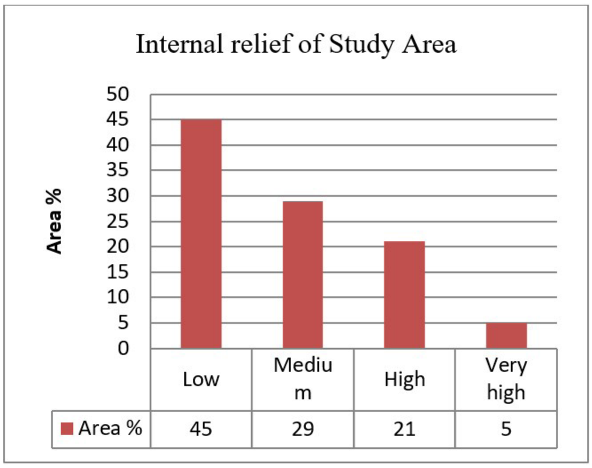

Figure 17: The area occupied by different internal relief.

k) Other factors:

Another component of landslide hazard mapping includes other construction activities other than roads, earthquake, mining activity and so on.

RESULT AND ANALYSIS

Hazard Map

In the study area, the landslides have been taken as the indicator of slope instability process. The Universe Transverse Mercator (UTM) projection is used. The slope instability is an outcome of a complex interaction among a large number of interrelated terrain factors (Yinka, 1988). Only some of the crucial terrain parameters: such as geology, internal relief, slope, aspect, land use pattern have been used for instability analysis. 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.

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 Figure 20.

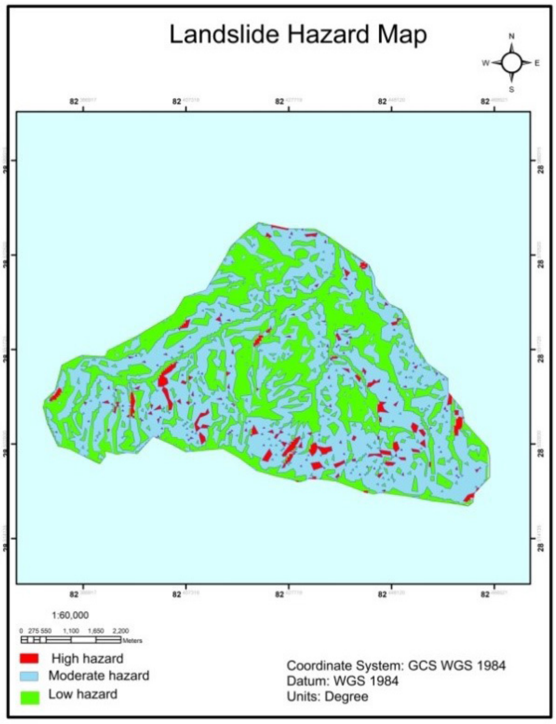

Figure 18: Landslide slope hazard map.

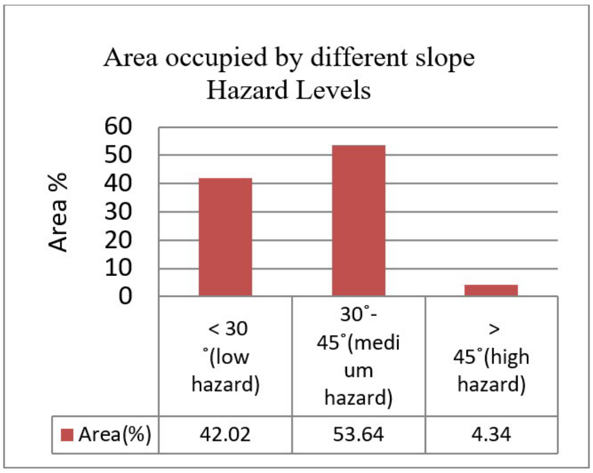

Figure 19: % of the area in different hazard level.

The landslides that were occurred during the last 5 years have been classified into three categories:

i. High hazard landslide
ii. Medium hazard landslide
iii. Less hazard landslide

The hazard level is determined by direct field observation, support of local people and local government. The level of hazard is classified according to its level of damage to the environment, human resources and the entire ecosystem.

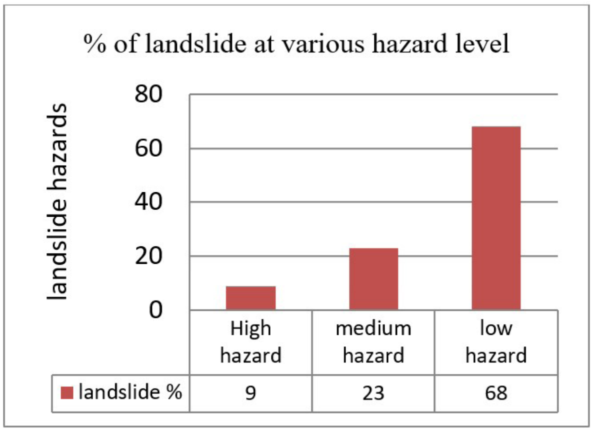

Figure 20: Landslide % at various hazard level.

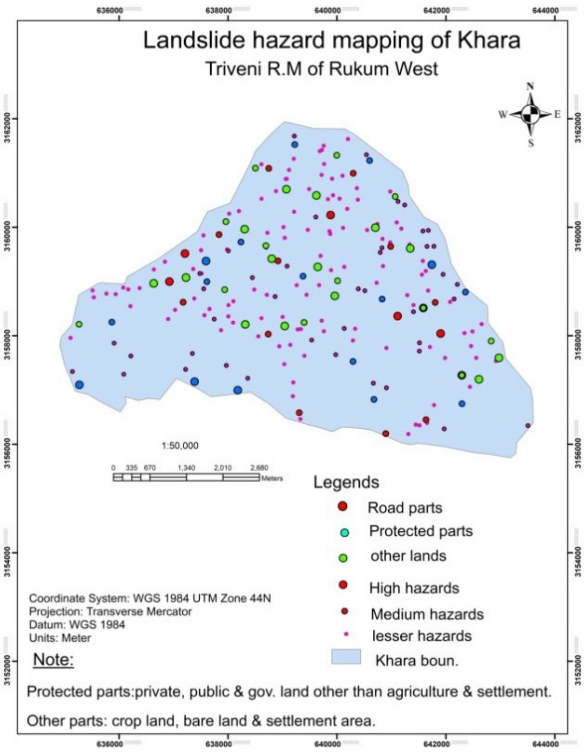

Figure 21: Landslide hazard level that was occurred.

DISCUSSION

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. This agrees with the fact that weak geological formations of the slope of the lesser Himalayas are greatly susceptible to landslide hazards. Moreover, such weaker formation in our study area is disturbed by the construction of roads and buildings. Construction of roads and construction of buildings or other heavy structure through slopes 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. Human activity i.e. construction of roads, building and other activity like agricultural activity is relatively high in moderate and lower slope area. And the other parameters like land use also showed the effects of human activity on the stability of the land. 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. 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.

Picture 1: Drunken tree due to steep slope.

The instability of slope is shown by drunken trees, trees displaced from their normal vertical alignment. This is due to the slow movement of the slope. Small subducted pits area found around the side of the hill indicate the instability of the hill.

CONCLUSION

The study focused mainly on the identification distribution mapping of landslides along with the classification of the hazardous zone as well as the identification of the causes of the slope instability that will help divert the preventive work to the area of high susceptibility indicated as high hazard region on the hazard zonation map. To minimize the implication of natural hazards by methods such as bio-engineering technique or immediate mechanical intrusion can be applied. This paper also demonstrates that the instability in the Khara area is due to the instability of the hill slope. Most of the area lies under the moderate hazard zone.

ABBREVIATIONS

CDG Community Development Group
DSCW Department of Soil Conservation &

	Watershed Management
FRM	Frequency Ratio Model
GIS	Geographical Information System
GPS	Global Positioning System
LHM	Landslide Hazard Map
LSM	Landslide Susceptibility Map
NRC	Nepal Research Council
UNDP	United Nation Development Program
VDC	Village Development Committee
WOE	Weight of Evidence

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