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Landslide Susceptibility Mapping of Siddhalekh Rural Municipality, Dhading, Nepal using GIS-based statistical and heuristic method

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Abstract
Siddhalekh Rural Municipality lies in the hilly region of Dhading district in the central region of Nepal. The complex geological, seismic and hydrological conditions in the region have resulted in numerous landslides in past years and have made the region vulnerable to landslides. The study follows a methodology for landslide susceptibility mapping using a GIS-based approach. The Landslide Susceptibility Mapping is done using Heuristic, Frequency Ratio, and Information Value methods using landslide inventory in Siddhalekh Rural Municipality. The data required for susceptibility mapping have been taken via topographic maps, field data, remote sensing, and other informative maps as inputs to the study. A total number of ten causative factors contributing to landslide occurrences in the region: Slope, Aspect, Plan Curvature, NDVI, Land use, Geology, Relative Relief, Rainfall, Distance to Road and Distance to Stream, have been taken in the study to generate thematic data layers. Using 33 training landslide inventories, a Landslide Susceptibility Map is generated which is classified into Low, Medium and High ranges of susceptibility using the Natural Break Method. The validation for predictability of each mapping method was tested using 15 testing data as landslide inventory, The validation of the model supported the Heuristic method as the most suitable method for the study with an AUC of 86.83 as goodness of fit and AUC of 86.76 in predictability in the validation. The susceptibility map is helpful in identifying susceptible areas and further making proper planning and emergency decisions, for providing support, formulating prevention, reduction and mitigation plans and facilitating implementation in reducing impacts and risk of future landslide hazards within Siddhalekh Rural Municipality.

Keywords
Landslide Susceptibility, Geographic Information System (GIS), Heuristic, Frequency Ratio, Landslide Vulnerability, Landslide Risk, Area Under Curve (AUC)

1. Introduction

Nepal is highly vulnerable to disasters such as earthquakes, water-induced disasters (flood and landslide), Glacial Lake Outburst Flood (GLOF), lightning, fire, drought, etc., due to the diverse topography of Nepal which causes high variation in the climatic conditions and rainfall characteristics along the country [1]. Landslide is a major hazard causing loss of lives, properties and ecosystem affecting the social, economic and environmental function of the affected region as well. The exogenous process, such as weathering, transportation and deposition activities of terrain by air and water and the endogenous process such as tectonic activities, compaction, metamorphism, sedimentation and rearrangement of grains in rocks, cause landslides over mainly the hilly and mountain regions of Nepal. Landslides are the most common natural hazards in Nepal, where about 83 percent of the area is in the mountainous and hilly regions.

When the driving force in the slope due to the causative factors exceeds the resisting force, a landslide occurs. These causative factors are both natural and human elements such as steep slopes, weak geology, intense rainfall, deforestation, and haphazard human development. Anthropogenic practices such as poor land use, expansion in slopes of sensitive land, and development activities such as road construction, construction of irrigation canals, and farming in slopes without any prior planning and protection measures invites and increases the danger of landslides. The occurrence of landslides in Nepal's Himalayas has been increasing in recent years. An average of 113 persons each year between 1971 and 2021 died as a result of landslides in Nepal, according to the spatial and temporal distribution of these disasters [2]. While some research has linked rising temperatures to an increase in heavy rainfall, other research has focused on anthropogenic effects on slope stability and the increased exposure of vulnerable individuals and property [3].

The objectives of the research is to identify the different level of landslide susceptibility in the study area using the Frequency Ratio method, Information Value method and Heuristic method. The natural factors affecting the susceptibility of landslides in the study area in conjunction with anthropogenic activities such as construction, road expansion, agriculture etc. have increased the occurrence of landslides every year. The susceptibility of the area compounded with the vulnerability of the population in the area, increases the risk. According to [4], at least 90 percent of landslide losses can be prevented or mitigated by conducting proper studies and acting along with it. Landslide susceptibility assessment is vital for well planning and preparedness for the risk posed by landslides.

2. Literature Review

Landslides based on mode of movement are: falls, topples, slides, spreads, and flows and mass materials which were: bedrock, debris, and earth [5]. A variety of factors including population increase, forest loss, urbanization, linear infrastructure development, and climate change, contribute to the impact and risk of landslides [6]. Landslide susceptibility is the probability of occurrence of slope failure within the given spatial and temporal conditions. It is an evaluation that provides a relative estimate of the spatial occurrences of landslides based on the topography conditions in the study area. [7]. Landslide susceptibility mapping involves identifying the geological and topographical characteristics of the area by the use of various tools and techniques, such as remote sensing, geographic information systems (GIS), and field surveys. GIS and Remote Sensing are widely used in landslide studies, which gives landslide susceptibility and landslide risk, and after further studies, mitigation measures for landslide risk are devised and implemented where necessary. A study to map and assess landslides in the Ramche-Jharlang area in Central Nepal used and generated maps of causative factors of landslides, which were elevation, slope, aspect, drainage, geology, soil, fault line, land cover, road, closeness to lineaments, and roadways and ranked into different classes [8]. The research emphasizes the importance of systematic landslide hazard mapping and mitigation measures to reduce loss from landslide disasters in the region and develop strategies to reduce the likelihood and severity of harm. Landslide susceptibility methods can be done by following the process of generating landslide inventories, then conducting heuristic approaches, deterministic methods, probabilistic methods, and statistical methods [9] [10]. These all techniques are further classified into qualitative, semi-quantitative, and quantitative approaches. The qualitative method is a relatively subjective approach that explains the level of landslide condition in a descriptive expression. Semi-quantitative methods combine qualitative and quantitative methods for grading and weighting of the causative factors of landslide factors. Quantitative approaches involve mathematical expression and relation and include statistical, deterministic, and probabilistic techniques. Even though landslides are unpredictable, there is a lot of potential for detection, evaluation, monitoring, and management of these events when GIS and Remote Sensing are applied in conjunction with other datasets. The technique of remote sensing enables topographic mapping and real-time landslide monitoring. GIS technology is an excellent tool for spatial analysis which analyzes the image data extracted via Remote Sensing, and perform operations as well as extract information for calculating susceptibility, risk and loss, as well as facilitate for further planning, prevention and mitigation measures[11] . Validation of Landslide Susceptibility Mapping To determine the level of accuracy of the model for various methodologies, the landslide susceptibility map needs model validation [12]. Validation can be carried out by contrasting the susceptibility map acquired with the known landslide location data. The validation techniques included in the study are success rate curve and prediction rate curve. The inventory datasets namely, training data sets and testing data sets are used to validate the goodness of fit in the model as well as prediction results [13].

Success rate curve or goodness of fit curve is plotted percentage area of landslides included in the study against percentage of map area and Prediction rate curve is obtained by plotting percentage area of landslides not included in the study against the percentage of map area [14].

Area under Curve (AUC) analysis is used for validation, wherein the range of 0-1, the higher the value of AUC, the higher the statistical accuracy of the model [15]. The minimum AUC needed for the study to be acceptable is 0.6, and an AUC value of 0.9 is considered an excellent model, 0.8-0.9 is a very good model, and 0.7-0.8 is a decent model classification.

3. Study Area

Siddhalekh Rural municipality is one of 13 municipalities of Dhading district of Bagmati province, Nepal. It has a total area of 106.09 sq.km.with a total population of 23,729. The municipality is divided into 7 wards. Siddhalekh Rural Municipality lies in hilly region of Dhading district, with its elevation ranging from 282m to 1481m.

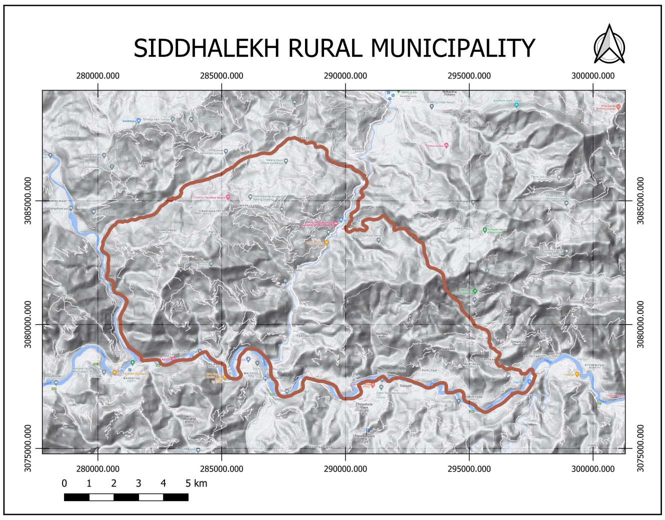

Figure 1: Study Area

A number of landslides has been recorded in various regions of Siddhalekh, resulting in numerous deaths as well as high loss of property and infrastructures. The landslides are prominent in monsoon season where road obstruction, loss of houses and lands are repeatedly seen each year. Among 7 wards of the Siddhalekh Rural Municipality, Landslide had the second biggest impact apart from Earthquake as the main hazard in all the wards except Ward no. 2. The impact seen by landslide included destruction of buildings, loss and injuries of people, and loss of cattles and agricultural land. Weak geological and geomorphological features are evident in the hill slopes. The area is formed from combination of metamorphic and sedimentary rocks, such as quartzite, limestone, dolomite, phyllite, slate, granite, schist and traces of carbonate. Considering rural areas, the failures of slopes and roads involve less damage to human lives and houses, however, there is high loss of agricultural land, loss of ecosystem and disruption of social and economic lifestyle. The frequency of landslides has increased annually due to road construction, anthropogenic social changes (such as excavations for building materials), the degree of urbanization, and the ongoing population growth.

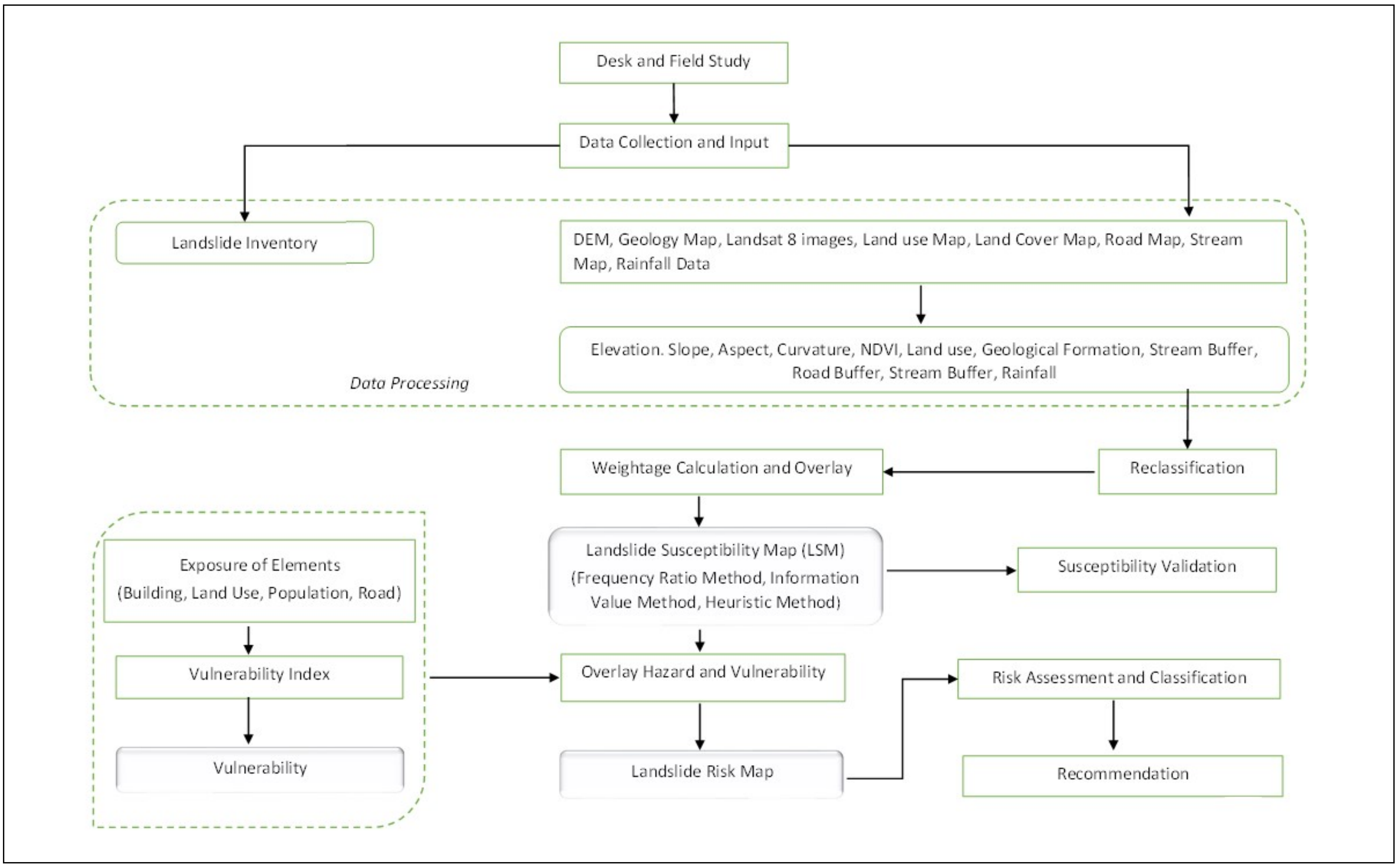

Figure 2: Methodology for Landslide Susceptibility Assessment

4. Methodology

4.1 Desk and Field Study

The desk research should be completed before the site investigation begins to gain as much information as possible. Through the field visit, the geology of the area, presence of new and old landslides and their probable causative factors can be ascertained. The results from the desk study can also be corelated during the field study. The causative factors can be well seen and studied and thus a proper planning of the work is well facilitated by the field visit.

4.2 Data Collection, Processing and Analysis

The data collected and prepared through desk study and field study are compiled and used in QGIS. The DEM (Digital Elevation Model) data of the study area as well as data for each causative factors need to be downloaded and compiled which must be used in QGIS for the assessment purpose. All thematic layers from GIS for the causative factors such as Slope, Aspect, Curvature, Altitude, Land use, Land Cover, Distance from streams, Distance from road networks, Soil Types, Geology etc. are obtained. All these parameters of the research together give landslide susceptibility map of study area by using probabilistic Frequency Ratio model on 10 m pixel resolution and the susceptibility map is reclassified and their validation is checked by suitable method.

4.3 Landslide Susceptibility Mapping Approach

Landslide Susceptibility Map (LSM) gives information to determine the frequency of landslides of a certain intensity. This frequency can be measured either as the number of landslides with specific characteristics that occur in a given period in a particular area, or as the probability of landslides occurring in a specific area above a defined threshold value. The latter method, which is based on probability and defined thresholds, is considered more effective for temporal prediction.

Frequency ratio method (FRM) The frequency ratio method is a bivariate statistical method used in landslide studies to find the correlation between the causative factors in the study area with the landslide inventories. The frequency ratio (FR) for each class of causative factor, is generated using the equation [16].

$$FR = (N_{\text{pix}}(1)/N_{\text{pix}}(2))/(N_{\text{pix}}(3)/N_{\text{pix}}(4)) \qquad (1)$$

Where: Npix(1) is the landslide pixel count in the class, Npix(2) ispixel count of the class in the study area, Npix(3) is total landslide pixel count, Npix(4) is total pixel count in the study area. The obtained value of Frequency Ratio is assigned as the weightage to the subclasses of each factor to obtain the reclassified map for each factor, all of which are combined using raster calculator in GIS to generate the Landslide Susceptibility Map. The obtained LSM need to be reclassified, which in this research, via natural break method, has been classified into three classes; low, medium and high.

Information Value method (IVM) The information value method is a bivariate statistical method for calculating the relationship between landslides and classes of causative factors for landslides, developed by Yin and Yan in 1988 with minor modification by Van Westen in 1993. Information value for each factor class can be calculated by:

$$IV = log(N_{\text{pix}}(S_i) * N_{\text{pix}}(N_i) / \sum N_{\text{pix}}(S_i) * \sum N_{\text{pix}}(N_i)) \quad (2)$$

Where, Npix(Si) is the landslide pixel count in the class; Npix(Ni) is the total pixel count in the class; Σ Npix(Si) is the landslide pixel count in the study area; Σ Npix (Ni) is the total pixel count in the study area [17]. If Information value is greater than 0.1, the factor classes will have higher probability of occurrence of landslides whereas the negative value indicates no significant contribution of the factor to occurrence of landslides [18].

Heuristic method Heuristic method is a qualitative weighted method, with a concept to assign weights to the factor maps as well as its subclasses, which are important variables in mapping. Initially, a landslide inventory map is generated and overlaid with causative factor map for landslide hazard mapping, where the weightage value for each factor is defined by the judgement of fiel-experienced specialist. This method is a qualitative weighted method [19]. The basic idea in Heuristic method is to assign weights to the maps which are the causative factors used in the study and then combine the factor maps giving weightage to each factor to produce a final map which is then classified into multiple classes as per the requirement of the study.

4.4 Validation of Landslide Susceptibility Map

The Landslide inventory sets of training data and testing data as well as the known landslide locations is used to validate the Landslide Susceptibility Maps. The testing data is the landslide inventory data which includes 70 percent of landslide inventory used in the study to generate the maps and training data includes 30 percent of landslide inventory data which is not used in the study. ROC is the “Receiver Operating Characteristics” curve between Sensitivity in Y-axis and 1-Specificity in X-axis. AUC through training data, evaluates goodness of fit of the model and through testing data, the predictability of the model. In the validation process, landslide Susceptibility Index (LSI) values of all cells are sorted in descending orders, the values of LSI are divided into 100 classes by natural break method and AUC is calculated by drawing cumulative percentage of landslide occurrence in the classes versus LSI curves.

5. Results and Discussions

5.1 Landslide Inventory Map

The landslide inventory in this study is prepared using Google Earth Pro. A total number of 48 small and large landslides are considered in this study, where 33 no. of landslides were used for training the model and 15 of them were used for testing the model.

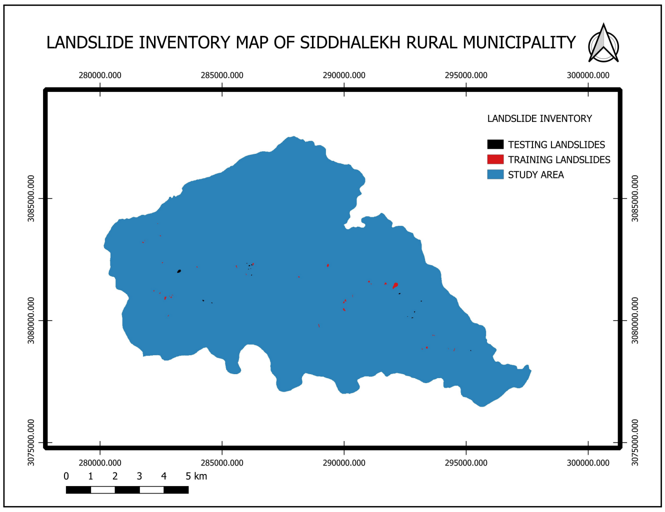

Figure 3: Landslide Inventory

5.2 Causative Factors Map

Maps

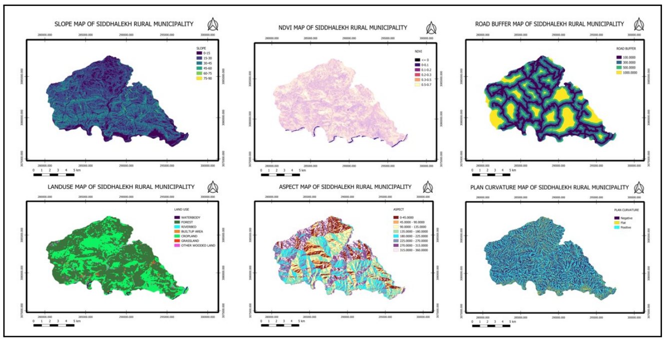

Figure 4: Causative Factors Map

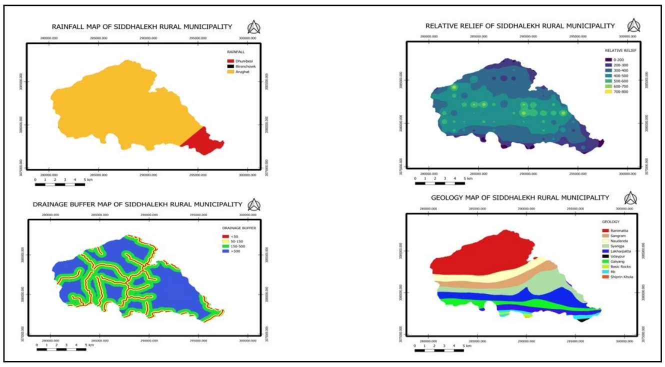

Figure 5: Causative Factors Map

Slope is the steepness or the degree of incline of a surface. The probability of occurrence of the landslide is more on the steep slope. The slope of the map of the study area is prepared from DEM data. It is classified into six classes; 0- 15°, 15°-30°, 30°-45°, 45°-60°, 60°-75° and 60°-75°.

Aspect is the orientation of slope, measured anti-clockwise in degrees from 0 to 360. Aspect is a features which determines exposure to sunlight, wind flow as well as preciptation. thus affecting soil and vegetative properties in the slope. The aspect map for the study area is derived from DEM data and it is divided into eight classes, 0°-45°, 45°-90°, 90°-135°, 135°-180°, 180°-225°, 225°-270°, 270°-315° and 315°-360°.

Plan curvature represents curvature of the surface. The Curvature map of the study area is generated from DEM data and it is classified into three classes; negative, flat, and positive surface.

Geology of an area governs the strength of rock and soil permeability thus; geology has an impact on landslide susceptibility. In this study, the geological map (1:1000000) of Nepal produced by ICIMOD (2020) is used. Eight types of geological formations are found in the study area; Ranimatta Formation, Sangram Formation, Naudanda Formation, Lakharpatta Formation, Galyang Formation, Syangja Formation; Udaypur Formation and Shiprin Khola Formation.

Land Use means the way, the land is used by the people. These land use and land cover aspects have an important impact on landslide. The land use map (30m resolution) prepared by ICIMOD (2021) is used in the analysis after resample to 12.5m resolution. The land use is classified as Water body, Forest, Riverbed, Built-up Area, Cropland, Grassland and Other Wooden land.

Distance to Roads are an important susceptibility factor to triggering landslides since the construction of roads modifies the land topography and slope. The road layer in the study is extracted from OpenStreetMap using the QuickOSM plugin and the distance from the road is developed using the buffer tool at a different distance in GIS and converted into a raster using rasterize tool. The map is classified into four subclasses; 0-100, 100-300, 300-500 and greater than 500.

Distance to Stream is a vital causative factor in landslide susceptibility as the drainage networks has a higher likelihood of a landslide occurring as they erode the slope base and saturate the underwater portion of the slope-forming material. Distance from the stream map is developed using a buffer tool at a different distance in GIS and converted into a raster using rasterize tool. This map is classified into five subclasses; 0-50. 50-150, 150-500 and greater than 500.

NDVI (Normalized Difference Vegetation Index) is the measure of greenness due to vegetation via understanding the density of vegetation throughout the area. NDVI is calculated as a ratio of difference between red (R) and near infrared (NIR) band of images from sentinel 2 data. It is given by:

$$NDVI = (NIR - R)/(NIR + R) \quad (3)$$

. The values from NDVI ranges from -1 to 1, where the higher value indicates a green and healthy vegetation, values closer to zero indicate little to no vegetation and values in the negative range indicates non-vegetative surfaces and water bodies. NDVI map is produced from the above relation of red and near infrared bands, with the values ranging from -1 to 1, and the values in the produced map are classified into six groups: <0, 0.1-0.2, 0.2-0.3, 0.3-0.5 and 0.5-0.7.

Relative Relief is the difference in elevation between two sites on the surface of the earth. It is a measurement of the height difference, given as a percentage or ratio, between a high point and a nearby low point. High relative relief can result in steep slopes and more possibility for erosion, which can increase the chance of landslides. High relief areas could also be more likely to contain bedrock faults and cracks, which might facilitate landslide activity. The values for relative relief range from 0-800m, which are classified into seven groups, 0-200m, 200-300m, 300-400m, 400-500m, 500-600m, 600-700m and 700-800m.

Rainfall greatly influence the occurrence of landslides. When there is a lot of rain, the extra moisture can seep into the ground and create pore pressure, which weakens and makes the soil unstable. To produce the rainfall map, rainfall stations near the area, Dhunibesi, Birenchowk and Arughat are taken. A Thiessen polygon from these station points is constructed with yearly average rainfall weightage given for each station.

Graphs

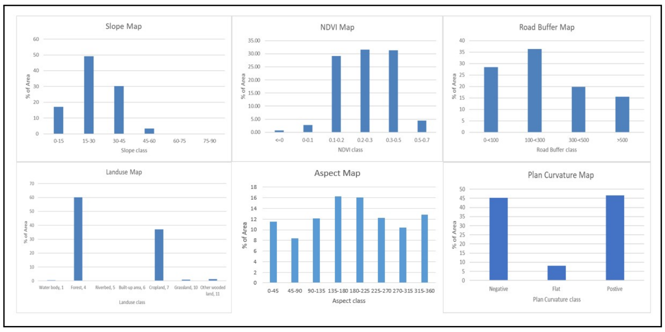

Figure 6: Weightage of classes in each causative factors

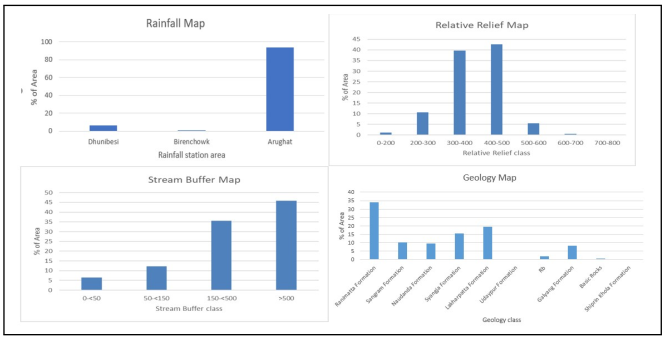

Figure 7: Weightage of classes in each causative factors

The graph for **Slope** map shows that most of the study area falls under the slope class of 15°-30° followed by 30°-45° slope class. Here, we can see that the area has a moderately steep slope as minimal area falls under 45°-60° slope and no area on slope 60°-75° and 75°-90°.

The graph of **Aspect** map shows that most of the study area falls under the aspect class of 135-180 and 180-225 aspect classes.

The graph of **Plan Curvature** map shows that most of the study area falls under the positive and negative curvature whereas minimal area lies on the flat curvature.

The graph of **Geology** map shows that most of the study area falls under the Ranimatta Formation followed by Lakharpatta Formation and Syangja Formation. However, negligible percentage of area falls in Udaypur Formation, Robang (Rb), Basic Rocks and Shiprin Khola Formation.

The graph of **Landuse** map shows that most of the study area is covered by forests and croplands. Negligible area is covered by water bodies, riverbed, grassland, other wooded lands and built-up areas. This shows that the area sees very less influence of human activities as compared to the natural aspects.

The graph of **Road Buffer** map shows that most of the study area falls within 100-300m buffer distance of roads, followed by 0-100m and 300-500m buffer distance of roads.

The graph of **Stream Buffer** map shows that most of the study area falls out of 500m buffer distance of streams, followed by 150m-500m buffer distance of streams, 50m-150m buffer distance and very less area falls within 50m distance of streams.

The graph of **NDVI** map shows that most of the study area falls under 0.2-0.3, 0.3-0.5 and 0.1-0.2 NDVI classes. However, negligible area lies in negative and 0-0.1 NDVI classes, which indicates that the study area is well vegetated.

The graph of **Relative Relief** map shows that most of the study area has a relative relief of 400-500m and 300-400m and negligible area has the relative relief within 0-200m, 600-700m and 700-800m.

The graph of **Rainfall** map shows that most of the study area is influenced by rainfall measured in Arughat station which recorded yearly average of 1940.362 mm, followed by a small influence of rainfall measured in Dhunibesi station with yearly average of 1555.851 mm and a negligible influence of rainfall measured by the Birenchowk station, with an yearly average of 1689.061 mm.

5.3 Landslide Susceptibility Map

The causative factors are classified into different classes and weighted as per the author's recommendation in the study in Heuristic approach and by landslide pixels in Frequency ratio and Information Value method. The weighted causative factors were then combined again as per the author's recommendation in Heuristic approach and by tabulation in Frequency ratio and Information Value method to produce Landslide Susceptibility Map of Siddhalekh Rural Municipality.

Heuristic Method

The final map by Heuristic method is classified into three groups: Low, Medium and High levels of susceptibility using Natural Break Method. The map shows that most of the area, i.e., 43.45 percent of total area lies in medium susceptibility of landslide. Similarly, 28.85 percent of the area lies in low susceptibility whereas 27.7 percent of area lies in high susceptibility of landslides.

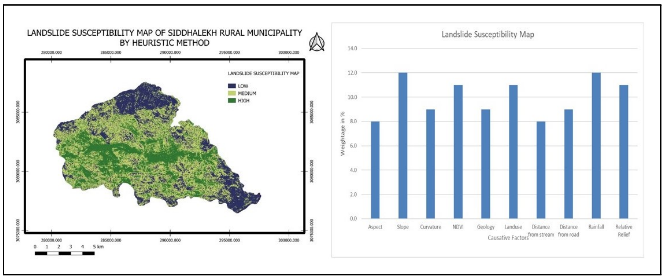

Figure 8: Landslide Susceptibility Map by Heuristic Method

The graph of causative factors in Heuristic method shows the weightage of causative factors in the landslide susceptibility map where Rainfall along with Slope has the highest weightage in the map followed by NDVI, Relative Relief and Land use, and Aspect and Distance from Stream together with the minimum weightage among the causative factors.

Table 1: Weightage of causative factors and classes in Heuristic method

SN	Layer	Class	Weight	Rank
1	Aspect	N	1	8
		NE	2	
		E	3	
		SE	8	
		S	9	
		SW	6	
		W	4	
		NW	3	
2	Slope	0 – 15	1	12
		15 – 30	3	
		30 – 60	7	
		60 - 90	6	
3	Geology	Lakharpata Formation	2	9
		Sangram Formation	6	
		Rb (Robang Formation)	1	
		Naudada Formation	5	
		Udaypur Formation	1	
		Basic Rocks	1	
		Shiprin Khola Formation	1	
		Syangja Formation	3	
		Galyang Formation	4	
		Ranimatta Formation	2	
4	Landuse	Waterbody, 1	1	11
		Forest, 4	3	
		Riverbed, 5	2	
		Built-up, 6	1	
		Cropland, 7	5	
		Grassland, 10	7	
		Other wooded land, 11	6	
5	Curvature	Negative	8	9
		Flat	1	
		Positive	4	
6	Distance to drainage	0 – 50	9	8
		50-500	7	
		> 500	3	
7	Distance to Road	0 – 100	9	9
		100-500	7	
		> 500	3	
8	Rainfall	1555	3	12
		1689	5	
		1940	7	
9	Relative Relief	78-275	1	11
		275-354	3	
		354-418	5	
		418-485	7	
		485-708	9	
10	NDVI	-0.33 to 0	9	11
		0 to 0.19	7	
		0.19 to 0.29	5	
		0.29 to 0.41	3	
		0.41 to 691	1	100

Frequency Ratio Method

Frequency Ratio method involves calculation of weightage of classes in each factor by tabulating the area of landslide polygon and performing GIS operations to assign weightage to the classes within causative factors. The maps for each causative factor are reclassified according to the weightage and again the weightage for each factor was calculated by frequency ratio method after which the causative factor maps were combined giving the weightage, thus generating a Landslide Susceptibility Map of Siddhalekh Rural Municipality. The range within the final map is classified into three groups: Low, Medium and High levels of susceptibility using Natural Break Method. The map shows that most of the area, i.e., 50.05 percent of total area lies in medium susceptibility of landslide. Similarly, 29.65 percent of the area lies in high susceptibility whereas 20.3 percent of area lies in low susceptibility of landslides.

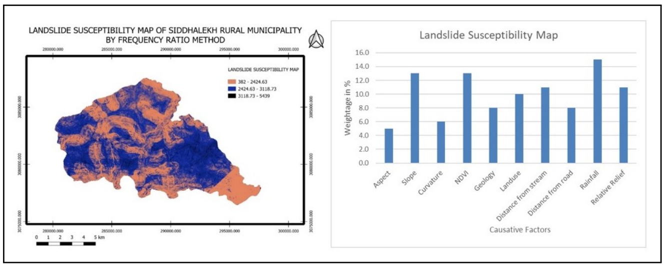

Figure 9: Landslide Susceptibility Map by Frequency Ratio Method

The graph of causative factors in Frequency Ratio method shows the weightage of causative factors in the landslide susceptibility map, where Rainfall has the highest weightage in the map followed by NDVI and Slope, however, Plan Curvature and Aspect has the minimum weightage among the causative factors.

Information Value Method

Information Value method is an extension in Frequency Ratio method where the log value of weightage of classes in each factor generated in Frequency Ratio method is calculated for reclassifying the maps for each causative factor. Then, the causative factor maps were combined to generate a Landslide Susceptibility Map of Siddhalekh Rural Municipality. The range within the final map is classified into three groups: Low, Medium and High levels of susceptibility using Natural Break Method. The map shows that most of the area, i.e., 50.36 percent of total area lies in medium susceptibility of landslide. Similarly, 33.54 percent of the area lies in low susceptibility whereas 16.1 percent of area lies in high susceptibility of landslides.

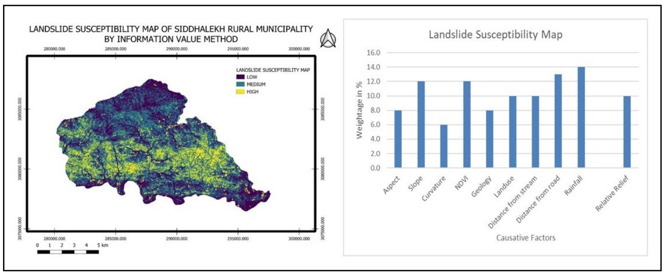

Figure 10: Landslide Susceptibility Map by Information Value Method

The graph of causative factors in Information Value method shows the weightage of causative factors in the landslide susceptibility map where Rainfall has the highest weightage in the map followed by Distance from Road, NDVI, Slope and Land use, and Aspect and Plan Curvature has the minimum weightage among the causative factors.

5.4 Validation of Landslide Susceptibility Map

The AUC for Goodness of fit using training datasets is 89.57 for the Frequency Ratio method, 84.51 for the Information Value method, and 86.83 for the Heuristic method. The AUC for Predictability using testing datasets is 81.50 for the Frequency Ratio method, 81.74 for the Information Value method, and 86.76 for the Heuristic method.

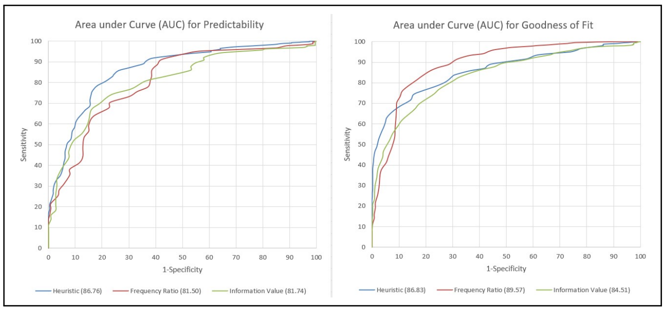

Figure 11: Comparison of AUC curve for validation

6. Conclusion

The susceptibility map from the above methods show that most of the study area falls under medium level of susceptibility to landslide and significant area also falls under low and high susceptibility. Also, from the methods used in susceptibility mapping, Rainfall, Slope, NDVI, Land use, Relative Relief and Distance from roads are the most influencing factors in landslide susceptibility in the study area. The AUC for goodness of fit and predictability from all methods exceed 80, regarding the model as a very good model. The highest AUC for goodness of fit is via Frequency Ratio method whereas the highest AUC for predictability is via Heuristic method. The AUC for predictability by Frequency ratio method is much lesser than that by Heursitic method. Even though AUC for both goodness of fit and predictability of landslides via all methods are quite comparable in the range of 80-90, the AUC for both goodness of fit and predictability by Heuristic method exceeds 85, so the Heuristic method is the better suited method for landslide study in the study area.

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References

[1] Beda Nidhi Khanal. Nepal: A brief country profile on disaster risk reduction and management.

[2] Basant Raj Adhikari and Suraj Gautam. A review of policies and institutions for landslide risk management in nepal. 2:93–112.

[3] A. Muñoz-Torrero Manchado, S. Allen, J. A. Ballesteros-Cánovas, A. Dhakal, M. R. Dhital, and M. Stoffel. Three decades of landslide activity in western nepal: new insights into trends and climate drivers. 18(6):2001–2015.

[4] E. E. Brabb. Proposal for worldwide landslide hazard maps. pages 15–27.

[5] D. J. Varnes. Slope movement types and processes. (176).

[6] David N. Petley, Gareth J. Hearn, Andrew Hart, Nicholas J. Rosser, Stuart A. Dunning, Katie Oven, and Wishart A. Mitchell. Trends in landslide occurrence in nepal. 43(1):23–44.

[7] Robin Fell, Jordi Corominas, C. Bonnard, Leonardo Cascini, Eric Leroi, and William Savage. Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. 102.

[8] Jharendra K.C., Deepak Gautam, Purushottam Neupane, and Kabi Paudyal. Landslide inventory mapping and assessment along the ramche-jharlang area in dhading, rasuwa and nuwakot districts, lesser himalaya central nepal. 55:103–108.

[9] P. Aleotti and R. Chowdhury. Landslide hazard assessment: summary review and new perspectives. 58(1):21–44.

[10] Fausto Guzzetti, Alberto Carrara, Mauro Cardinali, and Paola Reichenbach. Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, central italy. 31(1):181–216.

[11] Tri Acharya, Sharad Mainali, Intae Yang, and Dongha Lee. Analysis of jure landslide dam, sindhupalchowk using gis and remote sensing. XLI-B6:201–203.

[12] Azemeraw Wubalem. Landslide susceptibility mapping using statistical methods in uatzau catchment area, northwestern ethiopia. 8(1):1.

[13] Chang-Jo Chung and Andrea Fabbri. Validation of spatial prediction models for landslide hazard mapping. 30:451–472.

[14] Shraban Sarkar, Archana Roy, and Tapas Martha. Landslide susceptibility assessment using information value method in parts of the darjeeling himalayas. 82:351–362.

[15] Florence Elfriede Sinthauli Silalahi, Pamela, Yukni Arifianti, and Fahrul Hidayat. Landslide susceptibility assessment using frequency ratio model in bogor, west java, indonesia. 6(1):10.

[16] Sujit Mandal and Ramkrishna Maiti. Integrating the analytical hierarchy process (AHP) and the frequency ratio (FR) model in landslide susceptibility mapping of shiv-khola watershed, darjeeling himalaya. 2013:200–212.

[17] Alembante Genene and Matebie Meten. Landslide susceptibility mapping using GIS-based information value and frequency ratio methods in gindeberet area, west shewa zone, oromia region, ethiopia. preprint, In Review.

[18] Azemeraw Wubalem and Matebie Meten. Landslide susceptibility mapping using information value and logistic regression models in goncha siso eneses area, northwestern ethiopia. 2(5):1–19. Company: Springer Distributor: Springer Institution: Springer Label: Springer Number: 5 Publisher: Springer International Publishing.

[19] C. J. van Westen. Application of geographic information systems to landslide hazard zonation.