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Landslide Hazard Zonation Mapping in Dewathang Area

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ABSTRACT
The paper is a study on the landslide hazard zonation based in the local community of Dewathang Area, Samdrup Jongkhar Bhutan. The study intends to identify area that are prone to landslides and create zone map of the region depending on the geographical location of the place. Landslides are natural phenomena that are common in hilly area leading to loss of human life, damaging properties, and causing disaster to natural resources. Such phenomena has left overwhelming effect on the economy and social life in the communities. The study will hence contribute in foreseeing such impact that will benefit settlements of steep slope and hilly area in site planning and other development activities. The study considered thematic layers that includes slope, aspect, curvature, stream proximity, distance from road, elevation, land use, land cover, and precipitation. The thematic maps were prepared using Digital Elevation Model (DEM) data of 5 m resolution created from topographic map of Samdrup Jongkhar. Topographic data from National Land Commission Secretariat (NLCS), Bhutan was used to create DEM. These thematic layers were ranked and weighted based on their relative probability in causing landslide using Analytic Hierarchy Process (AHP) method. The total area of central and southern part of Dewathang Gewog (study area) is 142.85 sq.km. About 17.3 km^2 (12%) of the area falls under very low hazard zone followed by 41.2 km^2 (29%) under low hazard zone, 43.8 km^2 (31%) under moderate hazard zone, 30.9 km2 (22%) under high hazard zone and 8.6 km2 (6%) under very high hazard zone. The final map generated is expected to be used by engineers, architecture, surveyors, and local people for site plan of developmental and agricultural activities.
Keywords - Landslide Hazard Zone, Analytic Hierarchy Process, thematic layers, DEM

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I. INTRODUCTION

The geographical feature of Bhutan is characterized by rugged terrain and mountainous landscape with much of valleys and hills as a part of Himalayan ranges. With such land features, building of roads as well as infrastructure have become challenge. One of the most common natural disasters include landslide occurring among the settlements of hilly area across the country. Landslide is one of the major natural disasters, which have resulted into significant injury and loss to the human life and damaged property and infrastructure throughout the world [4]. The factors that initiate or trigger landslides are: (i) prolonged high intensity rainfall (ii) cutting and deep excavations on slope for construction of building, roads, canal and mining without appropriate disposal of waste debris, and (iii) earthquake shocks and tremors. The landslide hazard zone map shows the division of land surface into zones of varying degree of stability which is based on the estimated significance of the causative factors in inducing instability of the land surface. The land slide hazard zone maps have an important role in planning and implementation of development schemes in mountainous areas [8].

Since it is difficult to accurately predict the time of the landslide, it is important to identify areas susceptible to this phenomenon and its zoning according to the potential [5]. Landslide hazard zone maps can help the engineers to select a suitable place for development projects implementation. The results of these studies can be used as fundamental information by environmental managers and planners [2]. Identification of areas with landslide high potential and avoid possible dangers can be done with the help of landslide hazard zone map.

1.1 Study Area

As shown in Figure 1, Dewathang which is also known as Deothang is a town in South -Eastern Bhutan which falls under Samdrup Jongkhar District. It is located at an altitude of 870 meters (2855 feet). It is located 18 km away from the District Administration. The Gewog is bordered by Orong Gewog in the North, Phentshothang Gewog in the East, Pemagatshel Dzongkhag in the West and Assam in the South. The geographic location of Dewathang is 26º53'26.89'' North latitude and

91°30'91.5" East longitude. Dewathang is chosen because is located on the steep slope area and is more vulnerable to landslide. During monsoon season it was observed that many landslides have been occurred alongside the road in the past few years [11].

Figure 1: Study Area

II. METHODOLOGY

Different thematic layers corresponding to the causative factors that are responsible for the occurrence of landslides in a region were prepared from base map and DEM using ArcGIS 10.4.1. The detailed methodology adopted in the present study is represented in the form of a flow chart as shown in Figure 2. The factors considered for the preparation of landslide hazard zone map are such as Slope, Aspect, Elevation, Land Use Land Cover (LULC), Road Proximity (RP), Stream Proximity (SP), Plan Curvature (Plan C) and Profile Curvature (Profile C). Elevation, Slope Aspect, Slope Angle, Drainage Map and Curvature Map were prepared.

The LULC Map and Distance from Road were extracted from base map. All factor maps were converted to a raster grid with 15 m × 15 m cells size and assigned weight values with the use of the AHP method. The AHP is a structured technique, dealing with complex decisions that was developed by Thomas L. Saaty (1980). This technique is based on pair-wise comparison of the contribution of different factors and gives various scenario to the decision-makers. This technique is one of the most comprehensive algorithms designed for decision-making with multiple criteria, because the possibility of formulating a hierarchy provides natural complex issues and also consider the issue of qualitative and quantitative criteria. Since there is no linear relationship between the landslide and the factors influencing them, the usual statistical approach could not resolve much of the difficulties. In this respect AHP model provides condition to determine the landslide hazard zonation map with more details.

Thematic layers were prepared and reclassified in ArcGIS 10.4.1. Relative rank and weight are assigned to respective thematic layers using AHP technique. An effective criterion for landslide is given in Table 1. The rank was assigned based on experts view and literature review. The scale of preferences, pairwise, normalized pairwise comparison and computation of consistency vector are given in Table 2, Table 3, Table 4 and Table 5 respectively.

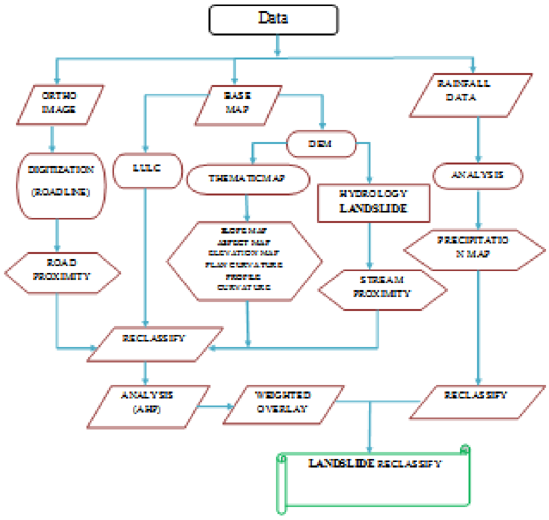

Figure 2: Overall Methodology Flow Chart

Table 1: Scoring or Ranking of Criteria

Parameter	Classes	Ranks
LULC	Forest	3
	Bushes	4
	Built-up Area	1
	Barren Land	5
	Cultivated land	2
Slope	0°-5°	1
	5°-20°	2
	20°-30°	3
	30°-40°	4
	40°-85°	5
Aspect	Flat	1
	North	5
	West	3
	South	4
	East	2
Elevation	140-392	5
	392-644	4
	644-896	3
	896-1148	2
	1148-1400	1

Plan Curvature	189.482-70	5
(-)	70-0	4
	0-75	3
(+)	75-150	2
	150-203.734	1
Stream Proximity(m)	0-50	5
	50-100	4
	100-150	3
	150-200	2
	200-250	1
Road Proximity (m)	0-100	5
	100-150	4
	150-200	3
	200-250	2
	250-300	1
Profile Curvature	314.529-30	5
(-)	30-0	4
	0-20	3
(+)	20-80	2
	80-252.267	1

After assigning rank, pairwise comparison has to be done using the scale of preferences.

2.1 Computation of criterion weights

After the formation of pairwise comparison matrix as shown in Table 3, computation of the criterion weight is done. The computation involves finding the sum of the value in pairwise comparison matrix and computation of average of element in each row of the normalized matrix that is dividing the sum of normalized score of each row by the number of criteria. These averages provide an estimate of the relative weight of criteria. The criteria value was compared with the consistency ratio to avoid bias thoughts.

2.2 Calculation of consistency ratio

It is to check consistency while comparing. Table 4 shows the determination of weighted sum vector and consistency vector.

Calculation of
λ=8.62+8.67+8.68+8.32+8.17+8.09+8.10+8.23

Note: Lambda (λ) is the average of consistency vector Condition 1: λ should be equal or greater than the number of criteria under consideration. The value calculated above satisfies this condition.

Calculation of CI: CI= (λ -n)/(n-1)
= (8.36-8) / (8-1)
= 0.05

Calculation of CR = CI/RI
= 0.05/ 1.41 (Since RI= 1.24 for n=8) = 0.04

Condition 2:
CR (=0.04) <0.10 indicated a reasonable level of consistency in the pairwise comparisons. Therefore, the values obtained to satisfy the said conditions, which denote that the weights obtained are agreeable.

Table 2: Scale of Preferences (Saaty, 1980**)**

Scales	**Degree of Preferences**
1	Equal Important
2	Equal to Moderate important
3	Moderate important
4	Moderate to strong important
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extremely importance

III. RESULTS AND DISCUSSIONS

An effective criterion for landslide hazard zonation with their individual importance is as given below:

a) The slope is the measure of steepness or the degree of inclination of a feature relative to horizontal plane. The maximum landslide occurs if the slope is stepper compared to gentle slope due to instability. The map was made into five classes as 0°-5°, 5°-20°, 20°-30°, 30°-40° and 40°-85°. Highest rank was assigned to 40°-85° due to gravity pull which is the driving force for instability. Lowest rank was assigned to 0°-5°.

Table 3: Pairwise comparison matrix

	Slope	LULC	RP	Aspect	SP	Plan C	Profile C	Elevation
Slope	1	2	3	4	4	5	6	8
LU/LC	0.50	1	2	3	3	4	5	7
RP	0.33	0.50	1	3	3	4	5	6
Aspect	0.25	0.33	0.33	1	2	3	4	5
SP	0.25	0.33	0.33	0.50	1	2	3	4
Plan C	0.20	0.25	0.25	0.33	0.50	1	2	3
Profile C	0.17	0.20	0.20	0.25	0.33	0.50	1	2
Elevation	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1
Sum	2.83	4.76	7.28	12.28	14.08	19.83	26.5	36.0

Table 4: Normalized pairwise comparison matrix and weight

Criteria	Slope	LULC	Road proximity	Aspect	Stream proximity	Plan Curvature	Profile Curvature	Elevation	Weight
Slope	0.354	0.420	0.412	0.326	0.284	0.252	0.226	0.222	0.312
LULC	0.177	0.210	0.275	0.244	0.213	0.202	0.189	0.194	0.213
Road proximity	0.118	0.105	0.137	0.244	0.213	0.202	0.189	0.167	0.172
Aspect	0.088	0.070	0.046	0.081	0.142	0.151	0.151	0.139	0.109
Stream proximity	0.088	0.070	0.046	0.041	0.071	0.101	0.113	0.111	0.080
Plan curvature	0.071	0.053	0.034	0.027	0.036	0.050	0.075	0.083	0.054
Profile Curvature	0.059	0.042	0.027	0.020	0.024	0.025	0.038	0.056	0.036
Elevation	0.044	0.030	0.023	0.016	0.018	0.017	0.019	0.028	0.024
Sum	1	1	1	1	1	1	1	1	1

Table 5: Computation of Consistency Vector

Criteria	(WS)	Consistency(C)
Slope	2.69	8.62
LULC	1.85	8.67
Road proximity	1.49	8.68
Aspect	0.90	8.32
Plain Curvature	0.43	8.09
Profile Curvature	0.29	8.10
Elevation	0.20	8.23
	Average of C	8.36

5°-20°, 20°-30°, 30°-40° and 40°-85°. Highest rank was assigned to 40°-85° due to gravity pull which is the driving force for instability. Lowest rank was assigned to 0°-5°. Steep slopes are disadvantageous because the mass movement is driven by shear stress which is generated by the mass of the block acting under gravity down the slope.

b) Land use land cover is also one of the key factors responsible for the occurrence of landslides since, barren slopes are more prone to landslides [6]. In contrast, vegetative areas tend to reduce the action of climatic agents such as rain, temperature etc., and thereby preventing erosion due to the natural anchorage provided by the tree roots and, thus, are less prone to landslides.

c) An aspect map shows the aspect direction of slope for a terrain. The maximum landslide occurs on the slope inclined towards north direction.

d) Stream proximity plays a vital role in landslide occurrence. The study found out that the landslide occurred at the point near to drainage, therefore, distance from drainage is an important factor.

e) Elevation is also one of the controlling factors in the stability of a slope. Elevation influences to landslides are often displayed as indirect relationships or by means of other factors.

f) Considering road proximity, landslide susceptibility decreases with increasing distance from the main roads located on hilly and mountainous areas. This consideration is based on the general hypothesis that landslides are more frequent in areas closer to roads, due to inappropriate road sections and drainage from the road.

g) Plan curvature (which is perpendicular to the direction of the maximum slope), and profile curvature (which is in the direction of the maximum slope). Curvature was selected as a causal factor on the basis that it affects the hydrological conditions of the soil cover. The concave slope profile areas have higher probability for a landslide occurrence than the convex areas. A value of zero indicates the flat surface. The more negative the value the higher the probability of landslide occurrence and the more positive the value the lower the probability. The low plan curvature indicates the surface is sideward concave at that cell and high plan curvature indicates the surface is sideward convex at that cell. The landslide occurring chance is higher in low plan curvature.

3.1 Landslide Hazard Zonation Map

All three criteria maps were converted into a raster format so that for each pixel, a score can be determined. All the criteria maps were integrated and overlaid and the final landslide hazard zonation map, was prepared by the following formula:

Landslide hazard zonation map= Σ [criteria map* weight]

Landslide hazard zonation Index = ([Slope]*0.312) + ([LULC]*0.213) + ([Road proximity] *0.172) + ([stream proximity] *0.080) + ([Aspect]*0.109) + ([plan curvature] *0.054) + ([profile curvature] *0.036) + ([elevation]*0.024).

The study area is divided into five different hazard zones. These are "very low hazard", "low hazard", "moderate hazard", "high hazard" and "very high hazard" zones. About 6% of area falls under very high hazard zone, 22% of area falls under high hazard zone, 31% of area falls under moderate, 12% of area falls under very low hazard zone and 29% of area falls under low hazard zone.

For production of landslide hazard zonation map, various criterion maps are used. Figure 3 shows the criterion maps (Thematic maps) and the final hazard map is given in Figure 4.

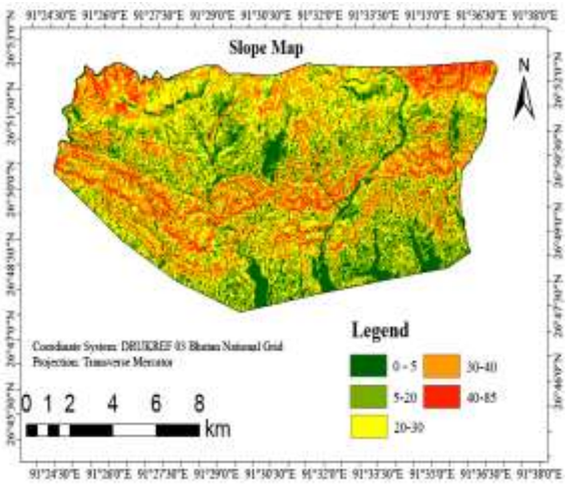

Figure 3(a): Slope map

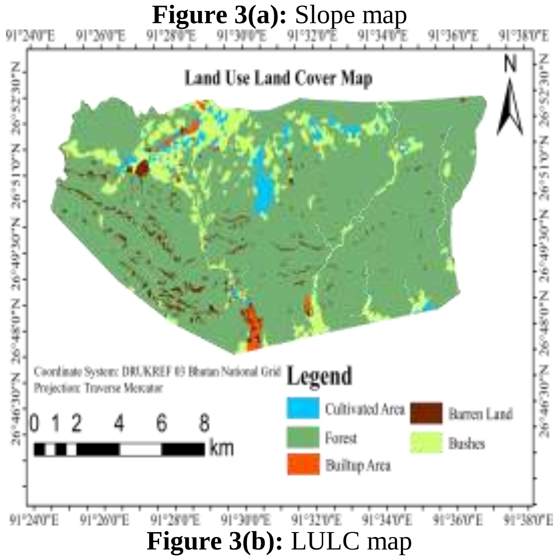

Figure 3(b): LULC map

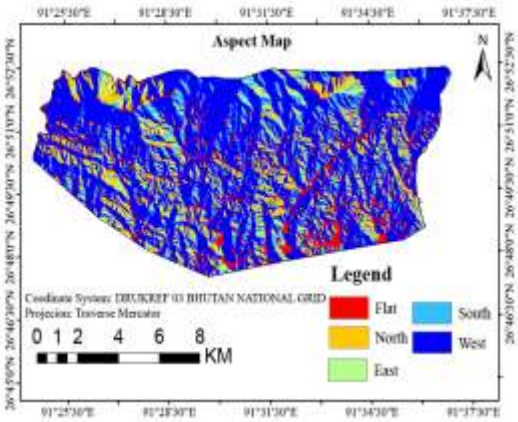

Figure 3(c): Aspect map

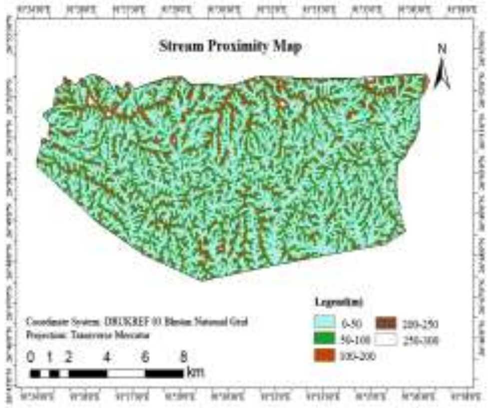

Figure 3(d): Stream proximity map

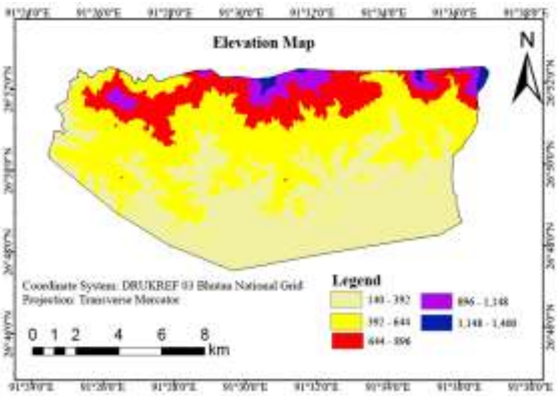

Figure 3(e): Elevation map

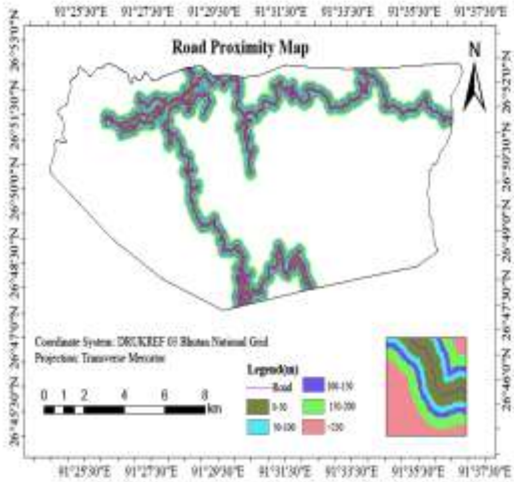

Figure 3(f): Road proximity map

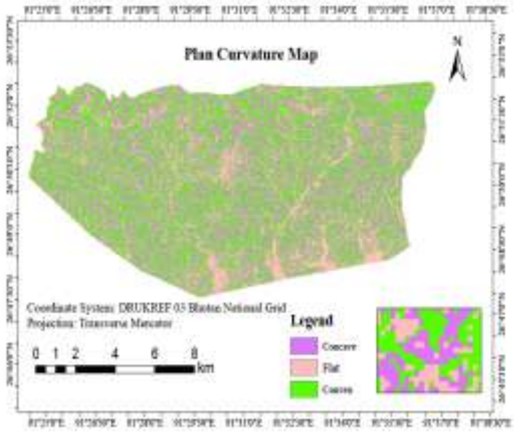

Figure 3(g): Plan curvature map

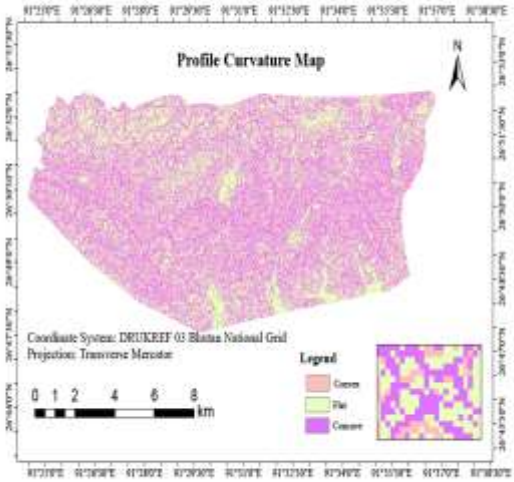

Figure 3(h): Profile curvature map

The distribution of area under different hazard zone in the study area is given in Table 6**.**

Table 6: Area distribution of the study area

Landslide Hazard Zones	Area Km^2	Area In %	Remarks
Very High	8.6	6	Unsafe for site selection for developmental activities
High	30.9	22	
Moderate	43.8	31	Vulnerable zone of instability
Very Low	41.2	29	Safe for site selection for developmental activities
Low	17.3	12	
Total	141.8	100	

IV. CONCLUSION

The study on geographical feature of land showed significant result in understanding the land structure for various developmental purposes. Landslides in the geographical challenged area are found common cause for major disruptions of human settlements, transportation systems including dams. Hence to forecast possibilities of the future landslides in an area with comprehensive knowledge of causative factors of land sliding is necessary. The wide applicability of geospatial technologies is used in solving various environmental tasks. This technology can be used as an effective aid in natural hazard investigation, as well as for the purpose of environmental planning.

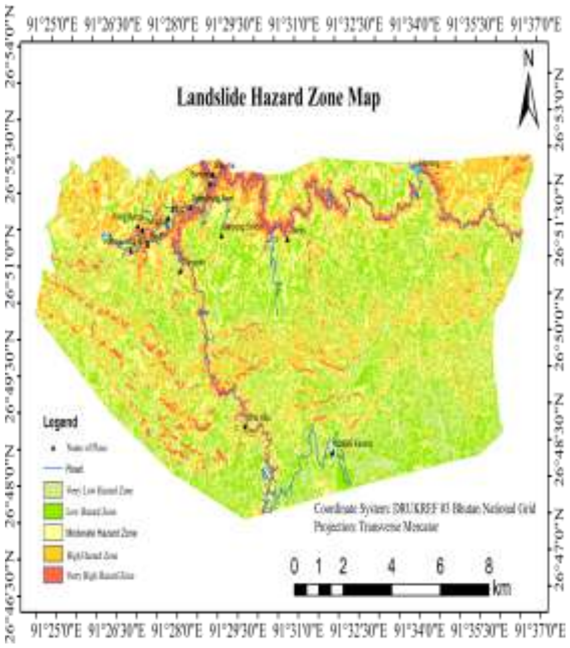

Figure 4: Landslide Hazard Zone Map

Stream proximity map, contour map, digital elevation model, slope angle map, land use / land cover map, aspect map, and distance from the road are basic requirement for landslide hazard zonation mapping for identification of landslide prone areas which can be delineated under GIS environment using remote sensing data. The study reveals that a large part of the study area i.e. 28% is unsafe and is not suitable for site selection for developmental activities in future. About 31% of area is vulnerable to instability and only 41 % of area is safe for developmental activities. This map can be useful for the local people and it will serve as the reference for the engineers, surveyors and planners for the planning of future developmental activities within Dewathang area.

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