Landslide susceptibility mapping in the municipality of southeastern Bangladesh: The case of Rangamati district

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Abstract
Landslide is a common natural hazard in the hilly areas of Bangladesh. Both Chittagong city and three hill districts faced the severe landslide on 11th June, 2007 and on 13th June 2017. Different research works also identified some causes such as catchment head failure, ridge side failure, roadside slope failure, drainage blockage outburst and toe cutting. In this study, the main objective is to landslide susceptibility mapping using Multi-criteria Decision Analysis (MCDA) methods viz. Weighted Overly Method (WOM) and Analytical Hierarchy Process (AHP) method. To conduct this analysis, ten causative factors layers i.e. slope, elevation, land use and land cover (LULC) of 2017, normalized difference vegetation index (NDVI), surface geology, stream distance, road distance, aspect, plan curvature, profile curvature were used and re-classified into different classes. Those layers and sub-classes were assigned to different weights based on literature review and field observation. The final susceptibility maps were categorized into three susceptible zones i.e. low susceptible, moderate susceptible and high susceptible. Based on WOM analysis, about 2282.054 ha (42.17%), 2252.97 ha (41.63%) and 876.97 ha (16.2%) represent the low susceptible, moderate susceptible and high susceptible area respectively. Whereas AHP analysis shows that about 2385.615 ha (44.08%), 1632.669 ha (30.17%) and 1393.716 ha (25.75%) represent the low susceptible, moderate susceptible and high susceptible area, respectively.

To compare the susceptibility maps with landslide status, a landslide inventory was conducted in study area. About 68 landslide locations were found in the study area. Based on landslide susceptibility maps and inventory results, ward numbers 5, 6 and 9 are mostly landslide susceptible and ward number 2, 3 4, 8 are moderately susceptible. Ward number 1 and 7 also correspond to some susceptibility area but no landslide location was identified during field visits. This study provides useful information for the local authorities and stakeholders to take proper actions for landuse planning and disaster risk reduction.

Keywords: Landslide susceptibility, Mapping, Bangladesh, GIS, Multi-Criteria Analysis.

Introduction

Landslide is a geographical phenomenon in which movement of soil, rocks, debris, mud occurred by gravitational forces[10]. This is very common in the mountainous regions for which natural process and human activities are mainly responsible[2]. The rainfall intensity, slope gradient, topography, relief, geological condition, material, earthquake, volcanic eruption, snowmelt are natural process whereas anthropogenic activities include deforestation, settlement infrastructure, unplanned development, hill cutting, land cover change, excavation change in slope profile.[2,9,20]

Landslide is a sign of slope instability where gravitational force and many other causes such as geological, anthropogenic, hydrological, morphological and environmental aspects are also considerable[14]. In simple words, landslide is an important geological hazard that causes serious damage to the both natural and social environment[17].

On the other hand, landslide susceptibility mapping is the prediction of future landslide vulnerable areas based on historic landslide data identifying selection of causative factors and its weights[21].

In recent era, modern technology such as Geographical Information System, Global Positioning System and Remote Sensing are widely used to assess landslide susceptibility[21].

Landslide susceptibility maps describe and identify the potential areas which are more susceptible to landslide in near future and help to policymakers to take effective initiatives based on landslide causative factors alike weather forecasting[21].

As like many countries in the world, landslide is a common natural hazard in southeastern Bangladesh especially in Chittagong, Rangamati, Bandarban and Khagrachhari districts. Rapid informal settlement in the steep hill slope, excessive hill cutting, heavy rainfall and illegal deforestation are the main driving forces of landslide occurrences in this region. Recent landslides on 12 June 2017 cause a total property damage of $223 million. Because of this landslide, the death toll went up to 118 and 1700 families of Rangamati District were devastated[5].

Most recently on June 11, 2018 and dawn of June 12, 2018 Rangamati faced heavy rainfall resulting severe landslide in this area. Due to this landslide, 4 people died at Boropulpara area of Shabekkhong union (the lowest administrative unit), 4 people died in Dharmacharon para of Burighat union and another 3 people died in Hatimara area of Ghilachari union under Rangamati district.

So far, no scientific investigation was conducted in this region. Therefore, the objective of this study aims to prepare landslide susceptibility maps of Rangamati Pouroshova and find out the most vulnerable ward (part of union) in this area. To prepare landslide susceptibility maps, Multi-criteria Decision Analysis (MCDA) methods i.e. Weighted Overlay Method (WOM) and Analytical Hierarchy Process (AHP) method were used. To conduct this analysis, ten causative factors layers such as slope, elevation, land use and land cover (LULC) of 2017, normalized difference vegetation index (NDVI), surface geology, stream distance, road distance, aspect, plan curvature and profile curvature were used and then classified into different classes. Those layers are reclassified in different sub class and those sub-classes were assigned to different weights based on literature review and field observation. The final susceptibility maps were categorized into three susceptible zones i.e. low susceptible, moderate susceptible and high susceptible.

Study Area

Rangamati Pouroshova is situated at the center of Rangamati hill district in Bangladesh. This district is surrounded by Tripura, India in north; Bandarban district and Mayanmar in south; Mijoram, India in east; Khagrachari district and Chittagong district in west [(Chittagong Hill Tracts Development Facility (CHTDF)]. Rangamati Pouroshova encompasses the urban area of Rangamati Sadar upazila. It consists of nine wards and 36 mahallahs and covers about 64.75 square kilometers including the hilly areas and Kaptai Lake. However, in this study, the shape file area is about 54.12 square kilometers (Figure 1).

The landscapes of the Rangamati region are of gentle slope with exception of steep slopes due to poorly consolidated sandstone and clayey silt[5]. The area is covered by Boka Bil, Tipam Bhuban and Dupi Tali formation[8]. The major rock type in this region is only sedimentary such as shale, silty shale, sandy shale, sandstone and mudstone. A thick cover of soil is overlaid due to softness and less compactness of the rocks[5].

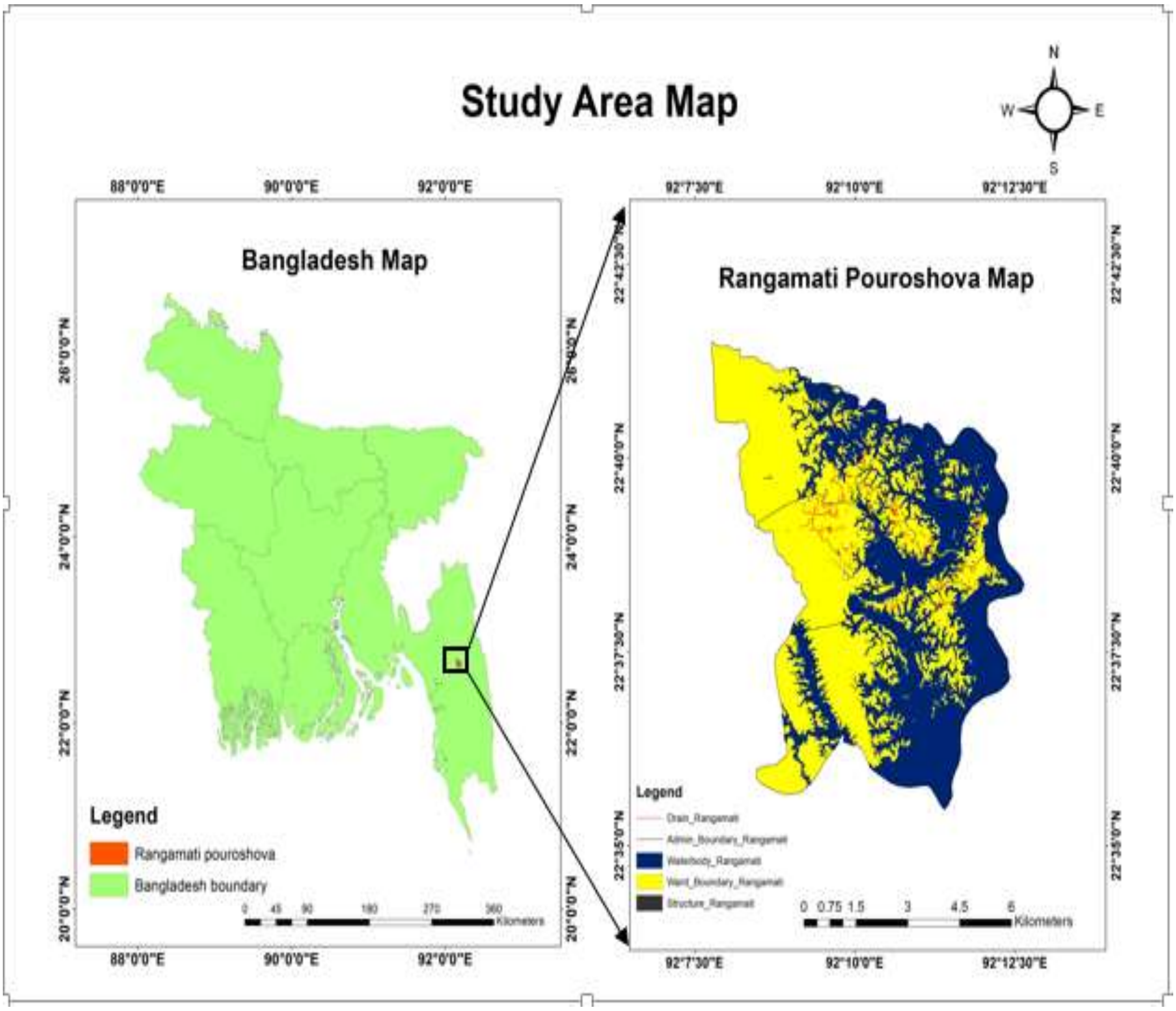

Figure 1: Study area map of Rangamati Pouroshova

Material and Methods

Data collection and processing: In this study, both primary and secondary data were collected from different sources. For landslide inventory, 68 possible landslide locations were determined by mobile apps "GPS Essentials". Some locations were inaccessible and were determined by capturing photo in mobile and by the help of Google Earth software.

The other important factors were selected and collected from different sources for landslide susceptibility mapping. In this study, slope, slope aspect, plan curvature, profile curvature, stream distance, land use, NDVI, Road distance and elevation were selected as landslide causative factors.

ASTGM DEM was retrieved from "Earth Explorer" for preparation of slope, slope aspect, plan curvature, profile curvature, stream distance and elevation layers. For land use and NDVI, Landsat 8 (10 November 2017) image was downloaded from "Earth Explorer". Rangamati Pouroshova shape file (administrative boundary, water body, ward boundary, road system, drainage system, structure etc.) was collected from Pouroshova office. All the collected parameter sources are shown in table 1.

To process the collected data, two multi-criteria decision analysis (MDCA) methods viz. weighted overlay analysis and analytical hierarchy process were used for landslide susceptibility mapping. To prepare susceptibility map, ArcGIS 10.5 and ERDAS IMAGINE 2015 software were used. ArcGIS 10.5 software was mainly used for factors' layers preparation (slope, aspect, plan curvature, profile curvature, stream distance and elevation layers), reclassifying factors layers, study area map preparation, band combinations, clipping, NDVI layer, MDCA method analysis and final susceptibility map preparation. ERDAS IMAGINE 2015 was also used for land use classification of Landsat 8 satellite images.

Flow chart of methodology

Landslide inventory: Landslide inventory means the basic information about the landslide of the landslide area such as the location, classification, volume, travel distance, state of activity and date of occurrence of landslide[16]. Different ways such as field observation, literature review and aerial photos etc. were used for landslide inventory. Among them field observation is commonly used for inventory mapping[16].

In this study, GPS location of landslide was determined by mobile apps and field observation. About 68 landslide locations were identified in study area.

Factors layer processing: In this study, slope is considered as the major controlling factor for landslide occurrences. The slope angle affects landslide directly. Slope gradient was extracted from ASTGM DEM in a resolution of 30 m. At first, the study area was clipped from raster DEM. Then elevation data or layer was extracted from the ASTGM DEM in a resolution of 30 m.

To prepare this layer, study area was clipped from DEM. Landslides occur on the side of the slopes near or affected by stream[16]. The closeness of the slope to streams greatly affects the slope stability[6,16].

Landslide potentiality is increased by the slope erosion and degree of saturation of materials of slope caused by stream[16]. This layer was extracted from ASTGM DEM using hydrological tool to get stream order. The stream order is divided into five distance classes using Euclidean distance tool in Arc Map.

Table 1
Causative factors and data sources

Causative Factors		Data	Data Types	Sources
	Parameters			
Topology	Slope	ASTER GLOBAL DEM (Advanced Spaceborne thermal emission and reflection radiometer) Global digital elevation model	DEM	https://earthexplorer.usgs.gov/
	Aspect			
	Plan curvature			
	Profile curvature			
	Elevation			
	Stream			
Land use		Landsat 8 image (November 2017)	Image	https://earthexplorer.usgs.gov/
Vegetation	NDVI	Landsat 8 image (10 November 2017)	Image	https://earthexplorer.usgs.gov/
Shapefile	Road	Polygon	Vector	Rangamati Pourosova Office
Surface geology	Geology	polygon	Vector	https://pubs.usgs.gov/of/1997/ofr-97-470/OF97-470H/linked_filepaths1.htm

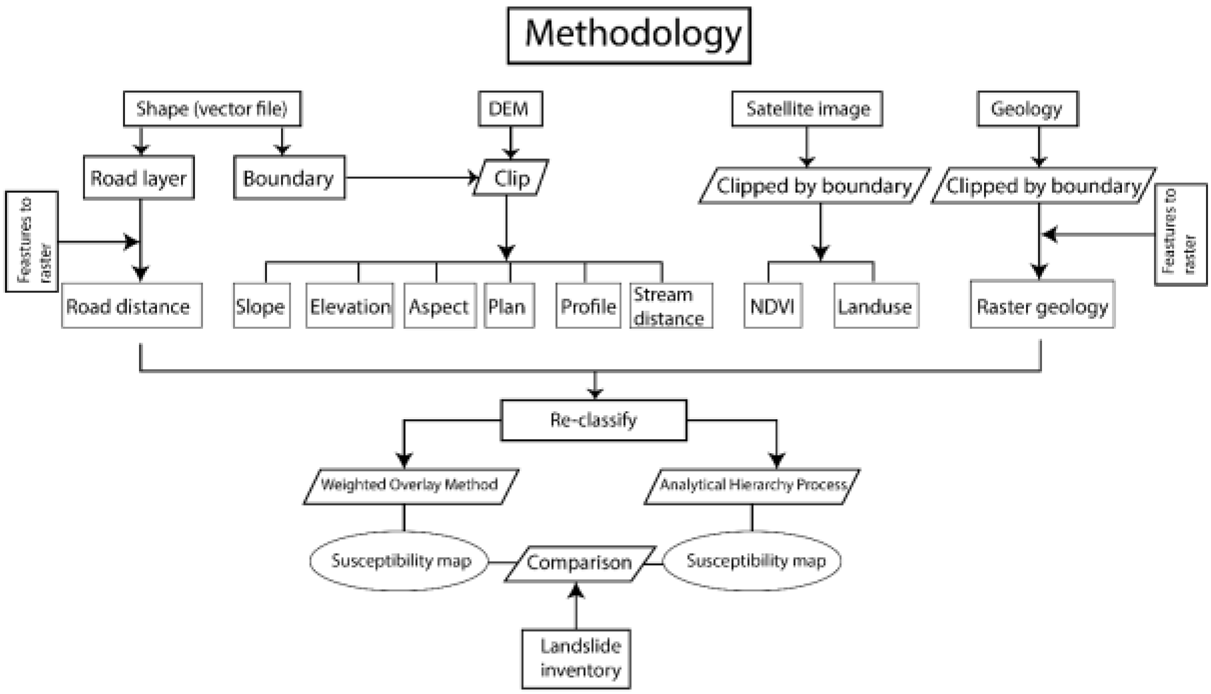

Figure 2: Flow chart of the methodology

Slope aspect means the direction of slope of the terrain surface. Aspect layer of the study area was extracted from ASTGM DEM in Arc Map. Then aspect was classified according to the angle such as Flat (-1), North (0 – 22.5), North-east (22.5 – 67.5), East (67.5 – 112.5), Southeast (112.5 – 157.5), South (157.5 – 202.5), Southwest (202.5 – 247.5), West (247.5 – 292.5), Northwest (292.5 – 337.5) and North (337.5 – 359.99).

The term curvature means the morphology of topography or the rate of change of slope gradient or aspect in a particular direction[22]. Plan curvature and profile curvature are two optional outputs of curvature[13]. Plan curvature is defined as the curvature of a contour line formed by intersecting a horizontal plane with the surface and convergence or divergence of landslide debris. The positive values indicate the convexity, zero (0) indicates the flat and negative values indicate the concavity surface[11]. The plan curvature values of the study area were extracted from ASTGM DEM and were classified into three classes using natural break method in ArcGIS.

Profile curvature relates to the convergence and divergence of flow across a surface and affects the acceleration or deceleration of flow across the surface (concave and convex). In convex (negative) profile curvature, the erosion will prevail and the concave (positive) profile curvature indicates deposition[11]. In the study area, the profile curvature values ranging from -3.60 – 4.07 were classified into three categories by using natural break methods in ArcGIS.

To prepare land cover and land use map, Landsat 8 satellite image on 10 November 2017 was used by using Arc map 10.5 and ERDAS imagine software. The map was prepared in ERDAS imagine by supervised classification process. In this classification, total four classes were identified representing different land covers including water body, settlement, vegetation and bare land plus agricultural land. After the preparation of land cover classes, an accuracy assessment was performed. After accuracy assessment of land cover map, the accuracy of the overall classification accuracy was 91.23% and the overall kappa statistics was 0.8725.

The NDVI is a standardized index which helps to generate an image that indicates the greenness. This index takes advantage of the contrast of the characteristics of two bands from a multispectral raster dataset and the chlorophyll absorb red band and reflects the near infrared (ArcGIS for Desktop). High NDVI values indicate the presence of dense green vegetation and sparse vegetation present low NDVI value[11]. NDVI value is calculated by the formula:[1]

$$NDVI = (NIR - Red)/ (NIR + Red) \quad (1)$$

The NDVI values ranges from -1 to 1 where 1 means the higher vegetation cover, values close to 0 or less than 0 mean no vegetation cover exists and -1 indicates high water body[11]. In this study, Landsat 8 image on 10 November 2017 was used for preparing NDVI layer in Arc Map 10.5. The layer was divided into three classes using natural break method.

Road distance is considered as an important parameter or causative factor for landslide susceptibility mapping[16]. Road construction or road activity changes the natural topography and decreases shear strength of toe slope[4]. To prepare this layer, the road network was collected from Rangamati pourosova office and converted from vector to raster layer. By using Euclidean distance tool in Arc Map, five distance classes were divided by natural break method. The surface geology vector file of Bangladesh was collected as a vector layer (Table 1). After clipping the study area, the layer was converted from vector to raster file in Arc Map 10.5. In this layer, only two classes (bed and lake) were found.

Weighted Overlay Methods

Reclassification of factor layers: For susceptibility mapping, the selected factors' layers viz. slope, aspect, plan curvature, stream distance, road distance, profile curvature, surface geology, land use and land cover, NDVI and elevation were reclassified into different subclasses. Reclassification of all factors' layers was done by using natural break method. Slope, elevation, stream distance and road distance were classified into five subclasses. NDVI, plan curvature and profile curvature were classified into three subclasses. Aspect, land use and surface geology were reclassified into ten, four and two subclasses respectively.

Assigning factors weights: Landslide susceptibility rating for individual factors and their subclasses for weighted overlay method is given in table 2. The influence of individual factors layers and scale values of each sub classes are assigned based on literature review, prior knowledge and direct field investigation. Slope was divided into 5 major classes such as 0 – 2.45, 2.45 – 6.72, 6.72 – 11.61, 11.61 – 18.33 and 18.33 – 38.97 degree. Here, 1^{st} class is assigned as restricted because it represents the water body. The 2^{nd} class is low susceptible for landslide so it is assigned low value 3. 3^{rd}, 4^{th}, 5^{th}, classes of the slope layer were assigned moderate and higher value such as 5, 7 and 9 respectively.

Aspect layers were divided into 10 classes based on Flat, North, North-east, East, South-east, South, South-west, West, North-west and North. The aspect classes are assigned based on literature review[12]. The elevation is directly proportional to the probability of landslide occurrence (Islam et al., 2017). Elevation map of the study area has been divided into five classes and high elevation was considered as high landslide susceptible and assign high weights. Plan curvature and profile curvature layers were reclassified into three classes: the concave curvature, concentrated surface water and increased landslide activity, hence this class assigned high weight value as 8.

In case of convex curvature, surface water diverges from slope which is imposing less potential to landslide. Therefore, this class was assigned moderate weight value as 5. For flat surface, there is low potential influence for landslide occurrence and was assigned very low weight value as 3.

Land use and land cover play a vital role in landslide activity. Classified image was reclassified into four class such as agriculture and bare land, waterbody, vegetation and Infrastructure. Water body has no landslide susceptibility. As a result, this class was assigned no weight value or was restricted. Other classes such as agriculture and bare land were assigned low weight value as 3 because in this image classification was agricultural land is low susceptible for landslide and bare land represents low land area. Vegetation cover was assigned moderate weight value as 5 because vegetation cover reduces soil erosion and directs infiltration of rainwater, eventually increasing the strength of near surface soil and decreasing the potential of landslide incidence. The infrastructure layer was assigned high weight value as 7. Because infrastructure represents the settlement and most of those settlements were established on top hill slope and bottom hill. NDVI value reflects the vegetation coverage rate and health.

In this study, NDVI value was reclassified into 3 classes such as -0.15 - 0.086, 0.086 – 0.32 and 0.32 – 0.58. The first class mainly represents the water body and this class was restricted. The second class represents the bare land plus settlement and was assigned higher weighted value as 8. Third class represents the vegetation cover and was assigned moderate weight value as 5. The surface geology layer was reclassified into two classes because this layer represents only two class such as bed and lake. The bed class was assigned high weight value and lake class was assigned moderate weight value as 8 and 6, respectively. Both road distance and stream distance layers were reclassified into five classes. Based on their distance, each class was assigned higher weights to low weights value.

Here, stream distance reclassified into (0 – 331.25), (331.25 – 738.94), (738.94 – 1261.3), (1261.3 – 1872.85) and (1872.85 – 3248.85) classes and was assigned weights as 8, 5, 3, 2 and 1 respectively. Road distance was reclassified into (0 – 398.168), (398.168 – 987.45), (987.45 – 1656.38), (1656.38 – 2436.79) and (2436.79 – 4061.32) classes and was assigned as 8, 5, 3, 2 and 1 respectively.

Analysis process: The overall analysis process of weighted overlay method is shown in figure 3.

Analytical Hierarchy Process

Layers Reclassification and assigning weights: For susceptibility mapping by Analytical hierarchy process (AHP), the selected factors layers such as slope, aspect, plan curvature, stream distance, road distance, profile curvature, surface geology, land use and land cover, NDVI and elevation were reclassified into different subclasses. Reclassification of all factors layers was done by using natural break methods.

Slope, elevation, NDVI, aspect, stream distance and road distance were classified into five subclasses. Plan curvature, profile curvature were classified into three subclasses. Land use and surface geology were reclassified into four and two subclasses respectively. In reclassification process, reclassified sub class were assigned based on literature review and field observation.

Table 2
Causative factors layers, factors weights and scale value of each sub-class

Parameters	Subclass	Influence (100%)	Number Value	Scale Value
Slope	0 – 2.45	20	1	Restricted
	2.45 – 6.72		2	3
	6.72 – 11.61		3	5
	11.61 – 18.33		4	7
	18.33 – 38.97		5	9
Elevation	10 – 28	15	1	2
	28 – 46		2	4
	46 – 68		3	7
	68 – 97		4	8
	97 – 199		5	9
Land use	Agriculture and bare land	10	1	3
	Waterbody		2	Restricted
	Vegetation		3	5
	Infrastructure		4	7
Surface geology	Bed	10	1	8
	Lake		2	6
NDVI	-0.15 - 0.086	5	1	Restricted
	0.086 – 0.32		2	8
	0.32 – 0.58		3	5
Aspect	Flat	5	1	1
	N		2	2
	NE		3	2
	E		4	3
	SE		5	7
	S		6	8
	SW		7	7
	W		8	2
	NW		9	3
	N		10	2
Plan Curvature	-2.84 – (-0.33)	10	1 (concave)	8
	-0.33 – 0.37		2 (flat)	3
	0.37 – 2.86		3 (convex)	5
Profile Curvature	-3.6 – (-0.41)	10	1 (convex)	5
	-0.41 – 0.37		2 (flat)	3
	0.37 – 4.19		3 (Concave)	8
Stream distance	0 – 331.25	10	1	8
	331.25 – 738.94		2	5
	738.94 – 1261.3		3	3
	1261.3 – 1872.85		4	2
	1872.85 – 3248.85		5	1
Road distance	0 – 398.168	5	1	8
	398.168 – 987.45		2	5
	987.45 – 1656.38		3	3
	1656.38 – 2436.79		4	2
	2436.79 – 4061.32		5	1

Pairwise comparison of factors layers: For AHP analysis, pairwise comparison is the most important element to get factors rank. This method calculates the weight for each element and performs a comparison of two advantages[18]. The consistency index (CI) determined by this process represents the consistency of the ranking. For this consistency, the value must remain below 0.1[19].

In this study, pairwise comparison of factors' layers was done by online AHP calculator (https://bpmsg.com/academic/ ahp_calc.php).

Analysis Process: In this AHP method, the following formula is used for landslide susceptibility mapping.[15]

$$LSM = \sum_{i=1}^{n}(W_i * R_i) \quad (2)$$

where W_i represents the reclassified factors layers and R_i represents the priority of the factors' layers which were found from pairwise comparison. The comparison result is shown in table 3. The analysis process for landslide susceptibility mapping by AHP method is shown in figure 4.

Results and Discussion

Landslide Inventory Map: A total of 68 landslide locations were identified in study area through field visits. Based on field inventory, the highest number of landslides was found in ward no. 6. Wards no. 1 and 7 had no landslide. The landslide distribution in different wards based on field inventory is given in table 4.

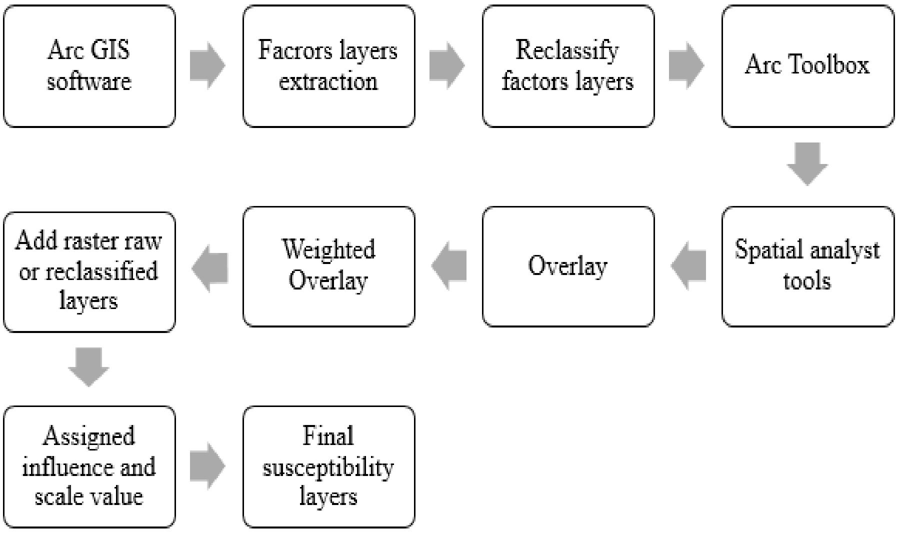

Figure 3: Analysis procedure by weighted overlay method in Arc Map 10.5.

Table 3
The AHP matrix for pairwise comparison of each factor

Factors	Slope	Elevation	Land use	Geology	Stream distance	Plan curvature	Profile curvature	NDVI	Aspect	Road distance
Slope	1	3	5	3	5	7	7	5	7	5
Elevation	0.33	1	3	3	5	7	7	5	7	5
Land use	0.20	0.33	1	0.33	3	7	7	1	5	5
Geology	0.33	0.33	3	1	5	7	7	3	5	3
Stream distance	0.20	0.20	0.33	0.20	1	5	5	0.33	5	3
Plan curvature	0.14	0.14	0.14	0.14	0.20	1	1	0.20	0.33	0.33
Profile curvature	0.14	0.14	0.14	0.14	0.20	1.00	1	0.20	0.33	0.33
NDVI	0.20	0.20	1.00	0.33	3	5	5	1	5	3
Aspect	0.14	0.14	0.20	0.20	0.20	3	3	0.20	1	0.33
Road distance	0.20	0.20	0.20	0.33	0.33	3	3	0.33	3	1

Table 4
Landslide distribution in different wards

Ward No.	1	2	3	4	5	6	7	8	9
Landslide occurrences	0	3	5	4	3	28	0	5	20

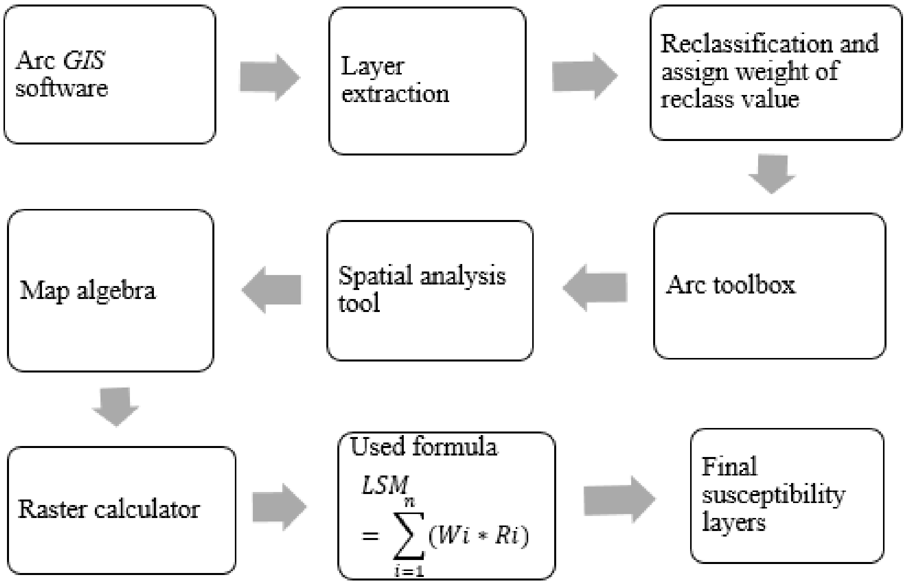

Figure 4: Analysis procedure by AHP methods in Arc Map 10.5.

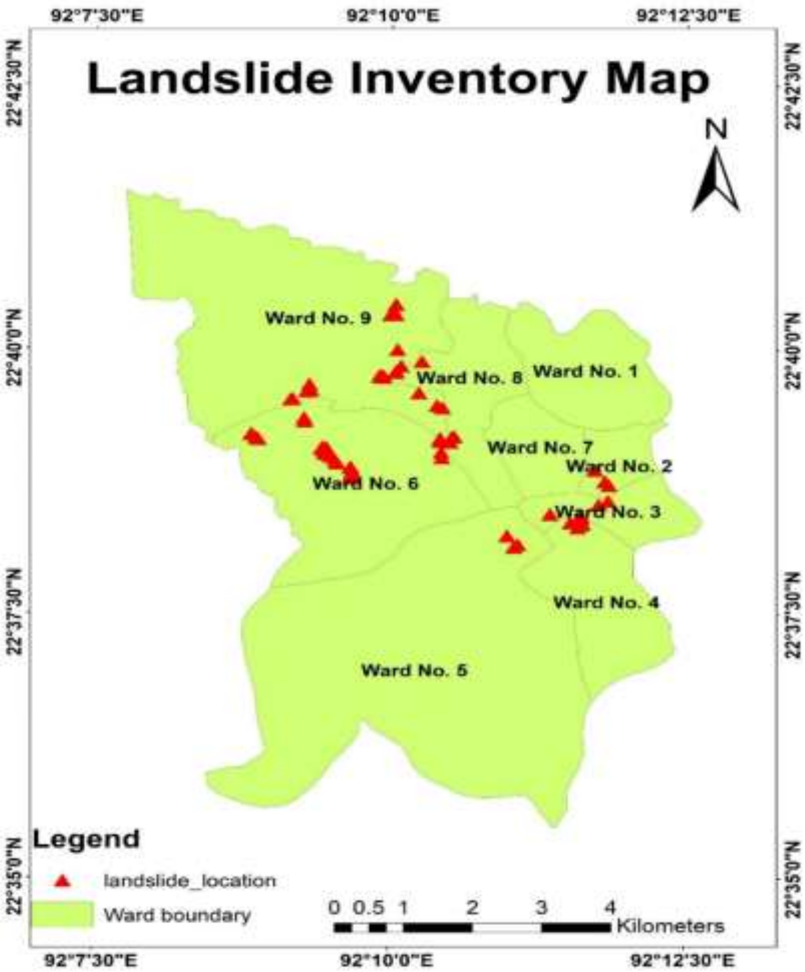

Figure 5: Landslide inventory Map in Rangamati Pourosova

Weighted Overlay Methods

Reclassified Map: All factors' layers were reclassified into different classes shown in table 5. For susceptibility mapping, the selected factors' layers viz. slope, aspect, plan curvature, stream distance, road distance, profile curvature, surface geology, land use and land cover, NDVI and elevation were reclassified into different subclasses. Reclassification of all factors' layers was done by using natural break method.

For WOM analysis, slope, elevation, stream distance and road distance were reclassified into five subclasses. NDVI, plan curvature, profile curvature was reclassified into three subclasses. Aspect, land use and surface geology were reclassified into ten, four and two subclasses respectively. Area of each reclassified sub-classes was calculated in Arc Map software. Area of each layer sub-classes is shown in table 5.

In figure 6a, reclassified slope map was divided into five classes by using natural break method and the class value represents the degree of the slope. The figure 6b represents the reclassified elevation map. The elevation class value and area of each classes are given in table 5. In figure 7c, represents the LULC of 2017 map and figure 8f represents the reclassified NVDI map respectively. The class value of NDVI map and the area of each classes are given in table 5.

Figure 8e represents the geology map and f- represent the stream distance map. The class values and area of reclassified stream distance map and the geology classes' area are given in table 5. Figure 9g represents the aspect map and figure 9h represents the road distance map. Figure 10i represents the plan curvature and j-represent the profile curvature.

Analytical Hierarchy Process:

Reclassified Map: All factors' layers were reclassified into different classes for landslide susceptibility map preparation by AHP method. the selected factors' layers viz. slope, aspect, plan curvature, stream distance, road distance, profile curvature, surface geology, land use and land cover, NDVI and elevation were reclassified into different subclasses shown in table 6. Reclassification of all factors' layers was done by using natural break method. For analysis with this method, slope, elevation, stream distance, NDVI, aspect and road distance were reclassified into five subclasses.

Plan curvature and profile curvature were reclassified into three subclasses. Land use and surface geology were reclassified into four and two subclasses respectively. Area of each reclassified sub-classes was calculated in Arc Map software. Area of each layer sub-classes is shown in table 6 and reclassified layers map is shown in figure 12 to 16.

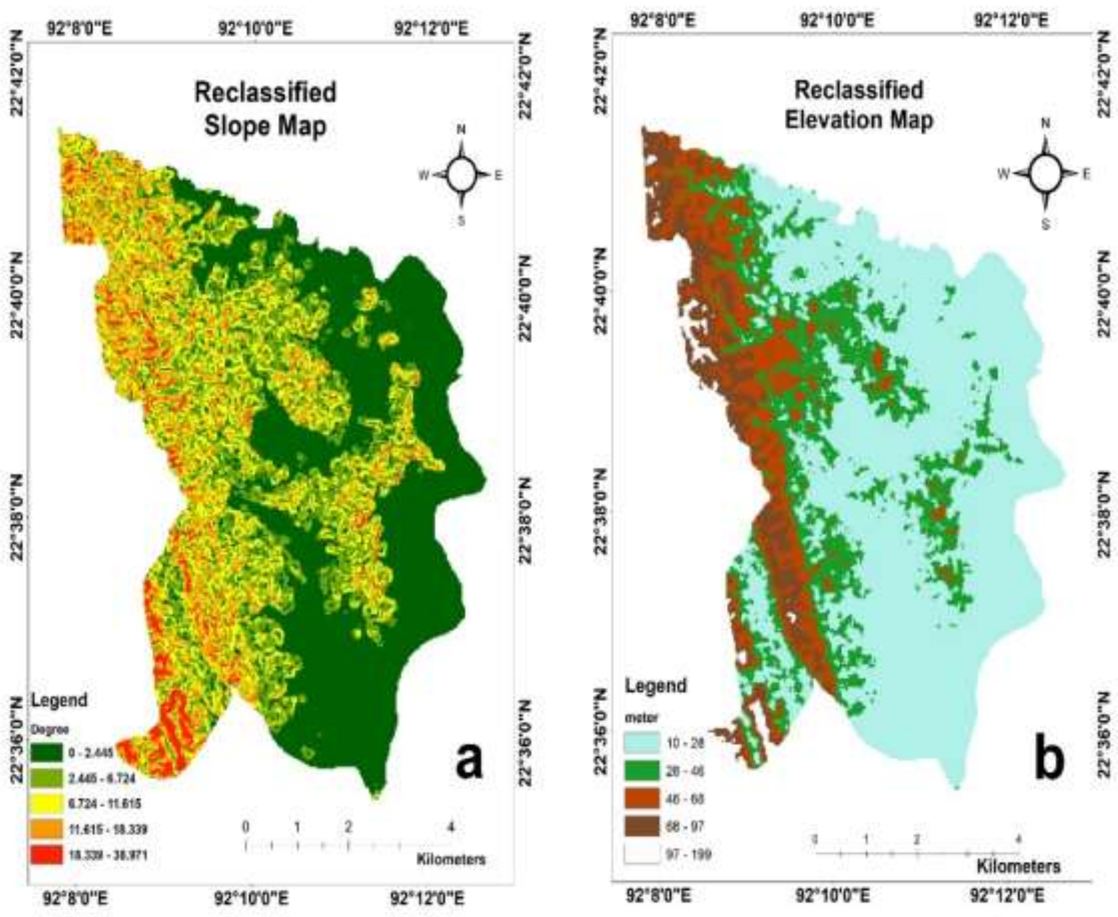

Figure 6: Reclassified factors map (a- reclassified slope map and b- reclassified elevation map)

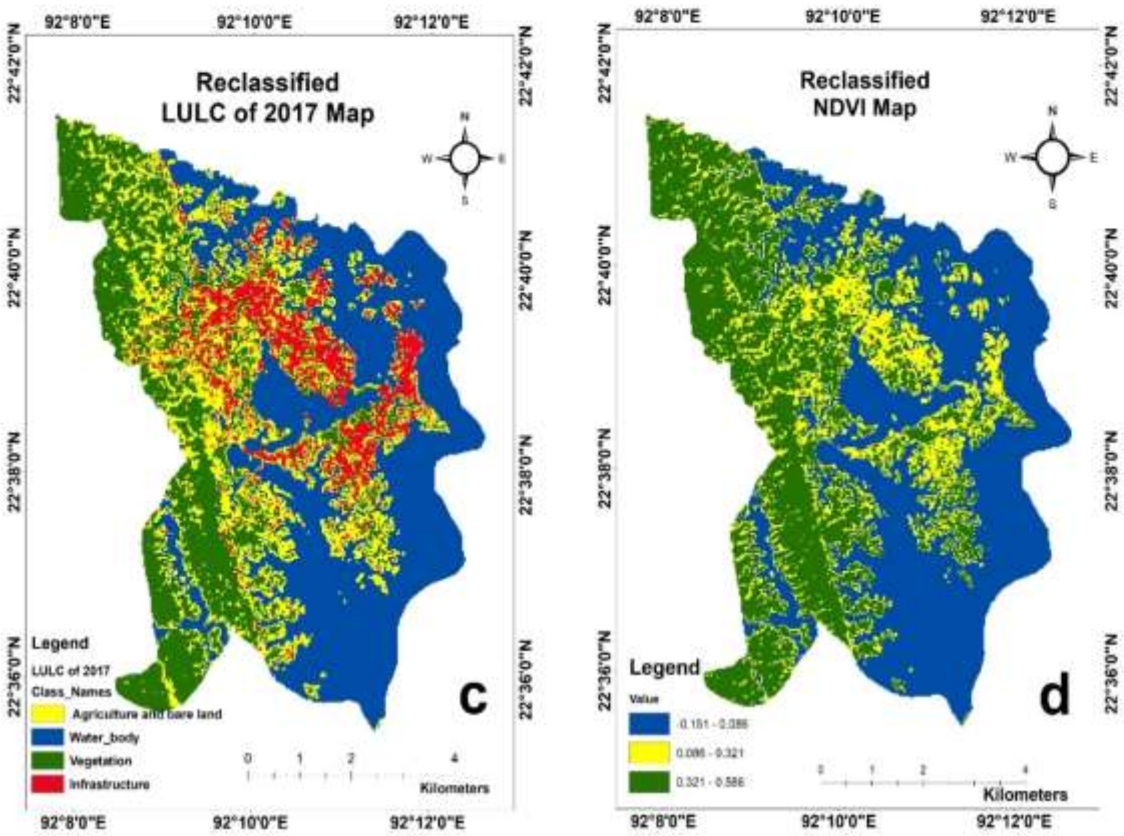

Figure 7: Reclassified factors map (c- LULC of 2017 map and d- reclassified NDVI map)

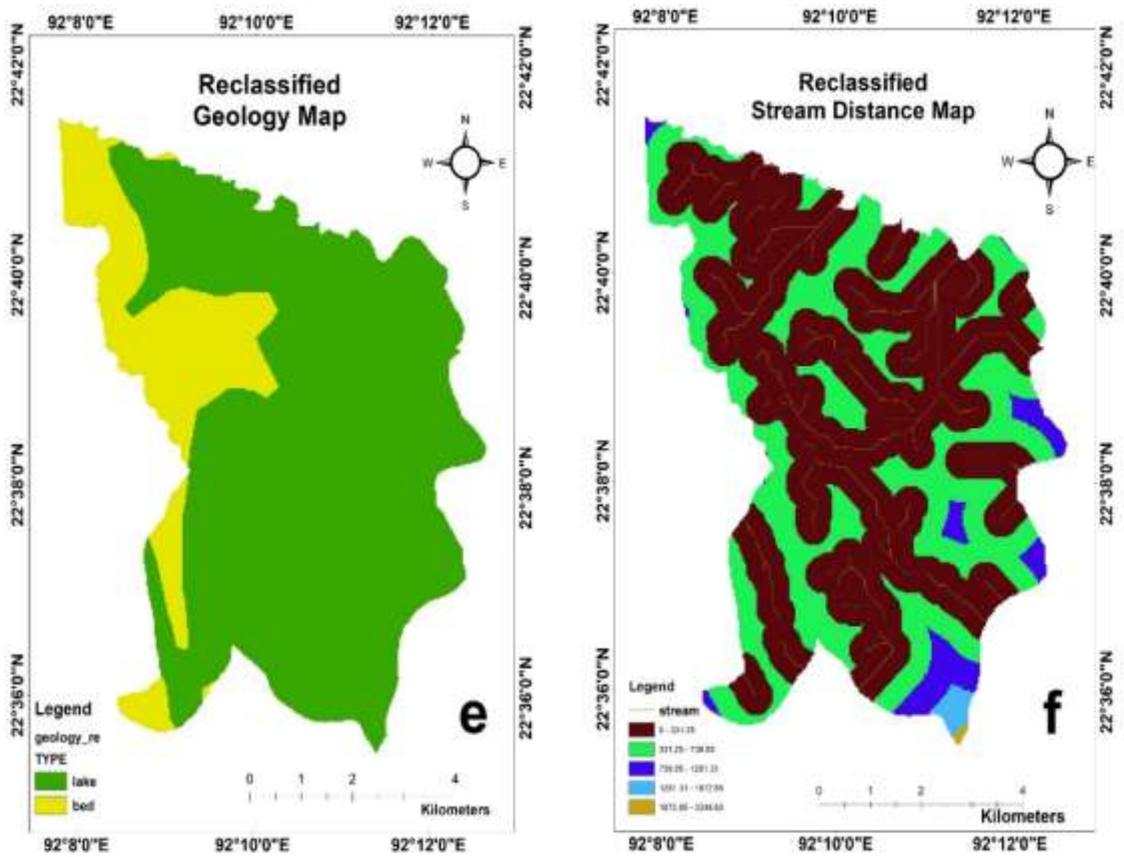

Figure 8: Reclassified factors map (e- geology map and f- reclassified stream distance map)

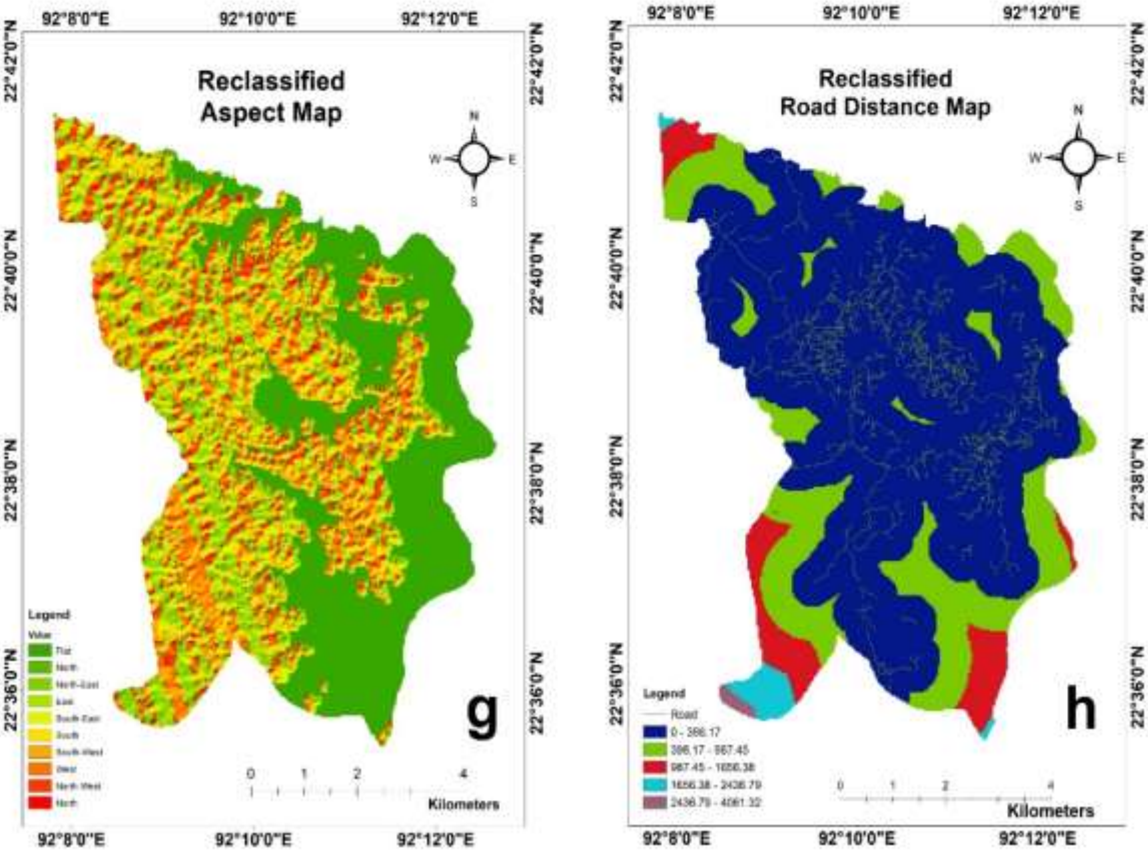

Figure 9: Reclassified factors map (g- reclassified aspect map and h- road distance map).

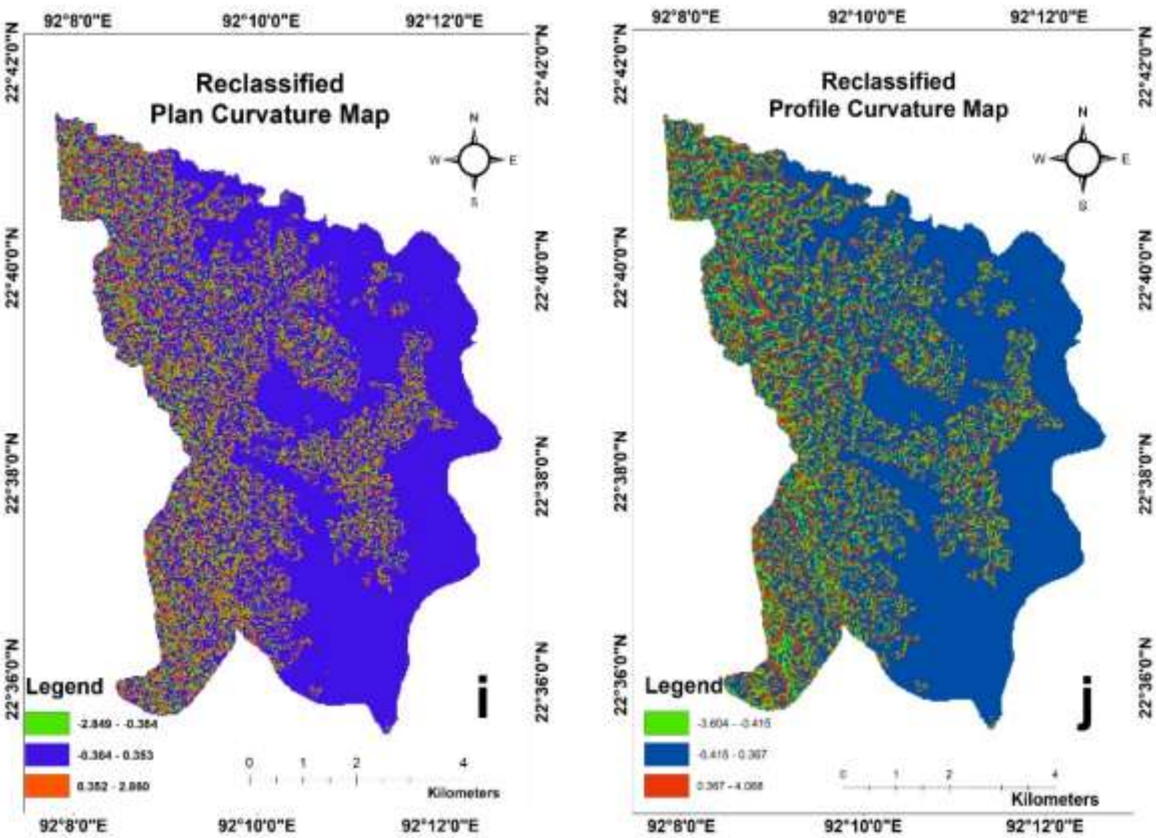

Figure 10: Reclassified factors map (i- reclassified plan curvature map and j- reclassified profile curvature map)

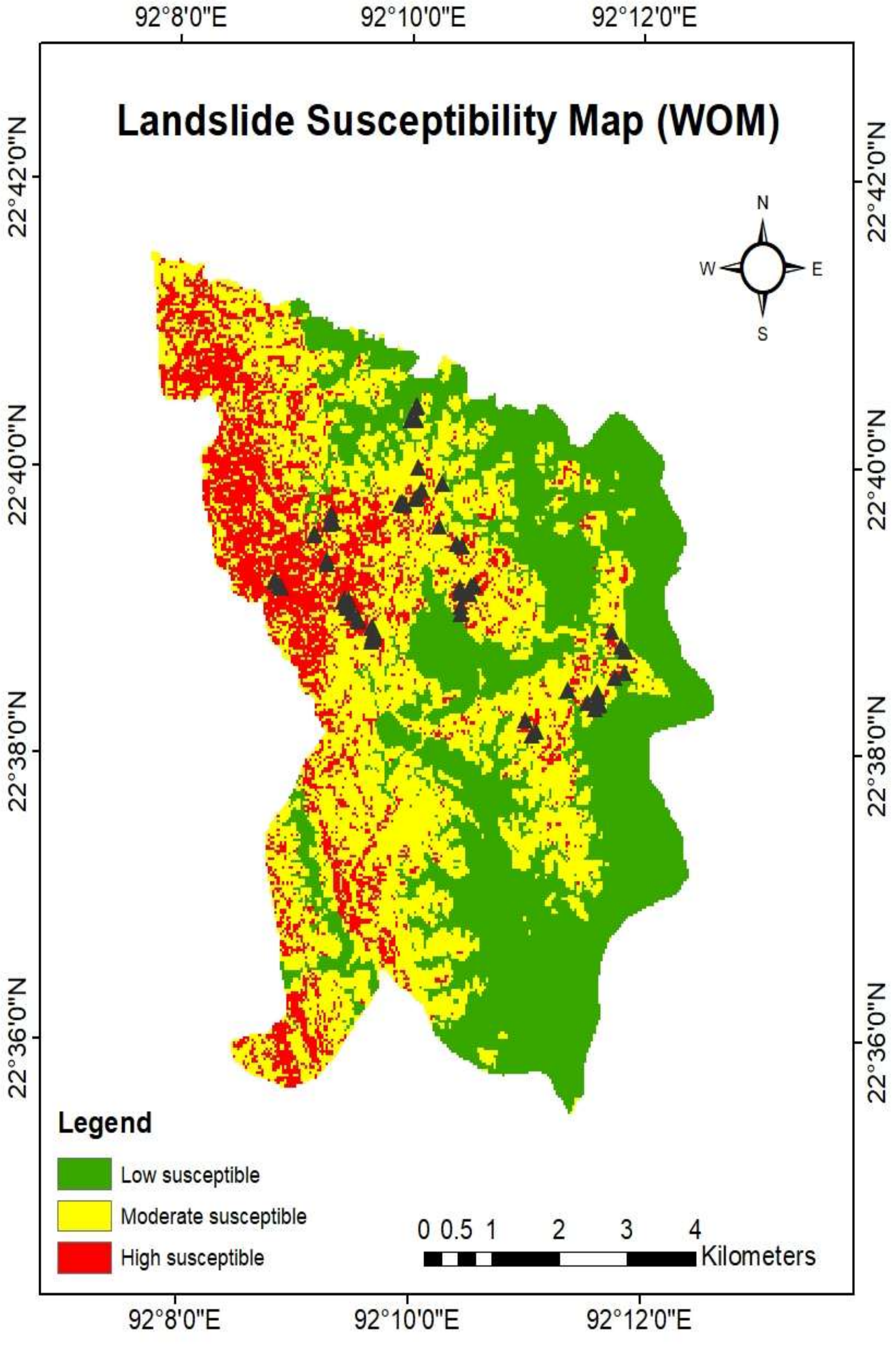

Figure 11: landslide susceptibility map by using WOM method.

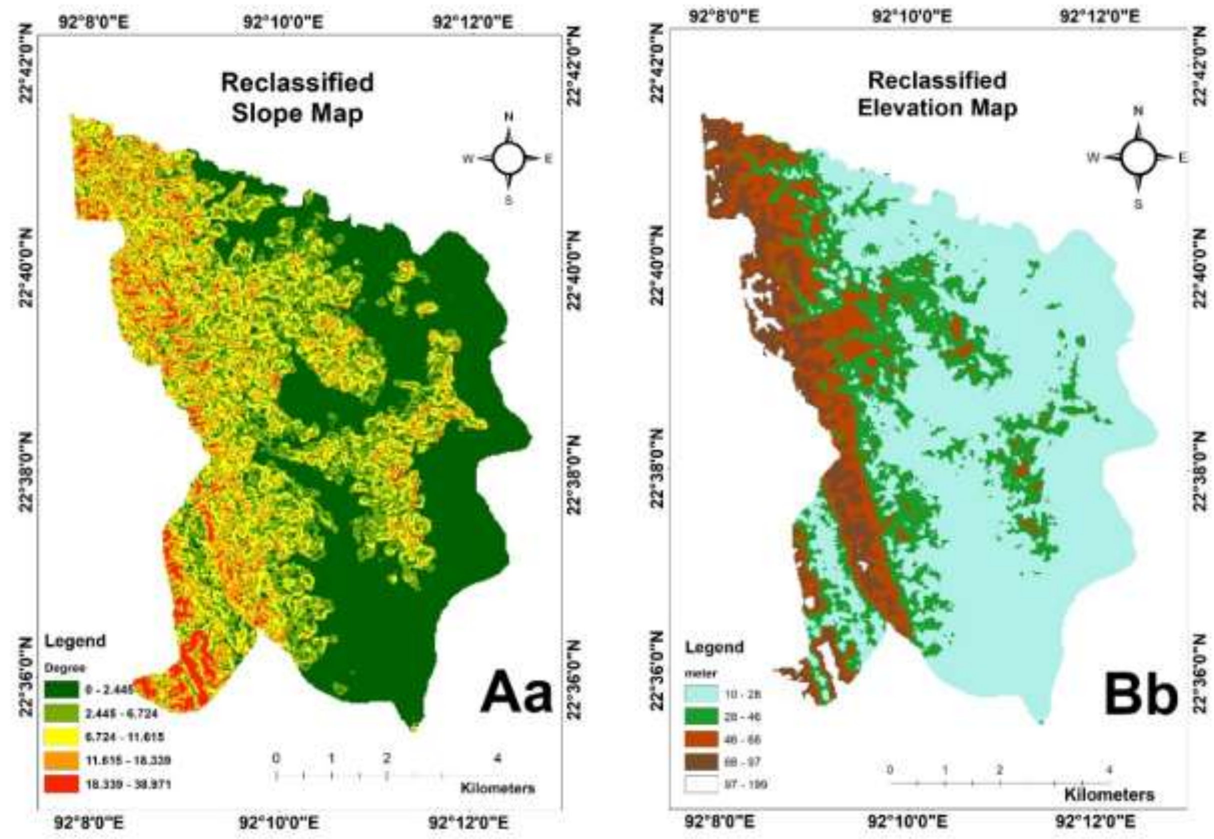

Figure 12: Reclassified factors map (Aa- slope map and Bb- elevation map)

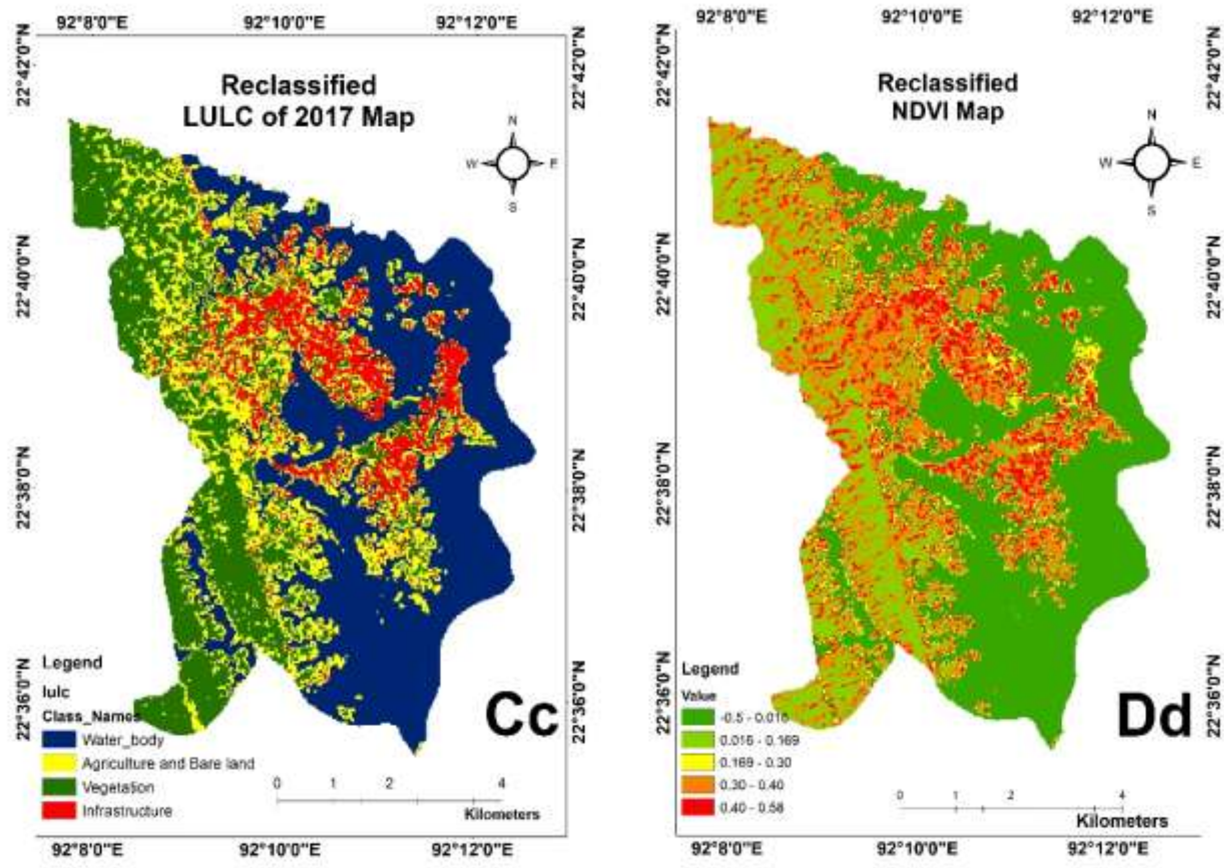

Figure 13: Reclassified factors map (Cc- LULC of 2017 map and Dd- NDVI map)

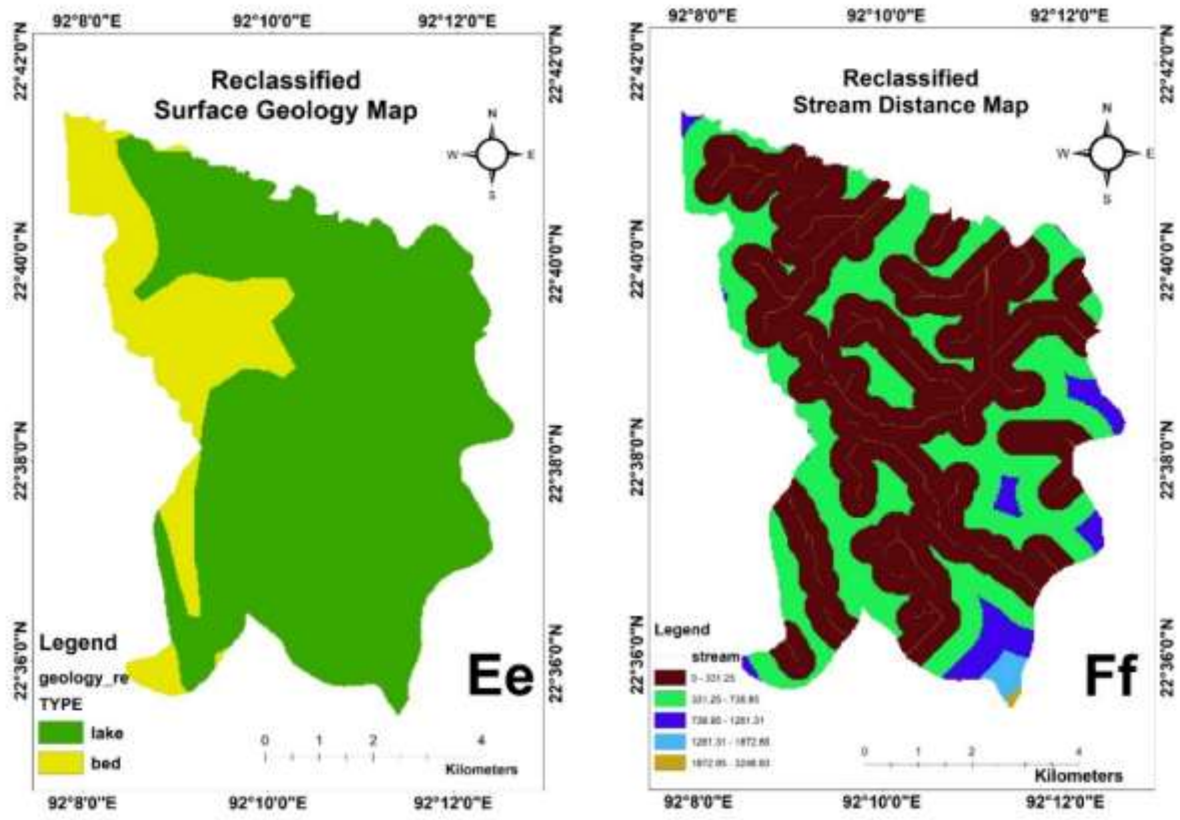

Figure 14: Reclassified factors map (Ee- surface geology map and Ff- stream distance map).

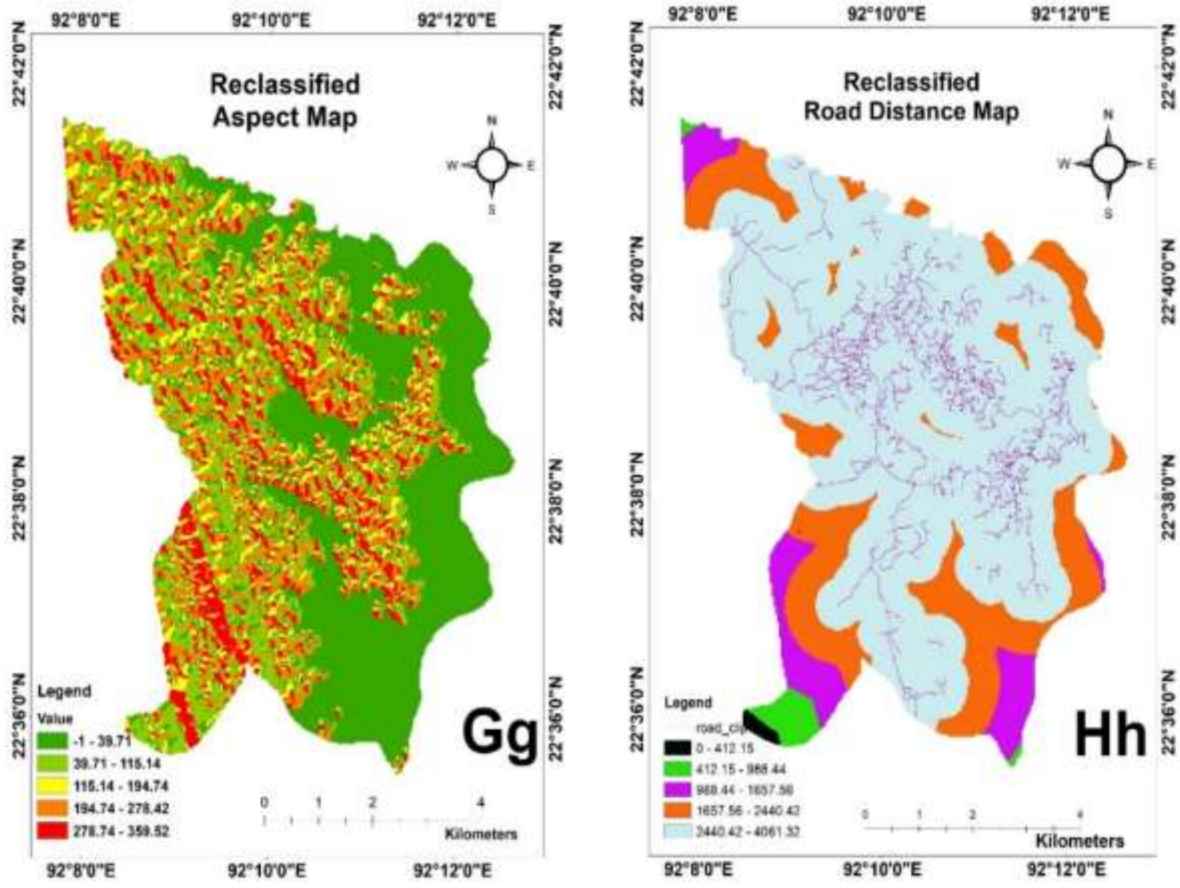

Figure 15: Reclassified factors map (Gg- aspect map and Hh- road distance map).

Table 5
Reclassified factors layers, subclasses and subclasses area

Parameters	Class	Area	Parameter	Class	Area
Slope	0 – 2.45	2310.43	Road distance	0 – 398.168	2344.85
	2.45 – 6.72	1285.7		398.168 – 987.45	1264.28
	6.72 – 11.61	1043.73		987.45 – 1656.38	858.46
	11.61 – 18.33	591.545		1656.38 – 2436.79	581.68
	18.33 – 38.97	179.754		2436.79 – 4061.32	362.72
Elevation	10 – 28	3154.77	Stream distance	0 – 331.25	3345.58
	28 – 46	1099.63		331.25 – 738.94	1793.87
	46 – 68	632.749		738.94 – 1261.3	223.777
	68 – 97	425.059		1261.3 – 1872.85	42.4222
	97 – 199	100.604		1872.85 – 3248.85	5.42061
Land use	Agriculture and bare land	1216.98	Profile Curvature	-3.6 – (-0.41)	779.07
	Waterbody	2287.91		-0.41 – 0.37	3784.15
	Vegetation	1383.50		0.37 – 4.19	848.78
	Infrastructure	523.61			
Aspect	Flat	1797.82	Plan Curvature	-2.84 – (-0.33)	768.78
	N	269.313		-0.33 – 0.37	3861.03
	NE	558.783		0.37 – 2.86	782.19
	E	549.104	Surface geology	Bed	1071
	SE	449.743		lake	4341
	S	426.302	NDVI	-0.15 - 0.086	2601.27
	SW	408.898		0.086 – 0.32	977.67
	W	365.655		0.32 – 0.58	1833.03
	NW	366.987			
	N	220.21			

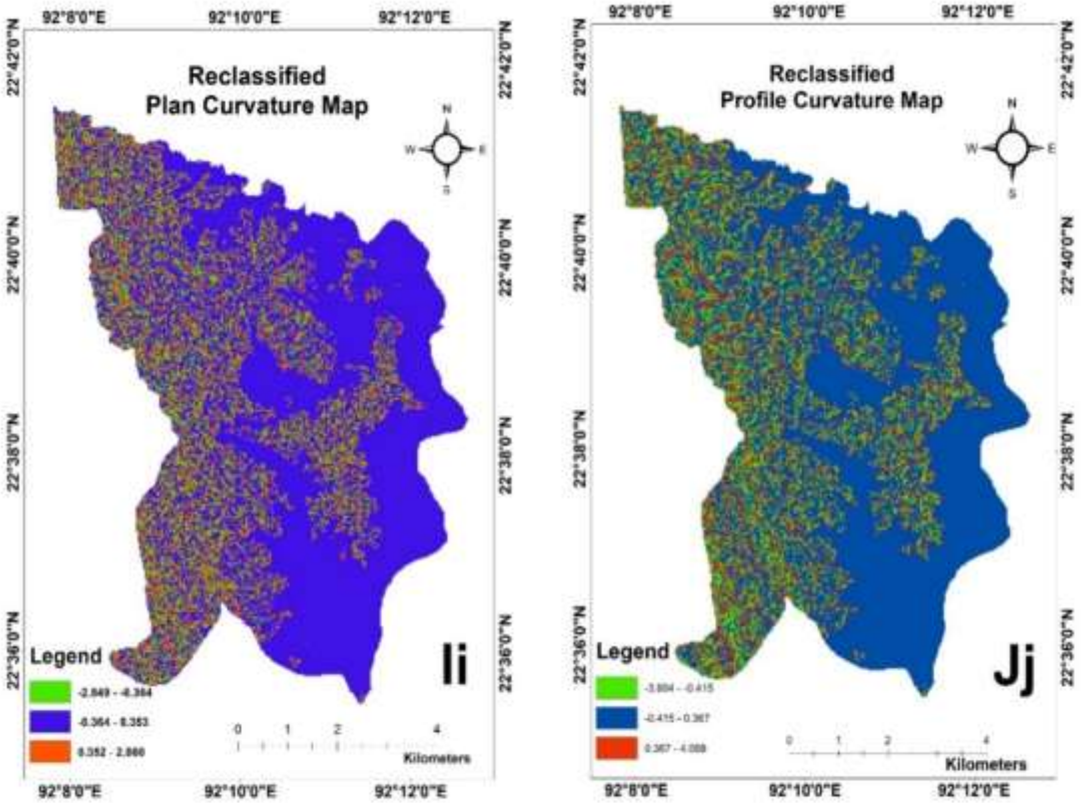

Figure 16: Reclassified factors map (e- geology map and d- reclassified stream distance map)

Table 6
The reclassified factors' layers subclasses, area of each sub-class, reclassified value, priority and ranking of factor's layers.

Parameters	Subclass	Value	Area	Priority (%)	Rank
Slope	0 – 2.45	1	2311.14	29.0	1
	2.45 – 6.72	2	1278.08		
	6.72 – 11.61	3	1039.52		
	11.61 – 18.33	4	594.01		
	18.33 – 38.97	5	189.22		
Elevation	10 – 28	1	3154.08	21.6	2
	28 – 46	2	1099.63		
	46 – 68	3	632.65		
	68 – 97	4	425.03		
	97 – 199	5	100.60		
Land use	Agriculture and bare land	2	2283.696	10.0	4
	Waterbody	1	1214.74		
	Vegetation	3	1380.952		
	Infrastructure	4	522.6508		
Surface geology	Bed	2	1070.91	14.9	3
	lake	1	4340.88		
NDVI	-0.15 - 0.016	1	2425.95	8.4	5
	0.016 – 0.16	3	991.17		
	0.16 – 0.30	5	396.54		
	0.30 – 0.40	4	988.74		
	0.40 – 0.58	2	609.57		
Aspect	-1 – 39.71	1	2264.08	2.6	8
	39.71 – 115.144	2	939.298		
	115.144– 194.74	4	695.0826		
	194.74 – 278.42	5	773.1328		
	278.42 – 359.52	3	740.3229		
Plan Curvature	-2.84 – (-0.33)	3 (concave)	3861.05	1.7	9
	-0.33 – 0.37	1 (flat)	768.68		
	0.37 – 2.86	2 (convex)	782.18		
Profile Curvature	-3.6 – (-0.41)	2 (convex)	3784.15	1.7	10
	-0.41 – 0.37	1 (flat)	779.02		
	0.37 – 4.19	3 (Concave)	848.79		
Stream distance	0 – 331.25	5	6.127649	6.1	6
	331.25 – 738.94	4	42.54002		
	738.94 – 1261.3	3	225.6625		
	1261.3 – 1872.85	2	1791.159		
	1872.85 – 3248.85	1	3345.578		
Road distance	0 – 398.168	5	19.15294	4.0	7
	398.168 – 987.45	4	87.4423		
	987.45 – 1656.38	3	342.7008		
	1656.38 – 2436.79	2	1041.897		
	2436.79 – 4061.32	1	3921.451		

In AHP analysis, ranking and priority of causative factors were derived by conducting pairwise comparison. The ranking and priority of each factor's layer is given in table 6 and the consistency ratio (CR) of pairwise comparison is 9.3%. From pairwise comparison, the most landslide susceptible factor is slope (29% priority) and low susceptible factors are plan curvature and profile curvature (1.7% priority).

Susceptibility Map (AHP): In this study, the susceptibility maps were evaluated for identifying the area and landslide distribution of each susceptible zone shown in table 7. In case of WOM, high susceptible zone covers about 16.2%, moderate susceptible zone covers about 41.63% and low susceptible zone covers about 42.17% of total area (Figure 11). In this analysis, high landslide location was found in moderate susceptible zone and it represents about 58.82% landslide location of total landslide location based on field inventory. High susceptible zone also covers about 41.18% landslide location and low susceptible zone does not represent any landslide occurrences. The details susceptibility result of WOM are shown in table 7.

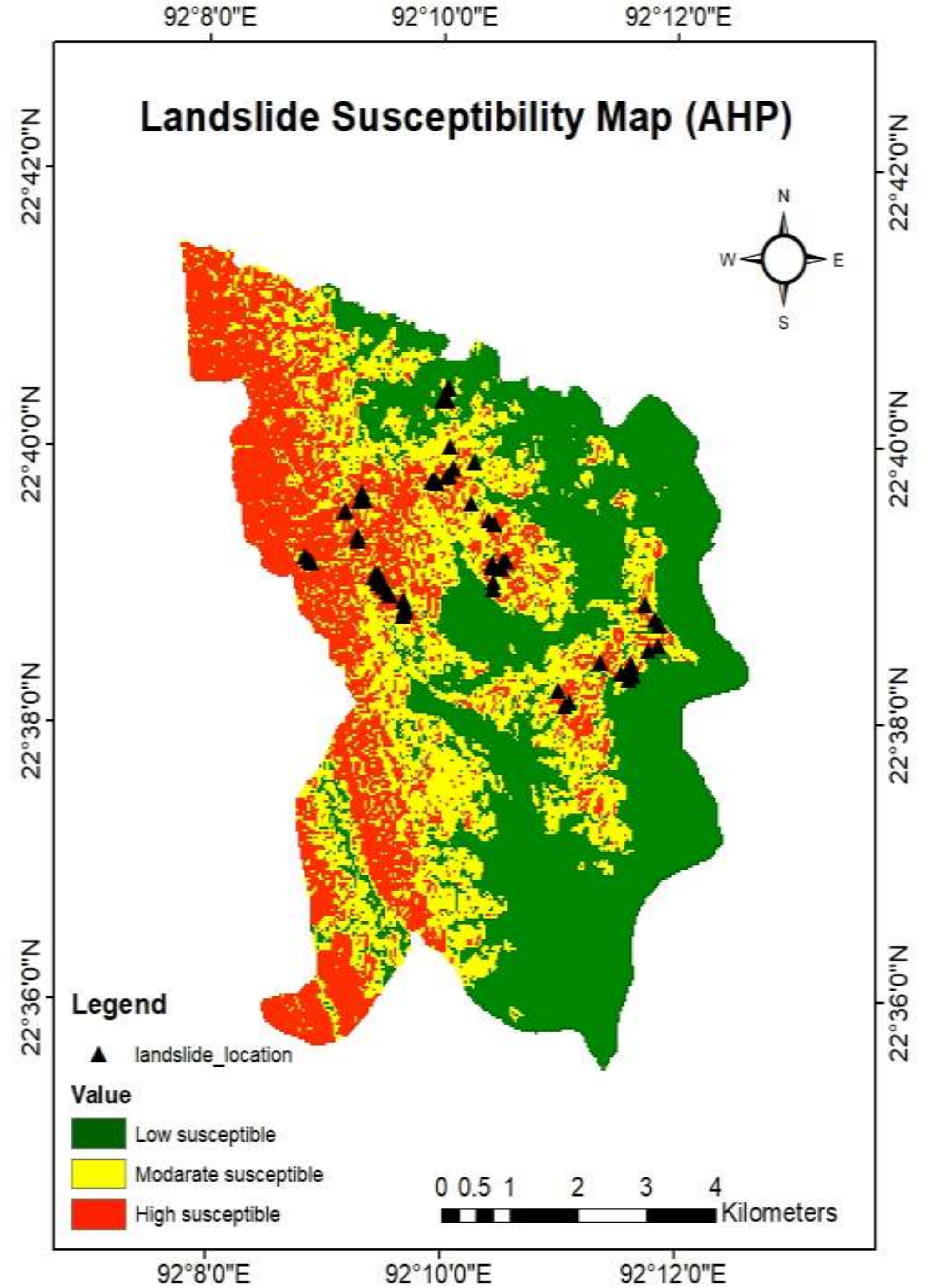

Figure 17: landslide susceptibility map by using AHP method.

Table 7
Class area of susceptibility map and landslide distribution (WOM).

Value	Class	Area (Ha)	Percentage of area	Landslide distribution	Percentage of landslide distribution
1	Low susceptible	2282.054	42.17%	0	0%
2	Moderate susceptible	2252.972	41.63%	40	58.82%
3	High susceptible	876.9736	16.20%	28	41.18%

Table 8
Class area of susceptibility map and landslide distribution (AHP)

Value	Class	Area	Percentage %	Landslide distribution	Percentage %
1	Low susceptible	2385.615	44.08	1	1.47
2	Moderate susceptible	1632.669	30.17	28	41.18
3	High susceptible	1393.716	25.75	39	57.35

In case of AHP method, low susceptible zone covers most of the area of the study area about 44.08% but it represents only 1.47% of landslide occurrences based on landslide inventory. The moderate susceptible zone covers about 30.17% of the area and represents about 41.18% of landslide occurrences (Figure 17). The high susceptible zone covers about 25.75% area of the total area and represents most of the landslide occurrences about 57.35%. The details of susceptibility results of AHP method are shown in the table 8.

Based on inventory map and field investigation, ward no. 6 and ward no. 9 were found as of most landslide locations. Rest of the wards such as 2, 3, 4, 5, 8 were identified as of less landslide location and ward no. 1 and 7 were not identified as of landslide location. Based on analyzed maps, ward no. 5, 6 and 9 are representing most of the high landslide susceptibility area and ward no. 2, 3, 4, 8 are representing less high susceptible area with moderate susceptible area. Low susceptible area mainly represents the water body in this study area. Total 68 landslide locations were identified based on field visits.

Those locations were used for accuracy of landslide susceptibility maps. Based on these analysis results, most of the landslide locations are found in high susceptible zone and moderate susceptible zone.

We can also claim that the analysis results or susceptibility maps represent the true picture of the study area. But it is difficult to say that the result or analysis is perfectly accurate because MCDA methods have also some limitations. MCDA methods are generally based on weighting the factors maps and overlaying of those layers.

In this case, any incorrect perception on the role of different layers criteria can change the output result. The errors can also occur in assigning factors weights of each layers and sub-classes, classifying factors maps and defining the susceptibility zones qualitatively[1-3]. So, it is important to keep the limitation as less as possible. The factors weights can be obtained through expert opinions, literature review and field survey.

Moreover, appropriate weighting combination also depends on the researcher's or policy makers' decision[1-3]. In this study, 10 causative factors layers were used and classified into different subclasses for landslide susceptibility map preparation. Those layers and sub classes were assigned in different weights for both methods to produce landslide susceptibility map.

Conclusion

Landslide is a common natural hazard in Chittagong Hill Districts, especially during the rainy season. High hill slope, deforestation, hill cutting, excessive rainfall and settlement on hill slope are the main reasons of landslide occurrences in this area. The main objectives of this research are to prepare acceptable landslide susceptibility maps for Rangamati Pourosova through which to reduce the landslide disaster and develop mitigation strategies. In this study, ward no. 6 and ward no. 9 were found as of most landslide locations.

In case of WOM, high susceptible zone covers about 16.2%, moderate susceptible zone cover about 41.63% and low susceptible zone cover about 42.17% of total area. For AHP method, low susceptible zone covers most of the area of the study area about 44.08%, the moderate susceptible zone covers about 30.17% and the high susceptible zone covers about 25.75% area of the total area.

Our findings provide fundamental information for landslide assessment which helps for further research in future. For landslide inventory, landslide locations are crucial. About 68 landslide locations were identified in Rangamati Pourosova.

Accessing to the previous landslide locations was difficult due to harsh topographical feature, new vegetation and transportation system which hindered data collection process. For that reasons, some landslide locations were not identified.

Recommendations

- Highly vulnerable landslide households should be identified based on the susceptibility maps and necessary steps should be taken to mitigate the landslides impacts.
- Regular monitoring of the hill cutting and hill slope settlement needs to be ensured.
- Awareness among the local people about hill cutting, hill slope settlement should be increased.
- Developing early warning system especially in rainy season is necessary.

References

1. Ahmed B., Landslide susceptibility mapping using multi-criteria evaluation techniques in Chittagong Metropolitan Area, Bangladesh, *Landslides*, **12**, 1077–1095 **(2015)**

2. Ahmed B., Rahman, M.S., Rahman, S., Huq F.F. and Ara S., Landslide Inventory Report of Chittagong Metropolitan Area, Bangladesh **(2014)**

3. ArcGIS for Desktop, Help, NDVI function [WWW Document]. URL http://desktop.arcgis.com/en/arcmap/10.3/manage-data/raster-and-images/ndvi-function.htm (accessed 2.23.19) **(2019)**

4. Ayalew L. and Yamagishi H., The application of GIS-based logistic regression for landslide susceptibility mapping in the Kakuda-Yahiko Mountains, Central Japan, *Geomorphology*, **65**, 15–31 **(2005)**

5. Bajracharya S.R. and Maharjan S.B., Landslides induced by June 2017 rainfall in Chittagong Hill Tracts, Bangladesh, Cause and Prevention, Field Report, Kathmandu **(2018)**

6. Cevik E. and Topal T., GIS-based landslide susceptibility mapping for a problematic segment of the natural gas pipeline, Hendek (Turkey), *Environmental Geology*, **44**, 949–962 **(2003)**

7. Chittagong Hill Tracts Development Facility (CHTDF), Earthquake Risk Reduction and Recovery Preparedness Programme in Chittagong Hill Tracts Area **(2019)**

8. Geological Survey of Bangladesh, Geological Survey of Bangladesh [WWW Document], Geological Survey of Bangladesh, URL http%3A%2F%2Fwww.gsb.gov.bd%2Fsite%2Fview%2Fcommondoc%2FMineral%2520Resources%2520Map%2F- (accessed 3.8.19) **(2019)**

9. Guzzetti F., Reichenbach P., Cardinali M., Galli M. and Ardizzone F., Probabilistic landslide hazard assessment at the basin scale, *Geomorphology*, **72**, 272–299 **(2005)**

10. Highland L. and Bobrowsky P.T., The landslide handbook: a guide to understanding landslides, US Geological Survey Reston **(2008)**

11. Huang J., Investigation on landslide susceptibility using remote sensing and GIS methods, Open Access Theses and Dissertations, https://repository.hkbu.edu.hk/etd_oa/33 **(2014)**

12. Islam M.A., Murshed S., Kabir S.M., Farazi A.H., Gazi M.Y., Jahan I. and Akhter S.H., Utilization of Open Source Spatial Data for Landslide Susceptibility Mapping at Chittagong District of Bangladesh—An Appraisal for Disaster Risk Reduction and Mitigation Approach, *International Journal of Geosciences*, **8**, 577 **(2017)**

13. Kirkby M.J. and Carson M.J., Hillslope form and process, Cambridge [Eng.], University Press **(1972)**

14. Marana B., A Simplified ArcGIS Approach for Landslides Risk Assessment in the Province of Bergamo, *Journal of Geographic Information System*, **9**, 699–716 **(2017)**

15. Mondal S. and Maiti R., Landslide susceptibility analysis of Shiv-Khola watershed, Darjiling: a remote sensing & GIS based Analytical Hierarchy Process (AHP), *Journal of the Indian Society of Remote Sensing*, **40**, 483–496 **(2012)**

16. Moradi M., Bazyar M.H. and Mohammadi Z., GIS-based landslide susceptibility mapping by AHP method, a case study, Dena City, Iran, *Journal of Basic and Applied Scientific Research*, **2**, 6715–6723 **(2012)**

17. Pardeshi S.D., Autade S.E. and Pardeshi S.S., Landslide hazard assessment: recent trends and techniques, *Springer plus*, **2**, https://doi.org/10.1186/2193-1801-2-523 **(2013)**

18. Saaty T.L., Decision making with the analytic hierarchy process, *International Journal of Services Sciences*, **1**, 83–98 **(2008)**

19. Saaty T.L., Decision-making with the AHP: Why is the principal eigenvector necessary, *European Journal of Operational Research*, **145**, 85–91 **(2003)**

20. Smith K., Environmental hazards: assessing risk and reducing disaster, Routledge **(2003)**

21. Tyoda Z., Landslide susceptibility mapping: remote sensing and GIS approach (Thesis), Stellenbosch, Stellenbosch University **(2013)**

22. Wilson J.P. and Gallant J.C., Secondary topographic attributes, Terrain analysis, Principles and applications, 87–131 **(2000)**.

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