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Urban
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URP

Landslide Hazard Mapping in Chittagong Metropolitan Area Implementing the Analytical Hierarchy Process

1. Introduction

Chittagong Metropolitan Area (CMA) is highly vulnerable to landslide hazard, with an increasing trend of frequency and damage. Devastating landslides have hit CMA (Fig. 1) repeatedly in recent years. The major recent landslide events were related to extreme rainfall intensities having short period of time. All the major landslide events occurred as a much higher rainfall amount compared to the monthly average. Moreover rapid urbanization, increased population density, improper landuse; alterations in the hilly regions by illegally cutting the hills, indiscriminate deforestation and agricultural practices are aggravating the landslide vulnerability in these cities[1]. At this drawback, it is therefore essential to determine the landslide prone areas of CMA(Fig. 1b) so that appropriate landslide risk reduction strategies can be developed. Producing up-to-date and accurate landslide susceptibility maps can ensure safety to people and property at risk and avoid extensive economic loss [2].

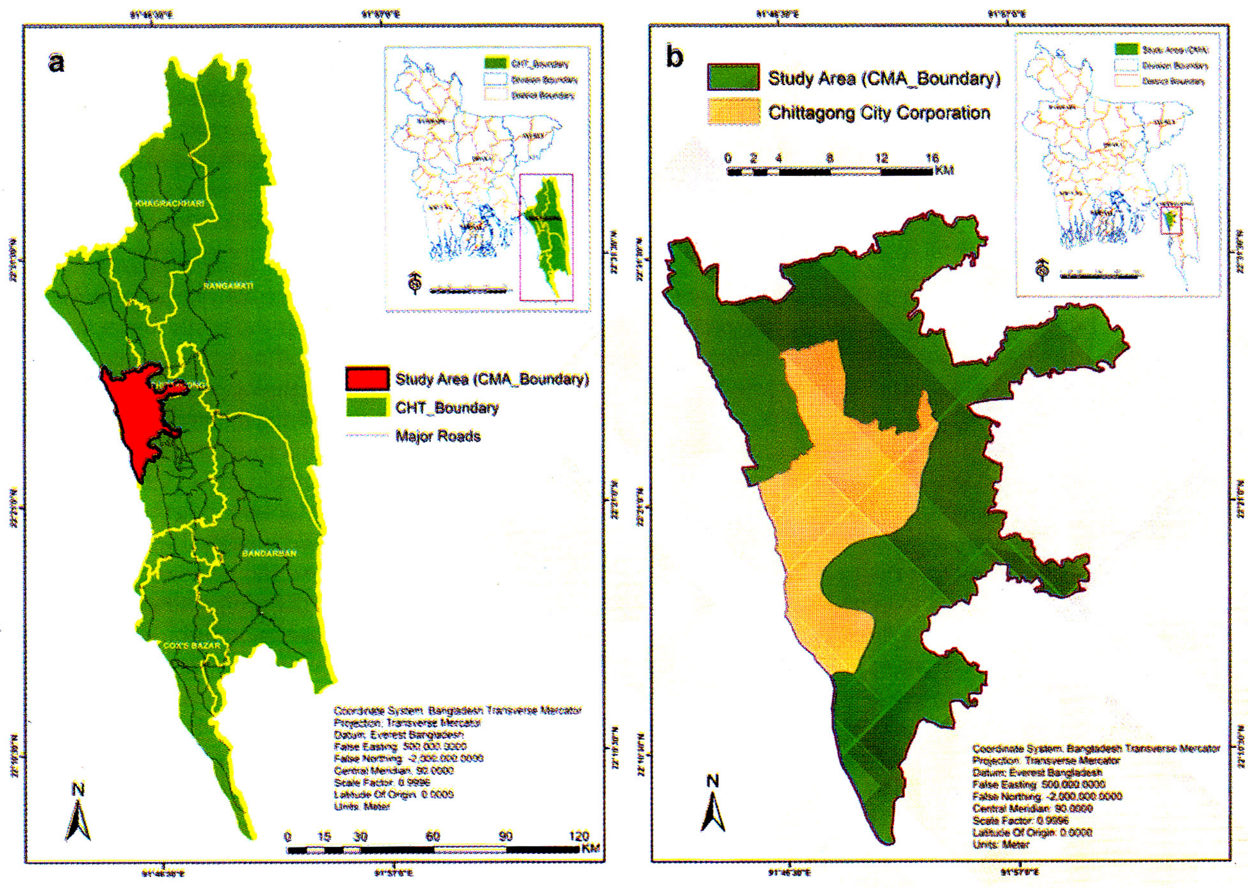

*Figure-1 : **(a)** Location of the study area in Chittagong hill tracts and **(b)** location of CMA*

2. Literary Works

Landslides are one of the most significant natural damaging disasters in hilly environments [3]. Social and economic losses due to landslides can be reduced by the means of effective planning and management. Geospatial technologies like the use of Geographic Information System (GIS), Global Positioning System (GPS) and Remote Sensing (RS) are useful in the hazard assessment, risk identification, and disaster management for landslides.

Mapping the areas that are susceptible to landslides is essential for proper landuse planning and disaster management for a particular locality or region. GIS based Multi Criteria Decision Analysis (GIS-MCDA) provides powerful techniques for the analysis and prediction of landslide hazards. These include the analytical hierarchy process (AHP), the weighted linear combination (WLC), the ordered weighted average (OWA) and so on [4].

Therefore, the primary objective of this article is to apply the AHP technique for the Landslide Susceptibility Mapping (LSM) in CMA, Bangladesh. The reason behind choosing the AHP is that it is widely being used in LSM in recent years.

3. Study Area Profile

Chittagong is the second-largest and main seaport of Bangladesh. The cityhas a population of about 5 millionand is constantly growing [5]. The study area, CMA, issituated within 22° 14′ and 22° 24′ 30″ North Latitude and between 91° 46′ and 91° 53′ East Longitude (Fig. 1b).The total area of CMA is approximately 775 square kilometres (Bangladesh Transverse Mercator projection).

The weather of the Chittagong Hill Tract (CHT) region (Fig. 1a) is characterised by tropical monsoon climate with mean annual rainfall nearly 2540 mm in the north- east and 2540 mm to 3810 mm in the south-west. The monsoon season is from June to October, which is warm, cloudy and wet [6].Moreover, due to climate change, CMA is experiencing high intensity of rainfall in recent years which is making the landslide situation worse [7]. A gradual upward shift in precipitation has been noted in the last five decades (1960-2010), with an abrupt fluctuation in the mean annual precipitation levels (Fig. 2).

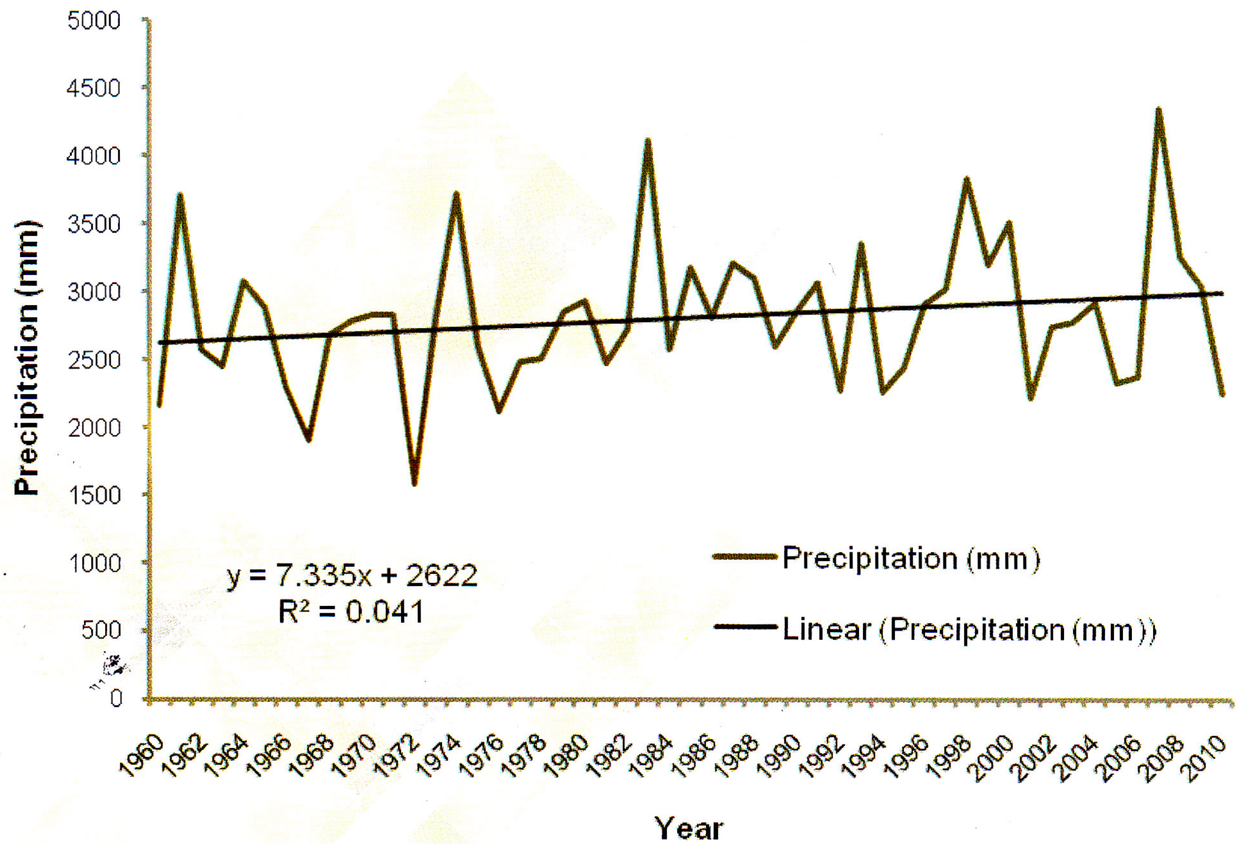

Figure-2 : Annual rainfall patternof Chittagong city from 1960-2010. Data source: Bangladesh Meteorological Department, 2013.

In general, the geological structures and soils are weak in CMA. Moreover the hills have steep slopes that are vulnerable to landslides [1]. The landslides in CMA were classified as 'earth slides' since those consist of 80% sand and finer particles. These landslides were shallow in nature and occurred just during/after the rainfall. It has been stated that the rainfall intensity and duration play very important role in producing these shallow landslides in CMA.Figure 3 depicts how people of Matijharna, a residential area within CMA, are living at the risks of landslide hazards. On 11 June 2007, about 128 people died and 100 others were injured exactly in this area due to landslides triggered by heavy rainfall for continuous 8 days.

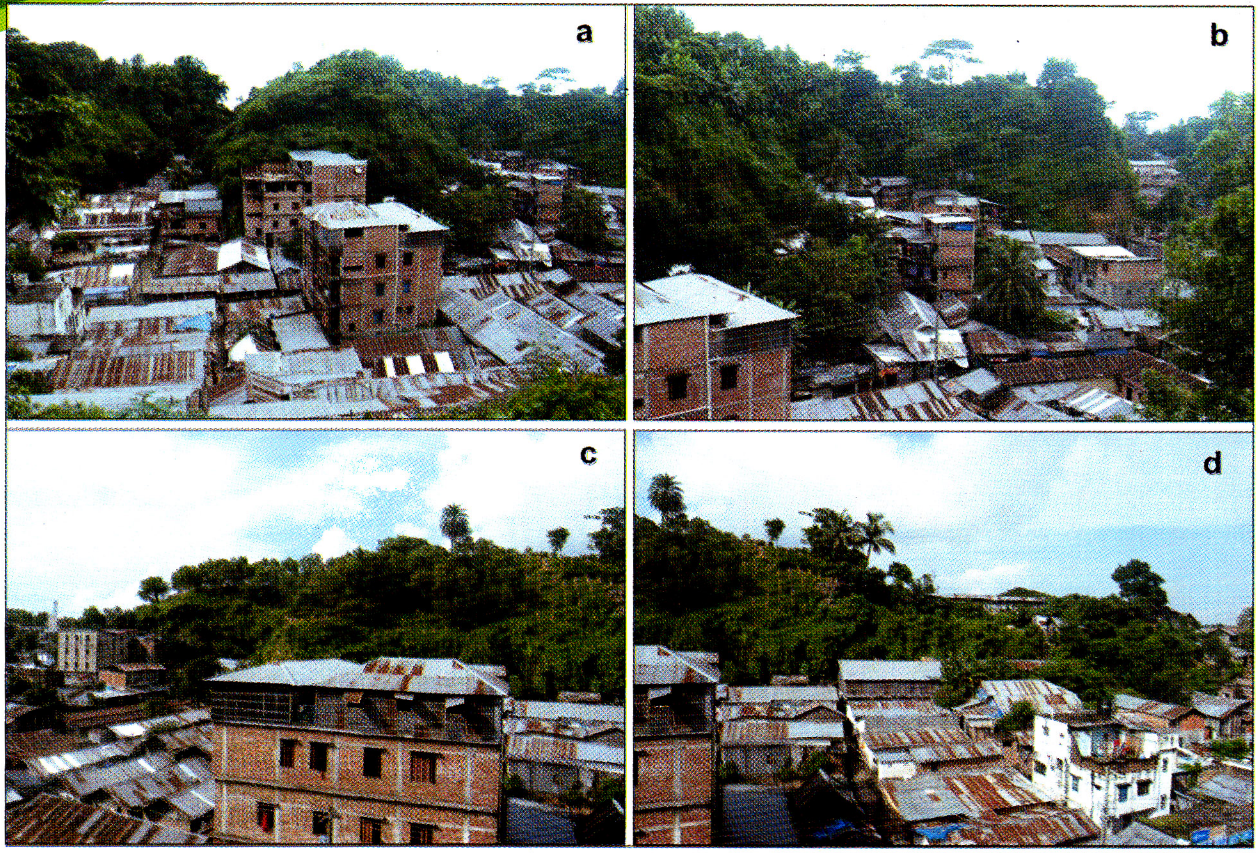

Figure-3 : Landslide vulnerable areas inMatijharna, CMA (Source: Field visit, September, 2013)

4. Data Collection

To produce the landslide susceptible map, it is important to know the causative factors and prepare the necessary thematic layers. For this research purpose, nine different GIS layers (land cover, precipitation, Normalized Difference Vegetation Index (NDVI), elevation, slope; distance from roads, stream and drain, and soil permeability map) have been produced for LSM. The datasets were collected from the Chittagong Development Authority (CDA), Geological Survey of Bangladesh, USGS, ASTER and Landsat images. All the raster images (30×30 m) were projected to 'BangladeshTransverseMercator (BTM)' using 'Everest Bangladesh' datum. Moreover, where necessary, the maps were classified using Natural Breaks (Jenks) method with 5 classes. Moreover, a total of 20 landslide locations were identified in CMA through field visit for model validation.

5. Analytical Hierarchy Process

The AHP method [8] is used to derive the weights associated with suitability/attribute map layers.Later the weights can be combined with the attribute map layers [9]. AHP can deal with complex decision making and also useful for checking the consistency of the evaluation measures as suggested by the decision makers. The input of this method can be price, weight etc. AHP builds a hierarchy of decision criteria through pairwise comparison of each possible criterion pair [4].

The weights can be derived by taking the principal eigenvector of asquare reciprocal matrix of pairwise comparisons between the criteria. It is also necessary that theweights sum to one. The comparisons concern the relative importanceof the two criteria involved in determining suitability for the stated objective. Ratings are provided on a 9-point continuous scale: (1/9, 1/8, 1/7,1/6, 1/5, 1/4, 1/3, 1/2, 1, 2, 3, 4, 5, 6, 7, 8, 9). The values range from 1/9 representing theleast important (than), to 1 for equal importance and to 9 for the most important (than),covering all the values in the set [10].It is also possible to determine the degree of consistency that has beenused in developing the ratings [10]. It is a procedure by which an index of consistency, known as a consistency ratio (CR), can be produced.The CR indicates the probability that the matrix ratings were randomly generated. Itis stated thatmatrices with CR ratings greater than 0.10 should be re-evaluated [8].

6. Analysis and Results

Calculating factors weights has a crucial role in the production of landslide susceptibility maps when applying the

MCDA methods [2]. The calculation of relative weights of the factors was based on experts' opinions, analysing landslide inventory map and knowledge obtained from field surveying.

To apply the AHP method, first it is necessary to construct a pairwise matrix. Then both the weight values of sub-criteria of the criterions and thedatasets/ factors were calculated (Table 1 and Table 2).In the next step, the CR was calculated in order to determine whether the pairwise comparisons were consistent or not [8]. In this research, the resulting CR for all the cases was found less than 0.10 (Table 1 and Table 2). It means the relative weights were appropriate and the comparisons were consistent [8].

It was observed that the highest weight was assigned to soil permeability map. Slope, elevation, land cover and NDVI factors were also found effective. The other layers (i.e., precipitation, distance to drain, road, and stream) were identified as less important (Table 2).

Table-1 : Pairwise comparison matrix, consistency ratio and weights of the sub-criteria of the data layers

Factors	(1)	(2)	(3)	(4)	(5)	Eigen values
Distance to drain (m)						
(1) 0 – 934.3992953	1					0.0448
(2) 934.3992954 – 1,940.67546	2	1				0.0699
(3) 1,940.675461 – 3,234.459099	3	2	1			0.1098
(4) 3,234.4591 – 5,318.888297	6	4	3	1		0.2408
(5) 5,318.888298 – 9,164.300781	7	6	5	4	1	0.5346
Consistency ratio: 0.04						
Elevation (m)						
(1) 2 – 8	1					0.0501
(2) 8.000000001 - 17	3	1				0.0964
(3) 17.00000001 - 29	4	2	1			0.1521
(4) 29.00000001 – 43	6	5	4	1		0.4548
(5) 43.00000001 – 67	4	3	2	1/2	1	0.2465
Consistency ratio: 0.03						
Land cover						
(1) Water body	1					0.0434
(2) Vegetation	3	1				0.1196
(3) Urban area	7	6	1			0.5019
(4) Semi-urban area	5	4	1/3	1		0.2537
(5) Bare soil	3	1/3	1/5	1/3	1	0.0814
Consistency ratio: 0.08						
NDVI						
(1) 0 – 0.055633098	1					0.4380
(2) 0.05563098 – 0.131871048	1/2	1				0.2913
(3) 0.131871048 – 0.203988027	1/4	1/3	1			0.1544
(4) 0.203988027 – 0.300830828	1/5	1/4	1/3	1		0.0881
(5) 0.300830828 – 0.525423706	1/9	1/8	1/7	1/6	1	0.0282
Consistency ratio: 0.07						
Precipitation (mm)						
(1) 2,870 – 2,880	1					0.0618
(2) 2,880.000001 – 2,900	2	1				0.0973
(3) 2,900.000001 – 2,930	3	2	1			0.1599
(4) 2,930.000001 – 2,970	4	3	2	1		0.2625
(5) 2,970.000001 – 3,000	5	4	3	2	1	0.4185
Consistency ratio: 0.02						
Distance to road (m)						
(1) 0 – 161.5549469	1					0.4185
(2) 161.554947 – 371.0794983	1/2	1				0.2625
(3) 371.0794984 - 711.196167	1/3	1/2	1			0.1599
(4) 711.1961671 – 1,210.826172	1/4	1/3	1/2	1		0.0973
(5) 1,210.826173 – 2,139.275635	1/5	1/4	1/3	1/2	1	0.0618
Consistency ratio:0.02						
Slope (°)						
(1) 0 – 1.222515914	1					0.0515
(2) 1.222515915 – 3.124207336	2	1				0.0718
(3) 3.124207337 – 5.976744469	3	4	1			0.1565
(4) 5.97674447 – 9.780127312	7	6	5	1		0.4869
(5) 9.780127313 – 34.6379509	4	3	2	1/2	1	0.2333
Consistency ratio:0.04						
Soil permeability						
(1) Mixed moderate	1					0.0385
(2) Moderate	2	1				0.0522
(3) Rapid	3	4	1			0.1088
(4) Slow	5	4	3	1		0.1900
(5) Very slow/low	9	8	7	6	1	0.6105
Consistency ratio:0.08						
Distance to stream (m)						
(1) 0 – 90.86816789	1					0.3999
(2) 90.8681679 – 237.6552083	1/2	1				0.2427
(3) 237.6552084 – 454.3408395	1/3	1/2	1			0.1592
(4) 454.3408396 – 789.8540748	1/3	1/2	1/2	1		0.1200
(5) 789.8540749 – 1,782.414063	1/4	1/3	1/2	1/2	1	0.0783
Consistency ratio:0.02						

Table 2. Pairwise comparison matrix, factor weights and consistency ration of the data layers

Factors	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	Eigen values
(1) Distance to drain	1									0.0469
(2) Elevation	5	1								0.1989
(3) Land cover	3	1/3	1							0.0975
(4) NDVI	2	1/4	1/2	1						0.0706
(5) Precipitation	1/3	1/7	1/4	1/3	1					0.0366
(6) Distance to road	1/3	1/8	1/6	1/5	1/2	1				0.0243
(7) Slope	5	1	5	4	3	6	1			0.1989
(8) Soil permeability	7	2	5	6	8	9	2	1		0.3074
(9) Distance to stream	1/2	1/7	1/6	1/5	1/4	1/3	1/7	1/8	1	0.0190
Consistency ratio: 0.07										

After applying the AHP generated weights in the data layers, the resulting map was reclassified into three meaningful levels as: low, medium and high susceptibility zones (Fig. 4). This is helpful for presentation and evaluation purposes.

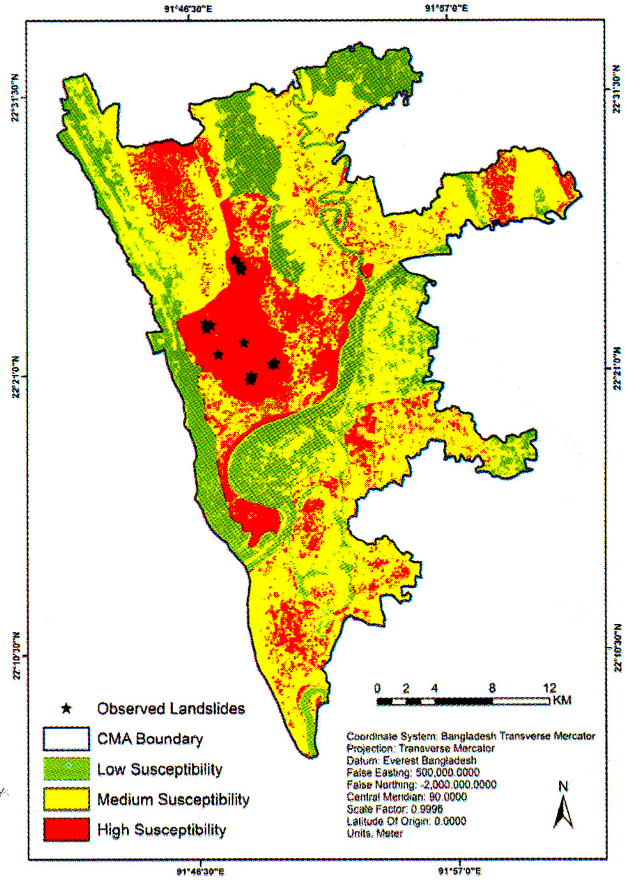

Figure 4. Landslide susceptibility map derived from AHP method

At first, the landslide susceptibility map was evaluated qualitatively. It helps to select the most appropriate method for LSM for a particular area [4]. In case of the AHP method, high susceptibility zones cover about 22.713% of the total area, while about 53.609% was classified as medium susceptible and the remaining 23.677% area was classified as being a low susceptible zone. Then the accuracy of the landslide susceptibility map was determined quantitatively. To do this, the landslide inventory map with 20 known landslide events was compared with the respective susceptibility map derived from the AHP method. For the AHP method, the comparison shows that 100% of the known landslides fall into the high susceptibility zone. No known landslide event is observed in the remaining categories.

7. Conclusion

Landslides are a common problem in highly urbanized hilly areas of Chittagong city, especially during the rainy season. The preparation of landslide susceptibility map is the first step towards the reduction of this hazard. But it is also important to create awareness among the local people based on the predictive landslide susceptibility maps. Moreover, developing early warning system; increasing cooperation among different public/autonomous/non-governmental organizations,launching public awareness campaign; and generating facilities for proper evacuation system in crisis moments are highly recommended.

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