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EVALUATION OF LANDSLIDE SUSCEPTIBILITY OF THE CHITTAGONG CITY USING THE METHOD OF MULTI CRITERIA ANALYSIS (MCA)

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ABSTRACT

Landslide has become a major concern for Bangladesh in the recent past. Even in medium rainfall, it is occurring with an increasing trend of frequency and causing huge damages to people, property, and resources. Chittagong division has become more susceptible to this hazard. In this study, we focused only on Chittagong City as it is one of the major metropolitan city having ample importance of its own. Here, the study is undertaken to assess the landslide susceptibility of the Chittagong City. Various open source spatial data and previous studies were used for the analysis and to show the huge possibility of remote sensing and GIS in the very field. Multi Criteria Analysis (MCA) method which is a heuristic approach was used to determine the Landslide Susceptibility Index (LSI). As per the experts of different discipline, seven key factors like slope, land use, and land cover etc. Are combined to assess the major criterion of the LSI and the higher value of LSI, indicates greater susceptibility. Finally, the susceptibility maps were generated for the region which will be essential to analyze the future landslide susceptibility of Chittagong City.The result of the study indicates a major portion of Chittagong City as susceptible to this hazard. With this study, appropriate landslide mitigation strategies can be taken by the local authorities and other stake-holders, concerned in disaster risk reduction and mitigation activists. Moreover, this study can also be advantageous for risk sensitive land use planning in the study area

Keywords: *Landslide, Susceptibility, Slope, Land use, GIS and Remote Sensing.*

1. INTRODUCTION

1.1 Background of the Study

The term ‘landslide’ is a geomorphic process by which soil, sand, and rock move downslope typically as a mass, largely under the force of gravity. But there are other contributing factors that affect the original slope stability [1]. Landslide is one of the most catastrophic natural disaster in hilly areas causing huge damages to mankind, properties and national economy. It also creates natural and ecological imbalance [2]. Chittagong Metropolitan Area (CMA) is highly susceptible to landslide hazard, with an increasing trend of frequency and damage. The major recent landslide events were related to extreme rainfall intensities having short period of time. Besides, rapid urbanization, growing population density, unplanned land use, cutting the hills i.e. illegal alterations in the hilly regions, indiscriminate deforestation, and agricultural practices are triggering the events of landslides in CMA [3]. In addition, the absence of strict hill management policy also worsen the situations. This has encouraged many informal settlements along the landslide-prone hill-slopes in Chittagong. Though these settlements are being considered as illegal, the settlers claim themselves as legal occupants. As a result, the conflict among the formal authorities, the settlers, and the local communities over the past few decades has also weakened the institutional arrangement for reducing the landslide vulnerability in Chittagong City [4].

Therefore determination of the landslide prone areas in CMA is a crying need for developing appropriate landslide disaster risk reduction strategies. Hence, an up-to-date and accurate landslide susceptibility maps can ensure safety to mass people and their property at risk and avoid the immense economic loss [5].

The susceptibility was measured in terms of Land Susceptibility Index (LSI) which is the relative spatial likelihood for the occurance of landslide. A heuristic approach has been used in the study to assess the susceptibility of the area named Multi Criteria Analysis. This might not be the guaranteed optimal approach but given the complexity, it is an approach to problem solving. The approach makes the options and their contribution to the different criteria explicitly and for the different criteria, measures those explicit relative weighting system. [6].

1.2 Study Area

Chittagong is the second largest both in size and importance and main seaport of Bangladesh, situated on the banks of the Karnaphuli River between the Chittagong Hill Tracts and the Bay of Bengal. It is situated within 22° 14' and 22° 24' 30" North Latitude and between 91° 46' and 91° 53' East Longitude[7]. The administrative boundaries divided Chittagong City into Chittagong Statistical Metropolitan Area, Chittagong Metropolitan Area, and Chittagong City Corporation. The study area for this research is Chittagong Metropolitan Area (Figure 1).

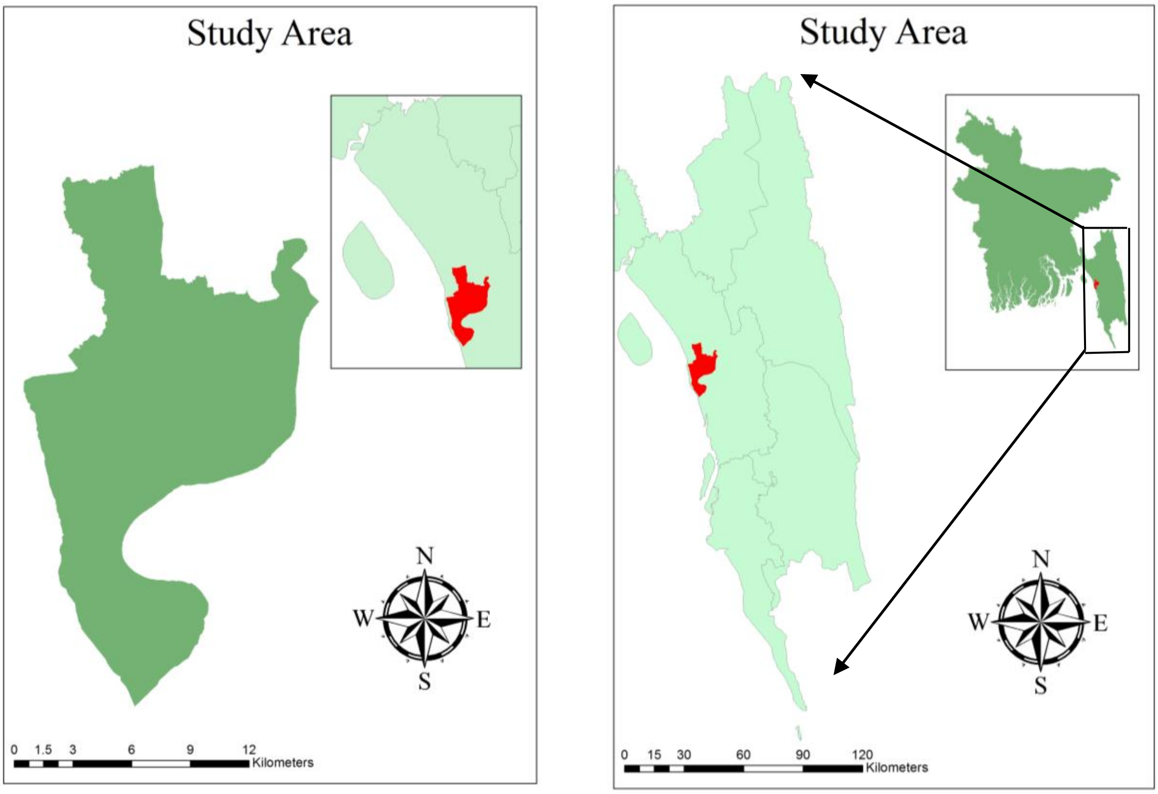


Figure-1 Map Showing the Chittagong Metropolitan Area and Chittagong City Corporation.

1.3 Objective of the Study

The aim of this research is to prepare the Landslide Susceptibility Mapping (LSM). The specific objectives of this research work are in the following:

(a) Landslide Susceptibility map generation.
(b) Preparing a handful materials for landslide mitigation strategies and risk sensitive land use planning.

2. LITERATURE REVIEW

Landslide hazard assessment is generally based on the concept that ‘the present and the past are keys to the future’. For this reason, most landslide hazard analyses take into account an up-to-date landslide inventory which represents the fundamental tool for identifying the factors causing landslides [8]. Different types of Geospatial technologies like the use of GIS, Global Positioning System (GPS), and Remote Sensing (RS) are useful in the hazard assessment and risk identification. The use of GIS for landslide mapping is common in various studies. Remote sensing (RS) is also used for monitoring and mapping of landslides [9].Mapping the susceptible areas is an essential task for proper land use planning and disaster management. This results in Social and economic losses due to landslides [10].

Throughout the years, different techniques and methods have been developed and applied for generating landslide susceptibility maps. These can be produced using both the quantitative or qualitative approach [11].Qualitative approaches weight each factors affecting the landslides based on the practical experience and expertise of the researcher [11]. Qualitative methods simply portray the hazard zoning in descriptive terms [12]. However, in recent decades quantitative techniques have become more popular because of the developments in computer programming and geospatial technologies.

There are mainly four methods available to map landslide susceptibility, namely landslide inventory based probabilistic, deterministic, heuristic, and statistical techniques [12]. Within these techniques, the probabilistic and statistical methods have been commonly used in recent years. These methods have become more popular, assisted by GIS and RS techniques [8]. Moreover, GIS-based Multi Criteria Analysis (GIS-MCA) provides powerful techniques for the analysis and prediction of landslide hazards. The primary objective of this paper is to apply GIS-MCA techniques for the Landslide Susceptibility Mapping (LSM).

3. DATA COLLECTION AND METHODOLOGY

3.1 Data Source and Spatial Techniques

Open source web portal namely United States geological survey (USGS) was used for all the spatial data required in this particular study. JAXA (Japan Aerospace Exploration Agency) DEM having spatial resolution of 30 m X 30 m was retrieved from (http://www.eorc.jaxa.jp/ALOS/en/aw3d30/data/index.htm) [13]. It was used for the preparation of various topographic parameters like slope, plan curvature, aspect, and relative relief of the current analysis. Geology information was taken from downloadable GIS data of Bangladesh which had been retrieved from U.S. Geological Survey Open-File Report. Retrieved from https://pubs.usgs.gov/of/1997/ofr-97-470/OF97-470H/linked_filepaths1.htm [14].

Slope, plan curvature and aspect maps were prepared from DEM file using spatial analyst tool of ArcGIS (version10.2). Before execution of these functions, a median filter was run over the entire DEM to minimize and remove artefacts. Next, the entire study area was divided by 30 m × 30 m grid size alongside each and individual grid filling with elevation range value for getting the relative relief map. This particular task had been done using geo-processing tools in ArcGIS (version 10.2). A vegetation map was generated by means of spectral enhancement techniques like NDVI. It comprises three major vegetation classes as high, moderate and low.

3.2 Parameter Weight Values

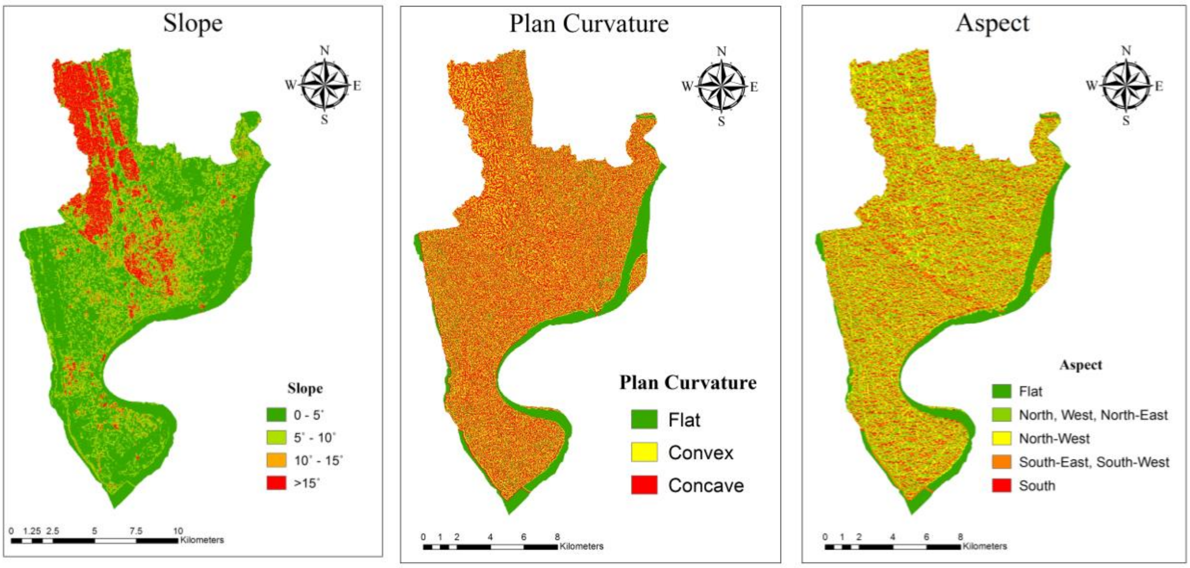
Landslide susceptibility parameters, their subclasses, and rating for individual parameters are given in Table 1.

Table-1 Weight and rank values for each and individual input parameters based on influence on landslide occurrence.

Parameter	Sub-Classes	Weight	Rank
[1] Slope	0°-5°	3	8
	5°-10°	4	
	10°-15°	6	
	> 15°	8	
[2] Plan Curvature	Flat	2	6
	Convex	3	
	Concave	6	
[3] Aspect	Flat	1	5
	North, West, North-East	2	
	North-West	3	
	South-East, South-West	7	
	South	8	
[4] Land Use/ Land Cover	River	2	4
	Urban	3	
	Vegetation	5	
	Roads	2	
[5] Geology	Beach, Dune Sand, Ocean and Wide River	1	3
	Vally Alluvium and Colluvium	3	
	Dihing Formation	4	
	Bhu-ban Formation	6	
	Tipam Sandstone	8	
[6] Relative Relief	< 15 m.	2	6
	15 m. - 25 m.	4	
	25 m. - 35 m.	6	
	35 m. - 45 m.	7	
	> 45 m.	8	
[7] Vegetation	High	3	3
	Moderate	5	
	Low	8	

The angle of the slope plays the most vital role in slope stability of a terrain. It is directly related to the landslides [15]. Moreover, residual soil gain more gravitation induced shear stress when the slope is potentially high resulting higher frequency of [16]. In this study, the entire study area was divided into 4 major slope classes. The past landslides put forward an observation that most of the slides were earth/debris flow, where natural slope angles were >15° [17]. This cognition led us to allotting higher weight value (i.e. 8) to this subclass. The other sub-classes are 0°-5°, 5°-10°, 10°-15° and their weight values are 3, 4 and 6 respectively.

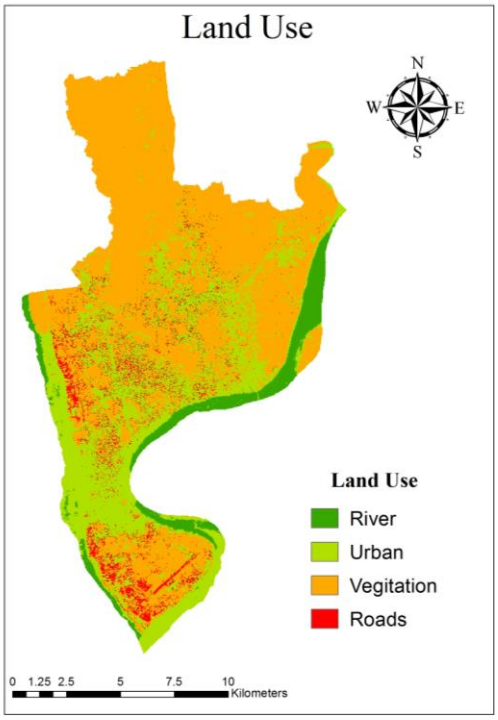
Plan curvature consists three sub-classes. Flat surface has no substantial influence in landslide thus given very low weight values as 2. Concave curvatures concentrate surface water and almost certainly trigger landslide activity, hence assigned high weight value as 6, on the other hand, in case of convex curvature surface water will diverge from slope toe thus imposing less threat to landslide, thereby, given low weight value as 3. Aspect infers exposure to sunlight and drying winds, those control the concentration of the soil moisture which may eventually control the occurrence of landslides [18]. The aspect map is divided into 5 classes as Flat; North, West, and North-East; North-West; South-East and South-West; South. Then, from the context that south, south east and south west facing slopes are more open to landslide in the studied area, higher weight values (i.e. 8, 7 and 7) were assigned to these classes, and rest of the subclasses were given lesser weight values within 1 to 3 since those are not likely to pose potential threat [19].



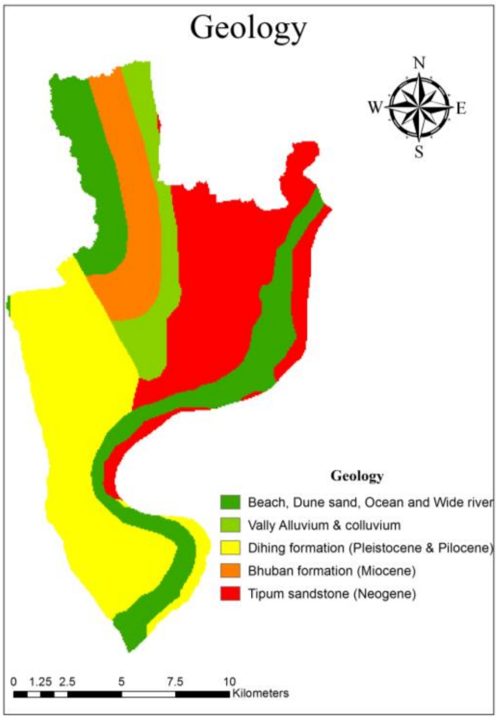
(a) (b) (c)

Figure-2(a) Slope map, (b) Plan curvature map and (c) Aspect map of the study area showing their subclasses.

Land use or land cover plays a vital role in landslide initiation. In general, the area was categorized as four classes' viz., river, urban, vegetation, and roads. Among them, vegetation areas were given highest weight value as 5, because sparsely vegetated areas exhibit faster erosion and more instabilities than forest area [20].Among the five geological units encountered in the study area Tipam / Dupi Tila formation, being comprised of, loose and less resistive sandstone layers account for maximum landslides in the study area; and thus alloted highest weight values 8 in context of landslide. Bhu-ban/Bokabill formation, on the other hand, are consist of hard and compact shale and believed to be comparatively less susceptible to landslide. Thereby, they are assigned moderate weight value as 6 in this study. Again, the Dihing Formation characterized by dominantly sand and clay lithology has given weight value 4. Rest of the units i.e. Beach, Dune Sand, Ocean and Wide River; valley alluvial and colluvial deposits, since not likely to pose any threat of landslides, are given very less weight values as 1 and 3 respectively. Relative relief is directly proportional to the probability of landslide occurrence as it controls several geologic and geomorphologic processes [19].The relative relief map of the study area has been divided into 5 classes: < 15 meter, 15 - 25 meter, 25 - 35 meter, 35 – 45 meter and > 45 meter: to show the susceptible relief of the study area. In metropolitan area, landslides occur in areas of relief above 30 meters; with this background knowledge, we put higher weight values to relief classes above 30 meter as 7 to 8.



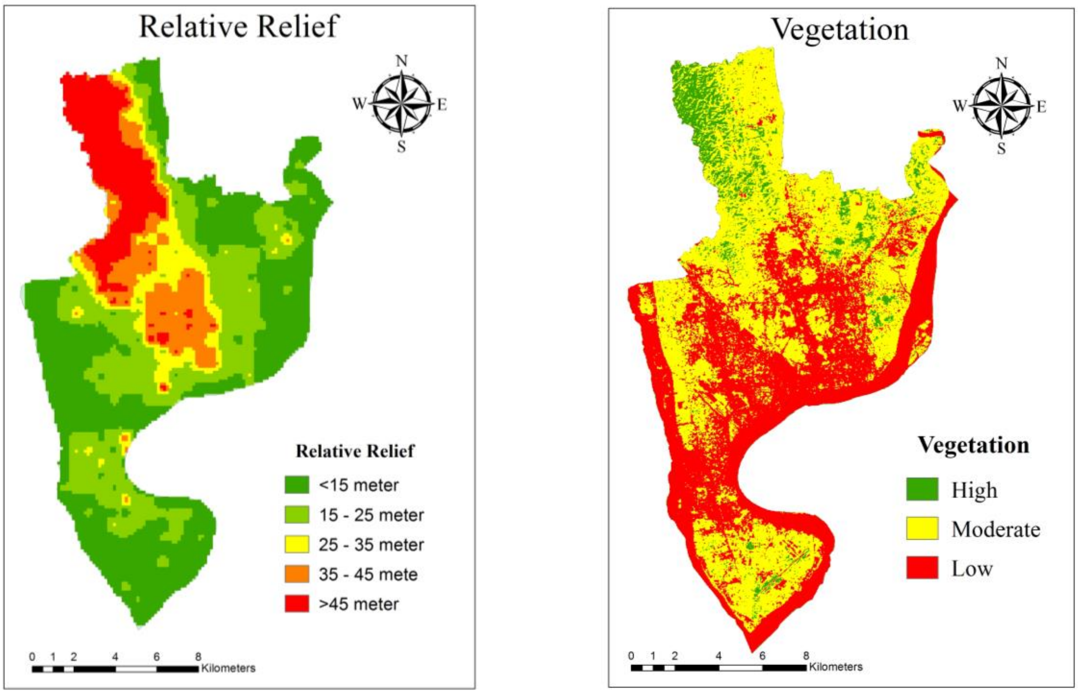
(a)



(b)

Figure-3(a) Land use map and (b) Geology map of the study area showing their subclasses.

Vegetation seems to be less risky to landslide, however, in this study, we adopted moderate weight value because of substantial occurrence of vegetation in the hilly areas of the study location. Slopes having sparse vegetation were assigned high weight value as 8 whereas moderate and high vegetation were given moderate weight values as 5 and 3 respectively [21].



(a) (b)

Figure-4(a) Relative relief map and (b) Vegetation map of the study area showing their subclasses.

3.3 Landslide Susceptibility Index (LSI) Mapping

The landslide susceptibility index (LSI) mapping was done with the conversion of all the spatial datasets to a common scale with weight and rank values. The reason of conversion into a common scale is that all the spatial dataset arrived from diverse source areas of the study region. Finally, integration of various thematic parameters in a single hazard index was accomplished by the procedure of weighted liner sum of the equation 1 [22].

$$LSI = \sum_{i}^{n} W_i * R_i \tag{1}$$

Where LSI is the ultimate landslide susceptibility index, W*i* is the weight of parameters subclasses, R*i* is the rank of the each and individual parameter. Once the integration was accomplished, using weighted overlay techniques in ArcGIS (version 10.2), the next step was the classification of the final outcomes.

4. RESULT AND DISCUSSION

LSI map depicts the division of land areas into zones of varying degree of stability, based on the estimated significance of the causative factors for inducing instability [23]. Using the weightage values discussed above landslide susceptibility maps were generated. The result exhibits that the values range from 79 to 258.Despite of observing the distributed pattern in histogram appearance, we applied three classification methods—natural break (79-129 as low, 129-169 as moderate and 169-258 as high risk zone), quantile (79-132 as low, 129-161 as moderate and 161-258 as high risk zone), and equal area intervals (79-138.67 as low, 138.67-198.33 as moderate and 198.33-258 as high risk zone) to attain the final hazard map. In this study, we have classified the final map into three hazard classes: Low, Moderate and High. Classification of different methods are shown in the following histograms in Figure 5(a) and 5(b)-

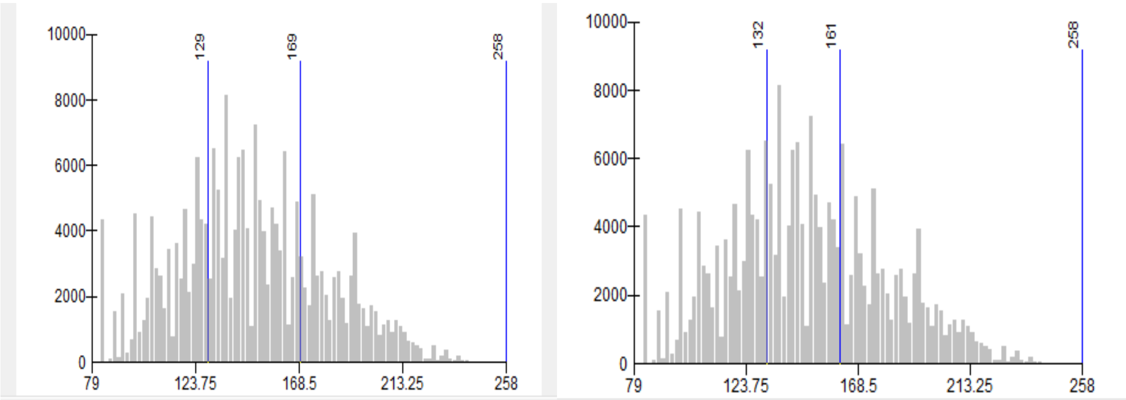


Figure 5(a). Histogram distribution for natural break (left) and quantile (right) scheme.

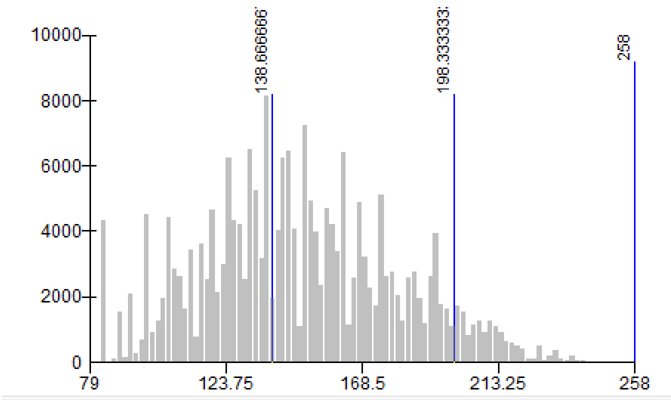


Figure 5(b). Histogram distribution for equal interval scheme.

Using these intervals following maps were generated which are showed in Figure-6(a) and,

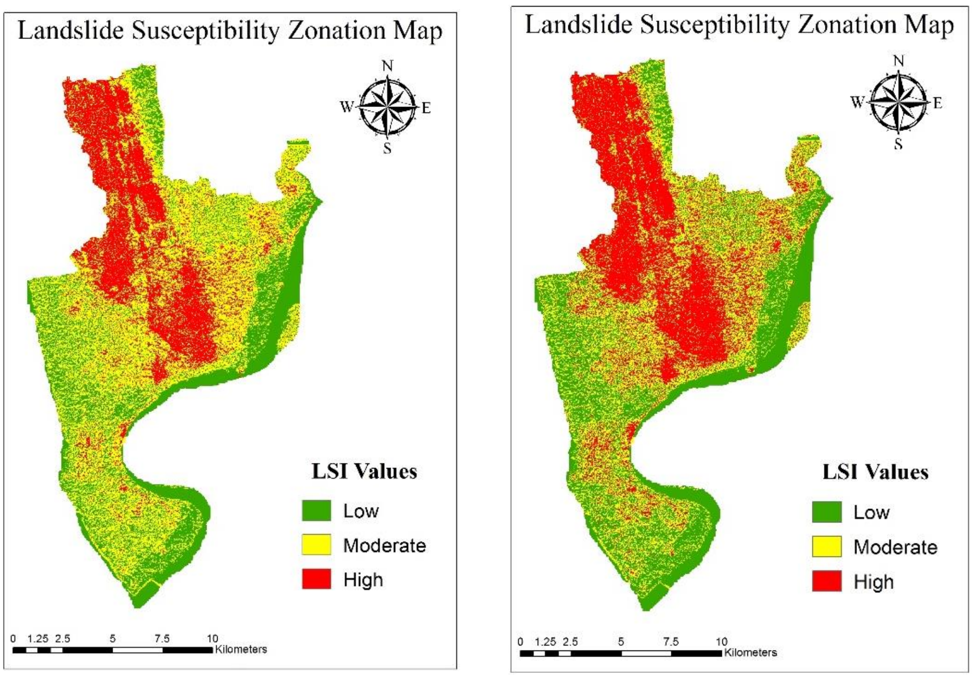


Figure 6(a). Landslide susceptibility zonation map based on natural break (left) and quantile (right) schemes.

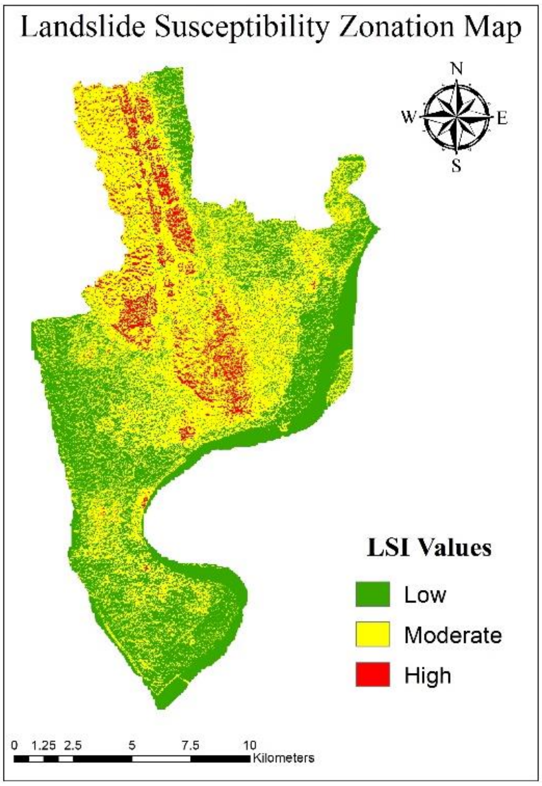


Figure 6(b). Landslide susceptibility zonation map based on equal interval scheme.

6(b). The result shows the central and northern part of the study area (Including Hathazari, Kotwali, Khulsi) is in highest risk of landslide. That means these zones are the most likely to encounter landslides. And previous major landslide events actually happened in these zones which supports the result of this analysis.

The distribution of different risk zones are shown in the following pie charts in Figure 7(a) and Figure 7(b). The result shows that about 25% of the study area (about 48 sq. km.) falls under high risk zone, about 45% of the study area (about 87 sq. km.) fall under moderate risk zone and about 30% of the study area (about 58 sq. km.) fall under low risk zone based on natural break scheme. About 33% of the study area (about 63 sq. km.) falls under high risk zone, about 33% of the study area (about 64 sq. km.) fall under moderate risk zone and about 34% of the study area (about 66 sq. km.) fall under low risk zone based on quantile scheme. About 7% of the study area (about 12 sq. km.) falls under high risk zone, about 51% of the study area (about 99 sq. km.) fall under moderate risk zone and about 42% of the study area (about 81 sq. km.) fall under low risk zone based on equal interval scheme.

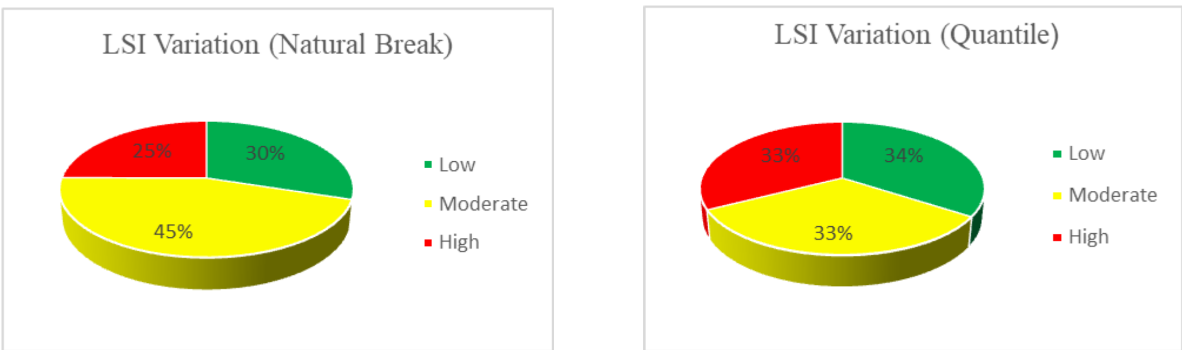


Figure 7(a). Percentage of different risk zones based on natural break (left) and quantile (right) schemes.

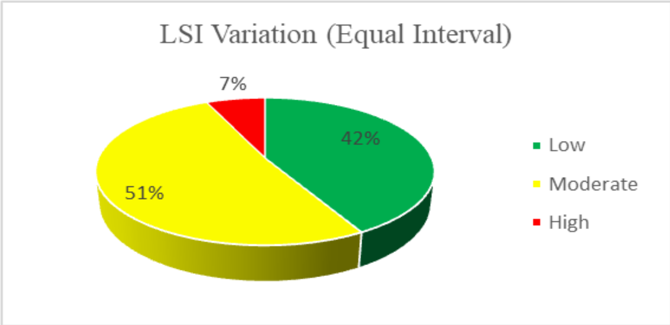


Figure 7(b). Percentage of different risk zones based on equal interval scheme.

5. CONCLUSIONS AND RECOMMANDATION

Landslide Susceptibility Index is a good measure to evaluate extend of the vulnerability prone area. The study is very important in aspect of disaster management, disaster risk mitigation, hazard mapping etc. The analysis shows that the central and Northern areas of the study area is the most vulnerable to this disaster. And the major landslides of Chittagong occurred exactly in this areas. This shows the potential applicability and importance of this sort of study. In this study seven parameters were used: Slope, Plan Curvature, Aspect, and Land use/land cover, Geology, Relative Relief, and Vegetation. For future studies, it is possible to incorporate more relevant parameters. Similar kind of studies can be carried out on other hilly areas of Bangladesh.

As this type of studies are very effective in finding out the vulnerable areas to landslide, future land development plans should incorporate this types of studies and consider for better understanding of human casualties and other damages. For this study, all the data used were open source. But many of the elements were larger in special resolution. In future, it is recommended to use more precious data sets if possible.

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