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# SUSCEPTIBILITY ANALYSIS OF LANDSLIDE IN CHITTAGONG CITY CORPORATION AREA, BANGLADESH

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**Abstract**

In Chittagong city, landslide phenomena is the most burning issue which causes great problems to the life and properties and it is increasing day by day and becoming one of the main problems of city life. On 11 June 2007, a massive landslide happened in Chittagong City Corporation (CCC) area, a large number of foothill settlements and slums were demolished; more than 90 people died and huge resource destruction took place. It is therefore essential to analyze the landslide susceptibility for CCC area to prepare mitigation strategies as well as assessing the impacts of climate change. To assess community susceptibility of landslide hazard, a landslide susceptibility index map has been prepared using analytical hierarchy process (AHP) model based on geographic information system (GIS) and remote sensing (RS) and its susceptibility is analyzed through community vulnerability assessment tool (CVAT). The major findings of the research are 27% of total CCC area which is susceptible to landslide hazard and whereas 6.5 sq.km areas are found very highly susceptible. The landslide susceptible areas of CCC have also been analyzed in respect of physical, social, economic, environmental and critical facilities and it is found that the overall CCC area is highly susceptible to landslide hazard. So the findings of the research can be utilized to prioritize risk mitigation investments, measures to strengthen the emergency preparedness and response mechanisms for reducing the losses and damages due to future landslide events.

Keywords: Analytical Hierarchy Process (AHP), CVAT tool, Geographic Information System (GIS), Landslide, Remote Sensing (RS) and Susceptibility

## Introduction

Due to its geographical location, Chittagong city suffers from numerous natural disasters like landslide, water logging, cyclone, flood etc. But at present landslides are the most burning issues in respect of Chittagong City Corporation (CCC) area. Because Chittagong hills are degrading by different anthropogenic stress such as hill cutting for construction, sand and clay mining purpose, increasing settlement in foothills, deforestation (Mahmoud and Khan, 2008) which are very much responsible for landslide occurrences. A north-south hill range crosses the city and many settlements and slums have been developed in the foothills and lower income people are living in these areas in a risky situation. Almost every year CCC has experienced several devastated landslide incidences that brought vast damage to properties and natural environment, and some loss of human life, as shown in Table 1.

**Table 1: Summary of the crucial landslide incidences in the last 10 years (2003-2013)**

| Date | Location | Consequence |
|---|---|---|
| 3 August 2005 | Nizam Road Housing Society | 2 people killed and 12 injured |
| 11 June 2007 | Mati Jharna Colony of Lalkhan Bazar | 128 people killed and 100 injured |
| 10 September 2007 | Nabi Nagar in Chittagong | 2 people killed |
| 18 August 2008 | Matijharna in Chittagong | 11 people killed and 25 injured |
| 26 June 2012 | Lebubagan Area and Foy's Lake | 90 people killed and 150 injured |
| 01 July 2011 | Batali hill, Tiger pass intersection | 15 people killed and 150 injured |
| 28 July 2013 | Lalkhan Bazar | 2 people killed |

Source: Comprehensive Disaster Management Programme-II 2012 and Field survey, 2014.

The landslides in Chittagong are classified as 'Earth Slides' since those consist of 80% sand and finer particles. It has been stated that the rainfall intensity and duration play very important role in producing these shallow landslides in Chittagong because of climate change (Khan *et al*., 2012). Heavy monsoon rainfall intensified by strong storm from the Bay of Bengal (BOB) can cause abnormal precipitation in the area which mostly triggered landslides in Chittagong (Sarwar, 2008).

Landslide hazard models are the most powerful analytical and diagnostic tool for geomorphologists and decision makers to predict the spatial and temporal occurrence of mass movement. The application of the analytical hierarchy process (AHP) method, developed by Saaty (1980), was widely used in landslide susceptibility mapping. Weighted linear combination (WLC) technique was reported in the study conducted by (Ayalew *et al*., 2004). Landslide becomes a problem when they interfere with human lives, activities and properties. Though landslide have become a severe problem in hilly areas, significant number of poor and vulnerable people often resides in such environments, adopting typical socio-economic activities (Acharya *et al*.,2006).

It is therefore essential to analyze the susceptibility of landslide for CCC area so that appropriate mitigation strategies can be developed to help combat impacts of climate change. To prepare community susceptibility map of landslide hazard, geographic information system (GIS) and remote sensing (RS) based analytical hierarchy process (AHP) model is used in this research. Community vulnerability assessment tool (CVAT) is used to assess susceptible areas according to physical, social, economic, environmental and critical facilities of CCC area.

## Study area

The city, under the jurisdiction of City Corporation (see Figure 1), has a population of about 2.5 million, is constantly growing with an area approximately 155 square kilometers (CDA, 2014).The city lies 21°54′ north to 22°59′ north latitude and 91°17′east to 92°14′east longitude and extend north bank of the *Karnafuli* River to west bank of the *Halda* River. Chittagong is the second largest city of Bangladesh where the largest sea port is located, which is one of the backbones for the economy of the country. The highest ground level within the city area is about 60m above MSL (Mahmood and Khan, 2008).

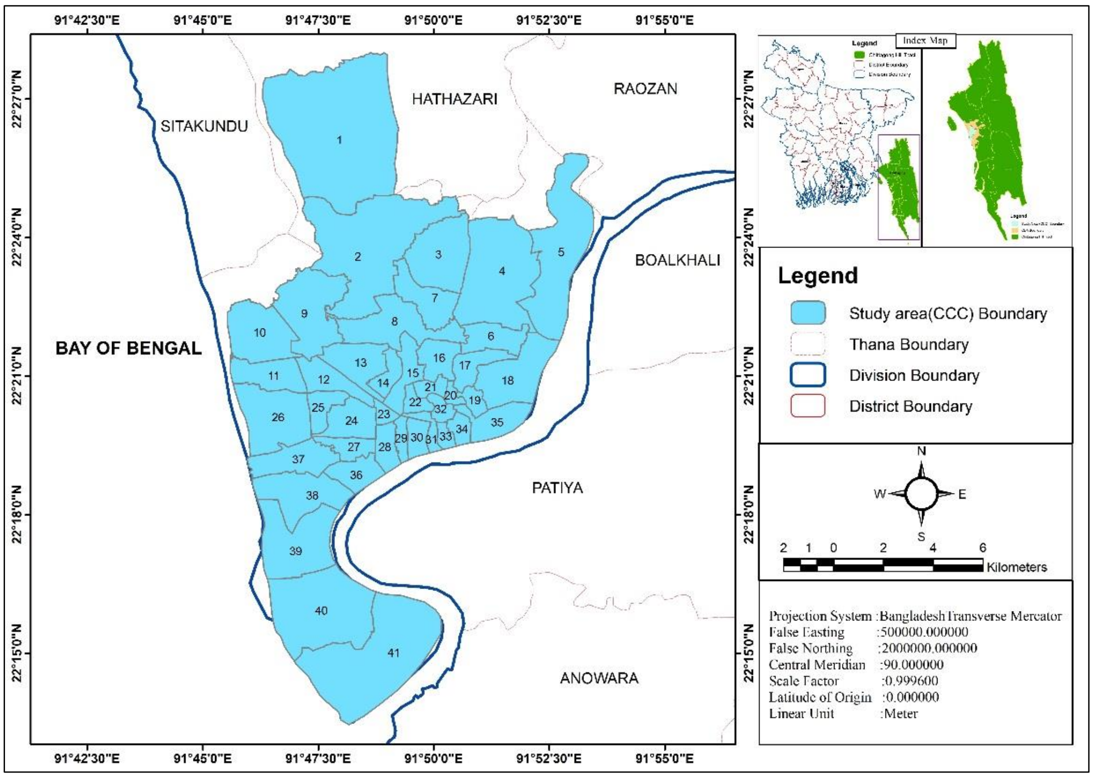



**Figure 1: Location map of the study area (CCC).**

## Methodology

The instability factors that can introduce severe landslides in some particular areas include surface and bedrock, lithology and structure, seismicity, slope, steepness, morphology, stream evolution, groundwater conditions, climate, vegetation cover, land use and human activity (Intarawichian and Dasananda, 2010). In this study, ten major factors are considered according to the importance of the location and data availability such as elevation, slope aspect, slope angle, land cover, available vegetation (NDVI), distance to road, distance to water body, drainage density, geology and geomorphology.

Landslide hazard incident data are collected from field survey's to prepare the landslide hazard inventory map. Informal interview and open discussion has also been conducted with the authorities of different concerned organizations, experts and people living in susceptible areas of Chittagong city. The secondary data such as rainfall data, demographic data, satellite image (character of data shown in Table 2), Geology and Geomorphology data and different types of GIS data base on CCC are also collected from archives of different organization. Data procession and its sources have been described in the following part.

**Table 2: Detailing of Landsat 8 and ASTER scene of CCC area.**

| Satellite Data | Year | Satellite | Sensor ID | Path & Row | Cell size (m) | Date DD/MM/YY | Output format | Cloud Coverage (%) |
|---|---|---|---|---|---|---|---|---|
| Landsat 8 | 2013 | Landsat 8 | OLI_TIR | 136 & 45 | 30×30 | 1/12/2013 | GEOTIFF | 0 |
| DEM | 2013 | ASTER | Global DEM | 136 & 45 | 30×30 | 10/12/2013 | GEOTIFF | 5 |

Source: US Geological Survey, 2013

All the collected data are converted to raster grid with 30 m × 30 m cells and the raster grids are projected to Transverse Mercator (TM) using DWGS 1984 datum. The details of the data collection procedure and ways of preparing the thematic layers are described as follows:

### Landslide inventory map

Landslide inventory is an essential part and basic information for any landslide zoning such as susceptibility, risk and hazard zonings (Fell *et al*., 2008). A total of 20 landslide locations are identified in the study area through field survey and the latitude and longitude values are collected using a Hand GPS device, shown in Figure 2.

### Land cover map

Land cover data are generated from Landsat 8 (2013), collected from the Global visualization viewer (GLOVIS) of United States Geological survey (USGS) website. It has been prepared using the supervised classification techniques followed by knowledge-based expert classification systems depending on reference maps to improve the accuracy of the classification process (Berberoglu and Evrendilek, 2007; Xiaoling and Xiaobin, 2006). Five (5) major classes are taken such as sandy land, vegetation, water bodies, built-up area, paddy fields and shrubs (see Figure 3) and reference pixels are compared with the base map (2010) collected from the Chittagong development authority (CDA). The overall accuracy is found as 85.25% and overall Kappa Statistics is 0.8160 (Wen *et al*., 2009).

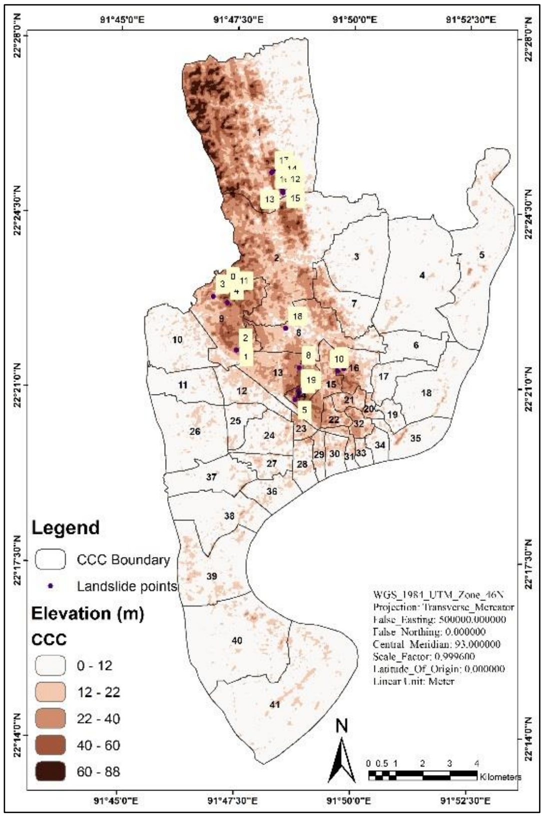



**Figure 2: Observed landslide locations in CCC area**

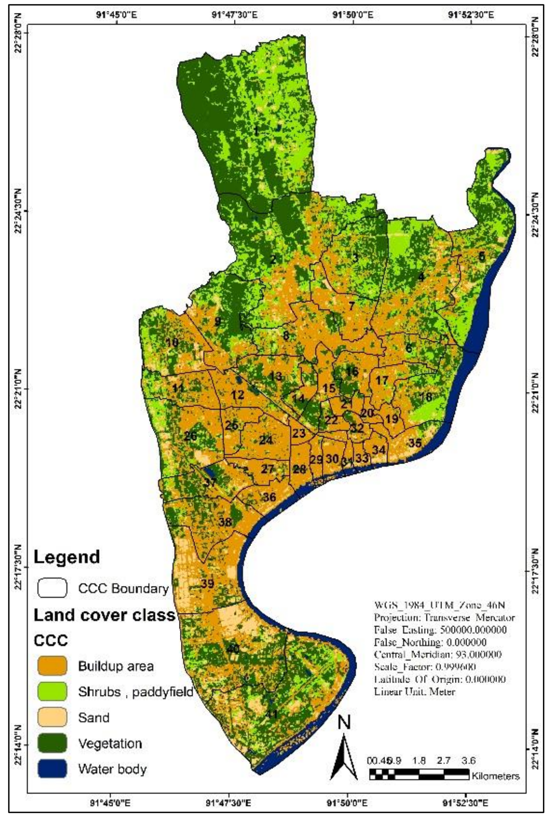



**Figure 3: Land Cover map of CCC area**

### Normalized Difference Vegetation Index (NDVI) map

The normalized difference vegetation index (NDVI) is developed from the reflective bands of Landsat 8 satellite data for estimating available type of vegetation cover (see Figure 4). It has been prepared using the following Eq.1 (ArcGIS 10@ Help, 2014).

$$\mathrm{NDVI} = \frac{(\mathrm{IR} - \mathrm{R})}{(\mathrm{IR} + \mathrm{R})} \qquad \mathrm{Eq.\,1}$$

IR=DN values from the infrared band (Band 5), R=DN values from the red band (Band 4). NDVI indices values range from -1.0 to 1.0, where higher values are for green vegetation and bare soil is symbolized with NDVI values which are contiguous to 0 and water bodies are characterize with negative NDVI values (Lillesand and Kiefer,2004; ArcGIS 10@ Help, 2014).

### Slope

Slope has been generated from the raster DEM 30-meter contour interval. The analyst tool identifies the slope (gradient, or rate of maximum change in z-value) from each cell of a raster surface (ArcGIS 10@ Help, 2014). Generally steeper slope is more susceptible to landslide but most of the observed landslide occurrences in Chittagong were found within a slope range from 15-45 degrees (Khan and Chang, 2007), shown in Figure 5.

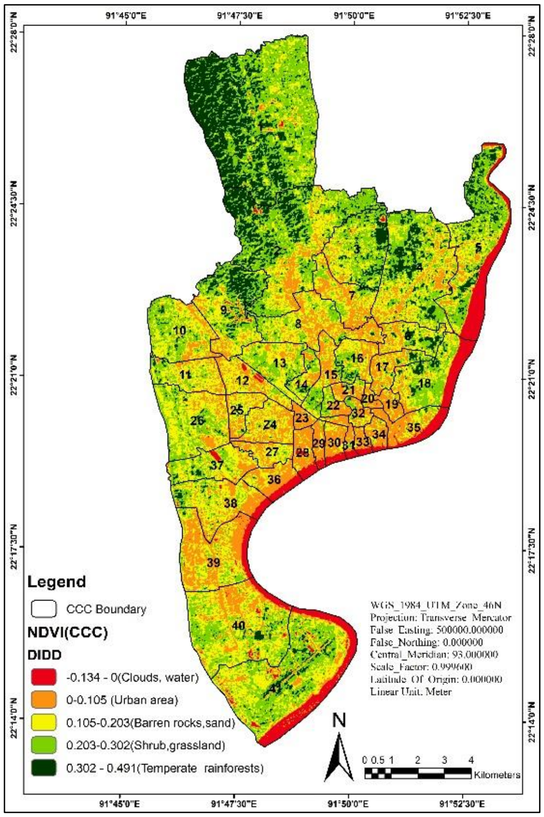



**Figure 4: NDVI map of CCC area**

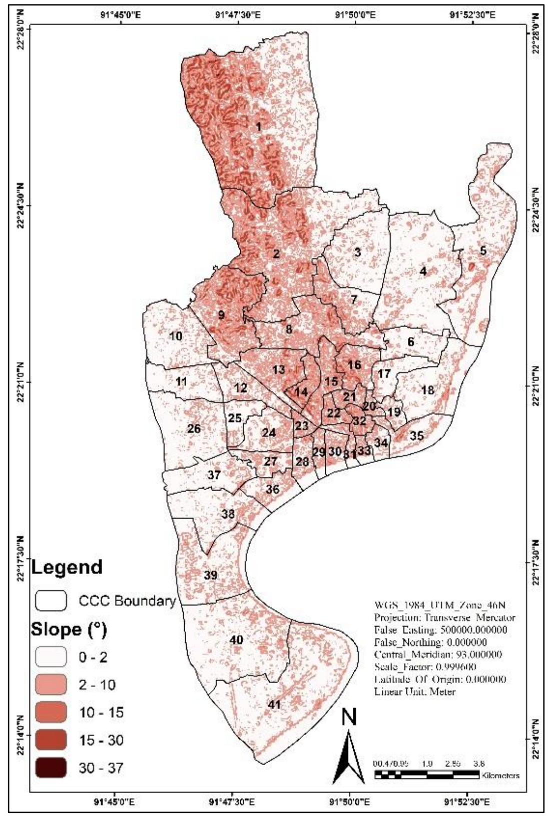



**Figure 5: Slope map of CCC area**

## Aspect map

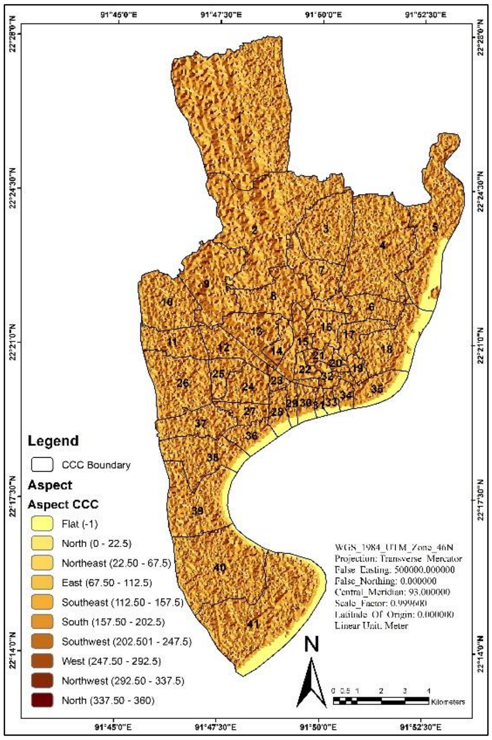
The aspect represents the down slope direction of the maximum rate of change in value from each cell to its neighbors (ArcGIS 10@ Help, 2014). Slope facing south, southwest, west receive maximum rainfall in Chittagong region (Khan and Chang, 2007). Any slope faces maximum rainfall is more susceptible to landslide than others as shown in Figure 6.

## Elevation map

The elevation map has been prepared from the DEM layer where the relative height of the layer is considered. Higher elevation is characterized by compacted sandstone in Chittagong city which is also resistance to sliding activity but moderate elevation of 8-12 m have also high susceptibility for landslide occurrences (Khan and Chang, 2007), shown in Figure 7.

## Distance to road

Landslides may occur on the road and on the side of the slopes affected by roads (Yalcin, 2008). The distance from road classes closer to the road covered the higher percentage of landslide area while the classes far from the road had lowest percentage of landslide (Bhatt *et al*., 2013) (see Figure 8). Euclidean distance is calculated from the center of the source cell to the center of each of the surrounding cells, true Euclidean distance is calculated in each of the distance (ArcGIS 10@ Help, 2014).



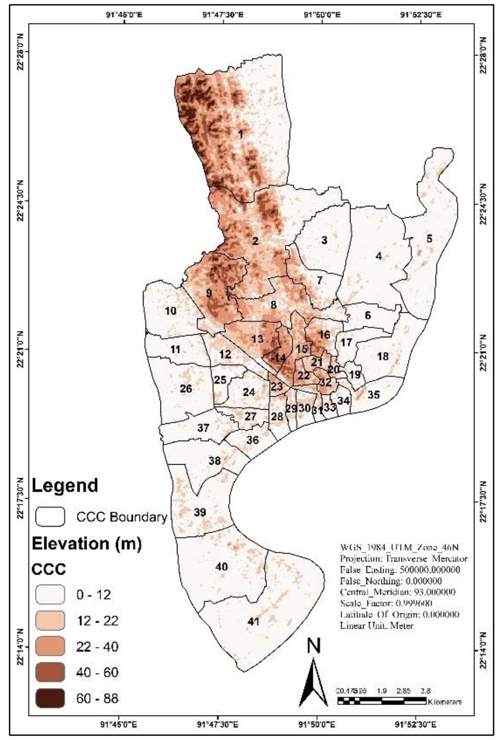
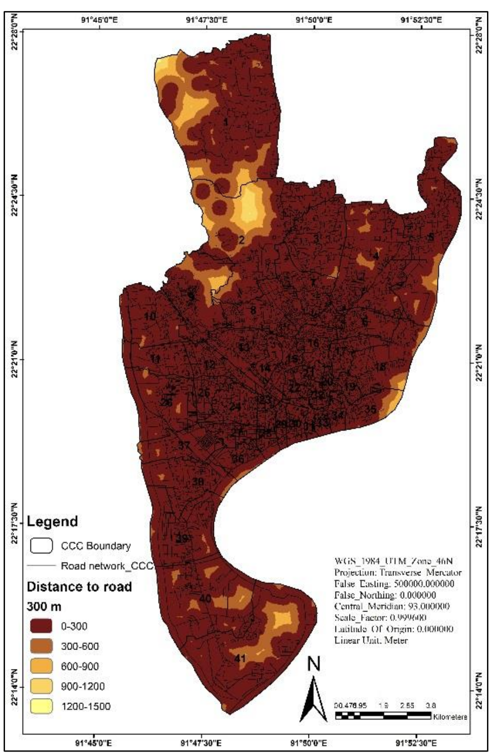




**Figure 6: Aspect map of CCC area**

**Figure 7: Elevation map of CCC area**

**Distance to water body**

The area closer to the river and stream has high level of landslide (Bagherzadeh and Mansouri, 2012). Euclidean distance (ArcGIS 10@ Help, 2014) is also used to prepare distance to water body layer map at 200 meter intervals (see Figure 9).



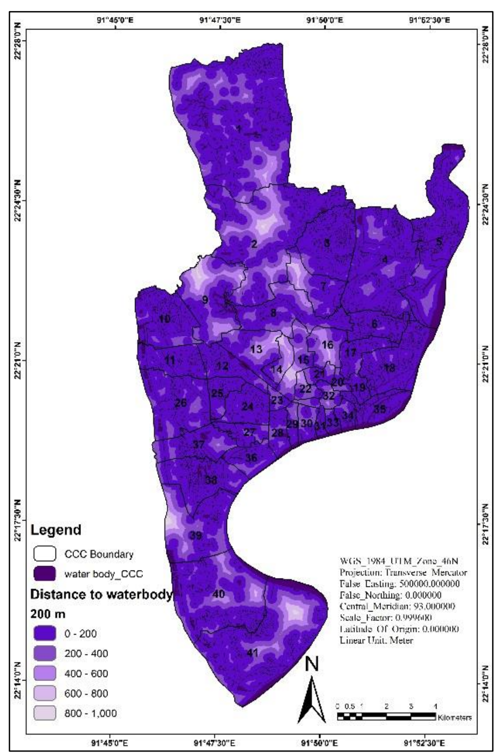




**Figure 8: Distance to road map of CCC**

**Figure 9: Distance to water body map of CCC**

### Drainage density

DEM data is used to prepare Drainage density. The presence of streams influences stability by toe erosion or by saturating the toe material or both (Gokceoglu and Aksoy, 1996).The distances from stream line of 100m intervals is produced using Euclidean distance technique, as shown in Figure 10.

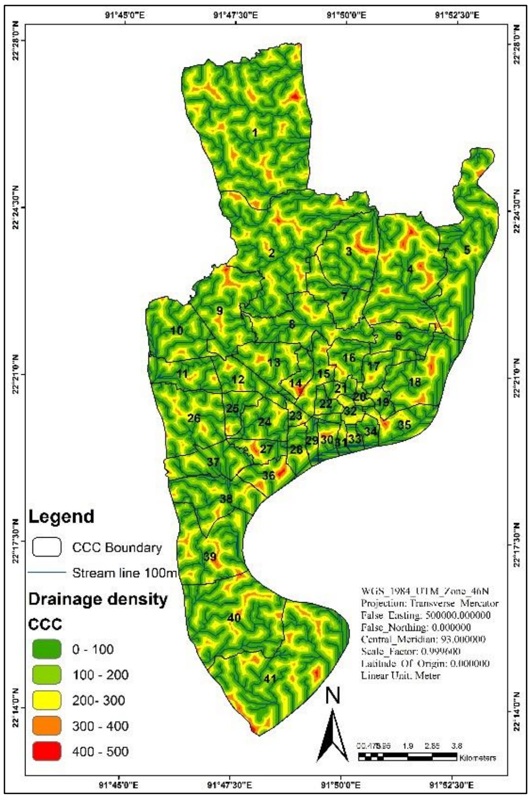



**Figure 10: Drainage density map of CCC area**

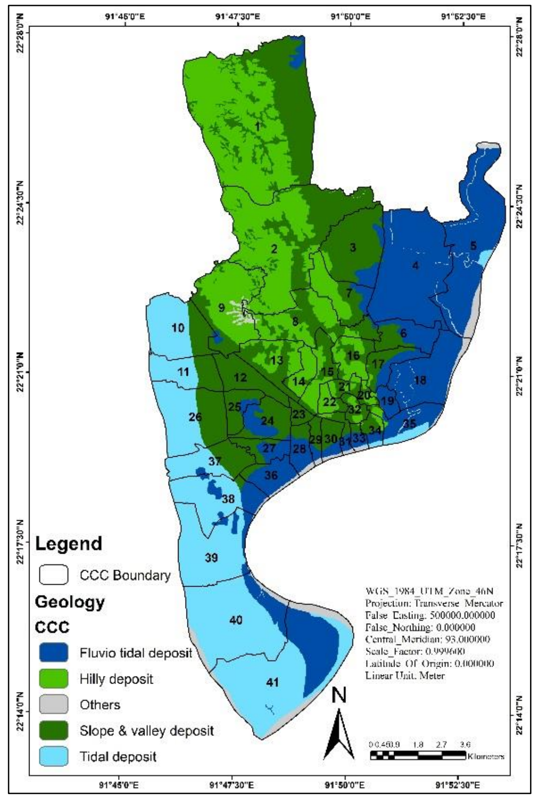



**Figure 11: Geology map of CCC area**

### Geology and Geomorphology

Geology and Geomorphology data are collected from Geological Survey of Bangladesh (GSB).The highest preference are given to the geologic formations of slope and valley deposit where majority of landslides had previously occurred. (see Figure 11). The geomorphologic data are also classified into four classes and according to expert opinions, hilly landforms are most susceptible to landslide occurrences. (see Figure 12).

### Precipitation

Due to climate change, CCC is experiencing high intensity of rainfall in recent years which is making the landslide situation worse (United Nation, 2011). Previous ten years (2003-2013) of precipitation data has been collected from Bangladesh Metrological Department (BMD, 2014) and the average daily precipitation of the whole CCC area is more of less same. Besides the study areas are too small and there is only one weather station installed in this area so the triggering effect of the precipitation factor is assumed to be uniform.

The demographic data such as population distribution, gender, age group on CCC area collected from Bangladesh bureau of statistics (BBS) and the GIS data base (physical facilities, critical facilities, economic facilities, environmental risk sites) for CCC area have also been collected from Chittagong development authority (CDA).

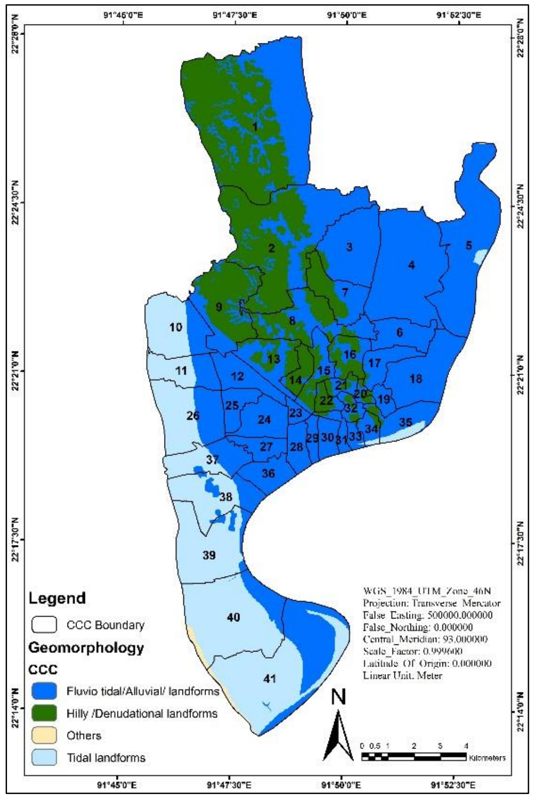



**Figure 12: Geomorphology map of CCC area**

**Analytical hierarchy process (AHP)**

Analytical hierarchy process (AHP) method is a multi-factor decision-making process which is used to derive the weights associated with suitability/attribute map layers (Saaty, 1977). AHP involves building a hierarchy of decision elements (factors) and then making comparisons between possible pairs in a matrix to give a weight for each element and also a consistency ratio (Malczewski, 1999). Factor weights for each criterion are determined by a pair wise comparison matrix (Saaty, 1977; Satty and Vargas, 2001). The CR is a ratio between the matrix's consistency index and random index and in general ranges from 0 to 1.The consistency ratio (CR) is obtained by comparing the consistency index (CI) with average random consistency index (RI).The consistency ratio is defined in Eq. 2.

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \qquad \text{Eq.2}$$

A CR close to 0 indicates the high probability that the weights were generated randomly (Saaty, 1977).The consistency index of a matrix of comparisons can be calculated through following Eq. 3.

$$\text{Consistency index (CI)} = \frac{(\lambda max - \mathrm{n})}{\mathrm{n} - 1} \qquad \text{Eq.3}$$

In this study, AHP considers weighting and rating system developed by collecting questionnaires from expert opinions and secondary data sources. The class weightage and the factor weightage are multiplied each other to produce a combined weightage map of landslide susceptibility as Eq.4:

$$SI = \sum_{i=1}^{n} (Wi \times Ri) \quad \text{Eq.4}$$

Where, SI is the required susceptibility index of the given pixel.

Ri and Wi are class weight (or rating value) and factor weight for factor i respectively.

The weightage maps are classified into five (5) classes using Natural breaks (Jenks) classification method characterized by very high, high, medium, low and very low susceptibility. Natural breaks are data-specific classifications which is used for this study purpose (ArcGIS 10@ Help, 2014).Validity of the map was examined using 20 known landslide locations within the area obtained from the field surveys and from official records of the responsible authorities.

Landslide susceptibility assessment for CCC area has been carried out through Community susceptibility assessment Tool (CVAT) (Goodwin, 2014). Landslide susceptibility analysis for CCC area has also been divided into five segments naming physical susceptibility analysis, critical facilities susceptibility analysis, social susceptibility analysis, economic susceptibility analysis and environmental susceptibility analysis (Leone Pippard and commission, 2012). The first step involved with physical susceptibility analysis of all types of road and residential structures which are located in landslide hazard prone areas. The physical structures location is overlaid over the map of land slide susceptible areas and the physical susceptibility analysis map is prepared. Then critical facilities (community services, education and research, service activity) and economic facilities (commercial, manufacturing and processing) that are within close proximity to susceptible areas are identified by overlying the critical facilities from GIS data location over the map of landslide susceptible areas. Social susceptibility can be analyzed through special consideration areas which are identified by population distribution, gender, age group of people and literacy rate. For environmental susceptibility analysis including dense forest, shrubs and water body's areas, which are considered to determine the potential threat to environment.

## Landslide susceptibility mapping and discussion

Landslide susceptibility mapping consists of the derived factor weights and class weights, and a calculated CR, as seen in Table 3. In this research, the resulting CR for all the cases is found less than 0.10 (Table 3 and Table 4). From Table 5, it is found that the LSI had a minimum value of 0.053, and a maximum value of 0.457, with an average value of 0.162 and a standard deviation of 0.061.The LSI represents the relative susceptibility of a landslide occurrence.These LSI values are then divided into five classes based the natural breaks range, which represent five different zones in the landslide susceptibility map showing in Figure 2. Only 11% of the total areas are classified as being in the VHS (4%) or HS (7%) landslide susceptibility zones but they have accommodated about 80% of the landslide reference points. Other areas are located in the MS (18%), LS (39%), and VLS (33%) susceptibility zones and only 4 landslide incidences (out of 20) are being observed in the MS zones.

**Table 3: Pairwise comparison matrix, consistency ratio and weights of the sub-criteria of the data layers**

| Factors | (1) | (2) | (3) | (4) | (5) | Eigen values |
|---|---|---|---|---|---|---|
| **Land cover** | | | | | | |
| (1)Water body | 1 | | | | | 0.0375 |
| (2)Vegetation | 7 | 1 | | | | 0.2959 |
| (3)Urban Area | 5 | 1/3 | 1 | | | 0.1357 |
| (4)Paddy Field | 2 | 1/6 | 1/3 | 1 | | 0.0589 |
| (5)Bare Soil | 9 | 2 | 5 | 7 | 1 | 0.4721 |
| Consistency ratio : 0.05 | | | | | | |
| **Slope angle (°)** | | | | | | |
| (1) 0 - 2 | 1 | | | | | 0.0502 |
| (2) 2-10 | 2 | 1 | | | | 0.0809 |
| (3) 10-15 | 4 | 2 | 1 | | | 0.1407 |
| (4) 15-30 | 7 | 6 | 5 | 1 | | 0.5146 |
| (5) 30-37 | 4 | 3 | 2 | 1/3 | 1 | 0.2137 |
| Consistency ratio :0.04 | | | | | | |
| **Slope aspect** | | | | | | |
| (1) South, South-west | 1 | | | | | 0.5489 |
| (2)West, north-west | 1/2 | 1 | | | | 0.2901 |
| (3)North, south-east | 1/6 | 1/3 | 1 | | | 0.1019 |
| (4)East, north-east | 1/8 | 1/5 | 1/2 | 1 | | 0.0591 |
| Consistency ratio : 0.008 | | | | | | |
| **Elevation (m)** | | | | | | |
| (1) 0-12 | 1 | | | | | 0.0453 |
| (2) 12-22 | 2 | 1 | | | | 0.0756 |
| (3) 22-40 | 4 | 2 | 1 | | | 0.1423 |
| (4) 40-60 | 8 | 6 | 4 | 1 | | 0.5000 |
| (5) 60-88 | 5 | 4 | 2 | 1/3 | 1 | 0.2368 |
| Consistency ratio : 0.03 | | | | | | |
| **NDVI** | | | | | | |
| (1) 0.134773 - 0 | 1 | | | | | 0.0436 |
| (2) 0 - 0.105841 | 9 | 1 | | | | 0.4745 |
| (3) 0.105841 - 0.203147 | 6 | 1/2 | 1 | | | 0.2935 |
| (4) 0.203147 - 0.302287 | 2 | 1/7 | 1/5 | 1 | | 0.0683 |
| (5) 0.302287 - 0.491584 | 3 | 1/4 | 1/3 | 2 | 1 | 0.1200 |
| Consistency ratio : 0.02 | | | | | | |
| **Distance to road (m)** | | | | | | |
| (1) 0-300 | 1 | | | | | 0.5424 |
| (2) 300-600 | 1/3 | 1 | | | | 0.2381 |
| (3) 600-900 | 1/6 | 1/3 | 1 | | | 0.0969 |
| (4) 900-1200 | 1/8 | 1/5 | 1/2 | 1 | | 0.0757 |
| (5) 1200-1500 | 1/9 | 1/4 | 1/2 | 1/3 | 1 | 0.0470 |
| Consistency ratio: 0.06 | | | | | | |

| Factors | (1) | (2) | (3) | (4) | (5) | Eigen values |
|---|---|---|---|---|---|---|
| **Distance to water body(m)** | | | | | | |
| (1) 0-200 | 1 | | | | | 0.5096 |
| (2) 200-400 | 1/3 | 1 | | | | 0.2367 |
| (3) 400-600 | 1/5 | 1/2 | 1 | | | 0.1275 |
| (4) 600-800 | 1/6 | 1/4 | 1/2 | 1 | | 0.0765 |
| (5) 800-1000 | 1/7 | 1/5 | 1/3 | 1/2 | 1 | 0.0497 |
| Consistency ratio : 0.04 | | | | | | |
| **Drainage density (m)** | | | | | | |
| (1) 0 - 100 | 1 | | | | | 0.0519 |
| (2)100-200 | 2 | 1 | | | | 0.0880 |
| (3)200-300 | 3 | 2 | 1 | | | 0.1423 |
| (4)300-400 | 5 | 3 | 2 | 1 | | 0.2562 |
| (5)400-500 | 7 | 5 | 4 | 2 | 1 | 0.4616 |
| Consistency ratio : 0.01 | | | | | | |
| **Geomorphology** | | | | | | |
| (1)Fluvio tidal/Alluvial/Depositional landforms | 1 | | | | | 0.1084 |
| (2) Hilly /Denudational landforms | 6 | 1 | | | | 0.6273 |
| (3) Others | 1/2 | 1/8 | 1 | | | 0.0610 |
| (4) Tidal landforms | 2 | 1/4 | 4 | 1 | | 0.2033 |
| Consistency ratio : 0.03 | | | | | | |
| **Geology** | | | | | | |
| (1) Fluvio tidal deposit | 1 | | | | | 0.0666 |
| (2) Hilly deposit | 5 | 1 | | | | 0.2856 |
| (3) Others | 1/2 | 1/7 | 1 | | | 0.0407 |
| (4) Slope & valley deposit | 6 | 2 | 9 | 1 | | 0.4456 |
| (5) Tidal deposit | 3 | 1/2 | 4 | 1/3 | 1 | 0.1615 |
| Consistency ratio : 0.02 | | | | | | |

The frequency ratio (FR) values are computed from ratio of the percentage landslide occurrences and the percentage area coverage (for each individual class to the whole study area).The possible values begin from 0 onwards where relatively high ones (much greater than 1) indicate high chance of having landslides while low values (close to 0) indicate lower chance of having landslide over the area.The FR values of 11.832 for the VHS zone and 5.289 for the HS zone indicate the higher chance of having landslide activities in these areas when compared to those of the MS (1.142) and LS (0), as shown in Table 5.

**Table 4: Pair wise comparison matrix, factor weights and consistency ration of the data layers**

| **Data layers** | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** | **(7)** | **(8)** | **(9)** | **(10)** | **Eigen values** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Land Cover (1) | 1 | | | | | | | | | | 0.0629 |
| Slope (2) | 4 | 1 | | | | | | | | | 0.1995 |
| Aspect (3) | 1/2 | 1/5 | 1 | | | | | | | | 0.0361 |
| Elevation (4) | 5 | 2 | 6 | 1 | | | | | | | 0.2575 |

| Data layers | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | Eigen values |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NDVI (5) | 2 | 1/3 | 3 | 1/4 | 1 | | | | | | 0.0787 |
| Distance to road (6) | 1/5 | 1/8 | 1/3 | 1/9 | 1/4 | 1 | | | | | 0.0179 |
| Distance to water body (7) | 1/3 | 1/7 | 1/2 | 1/8 | 1/3 | 2 | 1 | | | | 0.0252 |
| Drainage density (8) | 1/2 | 1/5 | 2 | 1/6 | 1/2 | 3 | 2 | 1 | | | 0.0445 |
| Geomorphology (9) | 2 | 1/2 | 4 | 1/2 | 2 | 7 | 6 | 3 | 1 | | 0.1233 |
| Geology (10) | 3 | 1/2 | 5 | 1/2 | 2 | 7 | 6 | 4 | 2 | 1 | 0.1545 |
| Consistency ratio : 0.03 | | | | | | | | | | | |

The very high susceptible landslide locations in CCC area are identified as *Akbarshah colony* (ID-1), *Foy's Lake area* (ID-2), *Batali hill area* (ID-3), *Motijharna area* (ID-4), *kusumbag residential area* (ID-5), *Nasirabad area* (ID-6), *North-east of Pahartoli* (ID-7), *Lebubagan area* (ID-8), *Khulshi residential area* (ID-9) in Figure 13. Among those locations, *Motijorana* area and *Batali Hill* are considered as the most susceptible locations in CCC. These areas are also heavily populated and occupied by lower income groups. Most of the inhabitants are poor factory workers. Any large scale landslide can cause massive destruction to these areas and cause death of many people. Since landslide occurrences only recorded in the very high and highly susceptible areas in CCC, the very high, high and moderate susceptible areas are taken in this research for susceptibility analysis process.

**Table 5: Allocation of the reference landslide points within the defined landslide susceptibility class and the associated frequency ratio (FR) of each class**

| Susceptibility classes | Susceptibility index values | Susceptible area (km) | % of Area | Number of landslide points | Frequency ratio (FR) |
|---|---|---|---|---|---|
| Very low susceptibility (VLS) | 0.053 - 0.130 | 57.11 | 33 | 0 (0%) | 0.000 |
| Low susceptibility (LS) | 0.130 - 0.189 | 67.58 | 39 | 0 (0%) | 0.000 |
| Moderate susceptibility (MS) | 0.189 - 0.233 | 30.29 | 18 | 4 (20%) | 1.142 |
| High susceptibility (HS) | 0.233 - 0.316 | 11.45 | 7 | 7 (35%) | 5.289 |
| Very high susceptibility (VHS) | 0.316 - 0.454 | 6.58 | 4 | 9 (45%) | 11.832 |

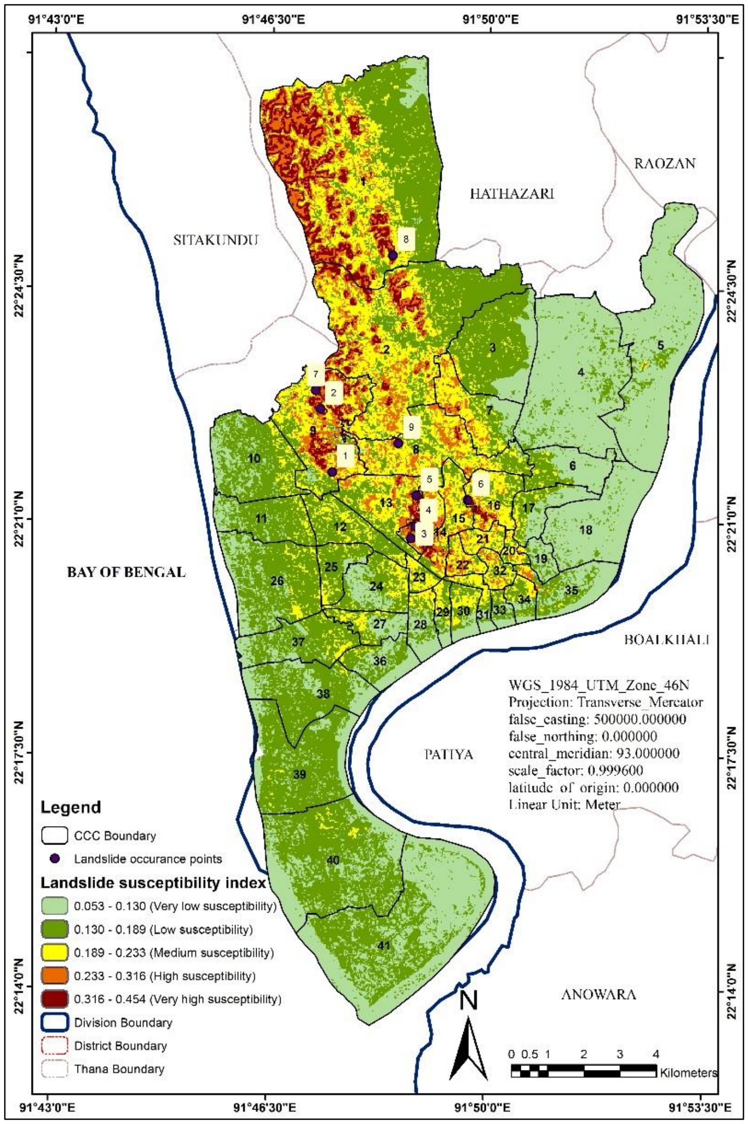



**Figure 13: Landslide susceptibility map of CCC area.**

## Susceptibility analysis and results

The susceptibility analysis is conducted based on the area located from landslide susceptibility mapping process. Involving the community in the preparation of the susceptibility assessment can improve its effectiveness and ensure that the assessment is relevant to those who are the most at risk.

## Physical susceptibility analysis

Physical susceptibility to landslide hazard is divided into two separate segments naming infrastructural susceptibility and road susceptibility for CCC area.

## Infrastructural susceptibility

The total numbers of residential structures in the CCC area are 186006, among which 71991 structures are found susceptible due to landslide hazard. Among all the susceptible structures in CCC, 7% are found very high susceptible, 21% high susceptible and 72% are also found medium susceptible, shown in Figure 14.The formation of informal settlements (generally termed "slums") on hill slopes with unplanned hill-cutting are the main cause of susceptibility to landslides (Ahmad and Ahmed, 2003). *Motijorna Tankir par* and *kusumbag*, *Badsha mia road* are the most susceptible location for landslide occurrences which are constructed on illegally occupied lands, mostly in hilly regions of CCC area

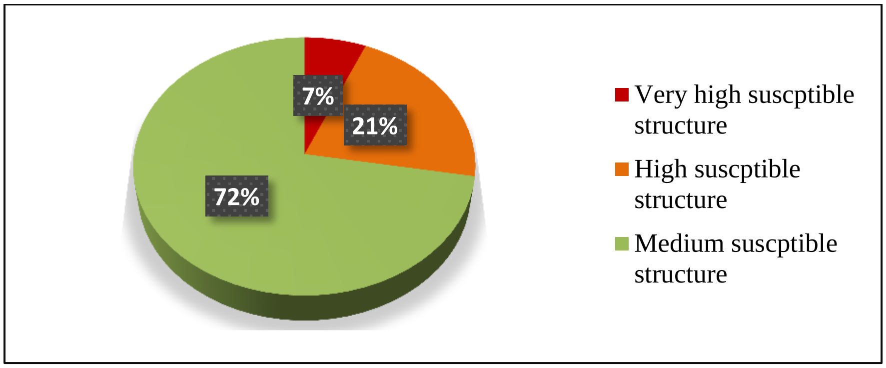



**Figure 14: Percentage of total residential structure susceptible to landslide**

## Road susceptibility

The entire CCC area is covered by network of roads such as *pucca*, *semi pucca* and *kacha road.* The total area also is served by 2888 km of road (using Bangladesh Transverse Mercator projection), among them approximately 806 km of road have been found susceptible. About 5% (43.36 km) of susceptible roads are very highly and more than 95% (800km) of roads are highly to medium susceptible to landslide hazard, as shown in Figure 15. Approximately more than 13 km of *katcha* road is identified as severely susceptible. The medium susceptible road occupies the larger portion of the road network.

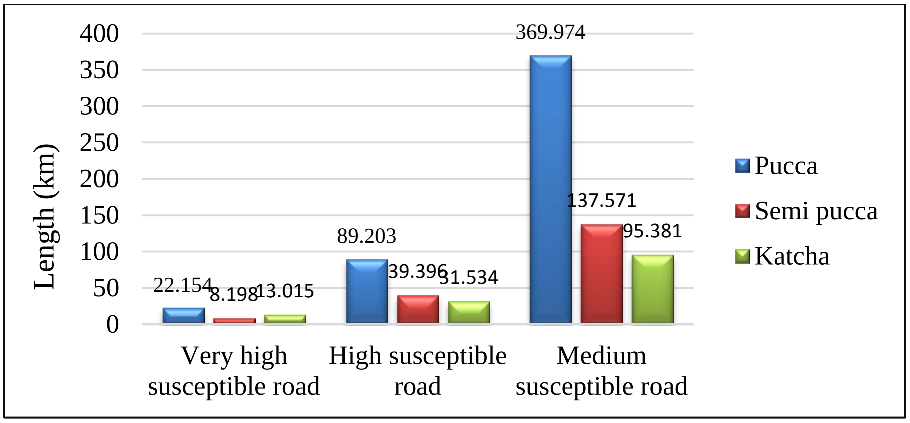



**Figure 15: Road susceptibility to landslide hazard.**

The roads located in very highly to highly susceptible areas such as *Akbarshah colony* (ID-1), *Gazjr matha (Biswa colony) B block* (ID-2), *Batali hill* (ID-3), *Motijorna Tankir par I* (ID-4), *kusumbag* (ID-5), *Badsha mia road* (ID-6),*Mukul ahmed primary school* (ID-7) are very much threatened by landslide hazard, as shown in Figure 16.

## Critical facilities susceptibility analysis

The critical facilities susceptibility analysis includes community service, education and research institute, service activity, transport and communication facilities of CCC area. The total numbers of very high susceptible critical facilities are 144 (Table 6), which is 4% of total critical facilities in CCC area. Accordingly, the high susceptible critical facilities are found as 636 (19%) and medium susceptible critical facilities are 2648 (77%), among which the education and research and service activity facilities possesses higher susceptibility to landslide occurrences.

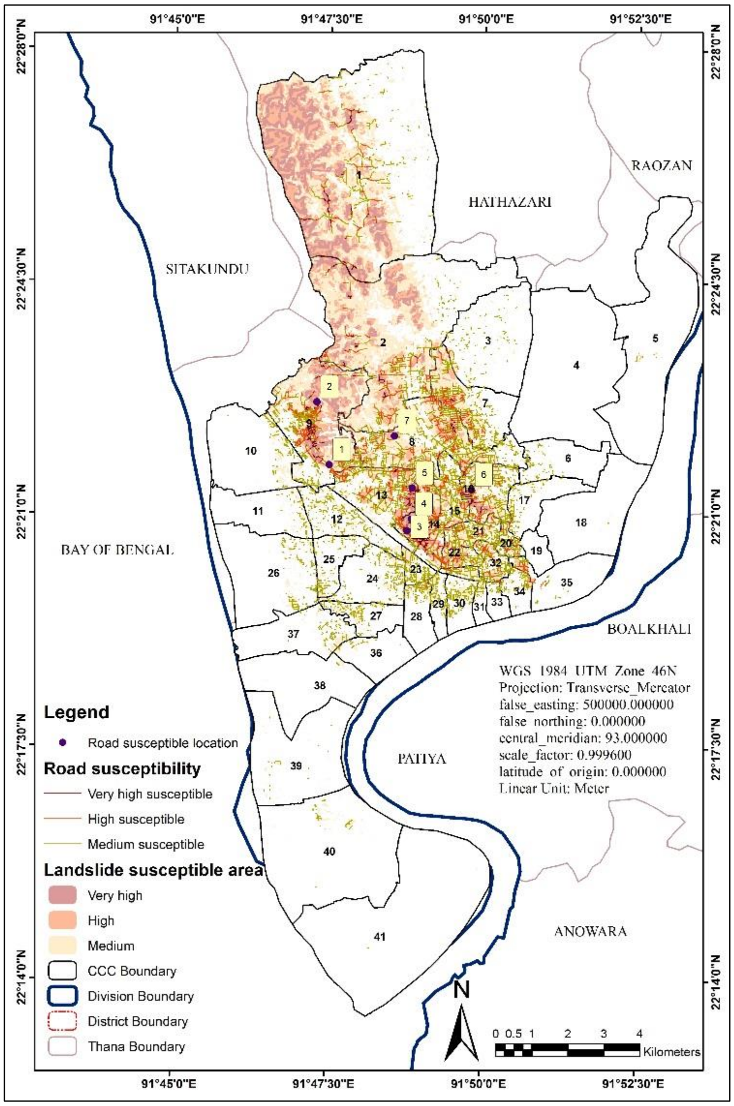



**Figure 16: Road susceptibility map of CCC area**

The overall number of educational institutions in CCC area are 1437, among those, 51 educational institutions are very highly and 737 are highly affected and 30 service oriented structures are very highly susceptible to landslide hazard, also shown in Table 6.

**Table 6: Number of susceptible critical facilities**

| Susceptibility | Type of facilities | Number critical facilities | Percentage |
|---|---|---|---|
| Very high susceptible critical facilities | Community Service | 59 | **4%** |
| | Education & Research | 51 | |
| | Service Activity | 30 | |
| | Transport & Communication | 4 | |
| **Total very high susceptible critical facilities** | | **144** | |

| Susceptibility | Type of facilities | Number critical facilities | Percentage |
|---|---|---|---|
| High susceptible critical facilities | Community Service | 194 | **19%** |
| | Education & Research | 198 | |
| | Service Activity | 217 | |
| | Transport & Communication | 27 | |
| **Total high susceptible critical facilities** | | **636** | |
| Medium susceptible critical facilities | Community Service | 758 | **77%** |
| | Education & Research | 737 | |
| | Service Activity | 1055 | |
| | Transport & Communication | 98 | |
| **Total medium susceptible critical facilities** | | **2648** | |

Important Critical facilities found in ward no 2, 9,14,15,16 such as *Pologround high school* (ID-1), *Railway security training center* (ID-2), *Government Charucola college* (ID-3), *Zamiatul Ulum Al-Islami madrasa (ID-4)*, *Tiger pass naval auditorium* (ID-5), *Motizharna mosque* (ID-6), *Panora Hospital* (ID-7), *Lalkhan Bazar Ward Commissioner* (ID-8) *etc.* are very highly susceptible to landslide, shown in Figure 17.

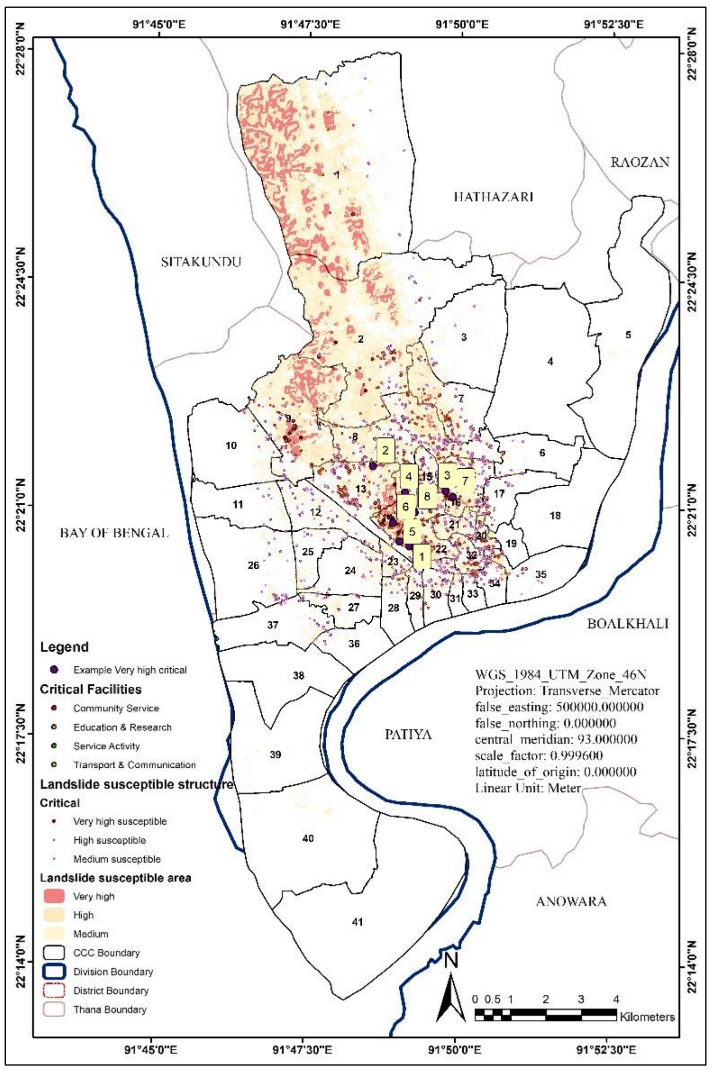



**Figure 17: Critical facilities susceptibility map of CCC area.**

**Economic susceptibility analysis**

Economic susceptibility depends on how many important economic activities are located in close proximity to susceptible areas which comprises of commercial and manufacturing industries. Among all the economic activities, 19 of manufacturing and processing industries and 299 commercial activities are threatened very highly to landslide hazard. There are also 1242 commercial centers and 208 manufacturing and processing industries that are highly susceptible to landslide hazard. The scarcity of land requirement forces to establish new commercial or manufacturing industries in the landslide prone hills and become highly susceptible to landslide hazard.

It is found from Figure 18 that, 4% structures are very highly and 16% of total susceptible structures are highly susceptible, since most of the economic activities are located in the plain land, the economic activities susceptibility is lower in the hilly regions.

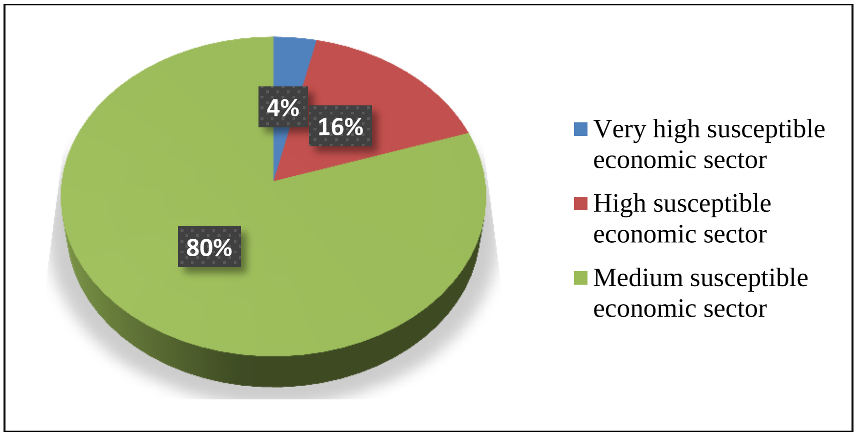



**Figure 18: Economic facilities susceptibility to landslide hazard**

Very important economic activities such as *Bangladesh agricultural research institute* (ID-1), *Fasions metal industries Ltd.* (ID-2), *Rotunpur steel mills LTD* (ID-3), *Mallick re-rolling mills LTD* (ID-4), *Berger paints BD Ltd* (ID-5) and *Bismillah super market* (ID-6) are located in very high susceptible zone, as shown in Figure 19.

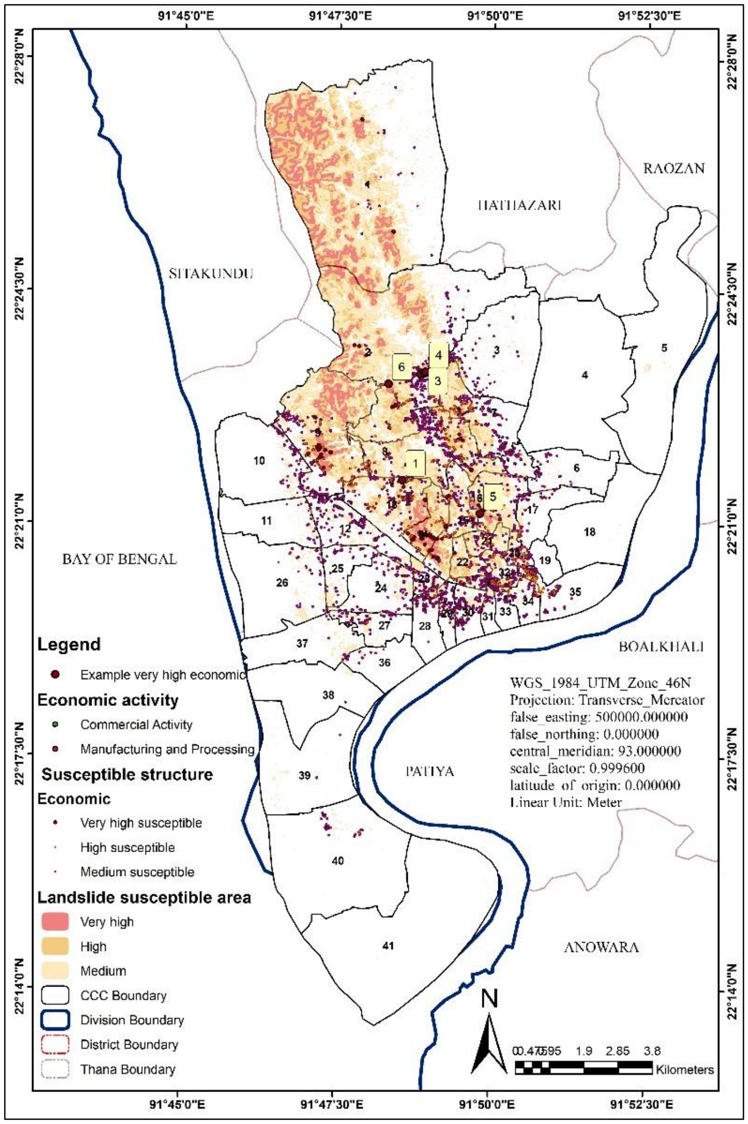



**Figure 19: Economic facilities susceptibility map of CCC area.**

## Social susceptibility analysis

Social susceptibility is analyzed through the identification of Population distribution, Gender, age group of people and literacy rate of the study area. The population density is not included because of not having density data of individual wards of CCC area. The susceptible population such as affected population, affected female population, affected population **below 10** years and affected population **above 60** years can be calculated in respect of total population residing in the landslide susceptible area.

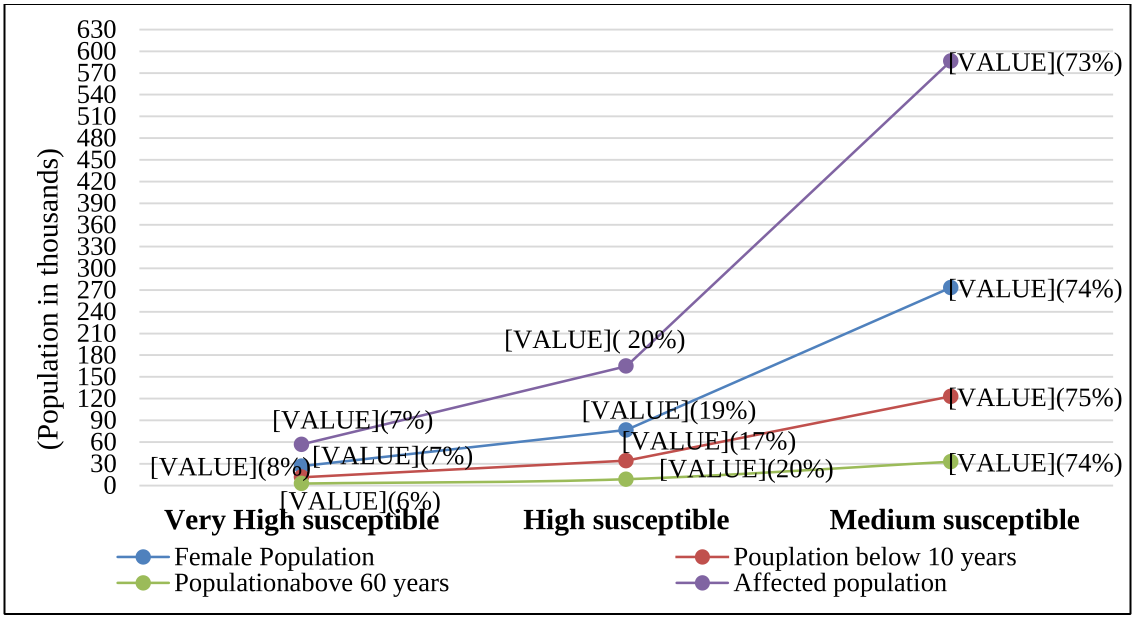



**Figure 20: Social susceptibility according to population criteria and susceptible area**

The susceptible areas in CCC are divided into three phases such as very high susceptible, high susceptible and medium susceptible area. The very high susceptible population is identified as 56777 which is 7% of total susceptible population in CCC area. The high susceptible and medium susceptible population comprises 20% and 73% of total susceptible population shown in Figure 20.Women are also more vulnerable to disasters because of their roles as mothers and caregivers, when disaster is about to strike, their ability to seek safety is restricted by their responsibilities to the very young and the very old, both of whom require help and supervision (Lisa *et al*.,2002).The percentage of female population susceptible to landslide hazard can be described as very high susceptible 7% (26668), high susceptible 20% (76713) and medium susceptible 73% (273511) of total affected female population. The selected age groups for this analysis are taken as "below 10 years" and "above 60 years". Then the population within the susceptible age groups is distributed among the affected community. The population below 10 years susceptible to landslide in CCC area are found to be 11312 (very high susceptible), 34214 (high susceptible) and 123123 (medium susceptible). The total population above 60 years in CCC area are 44016, among them 6% (2618) are found in very high susceptible, 20% (8625) high susceptible and 74% (32772) medium susceptible to several landslide occurrences also shown in Figure 20.

Literacy increases disaster awareness among people and has an influential effect on successful disaster management process. Literacy rate of almost all the wards of the study area is around 70% (BBS, 2011). Literacy rate has not been considered because it will not impose much difference in the susceptibility assessment process.

### Environmental susceptibility analysis

A landslide phenomenon in CCC area poses a serious effect on environment. Since most of the landslide occurrences are recorded on hilly areas composed with dense forest, there lies severe risk to landslide hazard. Among all the forest areas in CCC area, 24% (4.99 $km^2$) lies in very low, 16% (3.34 $km^2$) in low, 34% (7.29 $km^2$) in medium, 21% (4.47 $km^2$) in high and 5% (1.14 $km^2$) in very high susceptible areas, as shown in Figure 21. Though the dense forest in very high susceptible areas are lower but the overall susceptibility of forest areas are significantly higher because of having higher percentage of forest areas in very high susceptibility class. The medium susceptibility class has covered highest percentage of forest areas but the overall susceptibility to landslide occurrences are lower in this class (Figure 22). The very high susceptible areas in Figure 21, occupies 63% (1.14 km²) forest land, 27% (.49 km²) shrubs or agriculture land, 8% (.14 km²) barren land, 2% (.04 km²) urban area and 0% (0 km²) water which also shows forest areas in this class are very highly susceptible to landslide hazard.

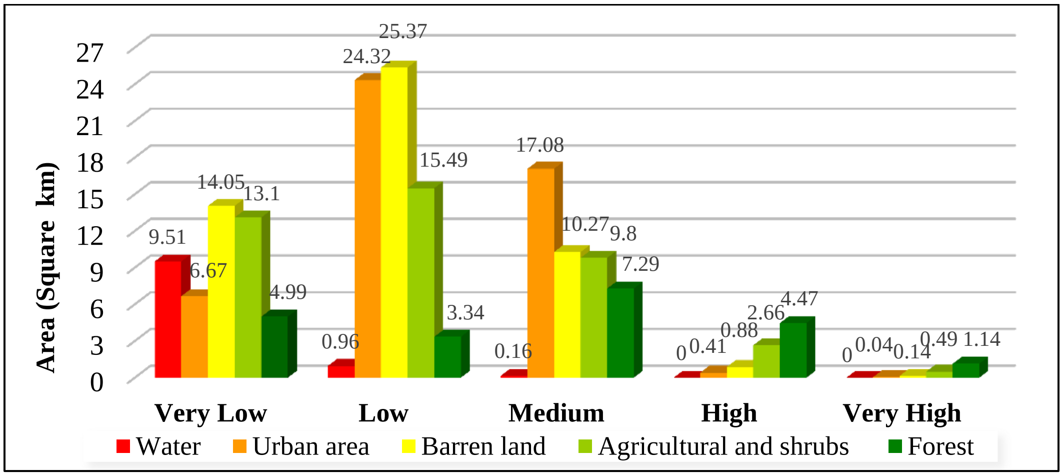



**Figure 21: Environmental susceptibility to landslide hazard**

The forest areas are higher in very high and high susceptible classes but in low susceptibility class, the amount of forest areas are lower. The highest numbers of urban areas are found in low and medium susceptible areas which have less probability of landslide occurrences. The shrubs and agriculture land are also higher in very low and low susceptible classes which can also be recognized as flat land, as shown in Figure 21.

## Major findings

In CCC, very high susceptible areas for landslide are found to be 6.5 sq. km and high susceptible areas are 11.45 sq. km which represents 4% and 7% of total areas respectively. The very high susceptible locations are identified as *Motijorna Tankirpar, Batali hill, Lebubagan, Foy's* lake, *Kusumbag* residential area, *Khulsi, Akbar shah mazar* hill and *Nasirabad residential area.* Since most of these locations are used as residential purposes, the infrastructural and social susceptibility to landslide are higher in these locations. Among all the susceptible residential structures in CCC, the very high susceptible, high susceptible and medium susceptible locations are found to be 7%, 21% and 72%. In case of road susceptibility, 5% (43.36 km) roads are very highly and more than 95% (800km) of roads are highly to medium susceptible. The medium susceptible road occupies the larger portion of the road network.

The very high susceptible critical facilities are identified as 144 (4%), high susceptible 636 (19%) and medium susceptible 2648 (77%) of total critical facilities in CCC area. The education and research and service activity facility possesses higher susceptibility to landslide occurrences.

Among all the economic activities, 19 of manufacturing and processing industries and 299 commercial activities are threatened very highly to landslide hazard. The number of very high susceptible population (56777) comprises 7% of total susceptible population in CCC area. The high susceptible and medium susceptible population comprises 20% and 73% of total susceptible population. The percentage of female population susceptible to landslide hazard can be described as very high susceptible 7% (26668), high susceptible 20 % (76713) and medium susceptible 73% (273511) of total affected female population. The population below 10 years susceptible to landslide in CCC area are found to be 11312 (very high susceptible), 34214 (high susceptible) and 123123 (medium susceptible). The total population above 60 years in CCC area are 44016, among those 6% (2618) are found in very high susceptible, 20% (8625) high susceptible and 74% (32772) medium susceptible to several landslide occurrences.

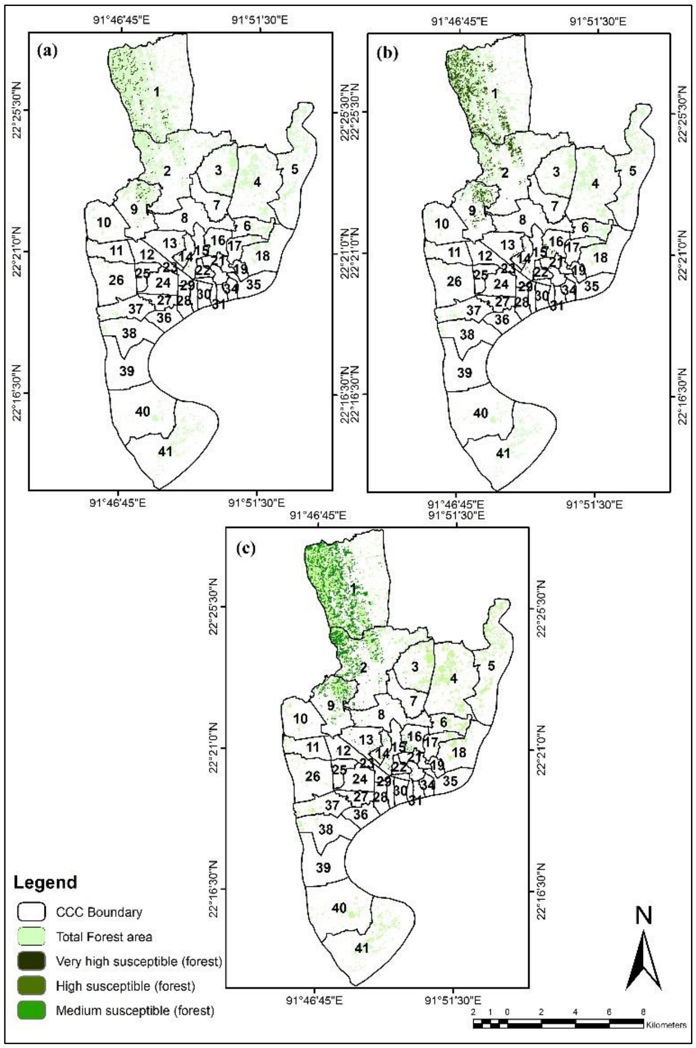



**Figure 22: Environmental susceptibility (dense forest) map of CCC area: Very high susceptible (a), High susceptible (b), Medium susceptible (c)**

Among all the forest areas in CCC area, 24% (4.99 $km^2$) lies in very low,16% (3.34 $km^2$) in low, 34% (7.29 $km^2$) in medium, 21% (4.47 $km^2$) in high and 5% (1.14 $km^2$) in very high susceptible areas. The forest areas are higher in very high and high susceptible classes but in low susceptibility classes the amount of forest areas are lower. On the basis of the major findings, the overall landslide susceptibility of CCC is summarized in the Table 7 and it can be concluded that the overall community susceptibility is high for landslide hazard.

**Table 7: Summarized result of the study**

| Hazard | Parameter | Status |
|---|---|---|
| Landslide | Physical susceptibility | High |
| | Critical facilities susceptibility | Medium |
| | Social susceptibility | High |
| | Economic susceptibility | Low |
| | Environmental susceptibility | Low |

## Conclusion

Hill cutting and heavy rainfall are prime factors for landslides in Chittagong that causes death to hundreds people with a great property loss. The study is an attempt to see the efficacy of AHP and CVAT tools for analyzing landslide susceptibility of the CCC area. As susceptible areas of the landslide are found in the study, it would be rational to provide supportive actions for preparing disaster management plan for these susceptible areas. Besides, several steps can be taken to reduce the effect of landslide such as to understand the processes and mechanisms of landslide, Sensitive hill areas needs special environmental impact assessment (EIA) before undertaking any development activity, density restriction should be established, Relocation of the foothill slums, comprehensive awareness is to be administered to enhance public awareness, harmonization of institutional mandates should be developed through an inter-organizational coordination mechanism etc. Finally on the basis of the study it can be concluded that if the government and other concerned authorities take necessary steps, susceptibility of landslide hazards can be reduced to an extent tolerable to the city people.

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