INTERIM REPORT

on

Developing Dynamic Web-GIS Based Early Warning System for the Communities at Landslide Risks in Chittagong Metropolitan Area, Bangladesh

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ABSTRACT

Landslides are one of the most significant natural damaging disasters in hilly environments. Chittagong Metropolitan Area (CMA), the second largest city of Bangladesh, is vulnerable to landslide hazard with an increasing trend of frequency and damage. Devastating landslides have hit CMA repeatedly in recent years. Landslide events occurred at a much higher rainfall amount compared to the monthly average. Moreover, rapid urbanization, increased population density, improper land-use, cutting of hills, indiscriminate deforestation and agricultural practices are aggravating the landslide vulnerability in CMA. Against this backdrop, it is essential to develop an early-warning system for the hilly communities of CMA incorporating local knowledge.

The first step of developing early warning system is to prepare an inventory of all previous landslide locations. A landslide inventory has been prepared for the CMA area by existing archive, field survey To prepare inventory three steps have been followed. At first, existing achieves of landslide have been studied. Some information that could not have been found from existing achieves were collected from field survey. Participation of local people in field survey was a big part of field survey. Some other data that could not have been collected from field survey were collected through image interpretation.

The survey phase shows the physical and socio-economic condition of the inhabitants of four study areas vulnerable to landslide namely Moti Jharna, Batali Hill, Golpahar and Goachibagan Medical Hill of CMA. At first, a total of 590 respondents were interviewed to study their socio-economic condition, physical aspects and landslide management. Then a community survey was conducted using Participatory Rural Appraisal (PRA) tools in the four communities. Lastly, eight experts in Chittagong Metropolitan Area (CMA) were interviewed to know their opinion about managing landslide disaster.

A stakeholder meeting was arranged with the help of Chittagong Development Authority (CDA) where the representatives of ICIMOD, the project team and the authority of CDA participated. Different suggestions and opinion on different issues were given through a lively discussion among the participants.

The objective of rainfall modeling is to predict the future rainfall pattern of Chittagong Metropolitan Area. The average annual rainfall is not same in each year. Excessive rainfall causes lose of soil and landslide in hilly areas. As a result, there is a huge loss of properties and lives in every year. To prepare for the preparedness and mitigation program it is necessary to know the return period of these devastating events calculating the long term rainfall data. From rainfall pattern modeling we have found the pattern of rainfall of the study area.

Soil investigation is a must for this research. It is must to know the physical characteristics of soil for making a water balance model. The variation of soil moisture and different processes (infiltration, evapotranspiration, percolation and groundwater flow) in soil layers depend on soil properties. The soil hydraulic properties are determined by two main characteristics of soil named texture and structure. The characteristics of soil are found in soil investigation part of this project.

Land cover change is an important issue in soil failure. Vegetation intercepts rainfall directly in the canopy (overlay) and decrease the amount of rain water reaching to the soil surface. A projected land cover map has prepared earlier during land cover modeling using satellite images (year: 1990, 2000 and 2010) from the United States Geological Survey (USGS).
Therefore it can be stated that there is a strong and positive correlation between land-use change and landslides. At this drawback, landcover map tries to project the future land cover change of Chittagong Metropolitan Area (CMA).

Landslide is the hazard significant for most casualties and damages on this earth. The damages in a landslide depend on the type, speed and volume of the soil movement. Hydrology is a major determinant of many natural hazards. Landslide occurs mainly due to slope instability of hilly areas. Slopes may become instable because of ground water fluctuation due to heavy rainfall for some consecutive days, typhoon, hurricanes, earthquake, human activity etc. So, it is very necessary to know about the stability of slope i.e, susceptible areas in a hilly and mountainous region before taking any measure to prevent or manage the devastating disaster and thus reduce the losses.

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CHAPTER 1: INTRODUCTION

1.1 PROJECT DESCRIPTION

The hilly areas of Bangladesh are vulnerable to landslide as like as the other hilly regions of the world. Every year landslide occurs in the port city of Chittagong in south-eastern part of Bangladesh. Heavy rainfall during monsoon season causes single and multiple landslides that destroy the houses as well as lives of slum dwellers around the hilly areas. Landslide causes damage to properties, death to people and collapse social life. To mitigate the death loss, it is necessary to develop a warning system for the people of those areas so that they can move to other places when there is possibility to a landslide.

In this connection, this project is being conducted namely 'Developing Dynamic Web-GIS based Early Warning System for the Communities at Landslide Risks in Chittagong Metropolitan Area, Bangladesh'. The project is funded by SERVIR-Himalaya, a joint initiative of USAID (United States Agency for International Development) and NASA (National Aeronautics and Space Administration). The International Centre for Integrated Mountain Development (ICIMOD) assists the project.

The aim of this project is to create a dynamic website that will warn the landslide vulnerable communities of Chittagong Metropolitan Area (CMA) in advance. To achieve this goal it is necessary to understand the mechanisms of landslides, litho logy, the human ecology to landslides, decision-making process, preparing the predictive susceptibility maps, and analyze the rainfall pattern of CMA. The website will incorporate all the relevant information and apply advanced geospatial technologies. This will help in reducing the impact of landslide risks on the people of Chittagong city.

1.2 BACKGROUND OF THE PROJECT

Landslides are one of the most significant natural damaging disasters in hilly environments. Social and economic losses due to landslides can be reduced by the means of effective planning and management [1]. Moreover, land-use and land-cover changes have been recognized as world's one of the most important factors stirring rainfall-triggered landslides [2]. Land cover changes (e.g. urbanization, deforestation) cause large variations in the hydro-morphological functioning of hill-slopes, affecting rainfall partitioning, infiltration characteristics and runoff production. All these factors trigger landslides in hilly areas [3]. On the other hand, worldwide heavy one or multiple-day precipitation events have increased alarmingly due to climate change [4].

The rapid land-cover change (e.g. unplanned urbanization in steep slopes, hill cutting), coupled with the increased intensity and frequency of adverse weather events (e.g. heavy rainfall in short time span), is causing devastating effects (e.g. landslides) in Bangladesh, which also has lower capacities to deal with the consequences of climate change [4]. Particularly in Chittagong Metropolitan Area (Figure 1.1), where many urban dwellers and their livelihoods, quality of life, property and future prosperity are being continuously threatened by the risks of rainfall triggered landslides that climate change is expected to aggravate. Devastating landslides have hit Chittagong repeatedly in recent years (Table 1.1). At least 90 people were killed in a recent landslide in Chittagong on June 26, 2012. The reasons were heavy rainfall and multiple landslides over three consecutive days. The officials reported that at least another 15,000 people were stranded [5].

In addition, there is no strict hill management policy within CMA. This has encouraged many informal settlements along the landslide-prone hill-slopes of Chittagong. These settlements are being considered as illegal by the formal authorities, while the settlers demand themselves as legal occupants. This is how; there is acute land tenure conflict among the formal authorities, the settlers and the local communities over the past few decades. This kind of conflict has also weakened the institutional arrangement for reducing the landslide vulnerability in CMA.

It is therefore, essential to develop an early warning system for the hilly areas of CMA incorporating local knowledge to reduce the loss of lives and property. The aim of this project is to create a dynamic website that will warn the landslide vulnerable communities of CMA in advance. This will help to enrich the landslide mitigation strategies for sustainable mountain development.

Figure 1.1: (a) Location of the study area in Chittagong hill tracts and (b) location of CMA

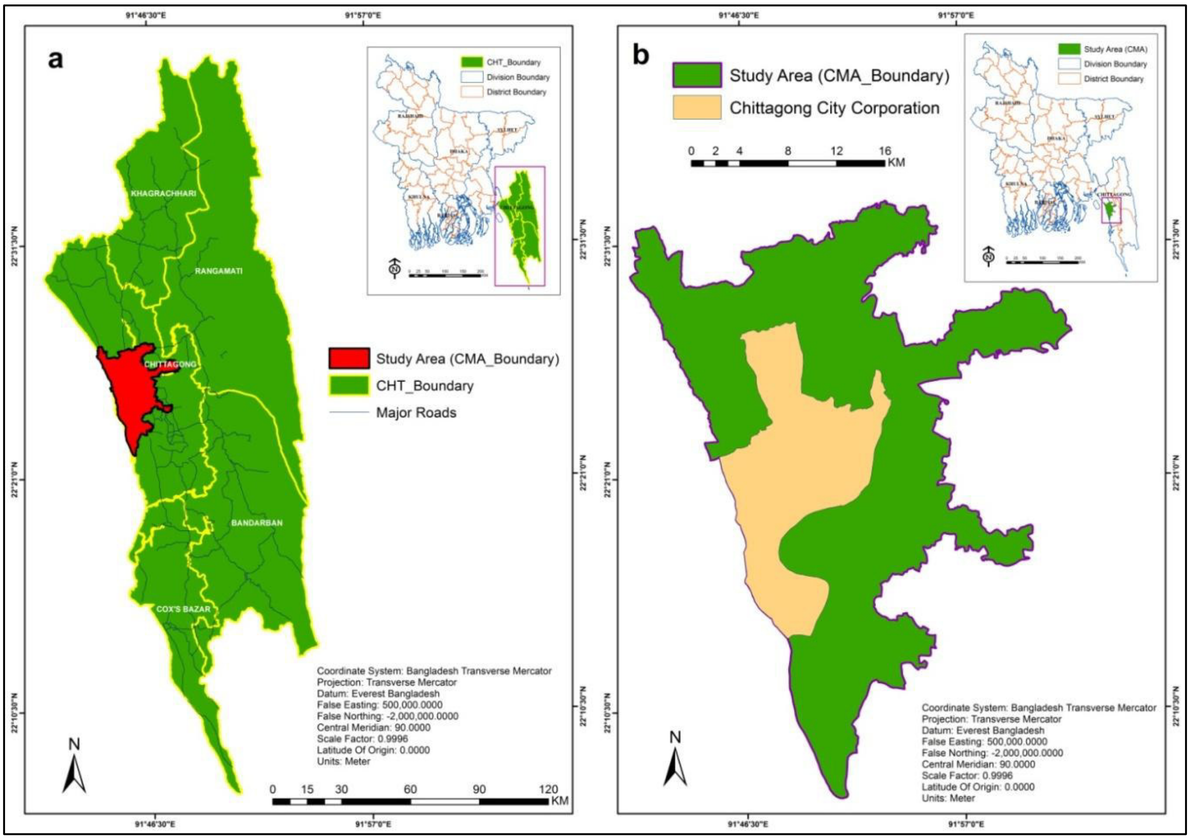


Table 1.1: Major landslide events in CMA in recent years.
Source: Comprehensive Disaster Management Programme-II (CDMP-II), Ministry of Food and Disaster Management, Bangladesh; and Field Survey, September 2013.

Date	Location	Rainfall sequence (cumulated rainfall)	Consequences
13 August 1999	Gopaipur, Kotwali Thana, Chittagong	435 mm – 12 days 2 – 13 Aug 1999	10 people killed
24 June 2000	Chittagong University Campus	108 mm – 8 days 17 – 24 June 2000	13 people killed and 20 injured
29 June 2003	Patiya, Chittagong	658 mm – 10 days 20 – 29 June 2003	4 people killed
3 August 2005	Nizam Road Housing Society, Panchlaish area	25 mm – 2 days 2-3 August 2005	2 people killed and 12 injured
11 June 2007	MatijharnaColony,Lalkhan Bazar	610 mm – 8 days 4 – 11 June 2007	128 people killed and 100 injured
10 September 2007	Nabi Nagar, Chittagong	452 mm – 7 days 4 – 10 Sept 2007	2 people killed
18 August 2008	Matijharna, Chittagong	454 mm – 11 days 8 – 18 August 2008	11 people killed and 25 injured
26 June 2012	Lebubagan area and Foy's lake surroundings	889 mm – 8 days 19 – 26 June 2012	90 people killed and 150 injured

It is also important to analyze how the local people and actors react to the landslides. The local people's perception, local level practices to disaster management and their real-world experiences also need to be incorporated (bottom-up integrated approach) in response to landslide hazard management planning of CMA.

1.3 OBJECTIVES OF THE PROJECT

This project will extensively use geospatial information, latest techniques and tools related to geoinformatics and spatial statistics to achieve the following objectives:

(a) To establish the nature of relationships among land-cover change, rainfall, climate change and landslide disaster.

(b) To produce the landslide susceptibility maps of CMA.

(c) To understand human adaptation to landslide risks under the condition of rapid urbanization and torrential rainfall.

(d) To assess community needs for effective implementation of early warning system for landslide.

(e) To create a web-based dynamic model to early-warn the people living in landslide vulnerable zones in CMA.

1.4 STUDY AREA PROFILE

Chittagong is the second-largest and main seaport of Bangladesh. The city comprises of flat land, small hills and narrow valleys; bounded by the *Karnaphuli* River to the south-east, the Bay of Bengal to the west and *Halda* River to the north-east (Figure 1.1-b). The city has a population of about 5 millionand is constantly growing [6]. The study area, CMA, is situated within 22° 14′ and 22° 24′ 30” North Latitude and between 91° 46′ and 91° 53′ East Longitude (Figure 1.1-b). The total area of CMA is approximately 775 square kilometres.

The weather of the Chittagong Hill Tract (CHT) region (Figure 1.1-a) 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 [7]. Moreover, due to climate change, CMA is experiencing high intensity of rainfall in recent years which is making the landslide situation worse [4]. 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 (Figure 1.2).

Figure 1.2: Annual rainfall pattern of Chittagong city from 1960-2010.
Data source: Bangladesh Meteorological Department, 2013

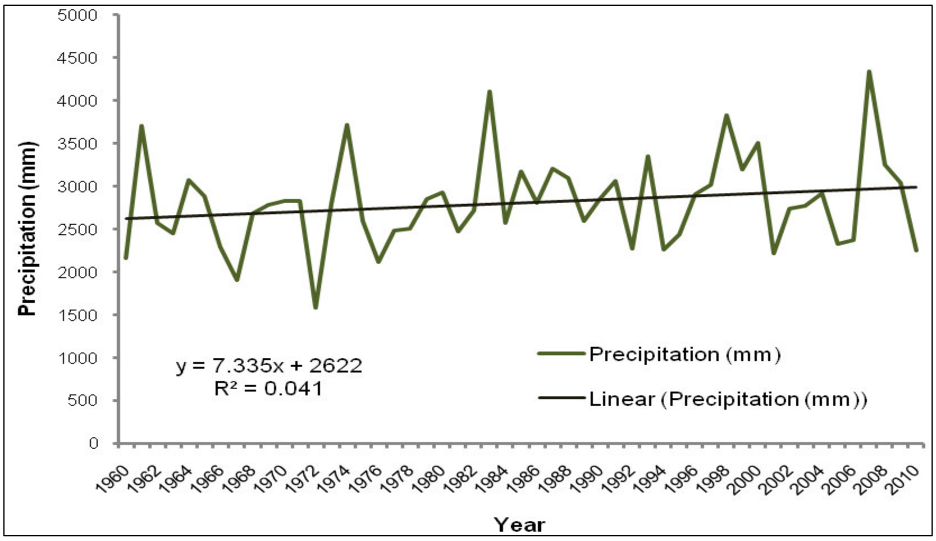


Figure 1.3: Landslide vulnerable areas in Moti Jharna, CMA
Source: Field Survey, September, 2014

In general, the geological structures and soils are weak in CMA. Moreover, the hills have steep slopes that are vulnerable to landslides [8]. 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 [9]. Figure 1.3 depicts how people of Moti Jharna, 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.

CHAPTER 2: INVENTORY OF CHITTAGONG METROPOLITAN AREA (CMA)

2.1 CHITTAGONG METROPOLITAN AREA

Chittagong Metropolitan Area (CMA) is located towards South-East of the Capital city of Dhaka which is around 280 KM. Chittagong city is situated on the bank of Karnaphully River and the city is surrounded by rich natural resources like the green Hilly Terrain (Figure 2.1-a) and the Bay of Bengal on the west (Figure 2.1-b). Chittagong is the second largest city, prime sea port and the heart of all commercial and business activities in Bangladesh. Accordingly, the government of the country has already declared Chittagong as the “Commercial Capital” of the country by this time. After the independence of Bangladesh in 1971, Chittagong has earned a significant status of the second important City because of the Chittagong Port, diversified Economic activities, Natural Beauties, Industrial activities and because of its suitable geographical location factor in the regional map [10].

Topographically Chittagong is a hilly city surrounded by Karnaphully River and the Bay of Bengal from different sides contributing the friendly urban growth. At the very beginning, Chittagong Town started to grow as a small Municipality in 1863 that was inhabited by 25,000 people only. In 1864 (the town area 4.5 sq. Miles) the city was reconstituted as Chittagong Municipality. It was further upgraded to Chittagong Municipal Corporation CMC) in 1982 and finally as Chittagong City Corporation (CCC) in 1990. The Chittagong Metropolitan Area (CMA) is administered by the Chittagong City Corporation (CCC) and the Chittagong Development Authority (CDA). At present, CMA area is approximately 775 square kilometres (Bangladesh Transverse Mercator Projection) [11]. Chittagong City is inhabited by approximately 6.6 million people [12].

Chittagong is a land on huge Natural Beauty; here there are Natural Gifts like Virgin Hilly region, the Bay of Bengal and the Karnaphully River. These Beautiful Natural features can be potentially developed with modern Tourist Facilities, which can attract local as well as foreign tourist in the city and surrounding areas. This would obviously enhance the Tourist

Industry along with small and medium size Industrial Activities in the whole region, where huge Employment Opportunities could be generated at the same time.

Figure 2.1 (a): Panoramic view of Chittagong city area from the top of Ispahani hill

Figure 2.1 (b): Location of Chittagong metropolitan area (CMA). Source: Banglapedia, National Encyclopedia of Bangladesh, 2012.

2.2 LITHOLOGY AND GEOMORPHOLOGY OF THE STUDY AREA

2.2.1 Soil Characteristics of Landslide Vulnerable Hills

The Chittagong Hill Tracts is originated as a result of the collision between India and Asia. After the breakup of Gondwanaland, Indo-Australian plate combinedly moved southeasterly of about 1750 km at a drift rate of 6 cm/yr. Later India broke apart from Australia and started to drift north northeasterly. That is the time when the history began for the Chittagong Hill Tracts [7].

Central Burma or Irrawaddy Basin represents the back-arc basin and Arakan-Yoma folded belt and its western extension up to Chittagong-Tripura hills, a part of which is the Chittagong Hill Tracts, representing the fore-arc basin. The thick sediments deposited in the Irrawaddy Basin during Miocene and Lower Pleistocene time are exposed in the Chittagong and Tripura hills [7].

In the Chittagong Hill Tracts the Upper Tertiary sandy-argillaceous sediments have been folded into a series of long submeridional (NNW-SSE) anticlines and synclines represented in the surface topography by elongated hill ranges and intervening valleys. The folded structures are characterized by en-echelon orientation with an increasing degree of intensity and complexity toward the east. Accordingly, the folded flank is divided into three parallel almost N-S trending zones from west to east as:

(a) the Western Zone is characterized by simple box-like or similar shaped anticlines with steep flanks and gentle crests separated by gentle synclines, viz Matamuhuri anticline, Semutang anticline, etc;
(b) The Middle Zone is characterized by more compressed structures, other than just simple box-like folds, with ridge like asymmetric anticlines frequently associated with faults and separated by narrow synclines vizSitapahar anticline, Bandarban anticline, Gilasari anticline, Patiya anticline, Changohtung anticline, Tulamura anticline, Kaptai syncline, Alikadam syncline, etc;
(c) The Eastern Zone is characterized by highly disturbed narrow anticlines with steep clipping flanks and mostly associated with thrust faults, vizBelasari anticline, Subalong

syncline, Utanchatra anticline, Barkal anticline, Mowdac anticline, Ratlong anticline, Kasalong syncline, Sangu Valley syncline and few others [7].

Figure 2.2 and figure 2.3 give more ideas about the geological condition.

Figure 2.2: Geological Map of CCC and its surrounding areas.
Source: Geological Survey of Bangladesh (GSB), 2013

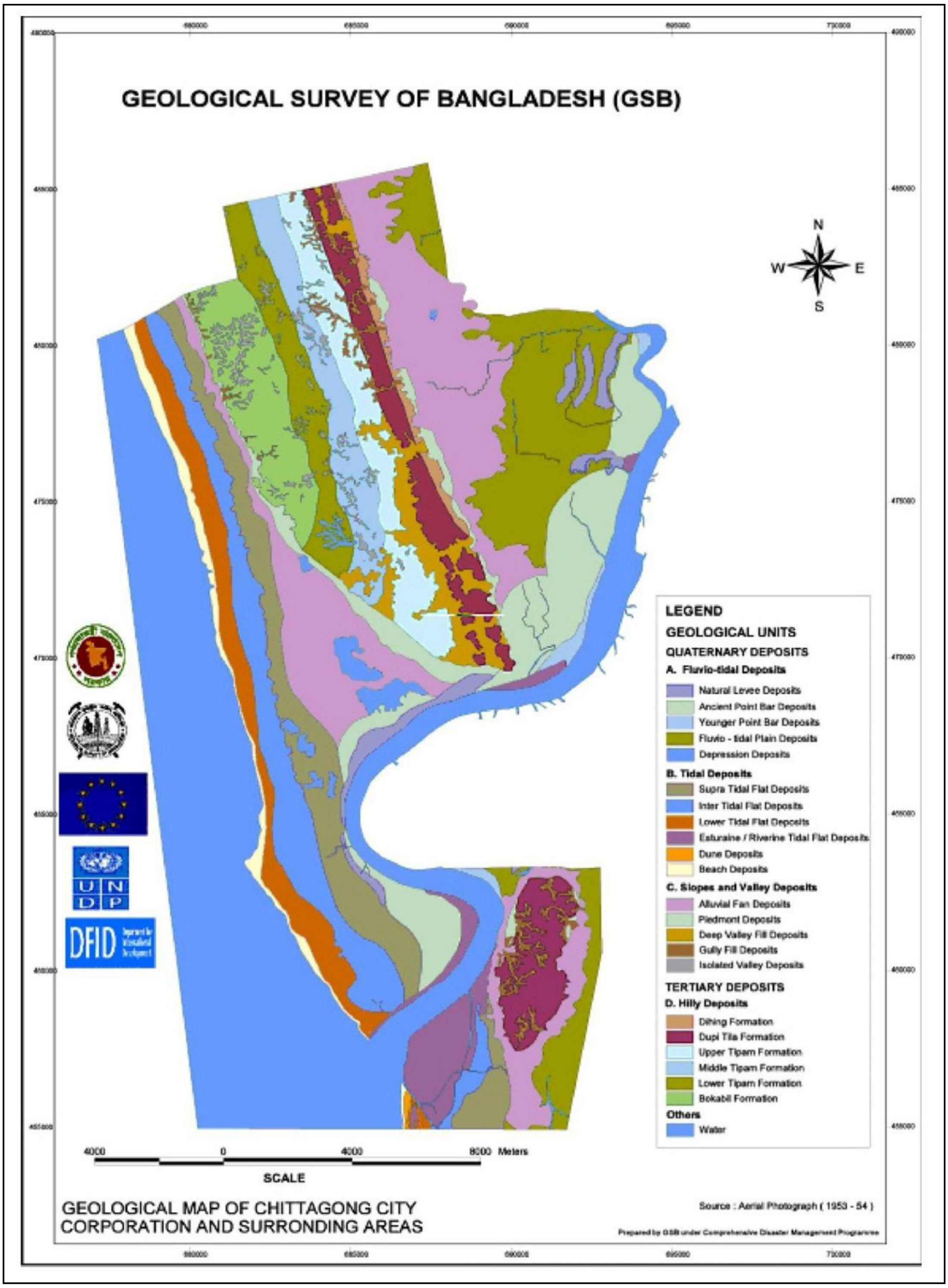
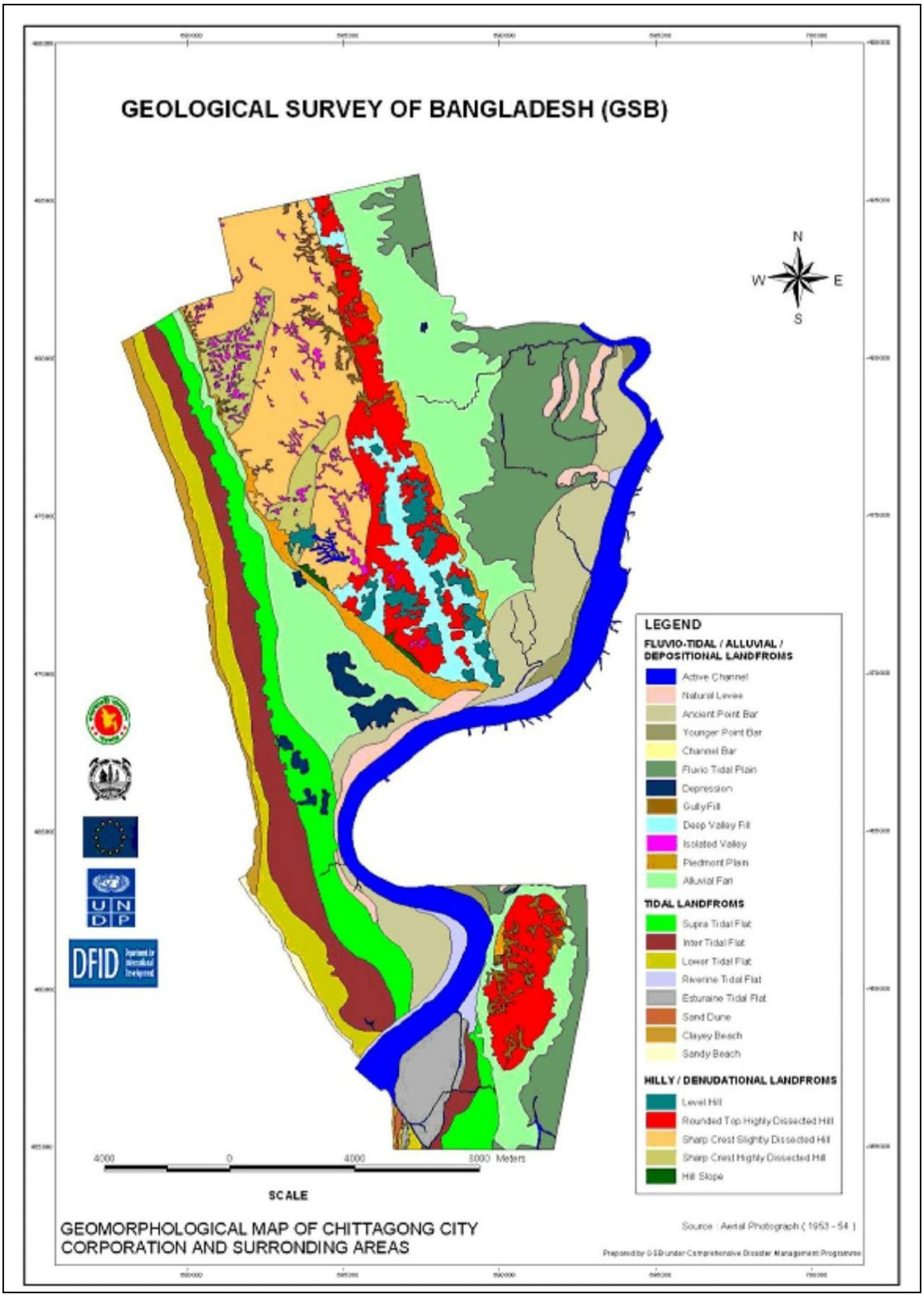


Figure 2.3: Geo Morphological map of CCC and its surrounding areas.
Source: Geological Survey of Bangladesh (GSB), 2013



2.3 IDENTIFICATION OF THE LANDSLIDE LOCATIONS

The main objective of the inventory is to prepare an informative report to understand the process and mechanism of previous landslide events occurred in Chittagong Metropolitan Area (CMA). For this, following factors have been studied:

(a) Landslide classification (using different available schemes)
(b) Landslide dimensions (different widths and lengths)
(c) Landslides activity and its distribution (advancing, enlarging, moving, widening etc.)
(d) Rate of movement of landslides (extremely slow to extremely rapid)
(e) Potential causes of landslides (geological, morphological, physical, human induced etc.)
(f) Landslide triggering mechanism (excessive rain, water level change, earthquake, human activities)
(g) Factors influencing slope stability (gradient, slope geometry, stress, vegetation, disturbance etc.)

2.3.1 Cluster-wise Landslide Location

From the field survey 57 locations have been found where landslide event occurred in previous years. These locations are organized into ten clusters (Table 2.1). The selection of the clusters was based on the landslide hazard locations, tentative similarity of the surroundings and landslide mechanisms. The locations of the clusters are attached in Appendix-C. Location of each cluster with respect to surrounding places has been described below:

Cluster 1

A Branch of Chanmari Road is at the North side of this cluster. At the South, East and West side there are Tiger pass railway colony, CDA Avenue and Ambagan Road respectively (Appendix-C, Figure-1).

Cluster 2

This cluster is inside the Chittagong Cantonment Area. The Cantonment Area is located at the North side of the major road Bayejid Bostami Road. Chittagong Cantonment Road is at the West side of Lebubagan and Kaccharghona area. The Bhatiari Hathazari Link Road and

Mobarok Road are at North and South side respectively. Chittagong Cantonment Railway station is at the East. Besides, Sekandarpara is at North side of Bhatiari Hathazari Link Road. (Appendix-C, Figure-2).

Cluster 3

Nasirabad Properties Limited and Cluster 7 are at the North side of this area. Hazrat Goribullah Shah Mosque is at the East, South Khulshi Mosque is at the West and Lankhan Bazar is at the South of this cluster. (Appendix-C, Figure-3).

Cluster 4

The locations in this cluster are in the Chittagong University Campus. At the North there are Tsunami Garden and Shahjalal Hall. The University Jame Mosque and Mosque of Faculty of Science are at North and West side of this area. The Golpukur is at the South of the cluster. (Appendix-C, Figure-4).

Cluster 5

This cluster is surrounded by North side Foy's Lake, Foy's Lake Road, Zakir Hossain Road and Bara Peer Hazrat Abdul Kader Zilani (R) Masjid at the North, East, South and West side. (Appendix-C, Figure-5).

Cluster 6

The Foy's lake is at North side of this cluster. The Cluster 5 is at the West side of this area. (Appendix-C, Figure-6).

Cluster 7

Bayejid Bostami Road is at the North-East side of this cluster. Zakir Hossain Road is at the South and the Foy's Lake is at the North-West corner. (Appendix-C, Figure-7).

Cluster 8

Amirbagh Residential Area is at the North side of this cluster. Badshah Mia Chowdhury Road at the West and the Bevery Hill Residential Area is at the East side. The Chatteswari Road is in between the Finley Hill and Dolphin Hill to the East-West direction. (Appendix-C, Figure-8).

Cluster 9

The Bevery Hill Residential Area and Chittagong Medical College Staff Quarter are at South and East side respectively. O R Nizam Road is in between the king of Chittagong and Medical Hill. (Appendix-C, Figure-9).

Table 2.1: Cluster of hills according to areas.

Source: Field Survey, August, 2014

Hill Name	Area	Cluster Name
Tankir Pahar 1	Moti Jharna	**Cluster 1**
Tankir Pahar 2		
Tankir Pahar 3		
Moti Jharna 1		
Moti Jharna 2		
Batali Hill 1		
Batali Hill 2		
Chanmari Bi Lane		
Tiger Pass Hill		
LebuBagan 1	Chittagong Cantonment	Cluster 2
LebuBagan 2		
LebuBagan 3		
Kaicchaghona 1		
Kaicchaghona 2		
Sekandar Para 1		
Sekandar Para 2		
Sekandar Para 3		
Kushumbagh Housing	Kushumbagh	Cluster 3
Goribullah Shah Mazar Hill		
Ispahani Hill		
Golachipa Hill	University of Chittagong	Cluster 4
Hill beside Shahid Minar		
KharaPahar1		
KharaPahar2		
Akbar Shah Mazar Hill	Akbar Shah Mazar	**Cluster 5**
LalPahar		
Golpahar 1		
Golpahar 2		
Golpahar 3		
Observation Tower hill	Foy's Lake	Cluster 6
Foy's Lake Zoo Hill 1		
Foy's Lake Zoo Hill 2		
Foy's Lake Zoo Hill 3		
Foy's Lake Zoo Hill 4		
Holy Crescent 1	Khulshi	Cluster 7

Holy Crescent 2		
Krishnochura Housing 1		
Krishnochura Housing 2		
Nasirabad Housing 1		
Nasirabad Housing 2		
Nasirabad Housing 3		
Zakir Hossain Road, South Khulshi		
AKS brickfield	Chotesshori	Cluster 8
Finley Hill		
Finley Hill		
Dolphin Hill		
Medical Hill (Goachi Bagan) 1	Pachlish	**Cluster 9**
Medical Hill (Goachi Bagan) 2		
Medical Hill (Goachi Bagan) 3		
Medical Hill (Goachi Bagan) 4		
The King of Chittagong		
The King of Chittagong		
Amin Taxtile	Others	Cluster 10
Blossom Garden		
A.K. Khan's House		

2.3.2 Instruments Used During Field Survey

(a) Measuring Tape:

The displacement of mass has been measured using long fiberglass measuring tape. (Figure 2.4-a)

(b) GPS Instrument: Garmin map 62s has been used to collect the GPS values in selected points. (Figure 2.4-b)

(c) Camera: The photographs of study locations have been captured using Samsung WB100 digital camera. (Figure 2.4-c)

Figure 2.4: Survey Instruments (a) Measuring tape, (b) GPS device, (c) Camera

(a) (b) (c)

2.3.3 Methodology

A methodology has been followed to prepare landslide inventory for Chittagong Metropolitan Area (CMA). Methodology has been described below.

Search for information of landslide

At first, the project team searched for the information of previous landslide events occurred in CMA and their intensity, damages, etc. from newspapers and websites/online documents. Different information related to this study was found. But some other information necessary for conducting this project could not be collected from existing achieves. To overcome this reconnaissance survey was conducted.

Reconnaissance survey

A reconnaissance survey was conducted to gather initial information of the project area/ locations. During this survey, some documents/ information were collected from different stakeholders namely Department of Environment (DOE), Chittagong Development Authority (CDA), Chittagong City Corporation (CCC), Assistant Commissioner (Land) of Chittagong Sadar Circle, Dept. of Soil Science and Dept. of Geography & Environmental Studies in University of Chittagong (CU). A list of vulnerable hills to study was made with the help of the information from DOE and CDA. A draft questionnaire was prepared to gather landslide information (Appendix-A). During reconnaissance survey a field visit was made to justify the contents of questionnaire. On the basis of the feedback found from field interview, the questionnaire was modified later.

Field Survey

Project team conducted the field survey for inventory in the areas of listed hills. During the field survey, it was difficult to identify the exact location of the landslide occurrence. In some cases, the areas were demolished/ lost in such a way that even local people never heard the name of the areas (Chittagong Cantonment, University of Chittagong). After asking so many of the local people, the team found the locations (Appendix-C). Total 57 locations have been identified and classified into 10 clusters (Table 2.1) where landslide events occurred in the previous years and also vulnerable to landslide in near future.

In this field visit information on location name, coordinates (latitude, longitude), datum and elevation, area of displacement mass, rainfall, landslide mechanism (type of movement, state, distribution, style, water content, material), existing land cover/ use type, causes of movement, landslide history (date of occurrence, duration of rainfall), consequences (casualties, injuries, damages, impacts) and future risk of landslide were collected.

Figure 2.5: Field Survey

(a) Taking GPS values, (b) Measuring displacement of mass, (c) Taking Photographs

Source: *Field Survey, August, 2014*

(a)

(b)

(c)

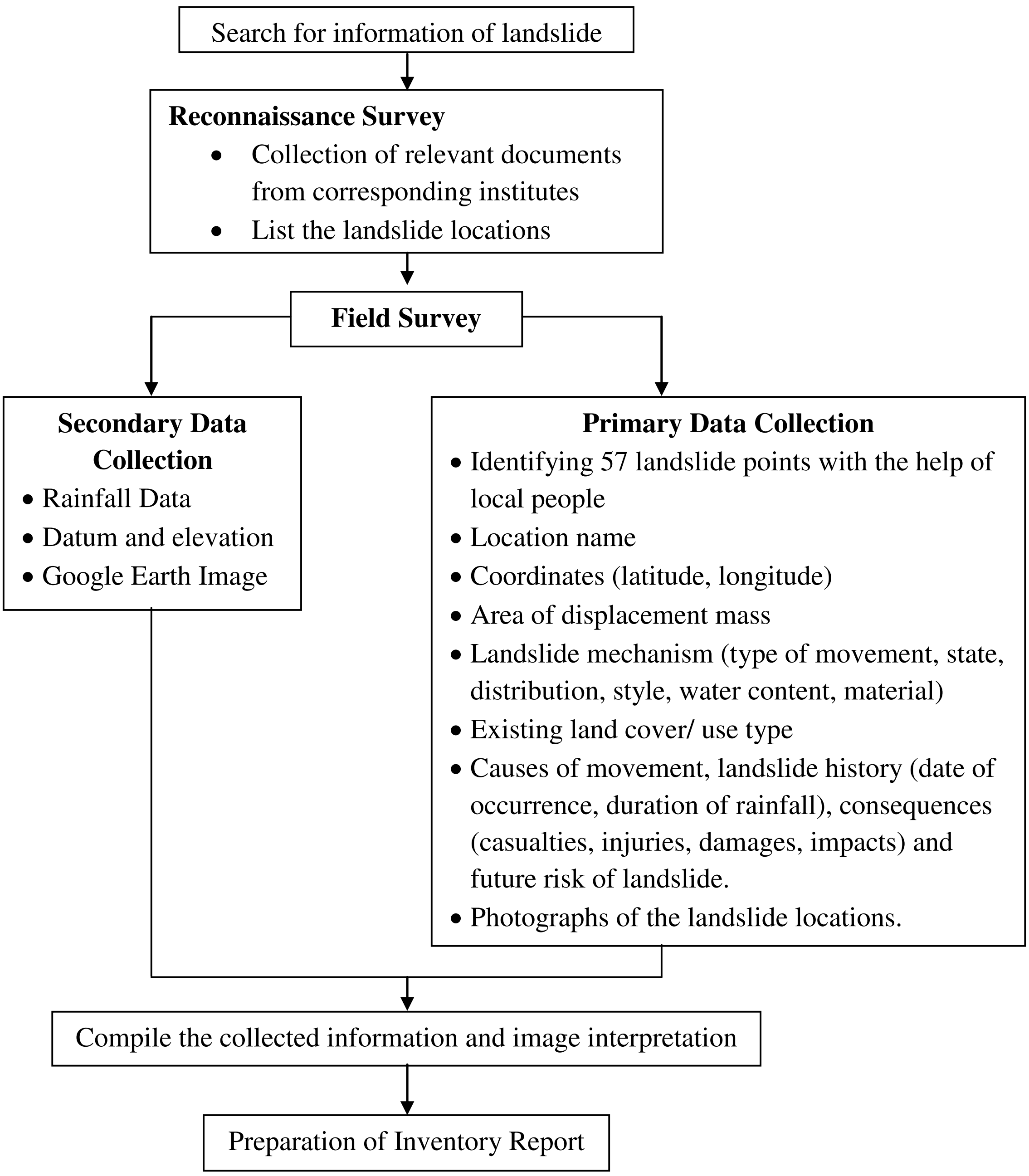
Location name was collected by interviewing people. Coordinate values of landslide locations was collected by using GPS (Figure 2.5-a). In case of some restricted/unreachable places information was collected through interpreting the Google earth image. The displacement of mass has also been measured (Figure 2.5-b). Besides, landslide mechanism, causes of movement, landslide history and consequences have been collected from the local people and the affected people to some places as the collected documents could not provide us with those information. The daily rainfall data have been collected from Bangladesh Meteorological Department up to the year 2010. However, as the exact date of some landslide events could not found from archive or the local people, the rainfall data could not be provided for those landslide events in the detailed inventory report. The future risks have been determined after over viewing the previous consequences of landslide and the opinion of the local people. Throughout the field survey photographs of the landslide areas considering different issues were collected by the project team (Figure 2.5-c).

Preparing landslide inventory

Finally GPS values have been used to prepare a landslide inventory location Map has by using GIS software. Related information to landslide of different locations has been organized into a report format. Lastly, a detailed landslide inventory has been prepared for the listed 57 landslide points in Chittagong Metropolitan Area.

The process of methodology has been shown in the following diagram (Figure 2.6):

Figure 2.6: Flow chart of the Methodology.



2.4 DETAILED INVENTORY OF THE STUDY AREA

Inventory map has been prepared indicating 57 landslide locations. There were some other landslide locations that could not be identified as local people have little knowledge on landslide. From the Landslide Inventory Map it is seen that landslide areas are located at the northern western part of Chittagong Metropolitan Area (Figure 2.7).

Analyzing landslide location with respect to geology it is seen that most of the land slide locations are located in Dulphi tila formation and Tipam sandstone geological class (Figure 2.8).

By analyzing landslide inventory with respect to slope characteristics it is seen that most of the lands in Chittagong Metropolitan Area are of flat slope. Slope of landslide location areas are found to be 30-40 degree (Figure 2.9). This is because; Inventory with respect to slope map has been prepared by using 30 m resolution Aster GDEM. As it covers a wide area the average slope value calculated is lower than the actual slope of landslide location. During the field survey it has been observed that there are many landslide locations whose slope is near vertical.

Figure 2.7: Landslide Inventory Mapping in Chittagong Metropolitan Area.

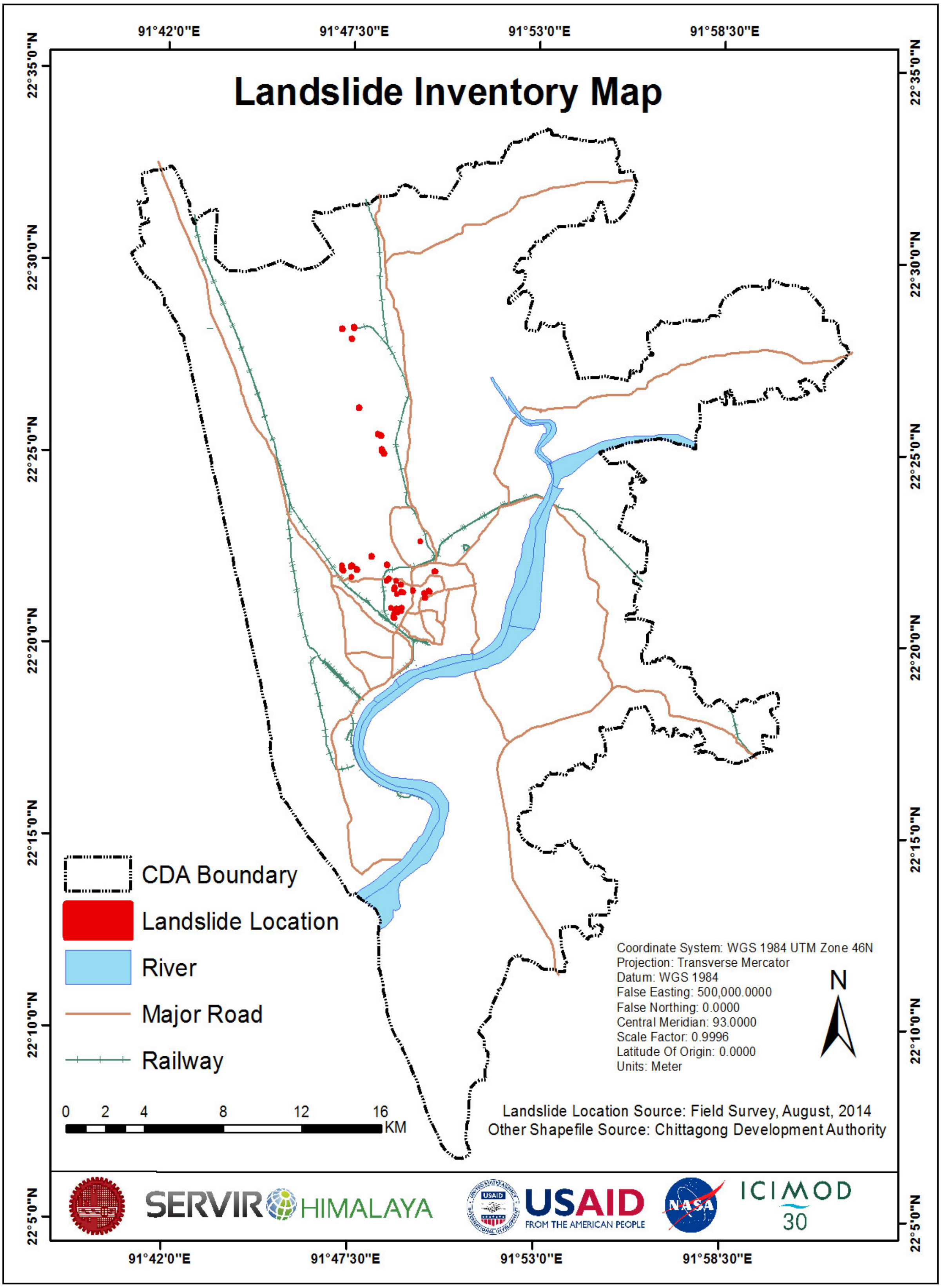


Figure 2.8: Landslide Inventory Mapping in respect of geology in Chittagong Metropolitan Area

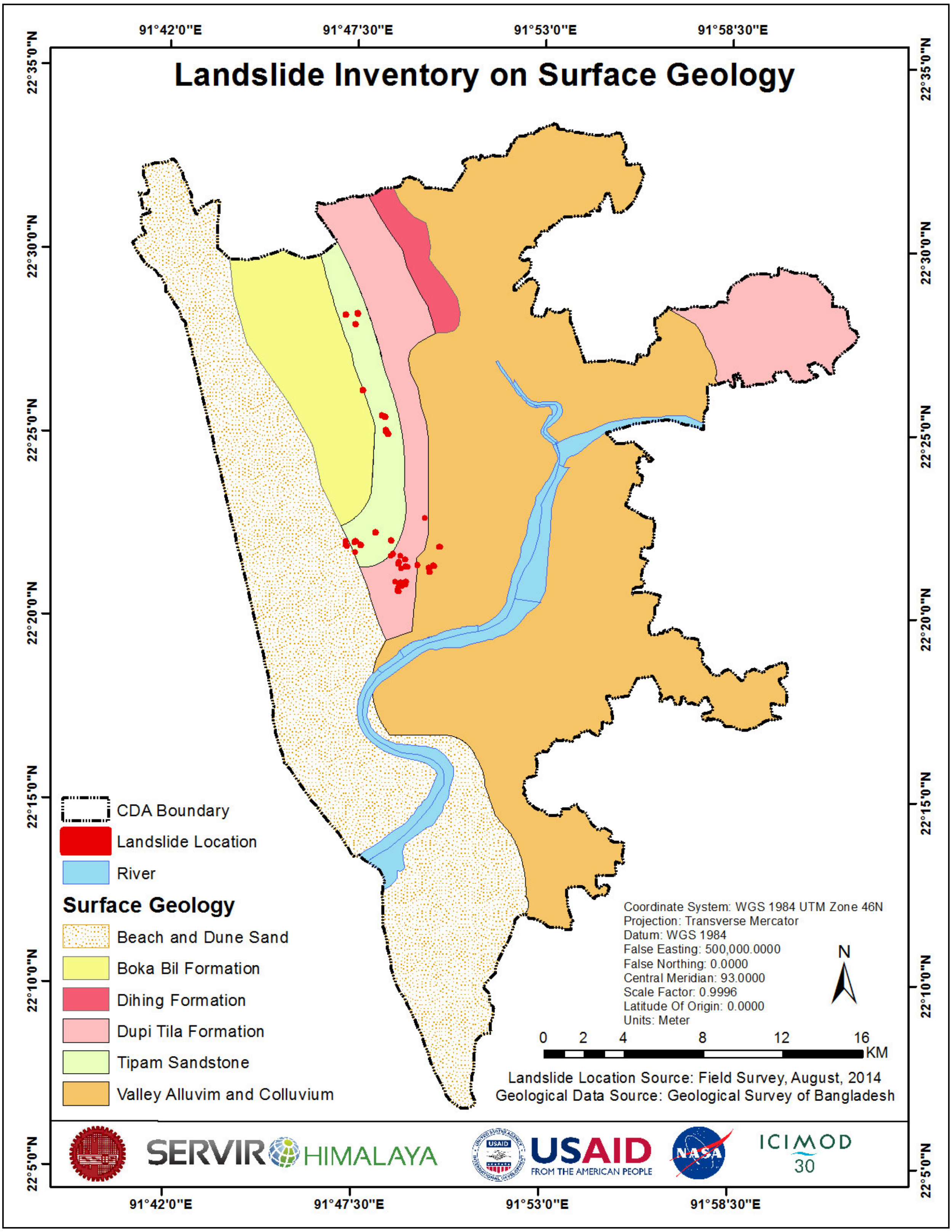
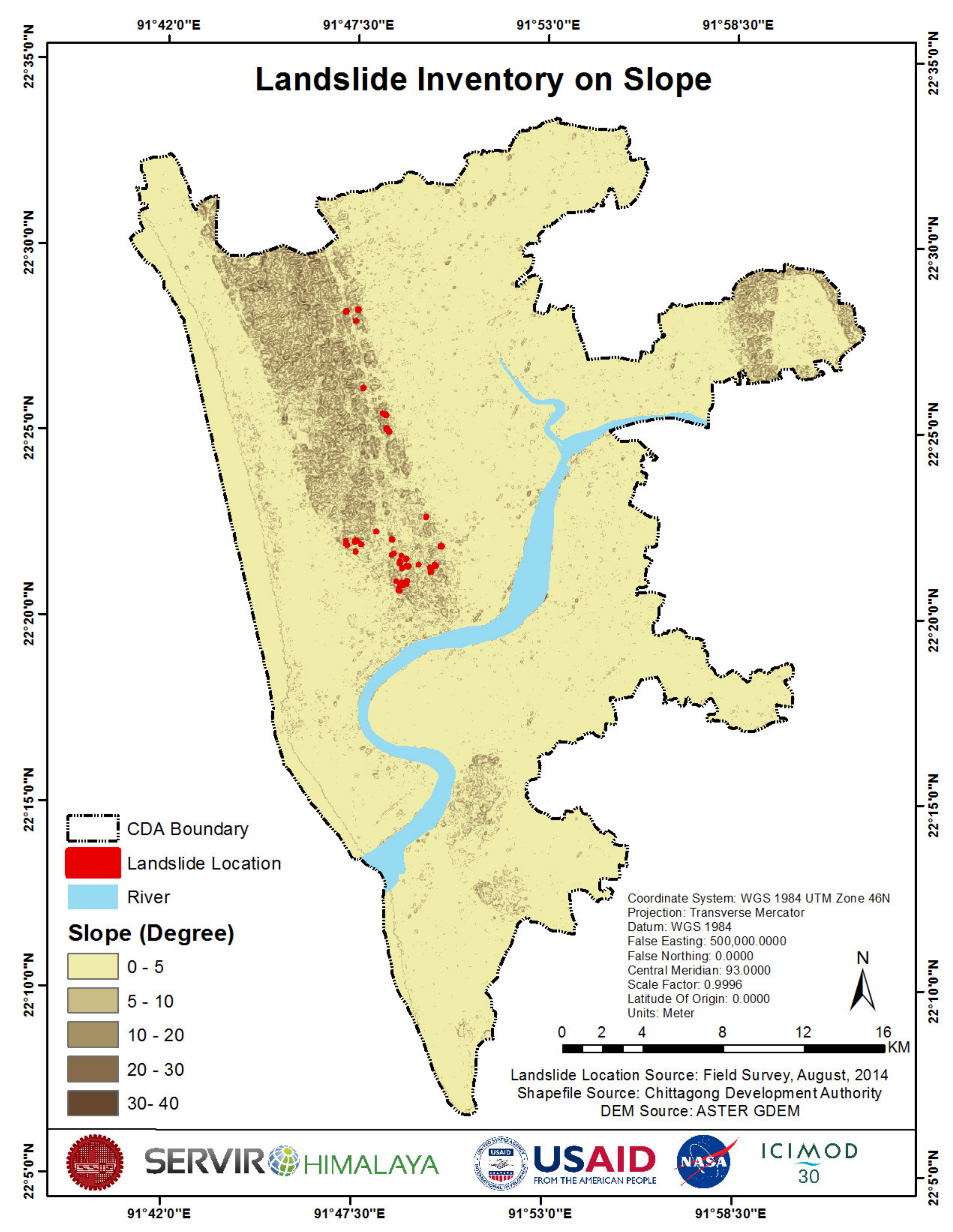


Figure 2.9: Landslide Inventory Mapping in respect of slope character Chittagong Metropolitan Area



Some major landslide events and future risks are described below:

CASE STUDY-01

<table>
<tr><td colspan="2">Basic Information</td></tr>
<tr><td>Landslide ID :05
Landslide Location: Tanker Pahar, Moti Jharna
Coordinates: 22° 20’54.27’’N, 91° 48’51.60’’E</td><td>Datum: WGS 1984
Elevation (m): 41.18
Area of Displaced Mass (sqm): 331.84
Rainfall: Unknown</td></tr>
<tr><td>
Source: Field Survey, August 2014</td><td>
Source: Field Survey, August 2014</td></tr>
<tr><td colspan="2">Landslide Mechanism</td></tr>
<tr><td>Type of Movement: Slide
State: Active, Reactivated, Suspended
Distribution: Advancing</td><td>Style: Single
Water Content: Moist
Material: Soil/Earth</td></tr>
<tr><td colspan="2">Land Cover/Use Type (%):
Herbaceous vegetation is the Primary land cover of Tanker Pahar. Forest/ woodland type is also visible in this hill.</td></tr>
<tr><td colspan="2">Causes of Movement:
Hill cutting is the major issue that caused landslide in this area and intense rainfall acted as a triggering factor for landslide.</td></tr>
<tr><td colspan="2">Land Slide History and Future Risk of Landslide</td></tr>
<tr><td colspan="2">Landslide in this site occurred in 1982, 1989,1991,1994,1996 and 2013. 10 houses got damaged and almost 22 people died due to landslide at different periods. Utility facilities were highly damaged in this incident. Economic activities were hampered so does the social life of people. Environment has been found to be severely damaged. Still there are many houses located at the down slope of the hill. Soil of this site has been found to be sandy. The escapement slope is found to be near vertical. The failed mass is a part of upper portion. Vertical Slope characteristics can be considered as a contributing factor to future landslide for this hill. Settlements located at the down slope of this hill are at a huge risk of massive landslide. The risk is high (Field survey, August 2014).</td></tr>
</table>

CASE STUDY-02

<table>
<tr><th colspan="2">Basic Information</th></tr>
<tr><td>Landslide ID :08
Landslide Location: Batali hill, Moti Jharna
Coordinates: 22°20’47.00’’N, 91°48’45.76’’E</td><td>Datum: WGS 1984
Elevation (m): 55.03
Area of Displaced Mass (sqm): 126.7
Rainfall: Unknown</td></tr>
<tr><td>
Source: Field Survey, August 2014</td><td>
Source: Field Survey, August 2014</td></tr>
<tr><th colspan="2">Landslide Mechanism</th></tr>
<tr><td>Type of Movement: Fall, Slide
State: Active
Distribution: Advancing</td><td>Style: Successive
Water Content: Moist
Material: Soil/Earth</td></tr>
<tr><td colspan="2">Land Cover/Use Type (%):
Forest/ woodland are the Primary land cover of Batali hill.</td></tr>
<tr><td colspan="2">Causes of Movement:
Hill cutting is the major issue that caused landslide in this area and intense rainfall acted as a triggering factor for landslide.</td></tr>
<tr><th colspan="2">Land Slide History and Future Risk of Landslide</th></tr>
<tr><td colspan="2">Landslide Batali hill has become very common phenomenon of rainy season. Landslide in this hill has been occurring since 2011 on every rainy season. Landslide of 2011 caused damaged to two houses. Heavy and prolonged rainfall easily cause debris flow as soil of this hill is found to be of loose, sandy characteristic. No casualties of landslide have been identified. Utility facilities got damaged during the landslide of 2011. During rainy season, people leave their houses and shift to other places. This incurs a loss to their economic activities. Environment has been found to be severely damaged due to landslides. Still there are many houses located at the down slope of the hill. The escapement slope is found to be near vertical. The failed mass is a part of upper portion. Settlements located at the down slope of this hill are at a huge risk of massive landslide. The risk is high (Field Survey, August 2014)</td></tr>
</table>

CASE STUDY-03

<table>
<tr><th colspan="2">Basic Information</th></tr>
<tr><td>Landslide ID :09
Landslide Location: Tiger Pass, Moti Jharna
Coordinates: 22° 20’42.41’’N, 91° 48’45.92’’E</td><td>Datum: WGS 1984
Elevation (m): 31.66
Area of Displaced Mass (sqm): 427.04
Rainfall: Unknown</td></tr>
<tr><td>
Source: Field Survey, August 2014</td><td>
Source: Department of Environment (DOE), 2011</td></tr>
<tr><th colspan="2">Landslide Mechanism</th></tr>
<tr><td>Type of Movement: Topple, Slide
State: Active
Distribution: Advancing</td><td>Style: Single
Water Content: Moist
Material: Soil/Earth</td></tr>
<tr><td colspan="2">Land Cover/Use Type (%):
Bare soil and built over have been found as the land cover in this site.</td></tr>
<tr><td colspan="2">Causes of Movement:
Weak foundation of wall as well as loose soil contributed to the movement.</td></tr>
<tr><th colspan="2">Land Slide History and Future Risk of Landslide</th></tr>
<tr><td colspan="2">Retaining wall of Tiger pass collapsed on July 1 in 2011. Seventeen people died in this incident (Demo News Portal, July 28 2014). Houses located down the slope got damaged severely. Utility facilities got damaged in this incident. Economic activities were hampered so does the social life of people. Environmental damage is unquantifiable. Incessant rains in the port city have caused a retaining wall to collapse at Batali Hill, triggering a hill slide (bdnews24, 2011).

The escapement slope is found to be near vertical. Vertical Slope characteristics and loose sandy soil can be considered as a contributing factor to future landslide for this hill. Settlements located at the down slope of this hill are at a risk of landslide. The risk is moderate.</td></tr>
</table>

CASE STUDY-04

<table>
<tr><th colspan="2">Basic Information</th></tr>
<tr><td>Landslide ID :11-18
Landslide Location: Lebubagan, Kaicchaghona, Sekandar Para at Chittagong Cantonment.</td><td>Datum: WGS 1984
Total Area of Displaced Mass (sqm): 1061.39
Rainfall: 88 mm</td></tr>
<tr><td>
Source: Field Survey, August 2014</td><td>
Source: Department of Environment (DOE), 2007</td></tr>
<tr><th colspan="2">Landslide Mechanism</th></tr>
<tr><td>Type of Movement: Slide, Fall
State: Dormant, Stabilized.
Distribution: Confined</td><td>Style: Single
Water Content: Moist
Material: Soil/Earth</td></tr>
<tr><td colspan="2">Land Cover/Use Type (%):
Forest/ woodland is the Primary land cover of these areas. Herbaceous vegetation is also visible in these hills.</td></tr>
<tr><td colspan="2">Causes of Movement:
Excessive rainfall is the main cause of movement.
Lebubagan and Kaicchaghona: 658 mm rainfall for 9 consecutive days.
Sekandar Para: 268 mm rainfall for 7 consecutive days.</td></tr>
<tr><th colspan="2">Land Slide History and Future Risk of Landslide</th></tr>
<tr><td colspan="2">A massive landslide occurred in these three areas at a time on 11 June, 2007. Almost 65 persons were killed and 188 people were injured in this event. The heavy rainfall saturated the hill sides in and around the city giving residents no chance to escape when a tide of mud and water swept down on their homes in the early hours of morning (between 7:00 am to 7:30 am), burying whole families under mud and debris while they were sleeping. The powerful current simply washed others away. At a place, 19 people were killed while recuing 1 people trapped into the mud. At present, there exists no settlement. People were moved from these places. Now this place has become woodland area. Future risk of landslide is low.</td></tr>
</table>

CHAPTER 3: PHYSICAL, SOCIO-ECONOMIC AND LANDSLIDE ASPECTS
(Individual and Community Perspective)

Chittagong Metropolitan Area (CMA), the second largest city of Bangladesh, is vulnerable to landslide hazard. The main aim of this project is to develop an early warning system for the hilly areas of CMA incorporating local knowledge. Early warning is expected to contribute to life safety and damage reduction for landslide events. The user groups of the Web-GIS based early warning system will be the people living in landslide risks. Therefore, it is important to understand human adaptation to landslide risks under the condition of rapid urbanization in a fast growing city like CMA. It is also important to analyze how the local people react to the landslides, cope with the situation and their expectations. This will help to enrich the landslide mitigation strategies for sustainable mountain development.

In this connection, a total of 590 respondents have been surveyed in four different areas named Moti Jharna, Batali Hill, Golpahar and Goachi Bagan Medical Hill. It is expected to have an idea about the physical aspects, socio-economic condition, experience related to landslide and its risk management of the people residing in the hilly areas in Chittagong Metropolitan Area (CMA).

3.1 SELECTION OF THE SITE

In the inventory phase of this project, 57 locations have found where landslide event occurred in previous years. Those locations were organized into ten clusters (Chapter 2: Table 2.1) based on the landslide hazard locations, tentative similarity of the surroundings and landslide mechanisms. At this stage, Moti Jharna and Batali Hill of cluster 1, Golpahar of cluster 5 and Goachibagan Medical Hill of cluster 9 have been selected for social vulnerability analysis. These sites have been selected based on the following criteria.

- Landslide occurrence: It has been observed from the experience of the landslide inventory phase that the maximum numbers of landslide events have occurred in the hills of cluster 1, 5 and 9.

- Settlement density: As people are the main element of social vulnerability analysis, it is desirable to conduct survey in those hills where a considerable number of people live. From the previous experience it has been observed that dense settlement pattern exists in the areas of cluster 1, 5 and 9. Population density is quite high in these areas comparing to the areas of other clusters.

3.2 DATA COLLECTION

For conducting this study both primary and secondary data have been collected. Primary data has been collected through household questionnaire survey and Participatory Rural Appraisal (PRA) method. Secondary data have been collected from different organizations like Department of Environment, Chittagong Development Authority, Ward Commissioner office etc.

3.2.1 Household Questionnaire Survey

Household survey technique has been applied in this study. Household surveys are one of the most important sources of social and demographic statistics. Household surveys collect comprehensive and diverse socio-demographic data pertaining to conditions under which people live — their welfare, demographic characteristics and cultural factors which influence behavior, as well as social and economic change. So to understand the socio economic conditions and influence of landslide events on the social life of people household questionnaire survey has been conducted.

Preparation of questionnaire

To conduct household survey a questionnaire has been prepared (Appendix-A). This questionnaire has been prepared in a few steps. At first, a sample questionnaire was prepared. Then a pilot survey in Moti Jharna area was conducted. The aim of this pilot survey was to examine the questionnaire to judge its suitability with the socio-economic condition of the area. Based on the result of pilot survey, the questionnaire has been modified.

Determination of sample size

Household questionnaire survey has been conducted in Moti Jharna, Batali Hill, Golpahar and Goachibagan Medical Hill area. Total 590 people from these areas have been surveyed in random selection process. The sample size has been determined based on the total population of these areas. Sample size for each area has varied from each other as population of each area differs from others. Among the four Moti Jharna and Goachibagan Medical Hill contain highest and lowest number of population respectively. So, the sample size is determined accordingly.

3.2.2 Participatory Rural Appraisal Technique (PRA):

Along with household questionnaire survey, Participatory Rural Appraisal (PRA) technique has been applied. The main focus of PRA technique is to involve communities and other stakeholders in an in-depth examination of their vulnerability to landslide and at the same time empowers or motivates them to take appropriate actions.

Household questionnaire survey provides information from the point of view of a person and different PRA techniques represent the overall condition of the community. As this study is focused on analyzing social vulnerability of landside of these communities, different PRA techniques have been found suitable to bring various social issues which are essential for this analysis. Ten different PRA tools have been applied during this study.

3.3 INDIVIDUAL RESPONDENTS' OPINION

3.3.1 Basic Information and Background of the Respondents

The respondents of Chittagong Metropolitan Area were very much co-operative while surveying. Among 590 respondents male participants (58.47%) are dominating in number and most of the respondents (56.95%) are in age range 19-40 years, i.e, they are economically active people (Appendix-D, Figure 1 and Figure 2).

The respondents are mostly from Chittagong, Comilla and Noakhali districts of Bangladesh (Appendix-D, Table 1). The locations of their previous places are shown in Figure 3.1. The main cause of migration is for better employment opportunity. Besides, 22% respondents live here by born (Figure 3.2). Maximum number of respondents resides in this area for about 10 to 30 years whereas only 1.86% people reside here for more than 60 years (Appendix-D, Figure 3). There is contradiction among the respondents' opinion about the duration of settlement in this area. From the respondents, it is found that the informal settlement in the study area was established before the liberation war of Bangladesh in 1971. But most of the people (35.93%) have reversed views and a significant number of people (34.58%) have no idea about it (Appendix-D, Figure 4).

Figure 3.1: Migration status of the inhabitants of Chittagong Metropolitan Area (CMA). Source: Field Survey, September, 2014

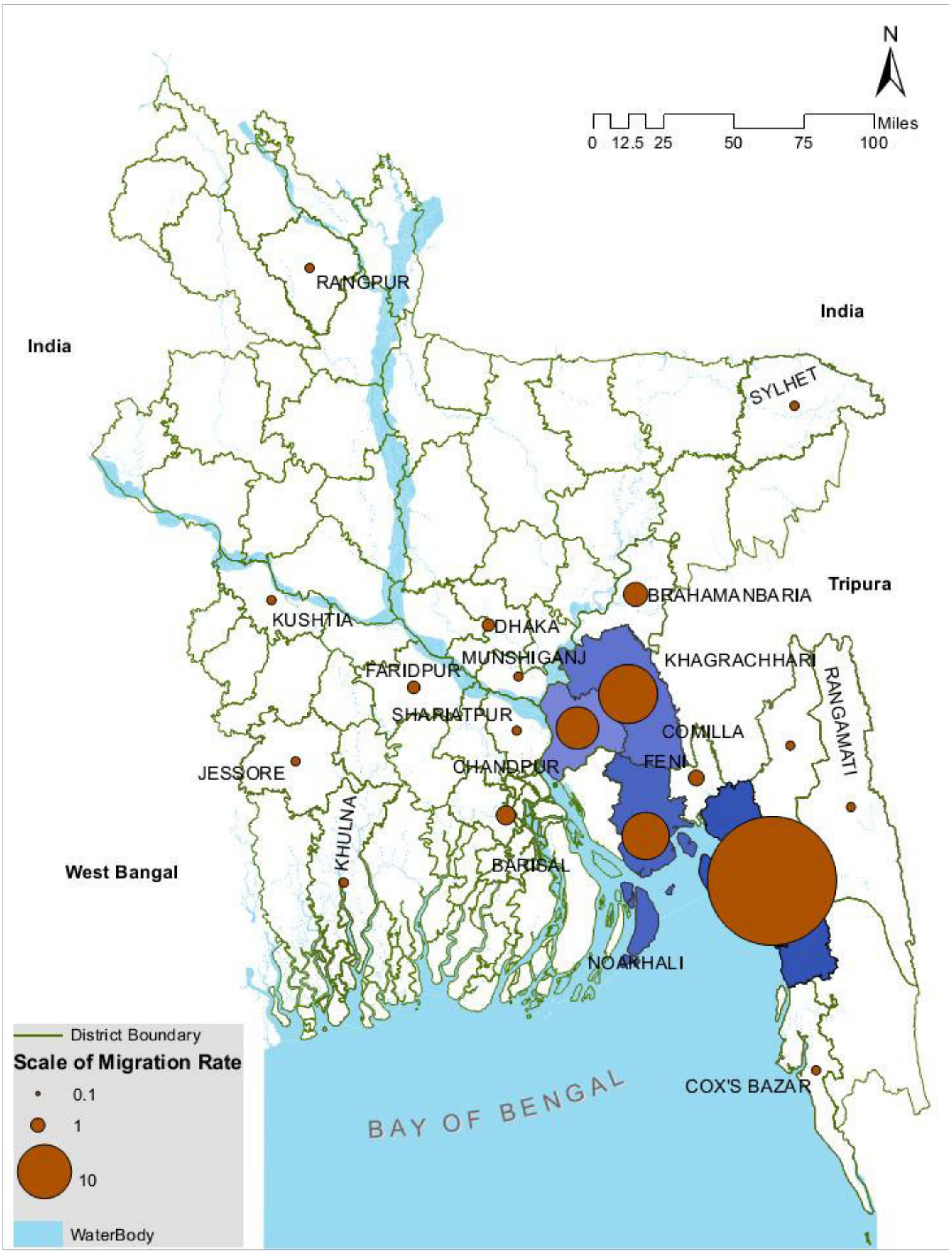
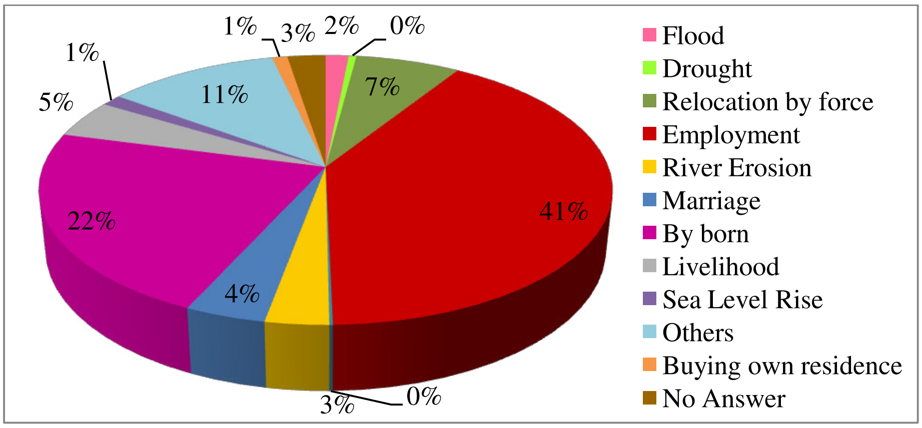


Figure 3.2: Respondents' Causes of migration to this area.

Source: Field Survey, September, 2014



3.3.2 Socio-economic Aspects

The majority of the respondents in this locality are illiterate (36.78%), besides there are significant number of respondents having secondary and primary level of education respectively (Figure 3.3). Employee and day labourer are the main occupation of the surveyed households. Shopkeeper, driver, garment worker, rickshaw puller are also significant in this area (Figure 3.4). Most of the respondents have average monthly household income of Tk.5001- Tk.10000 and Tk.10001-Tk.15000 respectively (Figure 3.5). Besides, there is same scenario in case of average monthly household expenditure (Figure 3.6).

Figure 3.3: Education level of the respondents in CMA.

Source: Field Survey, September, 2014

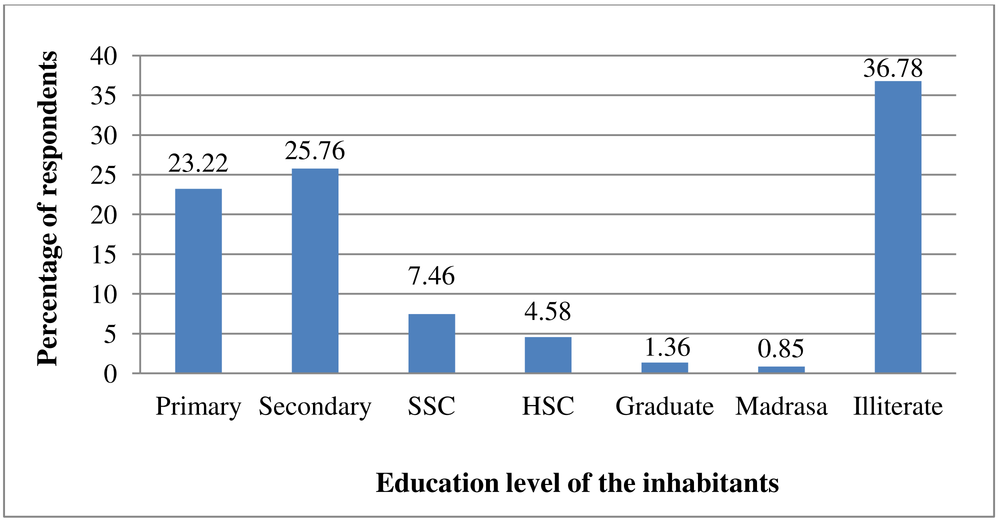


Figure 3.4: Main income sources (occupation) of the households.

Source: Field Survey, September, 2014

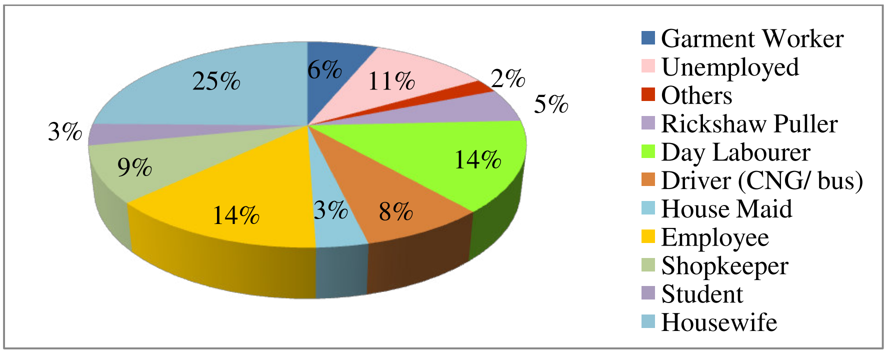


Figure 3.5: Average monthly income (in Taka) of the households.

Source: Field Survey, September, 2014

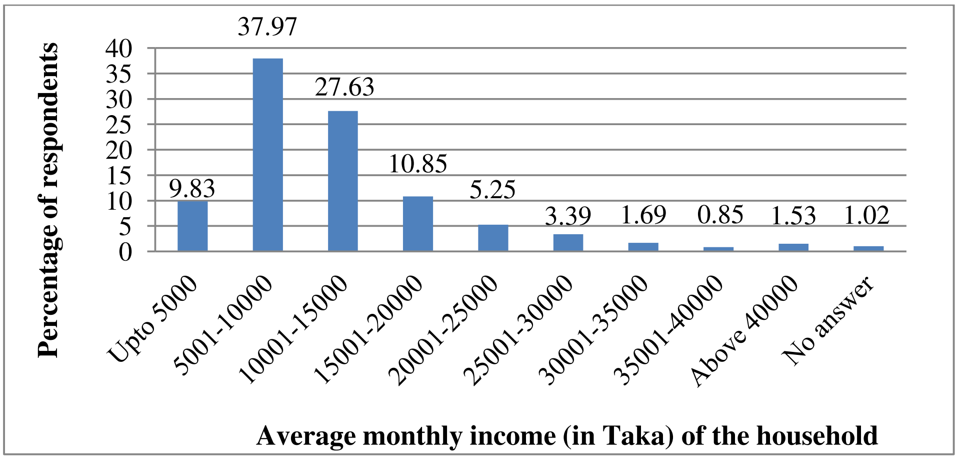
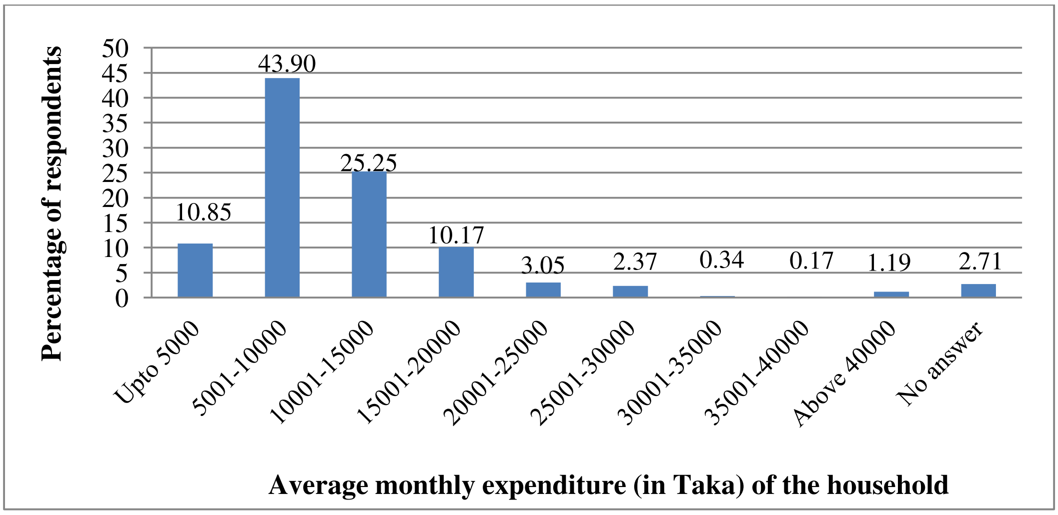


Figure 3.6: Average monthly expenditure (in Taka) of the households.

Source: Field Survey, September, 2014



From survey it is found that only 20 respondents get financial help from their family members living or working in Barisal, Brahmanbaria, Chittagong, Dhaka, Dinajpur, Lakshmipur and Shariatpur region in Bangladesh (Table 3.1). Most of them get the money on monthly basis (Figure 3.7). The amount of getting financial help is shown in Figure 3.8.

Table 3.1: Status of getting financial help from other regions of Bangladesh.
Source: Field Survey, September, 2014

	Districts in Bangladesh	**Number of respondents**	**Percentage**
Get financial help from other members within Bangladesh	Barisal	1	5.00
	Brahmanbaria	1	5.00
	Chittagong	4	20.00
	Dhaka	2	10.00
	Dinajpur	2	10.00
	Lakshmipur	1	5.00
	Shariatpur	1	5.00
	No answer	8	40.00
	Total	**20**	**100**
Do not get any financial help		570	
	Total	**590**	

Figure 3.7: Interval of getting financial help within Bangladesh.
Source: Field Survey, September, 2014

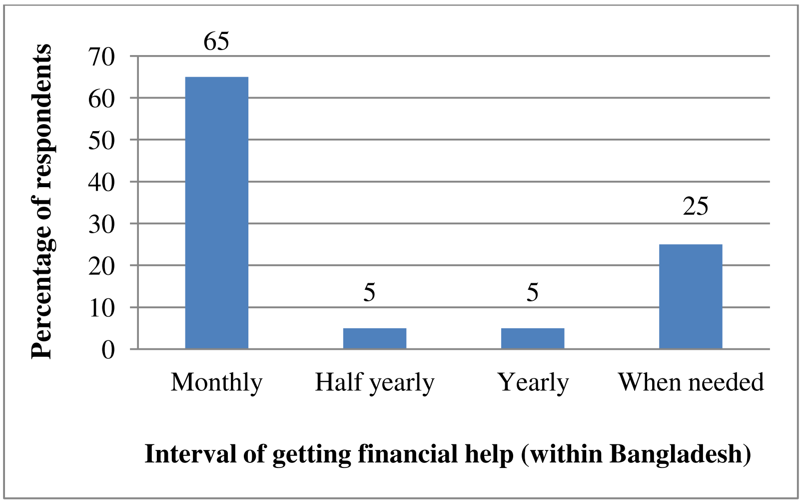


Figure 3.8: Amount (in Taka) of financial help respondents get from family members within Bangladesh.

Source: Field Survey, September, 2014

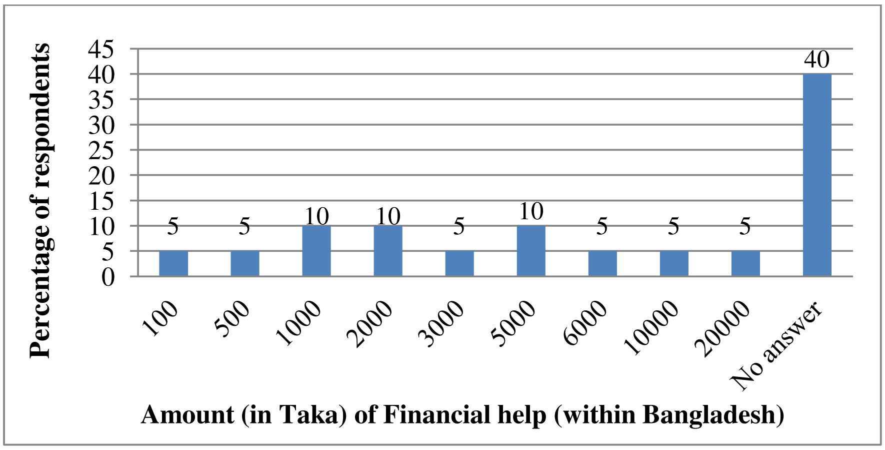


Table 3.2 shows the status of respondents' getting financial help from family members residing/ working abroad. 18 respondents get financial help from Mauritius, Oman, Saudi Arabia, South Africa and UAE. Most of them get financial support on monthly basis (Figure 3.9). The amount of getting financial help is shown in figure 3.10. 39.13% were unwilling to say the amount they get (Figure 3.10). Moreover, 24.07% of the total respondents (Appendix-D, Table 3) borrow loan from different sources named BRAC, ASA, Proshika, DSK, Shajeda Foundation, Co-operative, Shakti Foundation and Bhasha (Table 3.3). They use the loan in different purposes. Most of the respondents use the borrowed money for the purpose of business and building/repairing houses (Figure 3.11).

Table 3.2: Status of getting financial help from abroad.

Source: Field Survey, September, 2014

	Country	**Number of respondents**	**Percentage**
Get financial help from other members residing/ working abroad	Mauritius	1	4.35
	Oman	5	21.74
	Saudi Arabia	6	26.09
	South Africa	1	4.35
	UAE	5	21.74
	No answer	5	21.74
	Total	**23**	**100**
Do not get any financial help		567	
	Total	**590**	

Figure 3.9: Interval of getting financial help from abroad.

Source: Field Survey, September, 2014

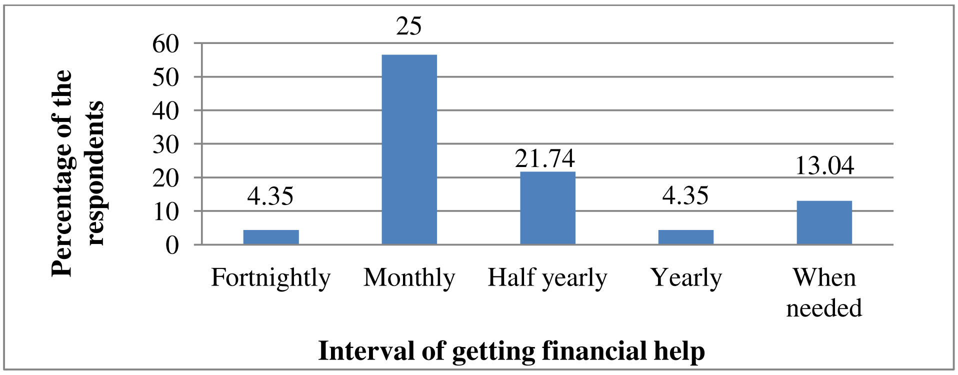


Figure 3.10: Amount (in Taka) of financial help respondents get from family members from abroad.

Source: Field Survey, September, 2014

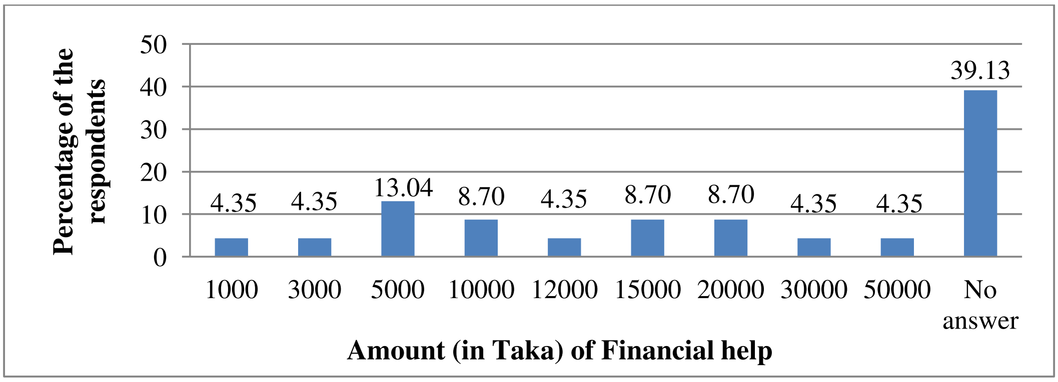


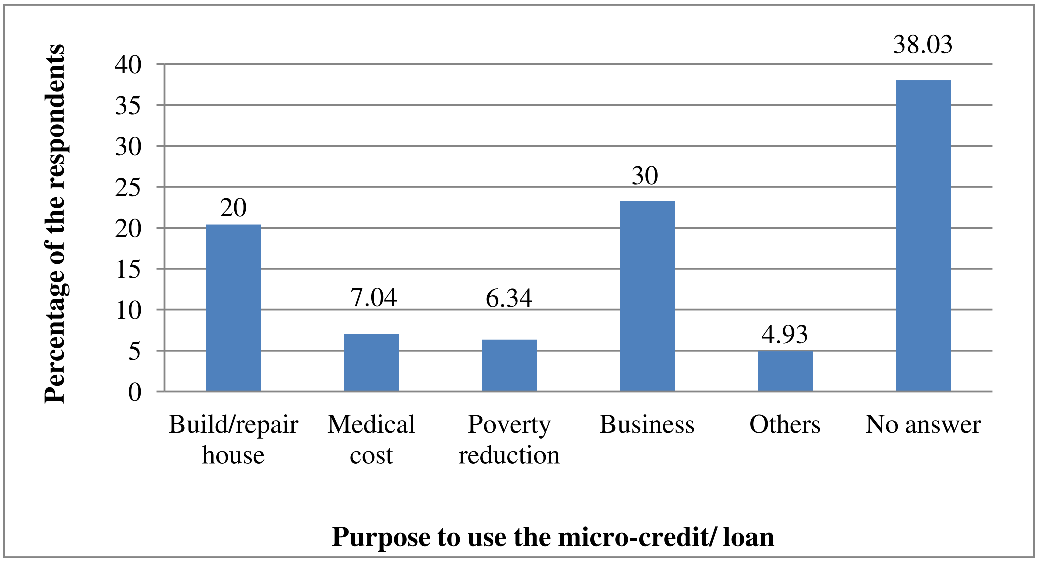
Table 3.3: Status of borrowing micro-credit/loan.

Source: Field Survey, September, 2014

	Institute	Number of respondents	Percentage
Get financial help by borrowing micro-credit/ loan	BRAC	30	21.13
	ASA	5	3.52
	Proshika	43	30.28
	DSK	10	7.04
	Shajeda Foundation	24	16.90
	Co-operatives	1	0.70
	Shakti Foundation	9	6.34
	Bhasha	4	2.82
	Others	16	11.27
	Total	**142**	**100**
Do not borrow micro-credit/ loan		448	
	Total	**590**	

Figure 3.11: Purpose to use the borrowed micro-credit/loan.

Source: Field Survey, September, 2014



Almost half of the respondents say that they do not face any type of threats to reside in this area. Some identified drug or illegal business, lack of utility facilities, political violence, social insecurity, theft and terrorism as problems of the study area. A small number of people said that they face problem due to eviction for illegal business and water logging (Table 3.4). The main advantages for which people reside in this area are less living expenses and better job opportunity. Some say they reside here because the area is close to city center and nearer to community facilities (Table 3.5). 54% respondents say that they will be in a more problematic situation if they are relocated or evicted from here (Figure 3.12). Homelessness, increased house rent to other places, unemployment, identity crisis, increased distance to workplace and school, Lack of safety are main problems for them to face in this regard (Table 3.6).

Table 3.4: Threats faced by the respondents to reside in this area.

Source: Field Survey, September, 2014

Threats faced to reside in this area	Number of respondents	Percentage
Terrorism	20	3.39
Social Insecurity	34	5.76
Political violence	38	6.44
Theft	32	5.42
Water Logging	8	1.36
Lack of Utility facilities	28	4.75
Drugs or illegal business	37	6.27
Eviction for illegal business	10	1.69
Inadequate Road/Drain	18	3.05
Theft, Water logging, Drug or illegal business	16	2.71
Social insecurity, drags or illegal business, inadequate road and drain	23	3.90
No Problem	271	45.93
Others	55	9.32
Total	**590**	**100**

Table 3.5: Respondents' advantages of residing in this area.

Source: Field Survey, September, 2014

Advantages of residing in this area	Number of respondents	%
Better job	106	17.97
Less living expense	215	36.44
Close to city center	23	3.90
Nearer to community facilities	30	5.08
Higher living standards	3	0.51
Better job & less living expense	52	8.81
Better job & close to city center	15	2.54
Less living expense & close to city center	28	4.75
Utility facility	5	0.85
Buying own residence	11	1.86
Living from childhood	2	0.34
Safety	1	0.17
Others	99	16.78
Total	**590**	**100**

Figure 3.12: Respondents' opinion regarding in a problematic situation if evicted from here.

Source: Field Survey, September, 2014

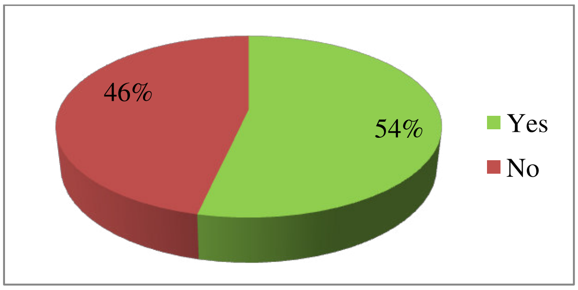


Table 3.6: Problems respondents will face if relocated or evicted from this area.

Source: Field Survey, September, 2014

Problem if relocated/ evicted	Number of respondents	Percentage
Increased house rent	107	33.86
Increased distance to workplace and school	17	5.38
Unemployment	27	8.54
Identity crisis	20	6.33
Homeless	121	38.29
Lack of safety	2	0.63
Others	22	6.96
Total	**316**	**100**

The respondents were asked about their future plan to improve present living standard. But most of them have no plan yet. 14.24% people have a plan to increase income through getting better job/ business and 4.58% people's plan is to educate and establish their children. A small number of respondents are planning to buy land/ house in their hometown and return there (Table 3.7).

Table 3.7: Respondents' plan to improve present living standard.

Source: Field Survey, September, 2014

Respondents' plan to improve present living standard	Number of respondents	Percentage
Better job/ business	84	14.24
live in better place	19	3.22
Buy land/ house in hometown	11	1.86
Children's education and establishment	27	4.58
Others	38	6.44
No plan	122	20.68
No answer	289	48.98
Total	**590**	**100**

3.3.3 Physical Aspects

Housing:

Maximum says that the land in the study area is owned by landlords (34.92%) and the respondents (25.76%). The other owners of the land are Government, Bangladesh Railway, WASA, PWD, CMC and others (Figure 3.13). Most of the residents (53.39%) live in rented houses (Appendix-D, Table 2). All of the houses are not built by the landowners. 45.93% of the respondents built their own houses and 40.85% houses were built by the landlords (Figure 3.14). Maximum respondents have to pay rent of Tk. 1001-2000 (Figure 3.15).

Figure 3.13: Ownership of the land

Source: Field Survey, September, 2014

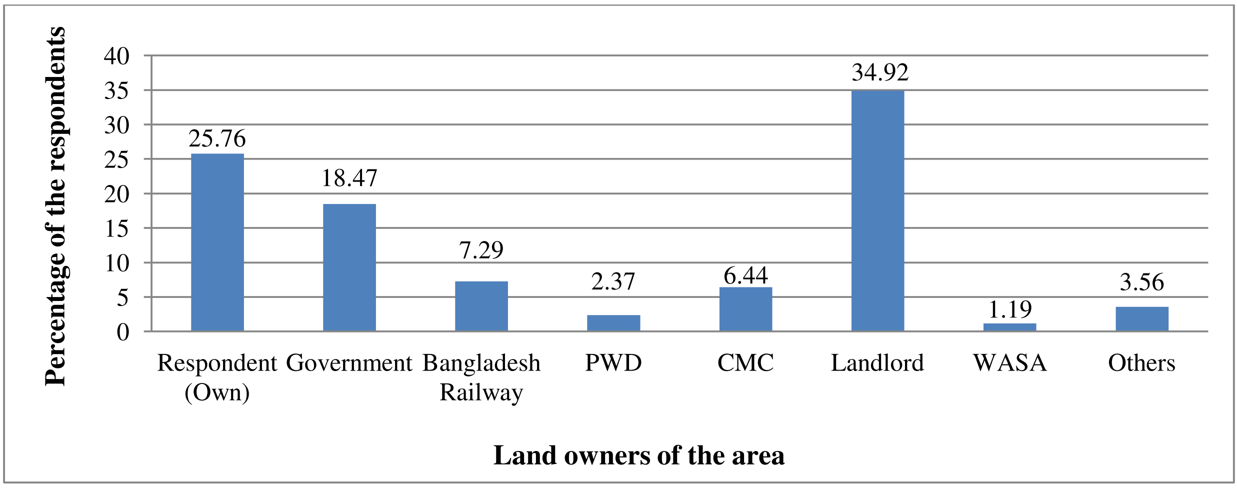


Figure 3.14: Builders of the houses

Source: Field Survey, September, 2014

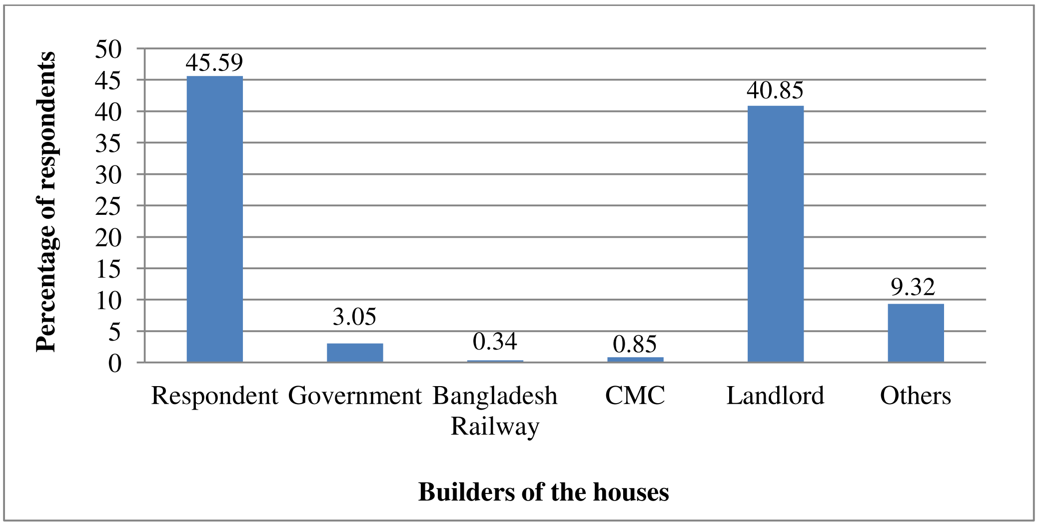
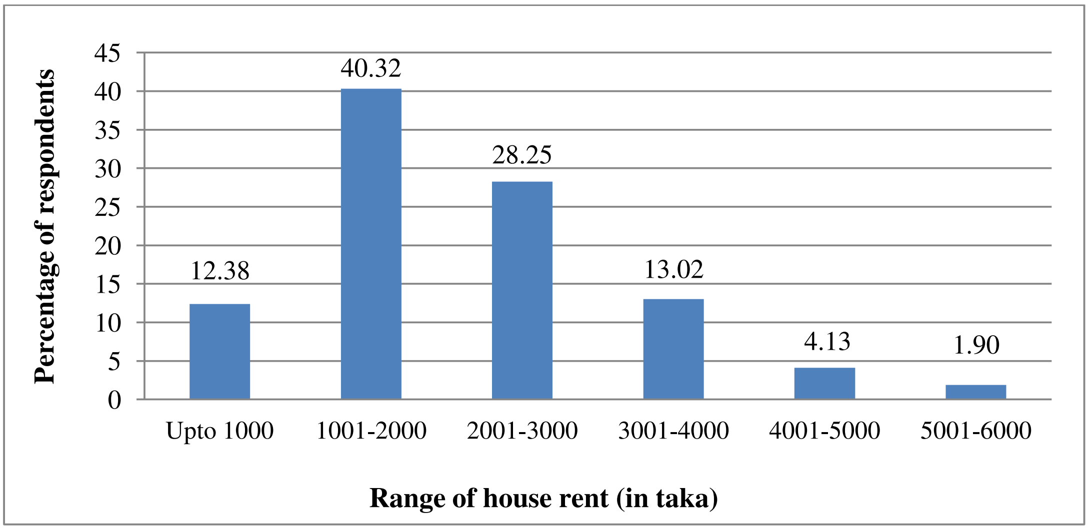


Figure 3.15: House rent per month (in Taka).

Source: Field Survey, September, 2014



Most of the houses in the study area are semi-built and non-built respectively (Figure 3.16). Only 13% houses are built. From field survey it is found that maximum (97%) respondents live in one storey houses (Figure 3.17). Almost all the people use the surrounding hills for their housing and the rest use for recreation, commercial activity, agriculture and tree plantation (Figure 3.18). From Table 3.8 it is seen that the respondents who are housewife and unemployed need not to travel from their home. Most of the shopkeepers reside nearer to their living place. Besides, the Day labourers and the drivers (CNG/ bus) have to travel to their working places >2 kilometres as their working places are the whole city (Table 3.8).

Figure 3.16: Building material of the houses

Source: Field Survey, September, 2014

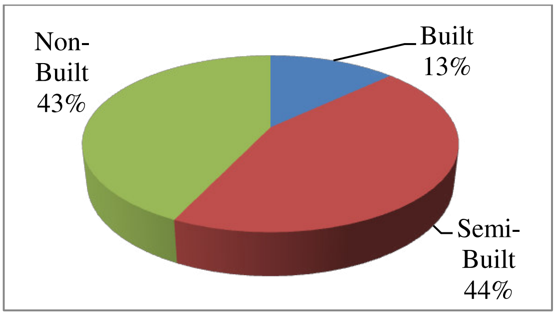


Figure 3.17: Number of storey of the houses

Source: Field Survey, September, 2014

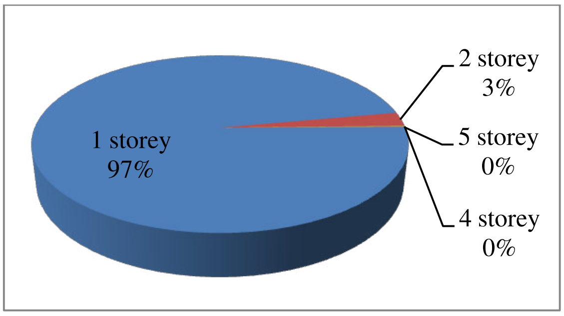


Figure 3.18: Purpose of hill use of the respondents.

Source: Field Survey, September, 2014

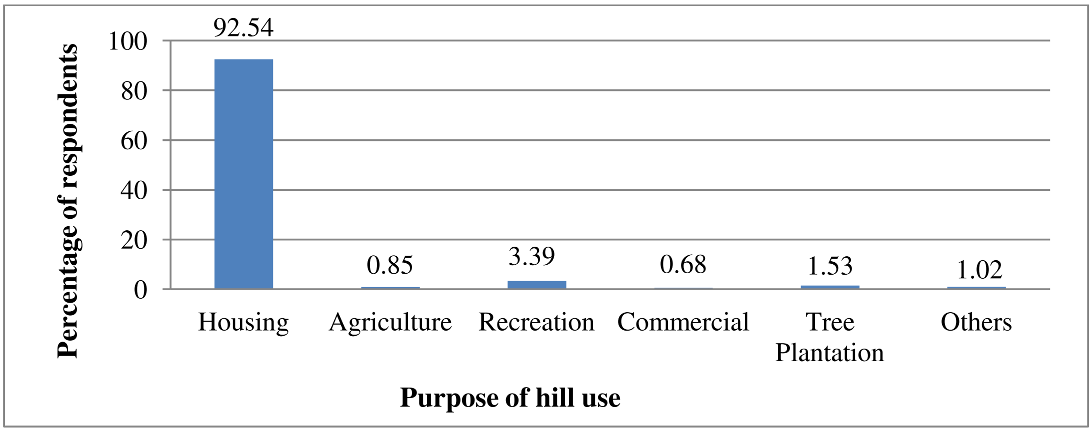


Table 3.8: Relation between occupation and distance from home to workplace of the respondents.

Source: Field Survey, September, 2014

Occupation	Distance between workplace and home (in km)																Total	
	0		0.25		0.5		1		1.25		1.5		2		>2			
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Garment Worker	5	1.95	1	8.33	2	5.56	5	9.62	0	0.00	2	15.38	5	11.63	17	9.71	37	6.27
Unemployed	62	24.12	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	62	10.51
Others	2	0.78	1	8.33	0	0.00	2	3.85	0	0.00	1	7.69	0	0.00	7	4.00	13	2.20
Rickshaw Puller	0	0.00	0	0.00	3	8.33	2	3.85	0	0.00	0	0.00	0	0.00	26	14.86	31	5.25
Day Laborer	0	0.00	0	0.00	7	19.44	12	23.08	2	100.00	1	7.69	18	41.86	44	25.14	84	14.24
Driver (CNG/ bus)	0	0.00	1	8.33	1	2.78	7	13.46	0	0.00	2	15.38	2	4.65	33	18.86	46	7.80
House Maid	3	1.17	2	16.67	0	0.00	5	9.62	0	0.00	2	15.38	3	6.98	4	2.29	19	3.22
Employee	11	4.28	2	16.67	17	47.22	13	25.00	0	0.00	4	30.77	9	20.93	24	13.71	80	13.56
Shopkeeper	23	8.95	4	33.33	4	11.11	3	5.77	0	0.00	1	7.69	3	6.98	14	8.00	52	8.81
Student	5	1.95	1	8.33	2	5.56	3	5.77	0	0.00	0	0.00	3	6.98	6	3.43	20	3.39
Housewife	146	56.81	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	146	24.75
Total	**257**	**100**	**12**	**100**	**36**	**100**	**52**	**100**	**2**	**100**	**13**	**100**	**43**	**100**	**175**	**100**	**590**	**100**
%	**43.56**		**2.03**		**6.10**		**8.81**		**0.34**		**2.20**		**7.29**		**29.66**		**100**	

3.3.4 Community and Utility Facilities in the Study Area

According to the respondents of CMA the school, market, bank and playground are within 1 kilometre from their residence. Most of the people (32.03%) said that the health care facility is in distant place from their living places (Table 3.9). Among the respondents 47.12% and 42.37% are satisfied with the existing roads and drainage facility respectively. Maximum number of the respondents says that water, electricity and sanitation are available in this area. There is gas supply in 32.2% respondents' houses (Figure 3.19).

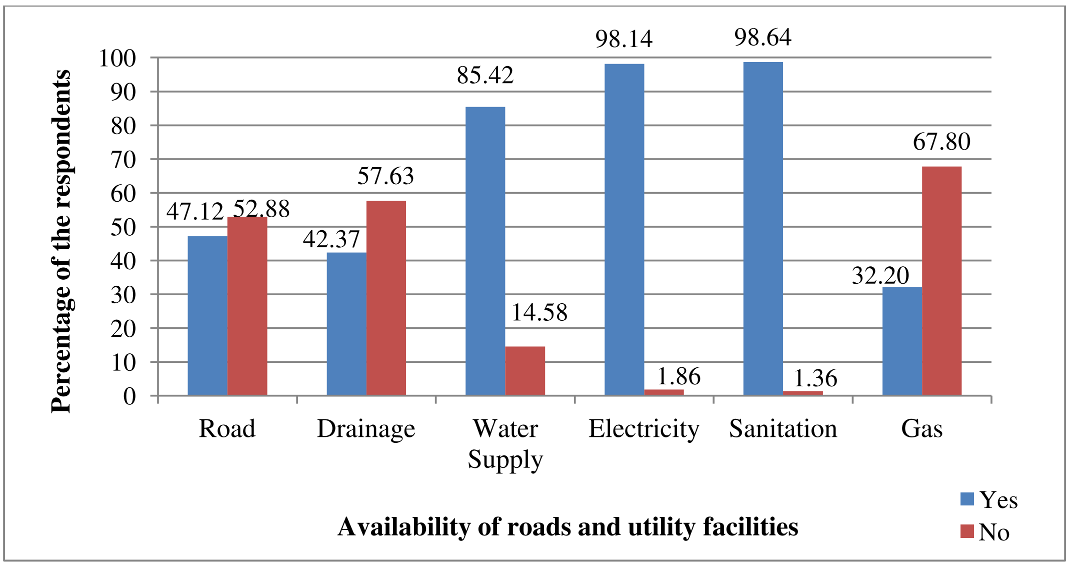
Table 3.9: Respondents' Opinion: Distance between community facilities and residence.

Source: Field Survey, September, 2014

Distance (kilometre)	Different community facilities in CMA									
	School		Market		Bank		Playground		Health care centre	
	No	%	No	%	No	%	No	%	No	%
0 km	31	5.25	44	7.46	13	2.20	50	8.47	19	3.22
0.25 km	92	15.59	71	12.03	28	4.75	87	14.75	40	6.78
0.50 km	313	53.05	289	48.98	139	23.56	248	42.03	136	23.05
1 km	125	21.19	103	17.46	187	31.69	69	11.69	122	20.68
1.25 km	6	1.02	3	0.51	2	0.34	2	0.34	1	0.17
1.50 km	4	0.68	19	3.22	27	4.58	15	2.54	27	4.58
1.75 km	1	0.17	2	0.34	2	0.34	1	0.17	0	0.00
2 km	11	1.86	13	2.20	64	10.85	16	2.71	56	9.49
> 2 km	7	1.19	46	7.80	128	21.69	102	17.29	189	32.03
Total	**590**	**100**	**590**	**100**	**590**	**100**	**590**	**100**	**590**	**100**

Figure 3.19: Availability of different facilities in the study area.

Source: Field Survey, September, 2014



3.3.5 Real life Experience to Landslide Disaster

Almost half of the respondents think that landslide is not a problem for this area at all and only 18% marks it as a very serious problem (Figure 3.20). According to the respondents people residing beside the hill are most vulnerable and so the community people. 21.54% people are not concerned about the vulnerability of the people (Table 3.10). More than half of the respondents (43.05%) say that landslide occurs once per year in this locality (Appendix-D, Table 4). High precipitation, hill cutting and both of them have been identified as the main triggering factors of landslide by the respondents (Table 3.11). There are negative impacts of landslides to the community people. According to respondents, due to the landslides in several years the houses were destroyed, property was damaged and people died (Table 3.12).

Figure 3.20: Intensity of landslide problem in the study area (Respondents' opinion).

Source: Field Survey, September, 2014

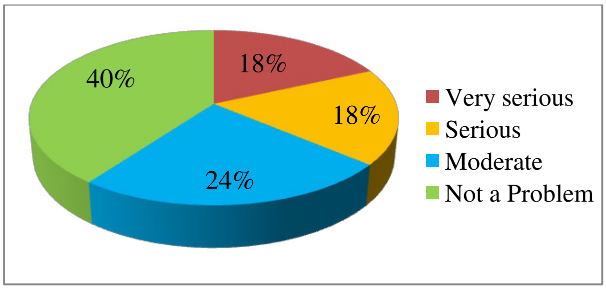


Table 3.10: Respondents' opinion: people vulnerable to landslide.

Source: Field Survey, September, 2014

Vulnerable people according to the respondents	Number of respondents	Percentage
Community people	88	14.92
No one	5	0.85
People residing near hill	151	25.59
People residing on hill top	21	3.56
Unknown	75	12.71
Women, poor and children	15	2.54
No answer	235	39.83
Total	**590**	**100**

Table 3.11: Causes of landslide in the study area (Respondents' opinion).

Source: Field Survey, September, 2014

Causes of landslide	Number of respondents	Percentage
Hill cutting	67	11.36
Deforestation	11	1.86
High precipitation	279	47.29
Residential use	3	0.51
Supernatural event	3	0.51
Earthquake/flash flood	1	0.17
Construction of road/structure	9	1.53
Hill cutting & high precipitation	131	22.20
Hill cutting & residential use	15	2.54
High precipitation & residential use	6	1.02
Hill cutting, high precipitation & residential use	29	4.92
Others	15	2.54
No answer	21	3.56
Total	**590**	**100**

Table 3.12: Negative impact of landslide in the study area (Respondents' opinion).

Source: Field Survey, September, 2014

Negative impact of landslide	Number of respondents	Percentage
House destroyed	38	6.44
Property damaged	16	2.71
Road blocked	18	3.05
People died	59	10.00
People injured	6	1.02
Damage of utility facilities	2	0.34
House destroyed & property damaged	59	10.00
House destroyed, property damaged & people died	204	34.58
House destroyed, property damaged, people died & people injured	112	18.98
Others	10	1.69
No answer	66	11.19
Total	**590**	**100**

The respondents were asked about their last landslide observance. It is found that 40.34% respondents never observed the landslide and the rest observed in different years of their lifetime. Most of the respondents (86.08%) observed last landslide between the years of 2005 to 2014 (Figure 3.21). Most of the landslides occurred at night (Table 3.13). During the landslide occurrence, 80% of the respondents were in this locality but they did not take any step to help the landslide victims. 20% of the residents participated in rescuing people (Figure 3.22 and Figure 3.23). During our survey we found 35 victims to landslide.

Figure 3.21: Respondents' last landslide observance (at 10 years interval) in last 30 years.

Source: Field Survey, September, 2014

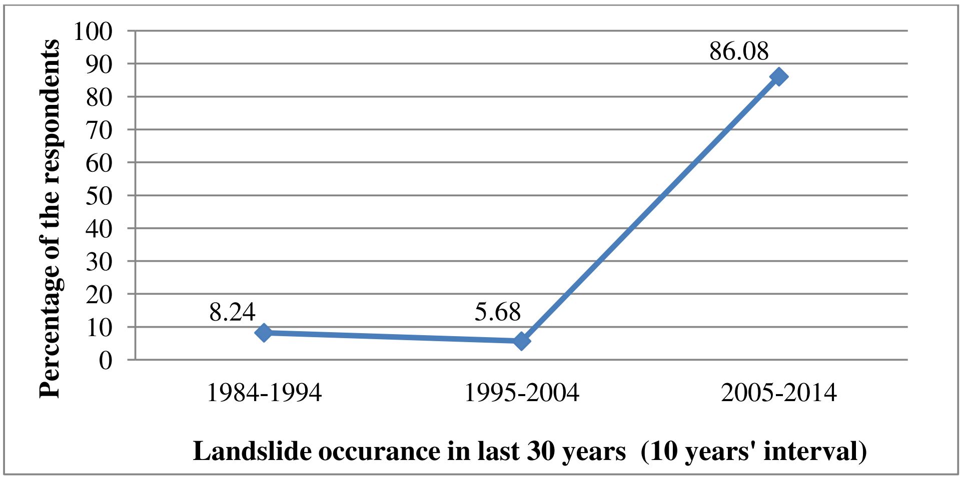


Figure 3.22: Respondents' location during the last landslide observed.

Source: Field Survey, September, 2014

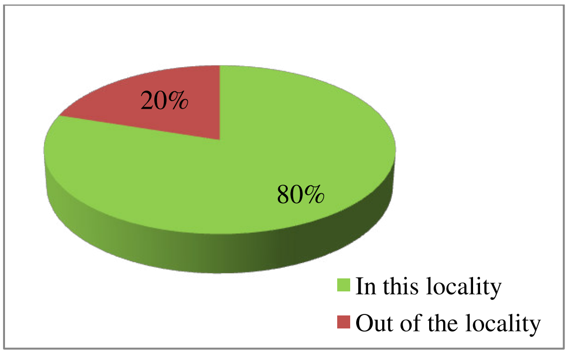


Figure 3.23: Respondents' response during last landslide observed.

Source: Field Survey, September, 2014

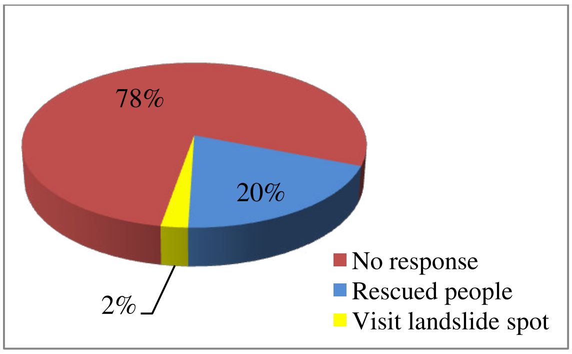


Table 3.13: Respondents' opinion regarding occurrence time of the last landslide observed.

Source: Field Survey, September, 2014

Time of landslide occurrence	Number of respondents	Percentage
Day	7	20.00
Early morning	2	5.71
Night	12	34.29
No answer	14	40.00
Total	**35**	**100**

3.3.6 Landslide Risk Management

The respondents have their opinion about the positive and negative impacts of monsoon rain in their day to day life. In both cases most of the residents said that there is no impact of rainfall to their life. Rest of the respondents marked water collection, washing & bathing, cleaning of drain & road as the positive impacts; and damage of roads, water logging, landslide and surface runoff as the negative impacts due to rain (Table 3.14).

Table 3.14: Respondents' opinion regarding positive impacts of monsoon rain.

Source: Field Survey, September, 2014

Positive impact of monsoon rain	Number of respondents	Percentage	Negative impact of monsoon rain	Number of respondents	Percentage
Water collection	123	20.85	Damage of road	161	27.29
Washing & bathing	36	6.10	Water logging	96	16.27
Cleaning of drain & road	18	3.05	Landslide	66	11.19
Water collection, washing & bathing	16	2.71	Surface runoff	10	1.69
			Road damage & landslide	66	11.19
No impact	391	66.27	No impact	158	26.78
Others	6	1.02	Others	33	5.59
Total	**590**	**100**	**Total**	**590**	**100**

From the household survey it is found that only 11% of the respondents are relocated from their usual living places during the monsoon rain rainfall (Appendix-D, Figure 5). Among the relocated people maximum take shelter to the nearby school provided free of cost by the authority of Chittagong City Corporation (Figure 3.24 and Figure 3.25). The relocation places for most of the respondents are within 1 kilometre from their residing place (Table 3.15). Table 3.16 shows the benefit got and problems faced by the relocated respondents of the study area during monsoon rain. 48.48% respondents said they get no benefit from the relocation place and 3.03% said nothing about the problems. Most of the respondents said that they can stay in the relocation place for 2-3 days if there is heavy rainfall (Appendix-D, Table 6).

Figure 3.24: Respondents' relocation place during monsoon rain.

Source: Field Survey, September, 2014

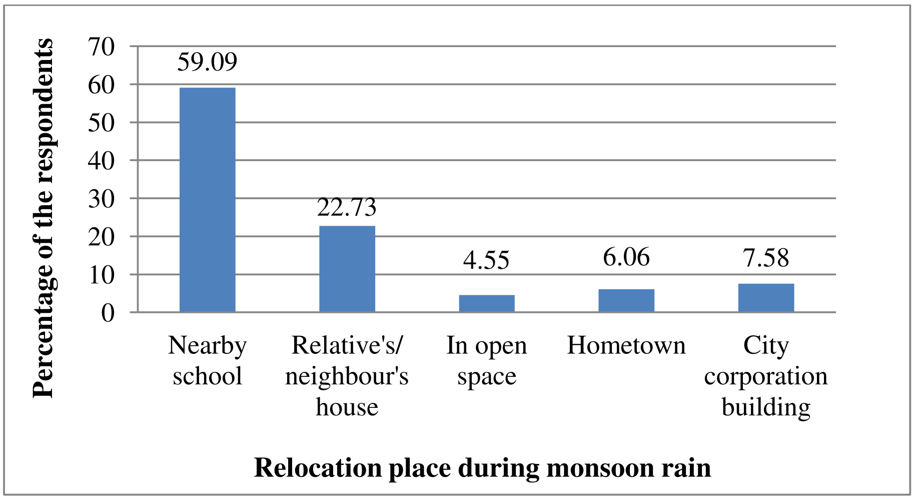


Figure 3.25: Providers of the relocation places to the respondents.

Source: Field Survey, September, 2014

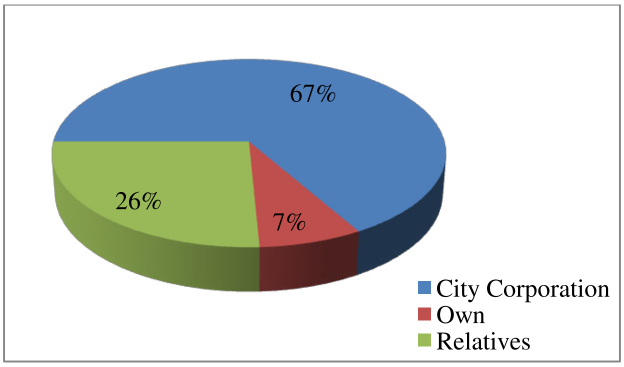


Table 3.15: Distance of relocation place from the respondents' house.

Source: Field Survey, September, 2014

Distance of relocated place	Number of respondents	Percentage
0 km	5	7.58
0.05 km	4	6.06
0.5 km	18	27.27
1 km	14	21.21
1.25 km	4	6.06
1.5 km	8	12.12
1 km	3	4.55
2 km	6	9.09
> 2 km	4	6.06
Total	**66**	**100**

Table 3.16: The benefit got and problems faced in relocation places by the respondents.
Source: Field Survey, September, 2014

Benefit got in relocation place	Number of respondents	Percentage	Problem faced in relocation place	Number of respondents	Percentage
Food help	10	15.15	Food	1	1.52
Save life	18	27.27	Lack of services	9	13.64
Safety	1	1.52	Low food supply and poor sanitation facility, fear of theft	54	81.82
Temporary shelter	5	7.58			
No benefit	32	48.48	No answer	2	3.03
Total	**66**	**100**	**Total**	**66**	**100**

Only 6.95% people said that there is landslide voluntary committee in the study area (Appendix-D, Table 7). They are Commissioner Group, City Corporation, DSK, BRAC, PSTC, Proshika and Lalkhan bazaar voluntary committee (Table 3.17). During landslide the emergency services are mainly provided by police, fire service, community groups, City Corporation officials, NGO and neighbours (Table 3.18). 54.24% are satisfied with the rescue effort (Appendix-D, Table 8). There are several causes behind dissatisfaction to the rescue effort also and late response is the major one identified by the respondents (Table 3.19). The relocated people get money, food, cloth and shelter as compensation from City Corporation, Government organization and ward commissioner (Table 3.20, Table 3.21; Appendix-D, Table 8).

Table 3.17: Existing landslide voluntary committee in the study area.
Source: Field Survey, September, 2014

Landslide voluntary committee	Number of respondents	Percentage
City Corporation	7	17.07
Commissioner Group	14	34.15
DSK	2	4.88
BRAC	1	2.44
Lalkhan bazar voluntary committee	1	2.44
PSTC	2	4.88
Proshika	2	4.88
Unknown	12	29.27
Total	**41**	**100**

Table 3.18: Organization offering the emergency services in CMA.

Source: Field Survey, September, 2014

Emergency service offering organization	Number of respondents	Percentage
Neighbours	112	18.98
Community groups	35	5.93
Volunteers	3	0.51
Police	5	0.85
Fire service	52	8.81
City corporation councils	91	15.42
NGO	12	2.03
Police & fire service	29	4.92
Police, fire service, community groups & city corporation officials	157	26.61
Others	5	0.85
Unknown	89	15.08
Total	**590**	**100**

Table 3.19: Causes of dissatisfaction to the rescue effort.

Source: Field Survey, September, 2014

Causes of respondents' dissatisfaction of the rescue effort	Number of respondents	Percentage
Insufficient roadway	1	0.85
Lack of manpower	1	0.85
Lack of proper attention	24	20.34
Late response	55	46.61
Low efficiency	4	3.39
Shortage of equipment	12	10.17
No answer	21	17.80
Total	**118**	**100**

Table 3.20: Type of compensation to the victims.

Source: Field Survey, September, 2014

Victims' compensation type	Number of respondents	Percentage
Money	73	40.11
Food	24	13.19
Money, food & cloth	37	20.33
Shelter	4	2.20
Others	5	2.75
Unknown	39	21.43
Total	**182**	**100**

Table 3.21: Organizations helped/ compensated the victims.

Source: Field Survey, September, 2014

Organization helped/ compensated the victims	Number of respondents	Percentage
CMC authority	3	2.01
Chairman	2	1.34
City Corporation	44	29.53
Community people	2	1.34
Government	45	30.20
Proshika	1	0.67
Ward Commissioner	35	23.49
Unknown	17	11.41
Total	**149**	**100**

Table 3.22: Warning system before landslide.

Source: Field Survey, September, 2014

Organization providing early warning system for landslide	Number of respondents	Percentage
Announcement through Mike	341	62.57
Ward Commissioner	7	1.28
Local volunteers	5	0.92
Newspaper/ press	16	2.94
Electronic Media	47	8.62
Announcement through Mike and Electronic Media	129	23.67
Total	**545**	**100**

Table 3.23: Response of the respondents after getting early warning system.

Source: Field Survey, September, 2014

Respondents' response after getting early warning	Number of respondents	Percentage
Shift to other place	68	12.48
Stay in house	475	87.16
No answer	2	0.37
Total	**545**	**100**

The respondents know about the landslide information mainly by announcement through mike (Table 3.22 and Appendix-D, Table 7). More than 80% respondents stay at their houses after getting warning. (Table 3.23) Most interesting thing is that 84.41% respondents do not have contact number of the nearest fire service/ police station/ volunteer groups/ emergency services/ relevant agencies for emergency purpose (Appendix-D, Table 7). Though living in this area for so many years the respondents gave some suggestion to reduce the risk of landslide of Chittagong Metropolitan Area (CMA). They mentioned permanent relocation, awareness building, stop hill cutting, engineering measurement through constructing retaining wall, tree plantation as the main thing to do in this regard. Some said a solution may be leveling the hills (Table 3.24). Among 590 respondents only seven gave their suggestions. Most of them focused on relocating vulnerable people. The rest three respondents suggested having job security for women and establishing a school, to have a planned administration to reduce the corruption and land encroachment and reduce police disturbance to the victims (Appendix-D, Table 9).

Table 3.24: Respondents' suggestion towards landslide risk reduction process.
Source: Field Survey, September, 2014

Landslide risk reduction process	Number of respondents	Percentage
Relocation	84	14.24
Tree plantation	22	3.73
Retaining wall	59	10.00
Engineering	24	4.07
Stop hill cutting	57	9.66
leveling the hill	63	10.68
Awareness building	74	0.85
Early warning	5	0.85
Stop precipitation	5	0.85
Stop deforestation	2	0.34
Proper planning	8	1.36
Government initiative	18	3.05
Others	5	0.85
No answer	116	19.66
Unknown	48	8.14
Total	**590**	**100**

3.4 COMMUNITY BASED OPINION (PRA Tools)

The Participatory Rural Appraisal (PRA) Techniques are applied in four communities namely Moti Jharna and Batali Hill area of Cluster 1, Golpahar area of Cluster 5 and Goachibagan Medical Hill of Cluster 9 (Chapter-2: Table 2.1). These areas are selected as landslide event is very frequent in these areas compared to other areas. Population density in these areas is quite high. In this interim report we will discuss the Moti Jharna community. Through the PRA the survey, the physical and socio-economic information, institutions within the community, potential organizations, problems and prospects of the community will be found out. The locations of the study area which are vulnerable to natural and social hazard would also be assessed. In Interim Report, we describe PRA outcomes for Moti Jharna community.

3.4.1 Historic Profile of Moti Jharna

Moti Jharna area is located in Chittagong Metropolitan Area. It is surrounded by Batali Hill, Tanker Pahar and A.K.K Hill area (Field survey). For this study it is very important to know about the study area properly. Historic information of study areas is gathered. For this purpose timeline tool is used.

Table 3.25: Time line of Moti Jharna area.

Source: Field Survey, September, 2014

Year	Incident	Remarks
After 1971	Commencement of settlement, Initiation of electricity facility	After the end of the liberation war of 1971, people from different region started to gather in this region.
1975	Establishment of Yusuf School	This was the first ever school in this area. At first the school building was constructed with tin. Later in 2004 this school building was rebuild with brick.
	Establishment of Moti Jharna Sahi Jame Mosque	This was the first mosque in this area
After 1975	Commercial activities started to increase	After the establishment of Yusuf school, many shops around the school started to develop.
1985-1986	Formation of Jalal sardar's committee	The main purpose of this committee was to solve different social issues as well as giving decision.
	Fire incident	Houses beside Hossain Saheb's house in Moti Jharna area were burnt in fire incident. 15 people died in this incident. Before this fire incident all houses were thatched house. After this incident semi built houses were made.
1988	Flood incident	This was the first flood incident in this area.
1989	Establishment of medical clinic	This was the first ever clinic in this area.
2000-2005	Commercial activities increased.	Different shops were settled in many places.
	Initiation of Utility facilities	Commencement of Water facility, Commencement of Electricity,

Year	Incident	Remarks
		Initiation of drainage system.
	Increase of hill cutting for the settlement of people	After 2000, population in this area increased. This resulted in indiscriminate hill cutting.
2008	Landslide event	Hills beside hossain saheb's colony collapsed. Two to three people died.
2010	Landslide event	Landslide occurred in Tanker Pahar area and it killed almost 20-25 people.
2013	Landslide event	Hills in Tanker Pahar area collapsed. There was some property damage due to this event.

3.4.2 Social Characteristics of Moti Jharna

In this study, social and resource mapping was used to know about the social dimensions, the nature of housing and social infrastructure of the study area.

Major findings from social and resource map of Moti Jharna area

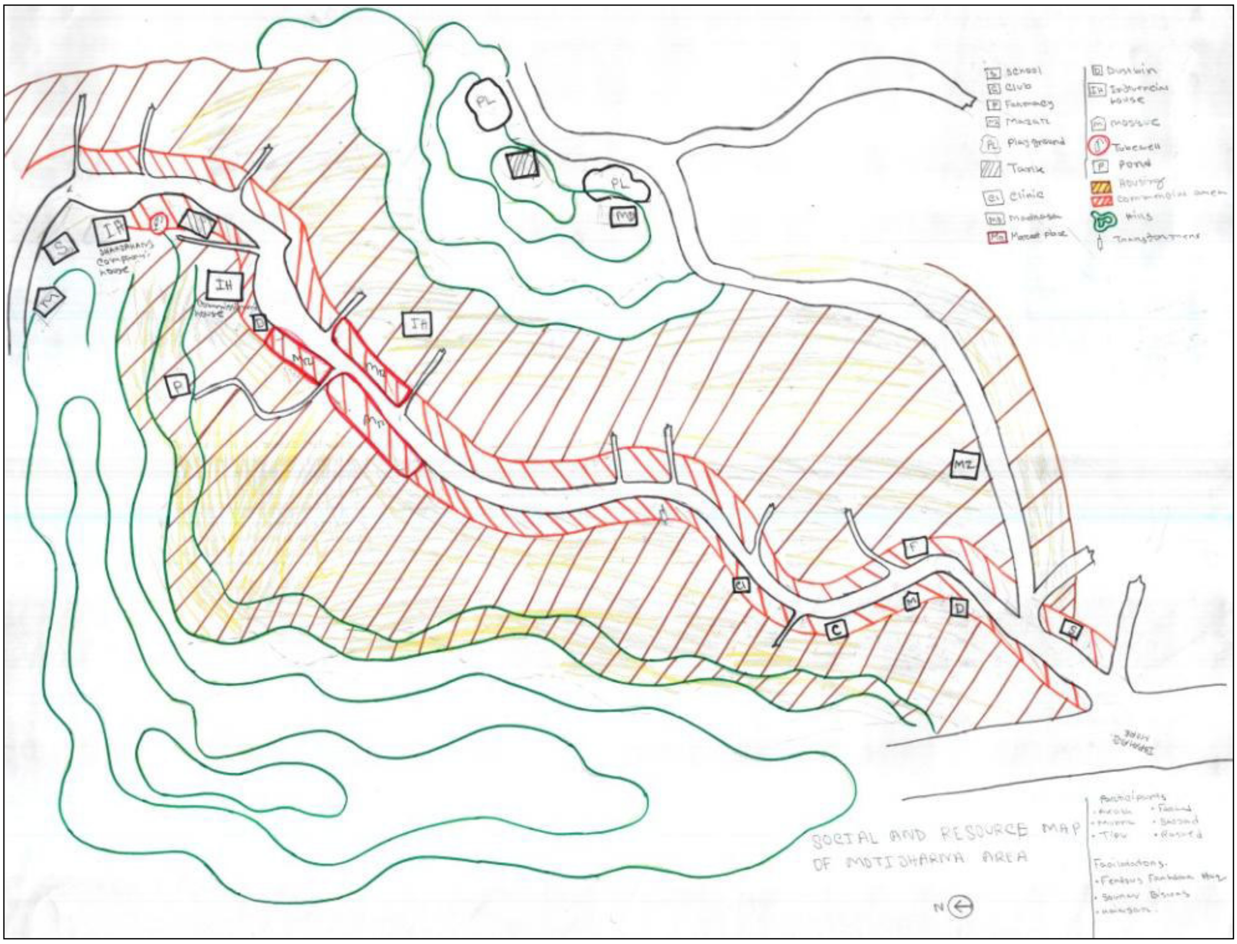
Social and resource map of Moti Jharna area represents the social institutions and resources of the area. From figure 3.26 we can see that there are hills at North, West and East part of the community which can be considered as natural resource of this area. There are a pond located in Moti Jharna area and two playgrounds located in Tanker Pahar area. There is a water tank in Tanker Pahar area which is used as the reservoir of water for the people of this whole area. One common tube well is identified which serves water facility to the people of this area. These are the resources of this area.

There are two schools, one mosque, one clinic, one pharmacy, one club, one madrasa in this area. These social institutions are located along the side of Moti Jharna main road. Schools are used as landslide evacuation shelter during heavy rain and landslide hazard. There is a market place at the center of this area. There are two houses of influential people of this area identified. These people are known as 'Zamindar' (landlord) of this area.

Commercial shops are located along the side of the Moti Jharna main road. Behind these shops, residential area development is seen.

Figure 3.26: Social and resource map of Moti Jharna area.

Source: Field Survey, September, 2014



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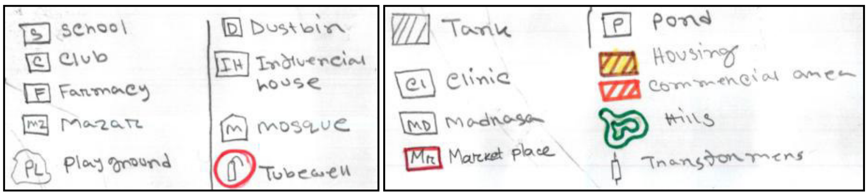
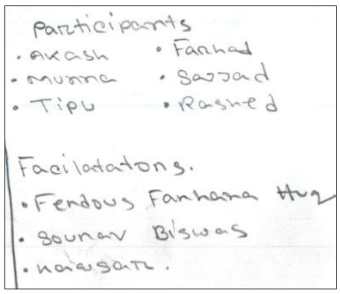




3.4.3 Movement Pattern of the People of Moti Jharna

Mobility map is a PRA tool that explores the movement pattern of people of a community. It shows where people go, for what purpose and how they go there.

Findings from the mobility map:

Mobility map of Moti Jharna area shows that people usually travel to fourteen places for different purposes. These places are as follows:

Educational institute: Al-Quran Nurani Madrasa, UNICEF School, Nurani madrasa and lalkhan bazaar primary school are educational institutes of this area. People travel to these places daily for educational purposes.

Religious institute: Tanker Pahar mazar, Batali hill jame masjid, Ispahani jame masjid are the religious institutes of this area. People travel to these places on foot daily for prayer. In mosques (masjid) people travel daily and in shrine (mazar) people travel once a month.

Commercial places: Fish markets, Uttara bank, Amen center are the commercial institutes of this area. People travel to these places daily to run commercial activities.

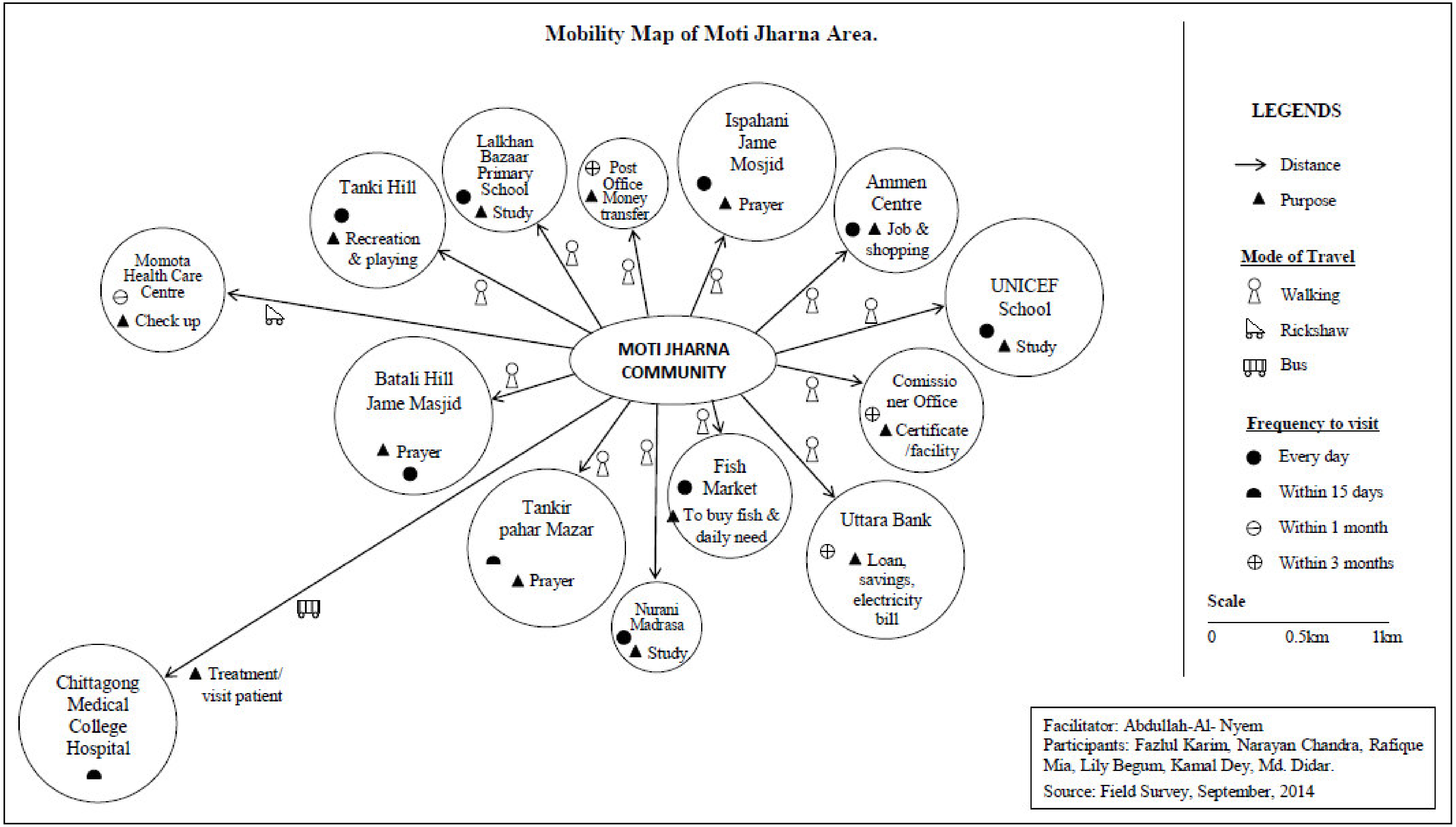
Recreational places: Tanker Pahar is the nearest place of this community where people travel on foot for playing and recreation.

Health care facility: Momota health care center and Chittagong Medical College are the health care facilities around this area. People travel these places by transport once in a month.

Others: Post office, commissioner’s office are other places where people go once in three months on foot.

Figure 3.27: Mobility map of Moti Jharna area.

Source: Field Survey, September, 2014



3.4.4 Physical Characteristics of Moti Jharna Area

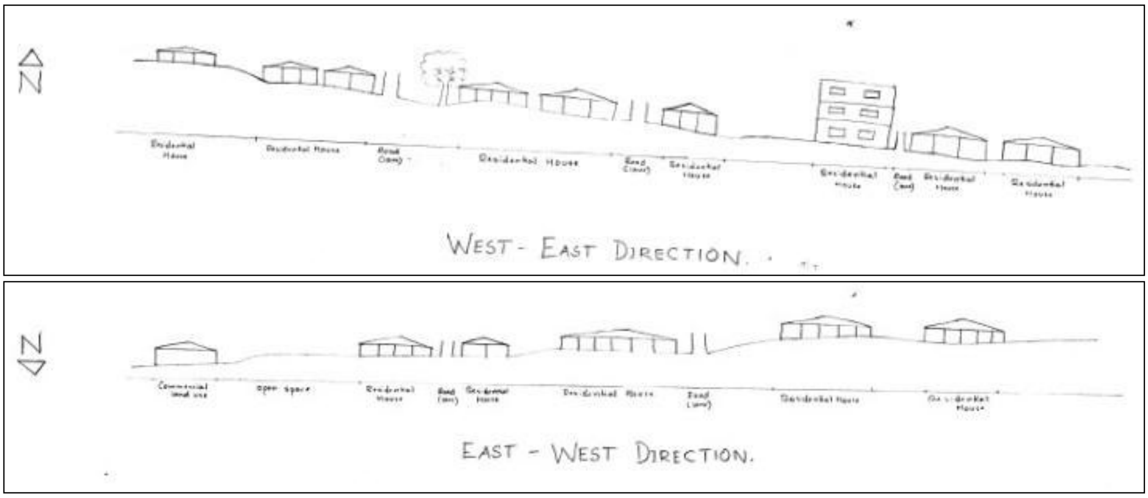
Transect Walk is another PRA method used to explore the spatial dimensions of people's realities. A transect walk depicts a cross sectional view of different features of an area. Here it provides a comparative assessment of the parts of the area on different parameters including topography, land type, building type, building height, problems, opportunities and solutions. Transect walk is used for verification of issues raised during other PRA exercises particularly during social mapping, natural resource mapping etc. (Kumar, 2002)

Major findings

In west-east direction most of the houses are made of tin and brick. Most of them are of one storey. One three story house is found along the side of the road. Roads are of three to five feet in width. Houses are constructed at the slope of the hills. All are residential houses. Similar characteristics can be seen in east-west direction. In east-west direction, density of houses is low.

Figure 3.28: Transect walk of Moti Jharna area.

Source: Field Survey, September, 2014



3.4.5 Institutional Context Associated to Landslide Vulnerability in Moti Jharna

There are different institutions in Moti Jharna area. People depend on these institutions and these institutions help people. These institutions can be an organization, individual or a group etc. To study the relationship between the community and different institutions venn diagram tool is practiced. From this notion, a venn diagram of the study area has been prepared.

Venn diagram of Moti Jharna Area

There are fourteen institutes identified who give support to the people of Moti Jharna community.

Batali hill masjid: This mosque is located just outside of the community. People go to the mosque and get announcement of landslide through mike from the mosque. A two way strong interaction exists between the community and mosque.

Garage Ambagan: This is a garage of rickshaw and cars. Rickshaw pullers and drivers use this garage for work purpose. Influence of this institution is low. One way weak interaction exists between this garage and community.

Post office: There is a post office within 0.5 kilometre in this area. But people use this post office rarely. There exists a one way weak interaction between this institute and the community.

Railway school: This school is located within 1 kilometre of the community. This is a big school with medium influence on community. Interaction type is one way and strong.

Momota Clinic: It is located within 2 kilometres of the community. People go to this clinic for getting medical help. This clinic has big influence on the people of the community. Interaction type is one way and strong.

BRAC Madrasa: This is the only madrasa of this community located within 0.5 kilometre. People have great dependency on this institution for educational purpose. This madrasa has a great influence on people. Interaction type is one way and strong.

Fish Market: This fish market is located at the center of Moti Jharna community. Fish from other areas of Chittagong come to this place. People buy fish and other things. This fish market has medium influence on the community. Interaction type is strong and one way.

UNICEF School: This is a highly influential school of this area. It is located within one kilometre from the community. There exists a one way high interaction between this school and community.

Uttara bank: This bank is located within 0.8 kilometre. This bank has high influence on the people of the community. Interaction type is one way and strong.

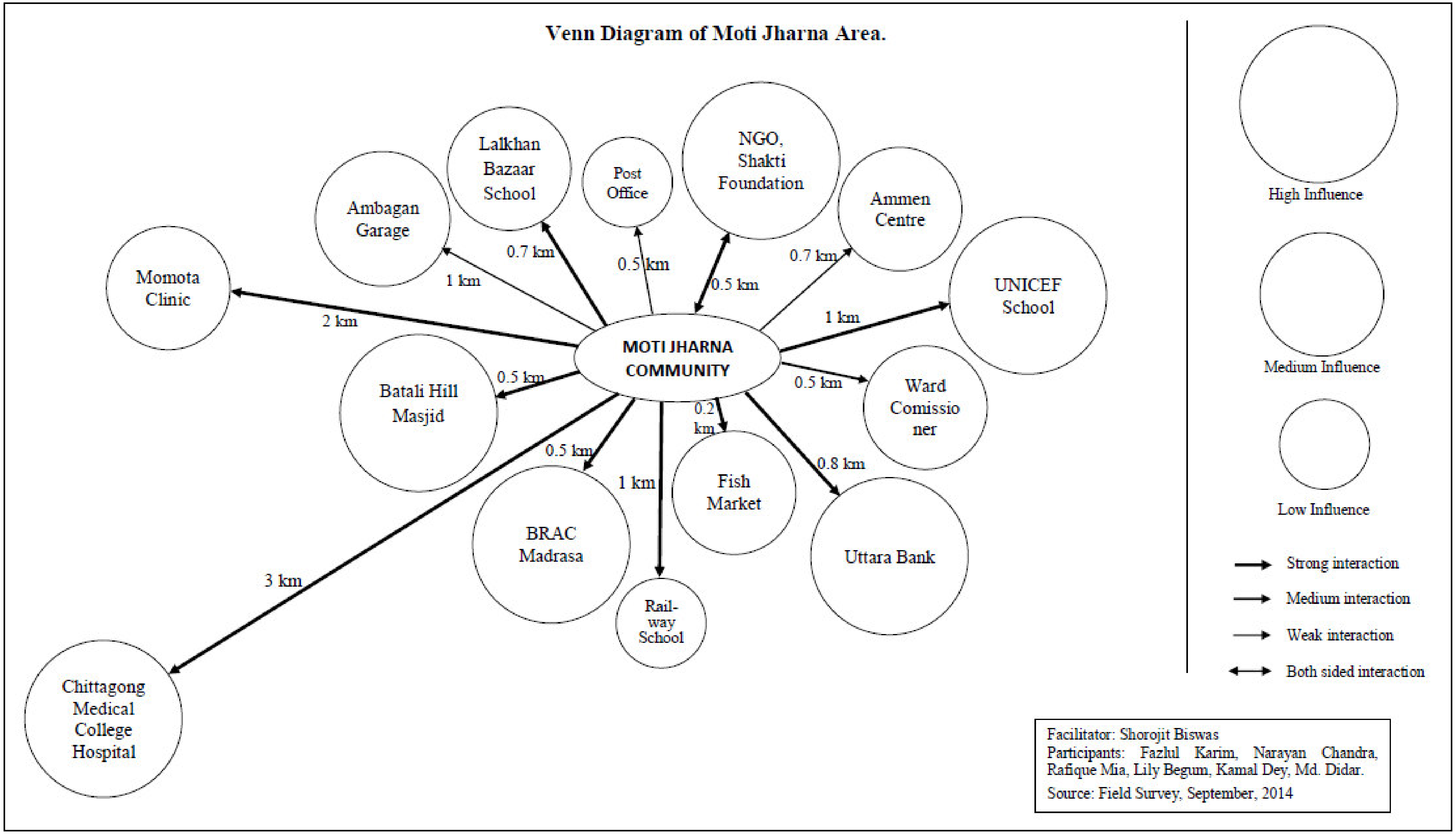
Ward commissioner: People go to the commissioner's office but commissioner never visits. This institute has medium influence on the people of community.

Shakti foundation (NGO): This is an NGO which helps people through proving financial and health facilities. This is a highly influential institute located in this area. There exists a two way strong interaction between this institute and the community.

Lalkhan bazaar school: This school is located within 0.7 kilometre of this area. This school is used as evacuation center during the time of landslide hazard. This school has a good influence on the community. There exists a one way strong interaction between the school and the community.

Figure 3.29: Venn diagram of Moti Jharna area.

Source: Field Survey, September, 2014



3.4.6 Assessment of Social and Landslide Vulnerability in the Moti Jharna

People of Moti Jharna area experienced landslide hazards in different periods. Many social problems also exist in these areas which make these areas vulnerable to different social hazards. It is necessary to identify the comparatively more and less vulnerable locations of the area so that the local people can take appropriate measures beforehand to mitigate the risks of landslide and other hazards. For this, a vulnerability map was prepared. This map is a tool for vulnerability assessment through a participatory approach. This map could also be a basis for preparedness and response plans for landslide and other hazards in the locality, to minimize loss of life and properties.

Major findings

Hills are located in north-western and eastern portion of Moti Jharna area. Settlements located at the down slope of the hills are indicated as high risk zone for landslide. Upper middle portion of the area is identified as medium risk and rest of the areas are considered as low risk zone for landslide. Water logging is a common phenomenon in this area. Moti Jharna main road is identified as vulnerable to water logging problem.

3.4.7 Dream Map of Moti Jharna

People of the Moti Jharna area live with landslide and many other problems. Still they have some hopes and aspirations to improve their social and economic condition. Dream map of the study area was produced to get idea about the dreams and aspirations of people regarding their areas.

Findings from dream map of Moti Jharna area

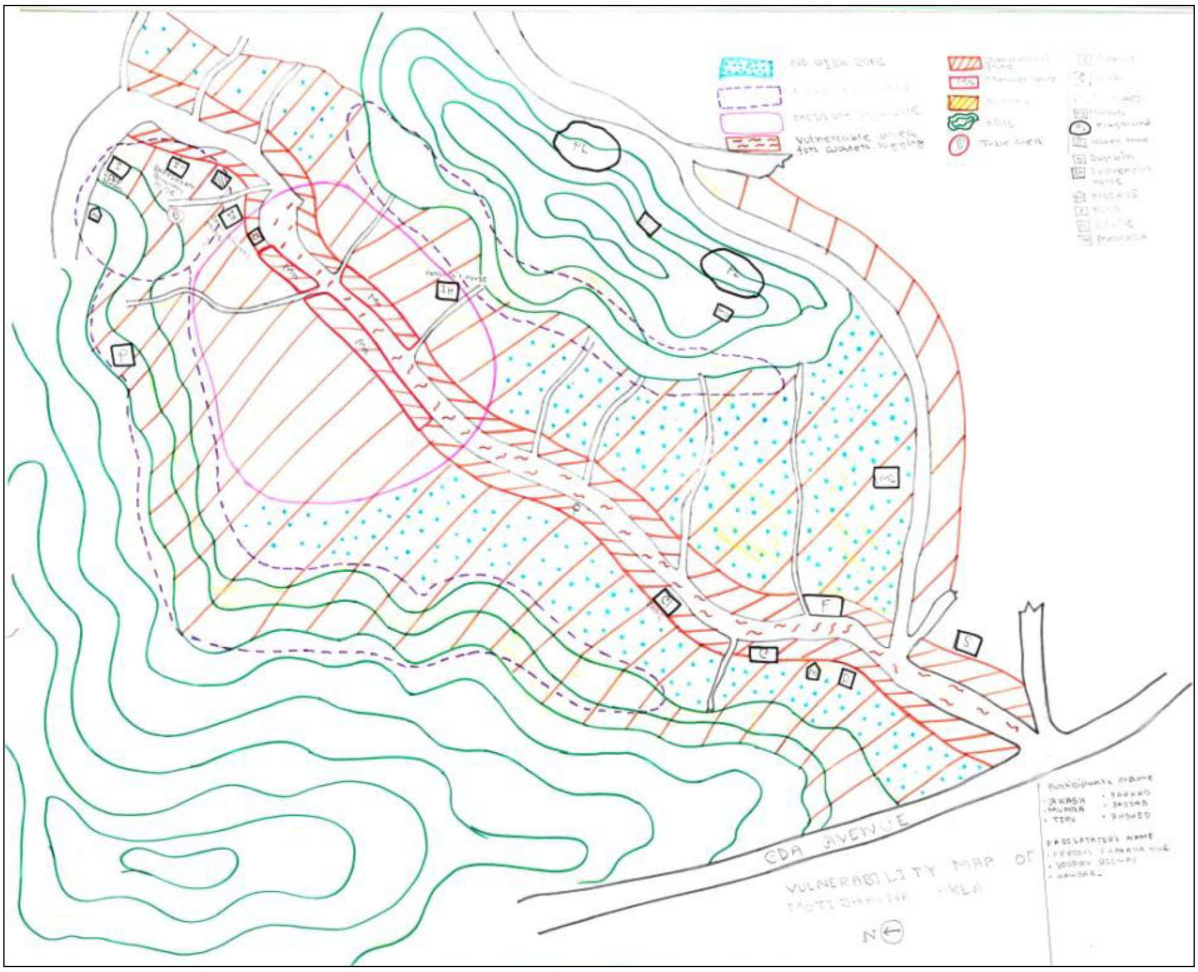
People of Moti Jharna gave their suggestions on three aspects.

- **Tube well installation**: As there exists huge water crisis in Moti Jharna, people want proper water facility in this area. People dream about sufficient number of tube well in this area. In dream map, proposed tube wells are indicated by red circle.
- **Retention wall:** As landslide is a common phenomenon in this area, people suffer a lot because of landslide each year. People suggested a retention wall along the side of hills. In dream map retention wall is indicated by dark black line.
- **Relocation of houses**: At present, many households are located at the down slope of the hills. People living in these houses are most vulnerable to landslide hazard. So, the

community people suggested the relocation of these people to other safe places. In dream map, houses to be relocated are indicated with black dots.

Figure 3.30: Vulnerability map of Moti Jharna area.

Source: Field Survey, September, 2014



Legends

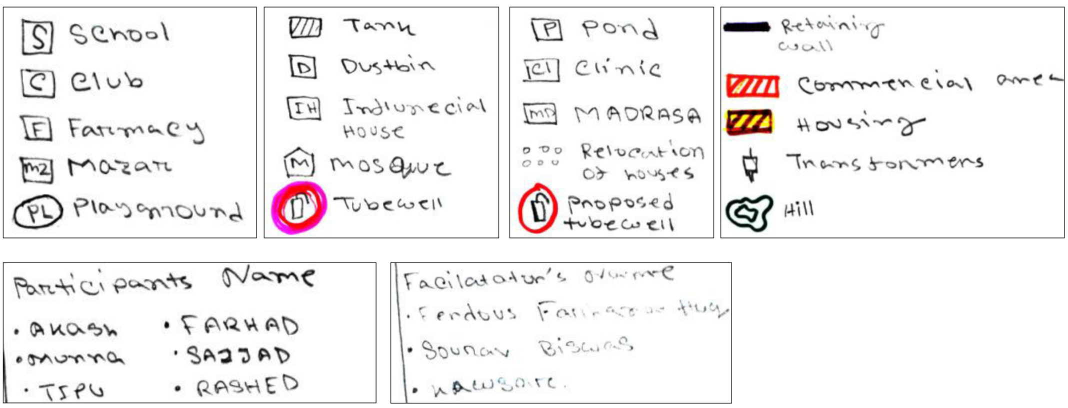
No Risk Zone
High Risk Zone
Medium Risk Zone
Vulnerable area for water logging
Commercial Zone
Market Space
Housing
Hill
Tubewell
School
Club
Pharmacy
Mazar
Playground
Water Tank
Dustbin
Influential House
Mosque
Pond
Clinic
Madrasa

Participants name	FACILATATOR'S NAME
· AKASH · FARHAD · MUNNA · SAJJAD · TIPU · RASHED	· FERDOUS FARHANA HUQ · SOURAV BISWAS · KAWSAR

Figure 3.31: Dream map of Moti Jharna area.

Source: Field Survey, September, 2014

Legends



3.4.8 Cause-Effect Analysis for Landslide Vulnerability in Moti Jharna

The vulnerability of the area is highly related with different causes that are responsible to increase the risk. Root causes of landslide vulnerability vary from area to area. The local problems of a particular area can best be described or identified by the people who live in that area. So, to identify the causes and effects of landslide vulnerability of Moti Jharna, Batali Hill, Golpahar and Goachibagan areas local people are incorporated using the PRA tool named 'Cause Effect Diagram'.

Cause and Effect Diagram is a tool that is useful for identifying and organizing the known or possible causes of specific problem. It graphically illustrates the relationship between a given outcome and all the factors that influence that outcome (Kumar S, 2002).

Causes associated with landslide vulnerability problem in Moti Jharna area

There are eight problems identified by the local participants which are thought to be responsible for landslide problem in Moti Jharna area (Figure 3.32).

High precipitation: High precipitation is thought to be one of the most important causes of landslide. In Moti Jharna area, landslide occurs in each year during monsoon.

Deforestation: People cut trees to clear hills for housing purpose. Trees are uprooted and so the soil gets loosen. This causes landslide.

Low economic condition: People with low economic conditions tend to live in low rent houses. Houses located just below the hills are rented low. So, people with low economic condition live there. This increases landslide vulnerability.

Hill cutting: Hills are cut for housing purposes. This destroys the natural slope characteristics of the hill. This is one of the main causes of landslide.

Lack of education: Education level of the people of Moti Jharna area is very low. They have a very low knowledge on the causes of landslide. Sometimes, their unconscious activities promote landslide.

Lack of awareness of people: People are not conscious about landslide events, its causes and effects. Their unconsciousness towards landslide event is one of the main reasons of vulnerability to landslide occurrence.

Building construction: People construct buildings on the slope of the hills. This causes landslide.

Lack of authority's awareness: Hill management of Moti Jharna area by the concerned authority is very poor. Lack of their awareness regarding hill management contributes the deteriorating conditions of hills.

Effects of landslide problem in Moti Jharna area

There are six major effects identified by the people of Moti Jharna area Figure 3.32.

Death of people: The most dominating effect of landslide is the death of people.

House damage: Many houses get destroyed due to landslide event.

People get injured: Many people get injured due to landslide events. Some people are injured so badly that they become paralyzed for the rest of their life.

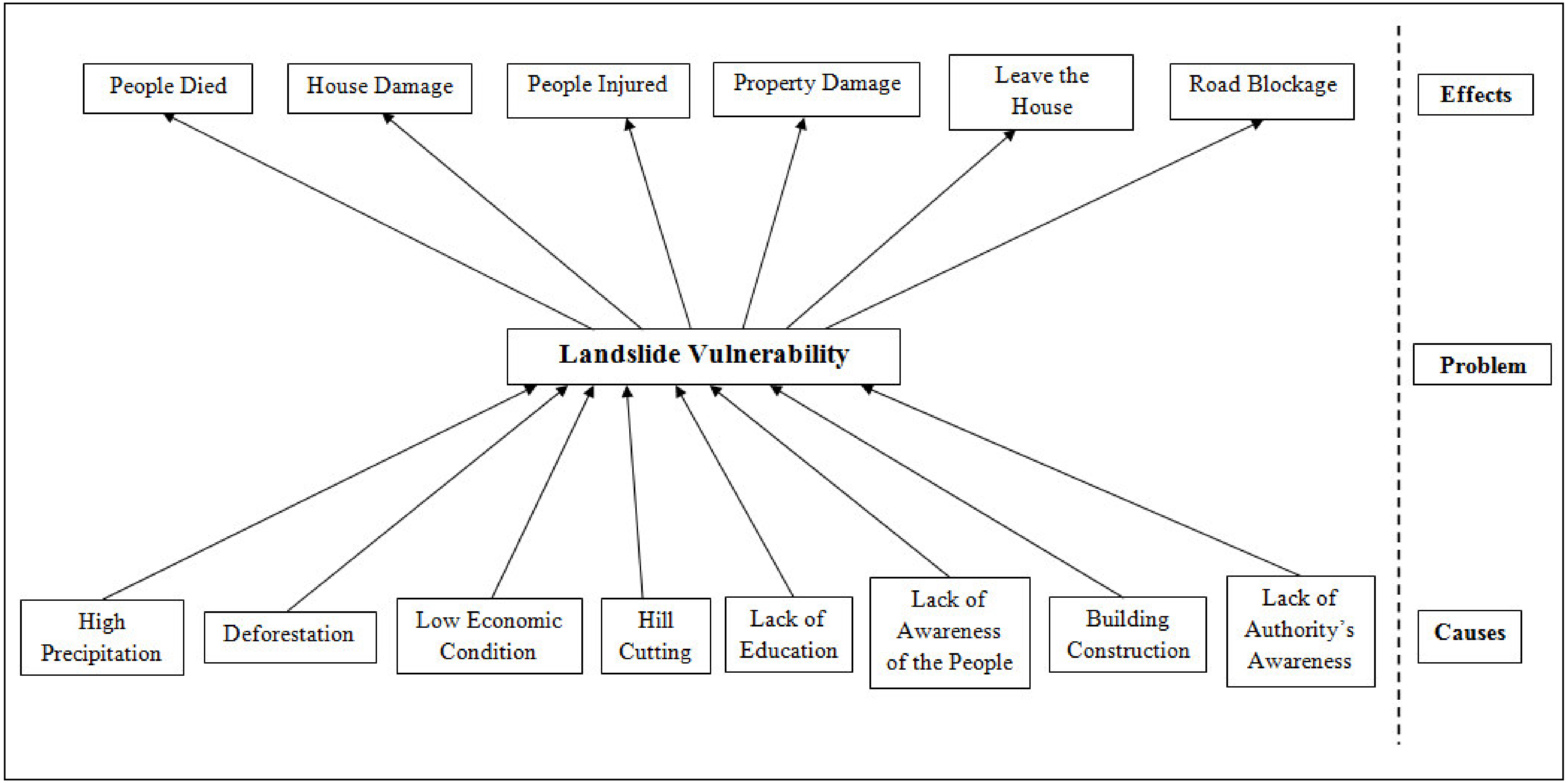
Property damage: Many properties are damaged due to landslide event.

Leave the house: Many people leave area to save themselves from the attack of the landslide.

Road blockage: When a landslide occurs, roads get blocked by the huge mass fallen from the hills. This disturbs the daily movement of the people.

Figure 3.32: Cause effect diagram for landslide vulnerability in Moti Jharna area.

Source: Field survey, September, 2014



3.4.9 Identification of Local Problems Related to Social Aspects

Social problems of the Moti Jharna, Batali Hill, Golpahar and Goachibagan are identified. Social problems are ranked according to the preference of the local people. Pair wise ranking method was applied for this purpose. Pair wise ranking method is a popular PRA method. It helps in arriving at people's priorities and preferences.

Findings from the Pair Wise Matrix

There are ten problems identified in Moti Jharna area (Table 3.26). Among these ten problems, low working facility is identified as the ranked one problem. People find this is the most serious problem of Moti Jharna area. Most of the people of Moti Jharna area go to the neighboring areas or distant places for work. Human violence is considered as the second most serious problem of this area. People often quarrel and cause harm to each other. Low economic condition and illegal business both are considered as third problems of the area. Illegal drug dealings are a common scenario of Moti Jharna area. Lack of education, Lack of daily needs, Low health facility and no water supply are fourth preferred problems of the area. Drug business and no gas supply are considered as least significant problems by the local people.

Table 3.26: Pair wise ranking of the problems in Moti Jharna.

Source: Field Survey, September, 2014

	Sl. No.	1	2	3	4	5	6	7	8	9	10	Frequency	Rank
Sl. No.	Problems	Low economic condition	Lack of daily needs	Drug's business	No water supply	No gas supply	Human violence	Illegal business	Lack of education	Low health facility	Low working facility		
1	Low economic condition	×	1	1	1	1	6	7	8	9	1	5	3
2	Lack of daily needs	×	×	2	4	2	6	7	2	2	10	4	4
3	Drug's business	×	×	×	4	3	3	7	8	3	10	3	5
4	No water supply	×	×	×	×	5	6	4	8	4	10	4	4
5	No gas supply	×	×	×	×	×	5	5	8	9	10	3	5
6	Human violence	×	×	×	×	×	×	6	6	9	6	6	2
7	Illegal business	×	×	×	×	×	×	×	7	7	10	5	3
8	Lack of education	×	×	×	×	×	×	×	×	9	10	4	4
9	Low health facility	×	×	×	×	×	×	×	×	×	10	4	4
10	Low working facility	×	×	×	×	×	×	×	×	×	×	7	1

3.4.10 Identification of Community's Positive and Negative Factors Regarding Landslide Vulnerability

Causes and their effects have been identified regarding landslide vulnerability and social perspective through cause-effect diagrams and pair wise ranking method (Section 3.2.8 and section 3.2.9). Now it is necessary to know the factors that can increase or decrease the influences of these problems. Because to find the possible solutions for the identified problems it is necessary to identify the factors and attributes that can fuel up or lessen these problems. The factors can be identified through Strength, Weakness, Opportunity and Threat (SWOT) Analysis.

The SWOT Analysis of Study Area

SWOT analysis (strengths, weaknesses, opportunities, and threats analysis) is a framework for identifying and analyzing the internal and external factors that can have an impact on the viability of a project, product, place or person. SWOT analysis groups key pieces of information into two main categories:

1. Internal Factors: The strengths and weaknesses are internal factors to the organization or place
2. External Factors: The opportunities and threats presented by the environment are external factors to the organization or place

SWOT analysis of Moti Jharna area

<u>Internal Factors</u>

Internal factors are the positive and negative factors or aspects inside the community regarding landslide vulnerability. These factors are known as Strengths (S) and Weaknesses (W) (Figure 3.33).

Strengths: The community's strengths are its resources and other factors that can increase their capabilities to face landslide disaster and can lessen the possible risks. The strengths for study area are as following.

Voting opportunity: People of Moti Jharna area think that their voting opportunity is a great strength. This opportunity allows them to give their decision on the selection of political leaders.

A helpful Lawyer in the Community: A helpful lawyer in Hossain saheb's colony is a great opportunity according to the people. Lawyer gives his valuable suggestion to the local people.

Link with some powerful and rich people: There exists good interactions between the local people with powerful and rich people of the community who help people.

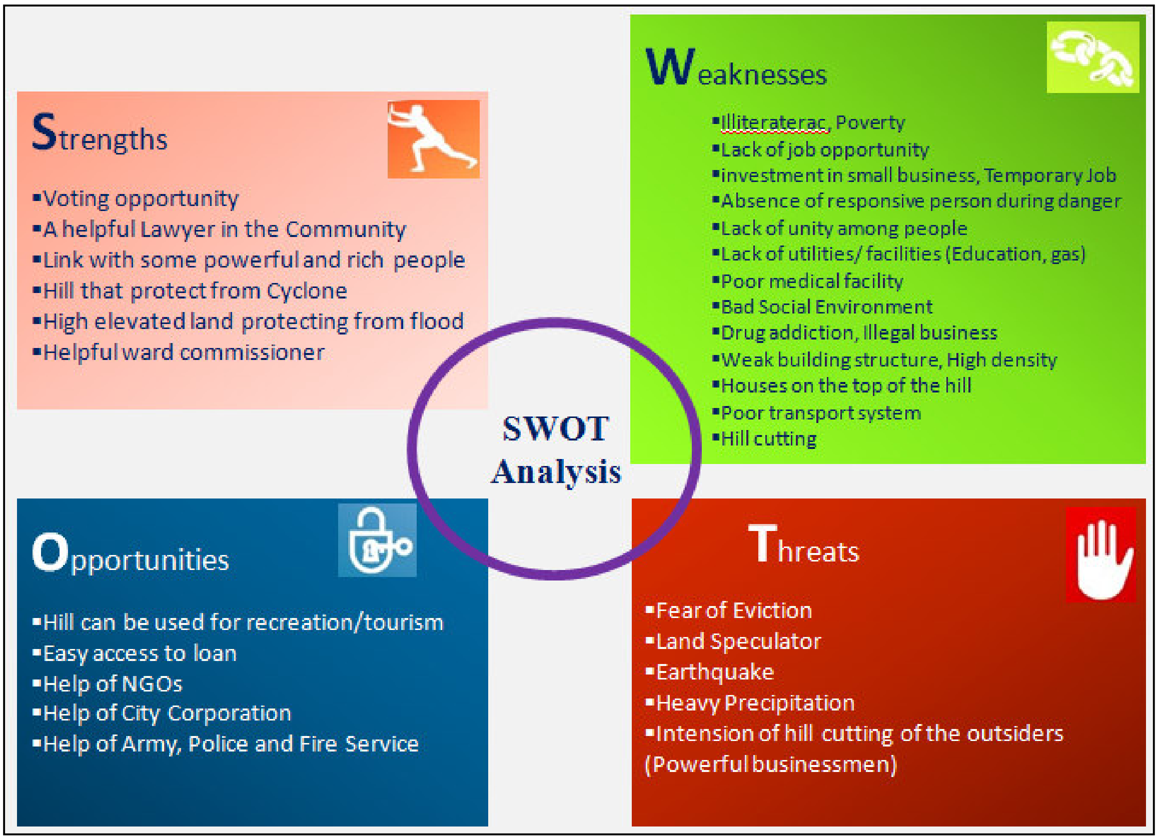
Hills that protect from Cyclone: Cyclone is a common phenomenon in Chittagong district. Hills protect people of the Moti Jharna area from the attack of cyclone.

High elevated land protecting from flood: As Moti Jharna area is located on hilly region, high land characteristics protect area from flood.

Helpful ward commissioner: According to the people of Moti Jharna area, ward commissioner is helpful to them which is a strength of their community.

Figure 3.33: SWOT analysis of Moti Jharna area.

Source: Field survey, September, 2014



Weaknesses:

Weaknesses are those factors that generate or come within the community and have negative impacts on risk reduction program of earthquake vulnerability. The weaknesses for study area are shown in Figure 3.33.

Illiterate people: According to the people of Moti Jharna area, illiteracy is the main weakness of this area.

Poverty: Most of the people of Moti Jharna area lead a very poor life. This is a weakness of this area.

Lack of job opportunity: Most of the jobs of this area are of temporary nature. People make their investment in small business.

Absence of responsive person during danger/disputes: There is no responsive person who can act with responsibility during a disaster. This makes the community weak.

Lack of unity among people: People of Moti Jharna area are not socially united. This is a weak point of community.

Lack of utilities/ facilities: There is lack of proper educational institutes and utility facilities in this area.

Poor medical facility/ absence of qualified doctor in the community: There is no qualified doctor and health facility in this area. For health facility people go to other areas like Lalkhan bazaar.

Bad Social Environment: Social condition is a big weakness of this community. People of different ages are addicted to drugs. Illegal business is a common scenario of Moti Jharna area.

Poor housing: Housing condition of Moti Jharna area is very poor. Buildings are made of tin, clay, bamboo etc. Houses are located on the slope of hills. Population density of this is very high.

Poor transport system: Transportation condition is very poor. Roads are poorly constructed and roads are very narrow.

Hill cutting: Hill cutting is major issue of this area. This makes area vulnerable to landslide.

External Factors

External factors are the positive and negative factors coming from outside the community. These external positive and negative factors or aspects can be classified as opportunities (O) and threats (T).

Opportunities

Opportunities are external chances to improve the situation of the study area regarding landslide risk reduction program as well as improving social condition. Opportunities for the study area are shown in Figure 3.33.

Hill can be used for recreation/tourism: Moti Jharna ares is located on hilly site. Hills can be used for recreation and tourism purpose and from this many people can be employed.
Easy access to loan: There are many small banks which provide financial assistance to the local people.
Help of NGOs: There are many NGOs working in this area. They provide financial as well as social and health facilities.
Help of City Corporation: City Corporation helps people through providing facilities and help during landslide.
Help of Army, Police and Fire Service: During landslide disaster these institution take part actively in rescue and relief distribution.

Threats: Threats are external aspects that can affect the community negatively regarding landslide risk reduction program. Absence of certain opportunities can be viewed as threats. The probable threats for the study area discussed in Figure 3.33.

Fear of Eviction: People of Moti Jharna area often face problems of threat of eviction
Land Speculator: There are many land speculators living outside of this area. This is a threat to the people of this area as land of this area is getting sold to the persons from other area.
Earthquake: Sometimes earthquake cause landslide to this area and this is a threat.
Heavy Precipitation: heavy precipitation causes landslide.
Intension of hill cutting of the outsiders: There are some powerful businessmen of other areas who cut hill of Moti Jharna for business purpose. This contributes to the landslide of this area.

CHAPTER 4: SOIL INVESTIGATION

4.1 OBSERVING THE CONDITIONS AND COLLECTING REPRESENTATIVE SOIL SAMPLES AT LOCATIONS OF SEVERAL CLUSTERS (FIELD STUDY)

4.1.1 TERMINOLOGY

Representative Soil Sample:

A soil sample that represents the constituents of the soil as in the field defined as a representative soil sample. A representative soil sample is essential in order to conduct laboratory tests.

Disturbed Soil Sample:

Disturbed soil sample is broken-up soil but representative soil, disturbed during the process of collection. Geotechnical engineers do not consider them to be representative of underground soils unless they're for tests that don't depend on the soil structure. Usually, scientists test the disturbed samples of soil for texture, soil type, moisture content, as well as the nutrient and contaminant analysis. Most of the soil samples that engineers and geologists collect are disturbed samples since they're a lot easier to collect and the need for obtaining an undisturbed sample isn't required for many soil tests.

For the purpose of collecting disturbed soil sample in this study a hand auger was used.

Undisturbed Soil Sample:

Undisturbed soil samples keep the structural integrity of the in-situ soil and they have a higher recovery rate in the sampler. It's actually tough to gather a perfectly undisturbed sample and the samplers may contain a small portion of disturbed soil at the top as well as the bottom of the sample length. Undisturbed samples allow the engineer to identify the properties of strength, permeability, compressibility, as well as the fracture patterns among others.

For the purpose of collecting undisturbed soil sample in this study, Two (2) feet long 'Shelby Tubes' were used.

Hand Auger:

The hand auger is suitable for unconsolidated soil formations: sand, silt and soft clay. The hand auger consists of extendable steel rods, rotated by a handle (Figure 4.1). A number of different steel augers (drill bits) can be attached at the bottom end of the drill rods. The augers are rotated into the ground until they are filled, and then lifted out of the borehole to be emptied (Figure 4.2).

Figure 4.1: A typical hand auger.

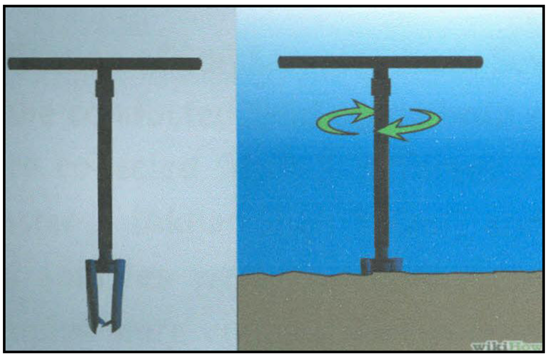


Figure 4.2: Extracting soil from bore-hole.
Source: *Field Survey, September, 2014*

Shelby Tube:

Shelby tube samplers are thin-walled, hollow steel tubes, which are driven into the ground to extract a relatively undisturbed soil sample for use in laboratory tests used to determine density, permeability, compressibility and strength. Each tube has one end that is chamfered to form a cutting edge and the upper end includes holes for securing the tube to a drive head (Figure 4.3). Shelby tubes are useful for collecting soils that are particularly sensitive to sampling disturbance, including fine cohesive soils and clays. The tubes can also be used to transport samples back to the lab as well.

Figure 4.3: Shelby Tube used for Collecting Undisturbed Soil Sample.

4.1.2 PROCEDURE OF COLLECTING SOIL SAMPLES

Classification of the Chittagong Metropolitan Area (CMA) into Different Clusters

In Inventory Phase, the Chittagong Metropolitan Area (CMA) was divided into 10 clusters initially taking into consideration the landslide hazard locations, tentative similarity of the surroundings and landslide mechanisms (Chapter-2: Table 2.1). After the preparation of landslide inventory, it was necessary to collect representative soil samples from different clusters.

Collection of Soil Samples from Several Clusters

In the conducted field study both disturbed and undisturbed soil samples were collected from 3 different clusters namely Cluster-l (Moti Jharna), Cluster-5 (Akbar Shah Mazar) and Cluster-9 (Panchlaish) (Appendix-C, Figure 1, Figure 5 and Figure 9). For Cluster-l soil samples were collected from 'Tankir Pahar', for Cluster-5 soil samples were collected from Two (2) hills namely 'Golpahar and Lal Pahar/ Kata Pahar' and for Cluster-9 soil samples were collected from 'Medical Hill (Goachibagan)'.

Figure 4.4: Closely packed temporary houses, narrow muddy pathways and settlements built on dangerous slopes. Source: *Field Survey, August, 2014*

Figure 4.5: Lal Pahar/ Kata Pahar (Cluster- 5); Clear signs of illegal hill cutting can easily be seen leading to the risk of a probable landslide any time - local authorities remain unaware of such problems.

Source: *Field Survey, August, 2014*

Procedure for Collecting Disturbed Soil Sample

1) Digging and removing the top cover of the soil surface with a Shovel initially. Even while taking disturbed soil sample at the surface level, soil sample cannot be taken from the very top. After removing almost 6 inches of soil (eye estimation) from the top considering for weeds and withering, soil sample for top surface was collected (Figure 4.6-a and Figure 4.6-b).

2) After collecting disturbed soil sample at the surface level, the hand auger was used to go down the soil surface, bore a hole in the process and dig into the soil gradually (Figure 4.6-c). A 3-feet long iron tube was attached with the auger and with that iron tube a rotating device was also incorporated. By means of the rotating arrangement, the auger gradually dug deep into the soil. After going certain depths into the ground, the excavated depth was measured with the measuring tape, the auger was taken out of the bore-hole and soil sample was extracted from the auger and kept inside a polythene bag (Figure 1.11). For most of the cases, e.g., the four hills that were studied, at a particular slope, 3 samples were collected at 3 different depths i.e. at the surface level, below 1.5 feet of surface, below 3 feet of surface.

Figure 4.6: (a) Removing the top layer of soil cover,

(b) Using rotating device to dig the auger deep into the ground,

(c) Extraction of soil from the bore hole

Source: *Field Survey, September, 2014*

(a) (b) (c)

Figure 4.7: Collection of disturbed soil samples into separate polythene bags.

Source: *Field Survey, September, 2014*

Procedure for Collecting Undisturbed Soil Sample:

A Two (2) feet long Shelby Tube was used to collect undisturbed soil sample. First, it was placed on the ground vertically and above it a square wooden plate was placed so that the blows from modified proctor hammer get distributed properly and also do not damage the steel Shelby tube (Figure 4.8).

Figure 4.8: Inserting the Shelby tube deep into the ground by means of a 10 lb modified proctor hammer, blows were at a constant rate.

Source: *Field Survey, September, 2014*

Figure 4.9: (a) Extracting the Shelby tube from the ground with the help of a twisted steel rod (b) Waxing both the ends of the Shelby tube after soil sample collection.

Source: *Field Survey, September, 2014*

(a) (b)

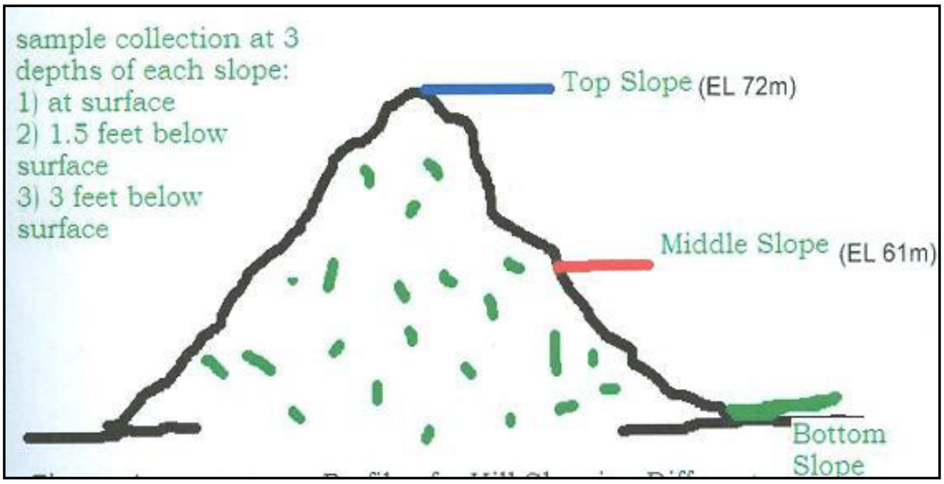
After that a 10 lb. modified proctor hammer was used to drive the Shelby tube vertically into the ground. Blows from modified proctor hammer were at a constant rate and also the ball was allowed to drop freely. The modified proctor hammer was placed just above the Shelby tube.

In between the hammer and the tube a 1 inch thick wooden plate was placed.

After going into the ground as much as possible, the Shelby tube was extracted from the ground. At the top of the Shelby tube, there are two holes. A twisted steel rod was entered through both the holes and then by twisting the rod with pressure applied by the hand, the Shelby tube was easily extracted from the ground (Figure 4.9).

After extracting the Shelby tube, with the soil sample still inside, both the ends of it were waxed to retain the original moisture condition of the field.

Figure 4.10: A vertical profile of a hill (Goachibagan Medical Hill, Panchlaish, Cluster-9) showing different slopes of it (Top, Middle and Bottom).
Source: *Field Survey, September, 2014*



4.1.3 Tests Performed on Disturbed Soil Samples

Determination of Atterberg Limits
Purpose:
This laboratory test is performed to determine the plastic and liquid limits of a fine-grained soil. The liquid limit (LL) is arbitrarily defined as the water content, in percent, at which a part of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm (1/2 in.) when subjected to 25 blows from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second. The plastic limit (PL) is the water content, in percent, at which a soil can no longer be deformed by rolling into 3.2 mm (1/8 in.) diameter threads without crumbling.

Standard Reference:

ASTM D 4318 - Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

Significance:

The Swedish soil scientist Albert Atterberg originally defined seven "limits of consistency" to classify fine-grained soils, but in current engineering practice only two of the limits, the liquid and plastic limits, are commonly used. (A third limit, called the shrinkage limit, is used occasionally.) The Atterberg limits are based on the moisture content of the soil. The plastic limit is the moisture content that defines where the soil changes from a semi-solid to a plastic (flexible) state. The liquid limit is the moisture content that defines where the soil changes from a plastic to a viscous fluid state. The shrinkage limit is the moisture content that defines where the soil volume will not reduce further if the moisture content is reduced. A wide variety of soil engineering properties have been correlated to the liquid and plastic limits, like "Atterberg Indices" namely Plasticity Index, Flow Index, Toughness Index.

Plastic Limit:

The plastic limit is the threshold point at which soil begins to behave as a plastic material. At plastic limit the soil must gain some minimum strength. According to Skempton and Northey (1953) the shear strength at plastic limit is about 100 times that at liquid limit.

Plasticity Index:

Plasticity Index is an indication of plasticity of soils. Plasticity Index greater than 20 indicates high plastic soil, 10-20 indicates medium plastic and less than 10 indicates non-plastic soils. It is known that high percentage of clay exhibit high plastic properties. Plasticity Index also a measure of the range of water content for which it remains plastic. The table below shows the quality of soil based on the vulnerability to landslides.

Test Procedure:

Liquid Limit:

Soil was pulverized, passed through a No. 40 sieve, air-dried. The soil was thoroughly mixed with a small amount of distilled water until it appears as a smooth uniform paste.

The liquid limit apparatus was adjusted by checking the height of drop of the cup. The point on the cup that comes in contact with the base should rise to a height of 10 mm. The block on the end of the grooving tool is 10 mm high and should be used as a gage. It was practiced to rotate the cup and the correct rate to rotate the crank was determined so that the cup drops approximately two times per second.

A portion of the previously mixed soil was placed into the cup of the liquid limit apparatus at the point where the cup rests on the base. The soil was squeezed down to eliminate air pockets and it was spread into the cup to a depth of about 10 mm (half inch) at its deepest point. The soil pat should form an approximately horizontal surface (Figure 4.11).

Figure 4.11: Liquid limit device.

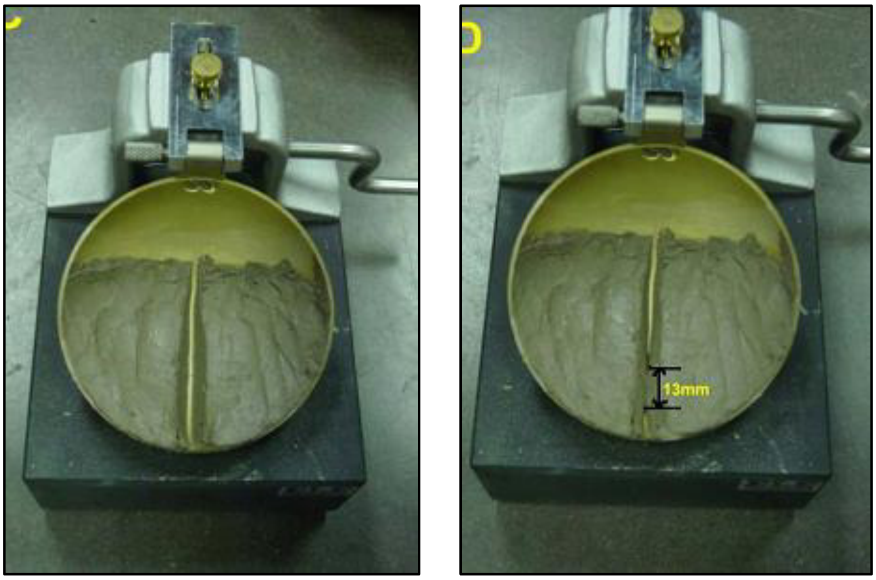
Source: *Field Survey, September, 2014*

The grooving tool was used carefully to cut a clean straight groove down the center of the cup. The tool should remain perpendicular to the surface of the cup as groove is being made. Extreme care was taken to prevent sliding the soil relative to the surface of the cup (Figure 4.12-a).

Figure 4.12: Determination of liquid limit.

Source: *Field Survey, September, 2014*

(a) (b)



It was made sure that the base of the apparatus below the cup and the underside of the cup was clean of soil. The crank of the apparatus was turned at a rate of approximately two drops per second and count the number of drops, N, it takes to make the two halves of the soil pat come into contact at the bottom of the groove along a distance of 13 mm (1/2 in.) (Figure 4.12-b).

If the number of drops exceeds 50 or is less than 10, then the number of drops was not recorded, otherwise, the number of drops was recorder on the data sheet.

Using the spatula, sample was taken from both sides of where the groove came into contact. The soil was placed into a moisture can, weighed and placed into the oven. The moisture can was left in the oven for 24 hours to obtain oven dry weight.

The entire soil specimen was remixed in the porcelain dish. A small amount of water was added into the specimen to increase the water content so that the number of drops required to close the groove decrease.

Steps six, seven, and eight were repeated for at least two additional trials producing successively lower numbers of drops to close the groove. One of the trials shall be for a closure requiring 25 to 35 drops, one for closure between 20 and 30 drops, and one trial for a closure requiring 15 to 25 drops. The water content from was determined for each trial. The same balance was used for all weighing.

From plot of number of blows versus water content, the flow curve is obtained. Number of blows corresponding to 25 blows is the liquid limit.

Plastic Limit:

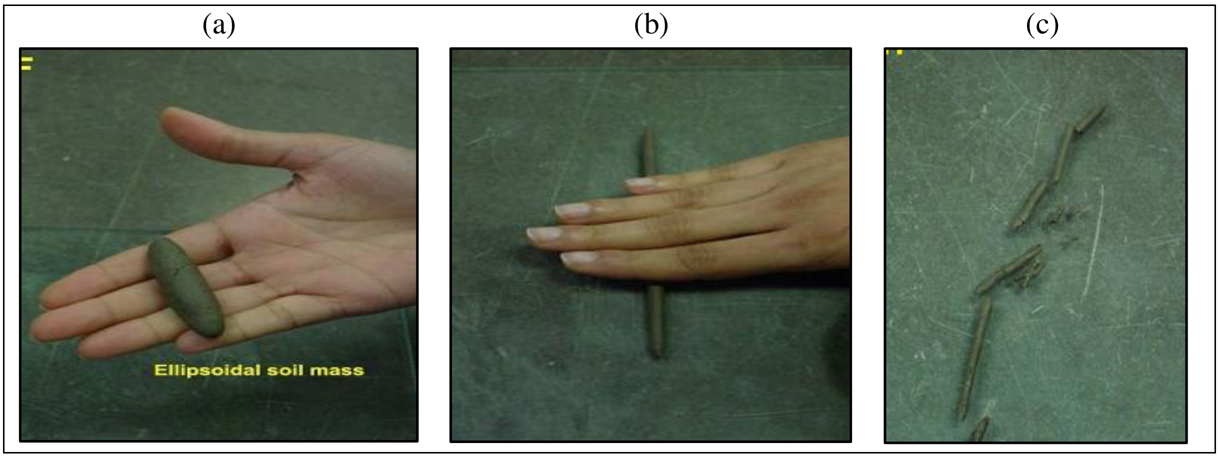
(1) Empty moisture cans were weighed.

(2) The soil sample was taken and water was added until the soil is at a consistency where it can be rolled into a thread without sticking to the hands.

(3) The soil was formed into an ellipsoidal mass (Figure 4.13-a). The mass was rolled between the palm or the fingers and the glass plate (Figure 4.13-b). Sufficient pressure was used to roll the mass into a thread of uniform diameter by using about 90 strokes per minute. (A stroke is one complete motion of the hand forward and back to the starting position). The thread shall be deformed so that its diameter reaches 3.2 mm (1/8 in.), taking no more than two minutes.

Figure 4.13: Determination of plastic limit.

Source: *Field Survey, September, 2014*



(4) The pieces were kneaded and reformed into ellipsoidal masses and rolled and re-rolled into threads. This alternate rolling, gathering together, kneading and re-rolling were continued until the thread crumble just begins to reaching a 3.2 mm diameter size (Figure 4.13-c).

(5) The portions of the crumbled thread were gathered together and the soil were placed into a moisture can, and then covered. If the can does not contain at least 6 grams of soil, soil was added to the can from the next trial (Step 6). Finally, the moisture can was left in the oven for 24 hours.

(6) Steps three, four, and five were repeated at least one more time.

4.1.4 Analysis:

Liquid Limit:

(1) The water content of each of the liquid limit moisture cans was calculated after they have been in the oven for 24 hours.

(2) The number of drops, N, (on the log scale) versus the water content (w) was plotted. Draw the best-fit straight line through the plotted points and the liquid limit (LL) as the water content at 25 drops was determined.

Plastic Limit:

(1) The water content of each of the plastic limit moisture cans was calculated after they have been in the oven for at 24 hours.

(2) The average of the water contents was calculated to determine the plastic limit, PL. If the difference between the water contents is greater than the acceptable range of two results (2.6 %) was checked.

(3) The plasticity index, PI=LL-PL was calculated. The liquid limit, plastic limit, and plasticity index were calculated to the nearest whole number, omitting the percent designation.

Table 4.1: Data of Lal Pahar (Akbar Shah Mazar Cluster).

Source: *Field Survey, September, 2014*

	Liqiud Limit and Plastic Limit Determination							
		Liquid Limi Determination						
blow number	Can Number	Can wt	Can+wt soil	Can+dry soil	Water	Dry soil	w%	Liquid Limit (graph)
10	809	6.4	16.5	13.1	3.4	6.7	50.75	
25	2233	10.5	21.6	18.3	3.3	7.8	42.31	42.31
28	2007	10.4	18.9	16.3	2.6	5.9	44.07	
32	2232	10.4	25.1	21	4.1	10.6	38.68	
		Plastic Limit Determnation						
	Can number	Can weight	Can+ wet soil	Can+Dry soil	Water	Dry soil	w%	Plastic Limit
	203	6.4	9.6	9	0.6	2.6	23.08	22.93
	832	11.3	21	19.2	1.8	7.9	22.78	

Result:

Liquid Limit: 42%

Plastic Limit: 23%

Plasticity Index: 42-23 = 19%

Figure 4.14: Flow curve- percentage of water content and number of blow Akbar Shah Mazar Cluster).

Source: *Field Survey, September, 2014*

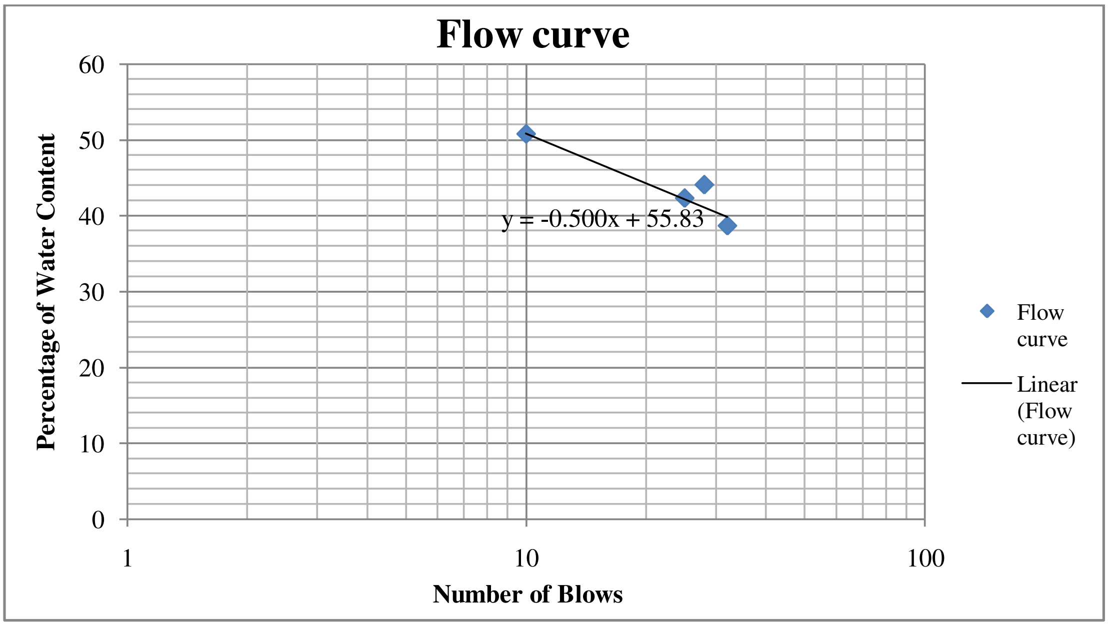


Table 4.2: Data for Tankir Pahar (Moti Jharna Cluster).

Source: *Field Survey, September, 2014*

			Liquid Limit and Plastic Limit Determination					
				(soil sample from Tankipahar)				
				Liquid Limit determination				
No. of blow	can number	can wt	can+ wet soil	can+dry soil	water	dry soil	moisture content w%	Liquid Limit
17	2120	9.7	24.6	20	4.6	10.3	44.66	
27	2047	9.1	23.9	20.3	3.6	11.2	32.14	36.57
31	2186	9.3	25.6	21.8	3.8	12.5	30.40	
40	2199*	9	21.6	18.8	2.8	9.8	28.57	
				Plastic Limit Determination				
	Can number	Can Wt.	can+ wet soil	can+ dry soil	water	dry soil	moisture content w%	plastic limit
	2244	8.7	27.7	24.1	3.6	15.4	23.38	23.10
	2080	10.8	22.1	20	2.1	9.2	22.83	

Result:

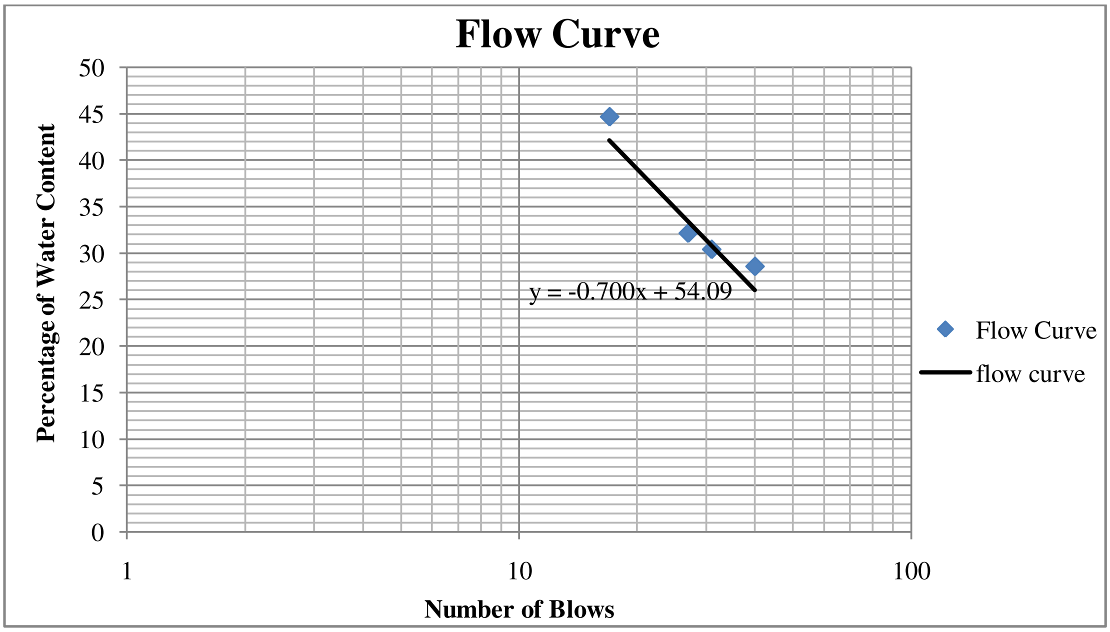
Liquid Limit = 37%

Plastic Limit = 23%

Plasticity Index = 37-23 = 14%

Figure 4.15: Flow curve- percentage of water content and number of blow (Moti Jharna Cluster).

Source: *Field Survey, September, 2014*



4.1.5 Determination of Specific Gravity

Purpose:

This laboratory test is performed to determine the specific gravity of soil by using a pycnometer. Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature.

Standard Reference:

ASTM D 854-00 – Standard Test for Specific Gravity of Soil Solids by water Pycnometer.

Significance:

The specific gravity of a soil is used in the phase relationship of air, water, and solids in a given volume of the soil.

Equipment:

Pycnometer, Balance, Vacuum pump, Funnel, Spoon.

Test Procedure:

- 50g of soil sample (passed through the sieve No. 10) was placed in the pycnometer. Distilled water was added to fill about three-fourth of the pycnometer. The sample was soaked for 10 minutes.
- A partial vacuum was applied to the contents for 10 minutes, to remove the entrapped air.
- The vacuum was stopped and the vacuum line was carefully removed from pycnometer.
- The pycnometer was filled with distilled (water to the mark), the exterior surface of the pycnometer was cleaned with a clean, dry cloth. The weight of the pycnometer and contents (W_1) was determined.
- 4 separate bowls were cleaned and their weights were determined.
- The pycnometer was left like this for about 24 hours. Then it was emptied and cleaned. The soaked soil was placed in bowls and then put into oven for 24 hours to be oven dried. Then the pycnometer was filled with distilled water only (to the mark). The exterior surface of the pycnometer was cleaned with a clean, dry cloth. The weight of the pycnometer and distilled water (W_2) was determined.

- The Oven dry sample was taken out after 24 hours and the weights was determined (W_s).

Data Analysis Procedure:

Specific gravity of the soil solids were calculated using the following formula:

$G_s = G_T W_s / (W_s - W_1 + W_2)$

Where,

W_1 = Wt. of pycnometer + water + soil

W_2 = Wt. of pycnometer + water

W_s = Wt. of soil

G_T = Specific gravity of water at room temperature (T^oC)

Table 4.3: Data for determining the specific gravity.

Source: *Field Survey, September, 2014*

Sample Name	Bottle+water+soil (W1)	Bottle+water (W2)	wt. of dish	Dish+dry soil	Dry soil (Ws)	Specific Gravity
Lalpahar	377.1	346.2	82.1	131.2	49.1	2.69
GuachiBagan	373.2	341.8	71	120.7	49.7	2.71
Golpahar	376.3	345.5	75.2	124.9	49.7	2.62
Tankiapahar	372.2	341.2	79.8	128.8	49	2.71

The room temperature was 27^oC and specific gravity of water at that temperature was 0.9965.

Result:

The specific gravities for the four hills are given below.

LalPahar: 2.69

GuachiBagan: 2.71

GolPahar: 2.62

Tankir Pahar: 2.71

Sample calculation for grain size analysis

<u>Selection of "Wash Sieve" over normal Sieve Analysis</u>

Soil samples of four different hills (Lal Pahar, Golpahar, Tankir Pahar, Goachibagan) were collected and tested for grain size analysis which will facilitate the classification of those soils. From observation it was understood that two of the hills had predominantly sandy soil

(Golpahar, Goachibagan) whereas the rest of the two had a mixture of sand, silt and clayey soil. Because of the presence of cohesive material "Wash Sieve" was performed.

Wash Sieve Procedure:

- For each of the hills, 100g of soil sample was taken at first. All of them were crushed and ground into very fine powder like substances. All the lumps were powdered too.
- Then it was sieved only with #200 sieve (opening 0.075mm). Then the sieve was shaken manually with hands and the soil that passed the #200 sieve and retained on the pan was weighed.
- The sample that was retained over the #200 sieve was subjected to "Wash Sieving", whereby clay lumps can be broken.
- The grain size from field survey is given in table 4.3

Table 4.4: Data for determining the grain size.

Source: *Field Survey, September, 2014*

Site	Sand (%)	Silt & clay (%)
Lalpahar	34.1	65.9
Tankir Pahar	18.2	81.8
Golpahar	58.4	41.6
Goachibagan	64.5	35.5

The following table summarizes the index properties of the soil samples from four hill top sites.

Table 4.5: Index proportion of soil sample collected from hill top sites.

Source: *Field Survey, September, 2014*

Site	Specific Gravity	Liquid Limit	Plastic Limit	Plasticity Index	Sand (%)	Silt & clay (%)
Lalpahar	2.69	42	23	19	34.1	65.9
Tankir Pahar	2.71	37	23	14	18.2	81.8
Golpahar	2.69	Non plastic			58.4	41.6
Goachibagan	2.71	Non plastic			64.5	35.5

Some parameters of soil are assumed during this study.

CHAPTER 5: LAND COVER MODELLING

5.1 BACKGROUND

Land use and land cover changes have been recognized as one of the most important factors stirring rainfall-triggered landslides [13].Numerous researchers as a response to land use/ land cover changes have identified landslide incidence. Thomas Glade (2002) has showed how landslide can take place because of the change in land use in the context of New Zealand [13]. Mugagga*et al.* (2011) has also depicted the impacts of land use changes and its implications for the occurrence of landslides in mountainous areas of Eastern Uganda [14]. Moreover, expansion of urban development, deforestation and increased agricultural practices into the hillslope areas are immensely threatened by landslide hazards [15, 1, 16].

Land cover changes (e.g. deforestation) cause large variations in the hydro-morphological functioning of hill slopes, affecting rainfall partitioning, infiltration characteristics and runoff production. All these factors trigger landslides in hilly areas [17, 18]. Therefore it can be stated that there is a strong and positive correlation between land-use change and landslides. At this drawback, this report tries to project the future land cover change of Chittagong Metropolitan Area (CMA).

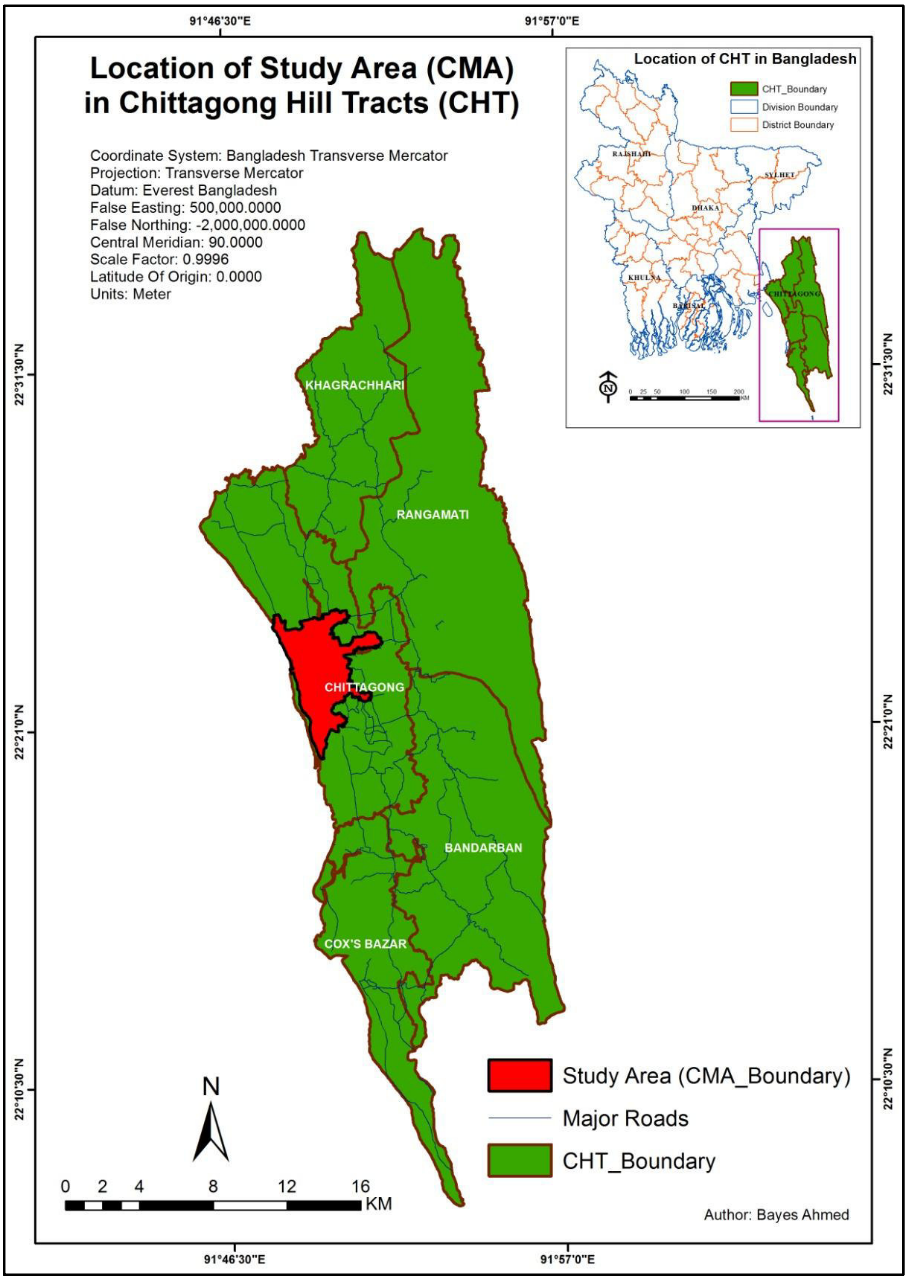
5.2 STUDY AREA

The selected study area is a part of Chittagong Hill Tracts (CHT) of Bangladesh (Figure 5.1). It is important to know about the characteristics of CHT, to understand the causes and geological reasons of landslides in CMA. Therefore, the extent of the study area for land cover modelling is chosen as CHT. The total area of CHT is 19887.70895 square kilometres (sq. km.) [Reference system: UTM-46N].

5.3 LAND COVER MAPPING

Landsat Thematic Mapper (TM) satellite images are used for the land cover mapping of CHT area. Initially four scenes were collected to cover the whole CHT area. TM sensor collects reflected energy in three visible bands (blue = 1, green = 2, and red = 3) and three infrared bands (two NIR = 4, 5 and one middle infrared = 7). The base years for land cover mapping are selected as 1990, 2000 and 2010.

Figure 5.1: Location of Chittagong Metropolitan Area in Chittagong Hill Tracts.



Among the four scenes, three were acquired using the Global Visualization Viewer (GLOVIS) of United States Geological Survey (USGS) and the one was from GISTDA (Geo-Informatics and Space Technology Development Agency), Thailand. However, thermal band was not used in this particular study. The details of the scenes used are listed in Table 5.1. All the image dates are of the dry season in Bangladesh.

The land cover classification methodology for this research is based on 'Object Based Image Analysis (OBIA)'. 'OBIA' is also called 'Geographic Object-Based Image Analysis (GEOBIA)'. 'OBIA' is a sub-discipline of geo-information science devoted to partitioning remote sensing imagery into meaningful image objects, and assessing their characteristics through spatial, spectral and temporal scale. The fundamental step of any object based image analysis is a segmentation of a scene representing an image into image objects [18, 19].

Table 5.1: Details of the Landsat 4-5 TM scenes of CHT.

Satellite	Sensor	Path	Row	Date (DD/MM/YY)	Source Agency
Landsat 4-5	TM	136	044	08/02/2010	USGS
		136	045	06/12/2009	
		135	045	01/02/2010	GISTDA
		135	046	01/02/2010	

The projection detail of all the raster images (cell size 30m × 30m)/ vector-shapefiles used in this report is as follows:

Projection: Bangladesh Transverse Mercator (BTM)
False Easting: 500000.000000
False Northing: -2000000.000000
Central Meridian: 90.000000
Scale Factor: 0.999600
Latitude of Origin: 0.000000
Linear Unit: Meter (1.000000)

Geographic Coordinate System: GCS_Everest_Bangladesh
Angular Unit: Degree (0.017453292519943299)
Prime Meridian: Greenwich (0.000000000000000000)
Datum: D_Everest_Bangladesh

Spheroid: Everest_Adjustment_1937
Semi-major Axis: 6377276.344999999700000000
Semi-minor Axis: 6356075.413140240100000000
Inverse Flattening: 300.801699999999980000

At first, the acquired Landsat TM images were inserted in 'eCognition Developer 64 8.7' software for processing. The ''multi-resolution segmentation'' algorithm was used which consecutively merges pixels or existing image objects that essentially identifies single image objects of one pixel in size and merges them with their neighbours, based on relative homogeneity criteria. Multi-resolution segmentations are groups of similar pixel values, which merge the homogeneous areas into larger objects and heterogeneous areas in smaller ones [19, 20].

During the classification process information on spectral values of image layers, vegetation indices like the Normalized Difference Vegetation Index (NDVI) and land water mask; which were created through band rationing, slope and texture information were used. Image indices are very important during the image classification. Image rationing is a "synthetic image layer" created from the existing bands of a multispectral image. This new layer often provides unique and valuable information not found in any other individual bands. Image index is a calculated result or generated product from satellite band/channels. It is help to identify different land cover from mathematical definition [19, 20].

NDVI is a standardized index that allows generating an image displaying greenness (relative biomass). NDVI was calculated using the formula: NDVI = (NIR - red) / (NIR + red). This index output values between −1.0 and 1.0, mostly representing greenness, where any negative values are mainly generated from clouds, water, and snow, and values near zero are mainly generated from rock and bare soil. Very low values of NDVI (0.1 and below) correspond to barren areas of rock or sand. Moderate values (0.2 to 0.3) represent shrub and grassland, while high values (0.6 to 0.8) indicate temperate and tropical rainforests [20].

Land and water mask: Land and water mask indices values can range from 0 to 255, but water values typically range between 0 and 50. The land and water mask was created using the formula: Land and water mask: IR/(Green×100) [19].

The next step is to code these image objects according to their attributes, such as NDVI, land and water mask, layer value, colour and relative position to other objects using user-defined rules. In this process, selected object that represent patterns were recognized with the help from other sources known as 'ground-truth' information and high-resolution Google earth images. Normally similar features observe similar spectral responses and are unique with respect to all other image objects [20].

After that comparison, features using the '2D Feature Space Plot' were used for correlation of two features from the selected image objects. Developing rule sets investigated single image objects and generated land cover map. Image objects have spectral, shape, and hierarchical characteristics and these features are used as sources of information to define the inclusion-or-exclusion parameters used to classify image objects. Over each scene, rules were generated for each land cover class and evaluated for their separation, tested for their visual assessment over Google earth images [20].

After ascertaining the class separation using segment-based approach, classification is performed to get land cover classification map for each scene. Each scene thus prepared was evaluated again with available field data and Google earth image over randomly selected points for accuracy assessment. After finalization of classification of each scene, all the scenes were gone through mosaic to obtain land cover map of CDA area (Figures 5.2-5.5). For this research purpose, 5 broad land-cover classes (urban area, semi-urban area, water body, vegetation and bare soil) were chosen by reclassification technique. Here the land coverage is as follows:

Builtup Area = Urban and rural area, settlements and transportation infrastructure
Vegetation = Shrub land, rubber plantation, rained herbaceous crops, mangrove plantation, irrigated herbaceous crops, and crop in sloping land/tea
Water Body = River, reservoir/ponds, lake, canal, Bay of Bengal and low land
Hilly Forest = Hilly areas, forest in hills and highly dense rain forest
Bare Soil = Sand, sea beach, fallow land, earth and sand land in-fillings, open space, bare and exposed soils etc.

The overall accuracies of the lands cover images (1990, 2000 and 2010) were found approx. 89%, 92% and 88.6% respectively.

Figure 5.2: Land Cover Map of CDA (1990).

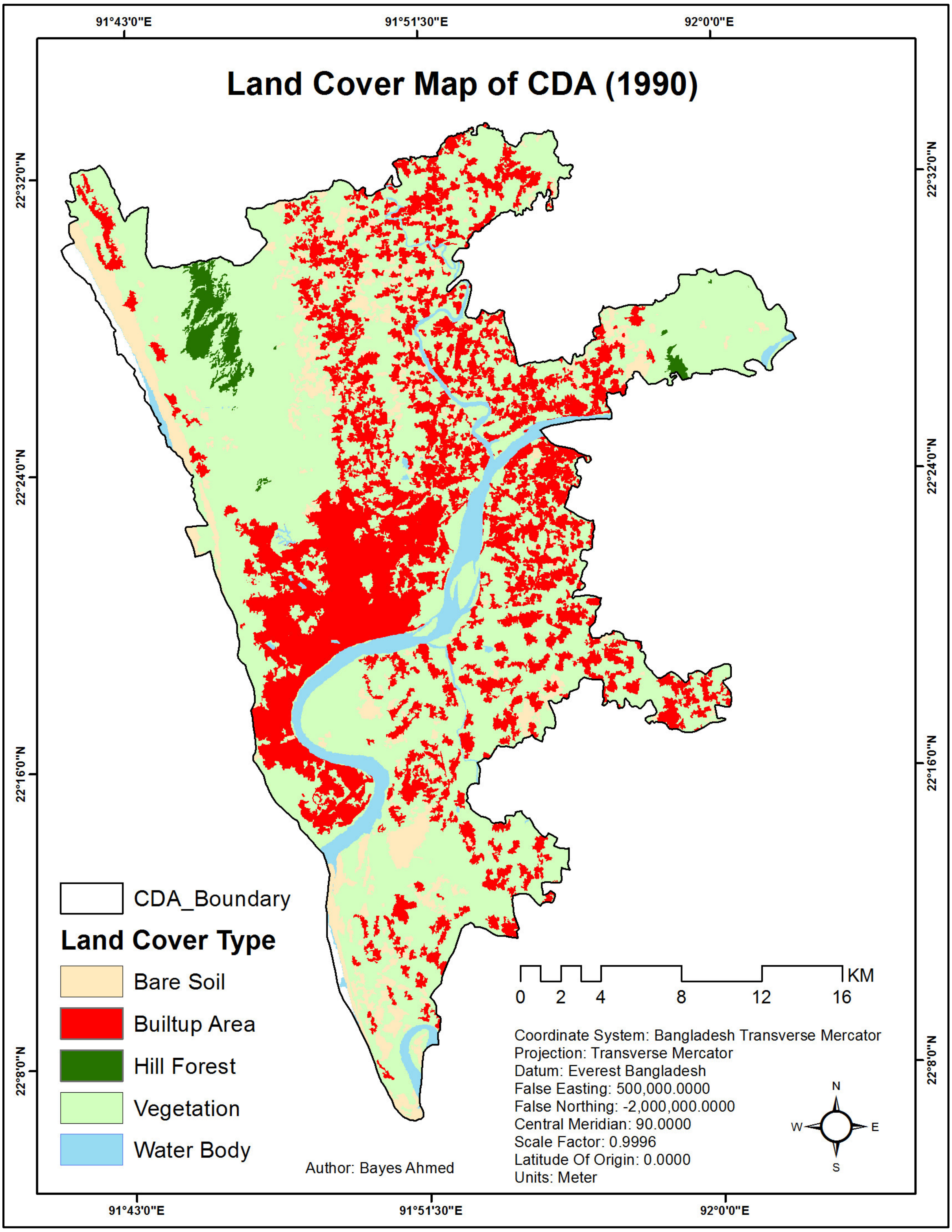


Figure 5.3: Land Cover Map of CDA (2000).

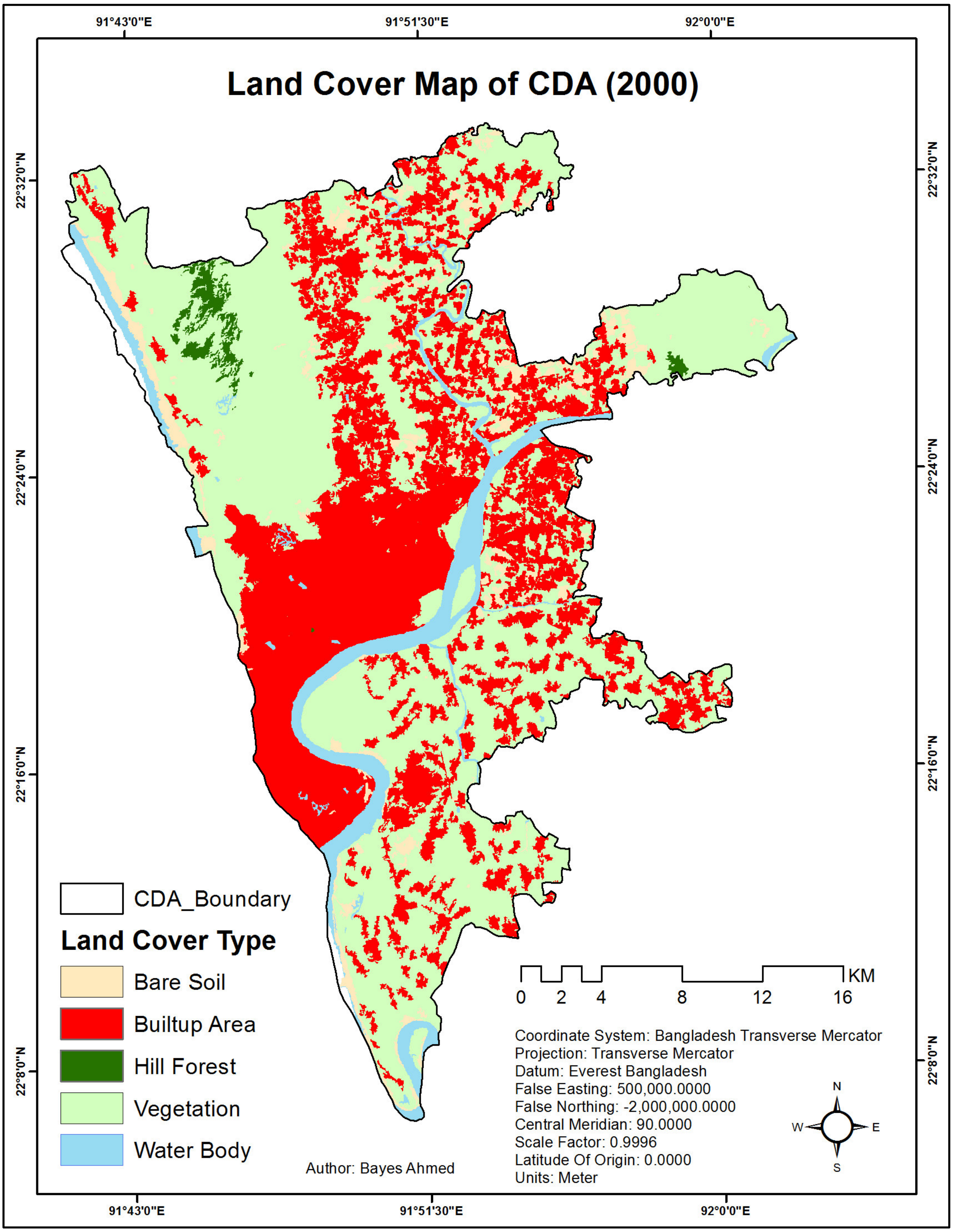
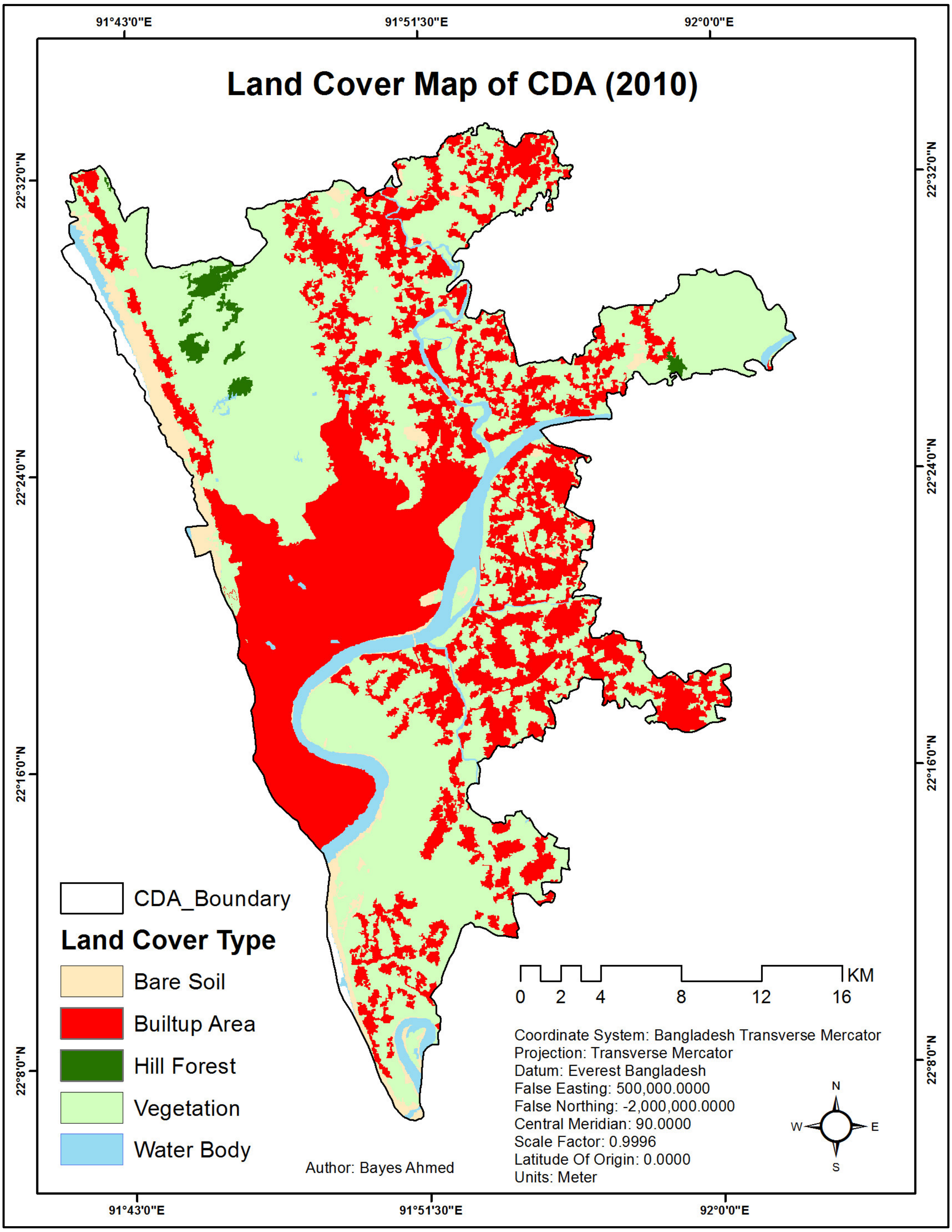


Figure 5.4: Land Cover Map of CDA (2010).



5.4 CHANGE DETECTION

In remote sensing, “Change Detection” is defined as the process of determining and monitoring the changes in the land cover types in different time periods. It provides the quantitative analysis of the spatial distribution in the area of interest [21]. The percentage of change in area is depicted in Table 5.2.

Table 5.2: Percentages of Presence of Land Cover Types in CHT (1990-2010).

Land Cover	1990	2000	2010
	% of Area		
Hill Forest	58	55	54
Vegetation	32	35	35
Builtup Area	3	3	4
Water Body	4	5	3
Bare Soil	3	2	3

Here the change detection is performed between 1990 and 2010. Figure 5.5 is showing the major transitions (by ignoring transitions less than 0.5 sq. km.) among different land cover types. The figures showing the changes (gains, losses and persistence) for each land cover type are attached in Appendix-E.1. Some major changes are as follows:

i. 1128.2664218 sq. km. areas converted from Hill Forest to Vegetation.
ii. 421.1719313 sq. km. areas converted from Vegetation to Builtup Area.
iii. 281.4113228 sq.km areas were converted from Vegetation to Bare Soil.
iv. 108.1640835 sq.km were converted from Water Body to Bare Soil.

The following changes are also notable:

i. Gains in vegetation (approx. 700 sq. km.) and builtup area (approx. 380 sq.km.) were highest (Figures 5.6 and 5.7).
ii. Hill forest is decreasing alarmingly (780 sq. km) and the major contributor to it is the vegetation land cover type (Appendix-E.2).
iii. Bare soil (100 sq. km) and water bodies (80 sq. km) were converted to vegetation type (Appendix-E.2).
iv. Vegetation (320 sq. km) and bare soil (35 sq. km) were the major contributors to convert into built-up area (Appendix-E.2).

v. Approximately 115 sq. km and 80 sq. km water body type were converted to vegetation and bare soil respectively (Appendix-E.2).

vi. Bare soil was converted to vegetation (140 sq. km) and builtup area (30 sq. km).

Figure 5.5: Transitions among Different Land Cover Types (1990-2010).

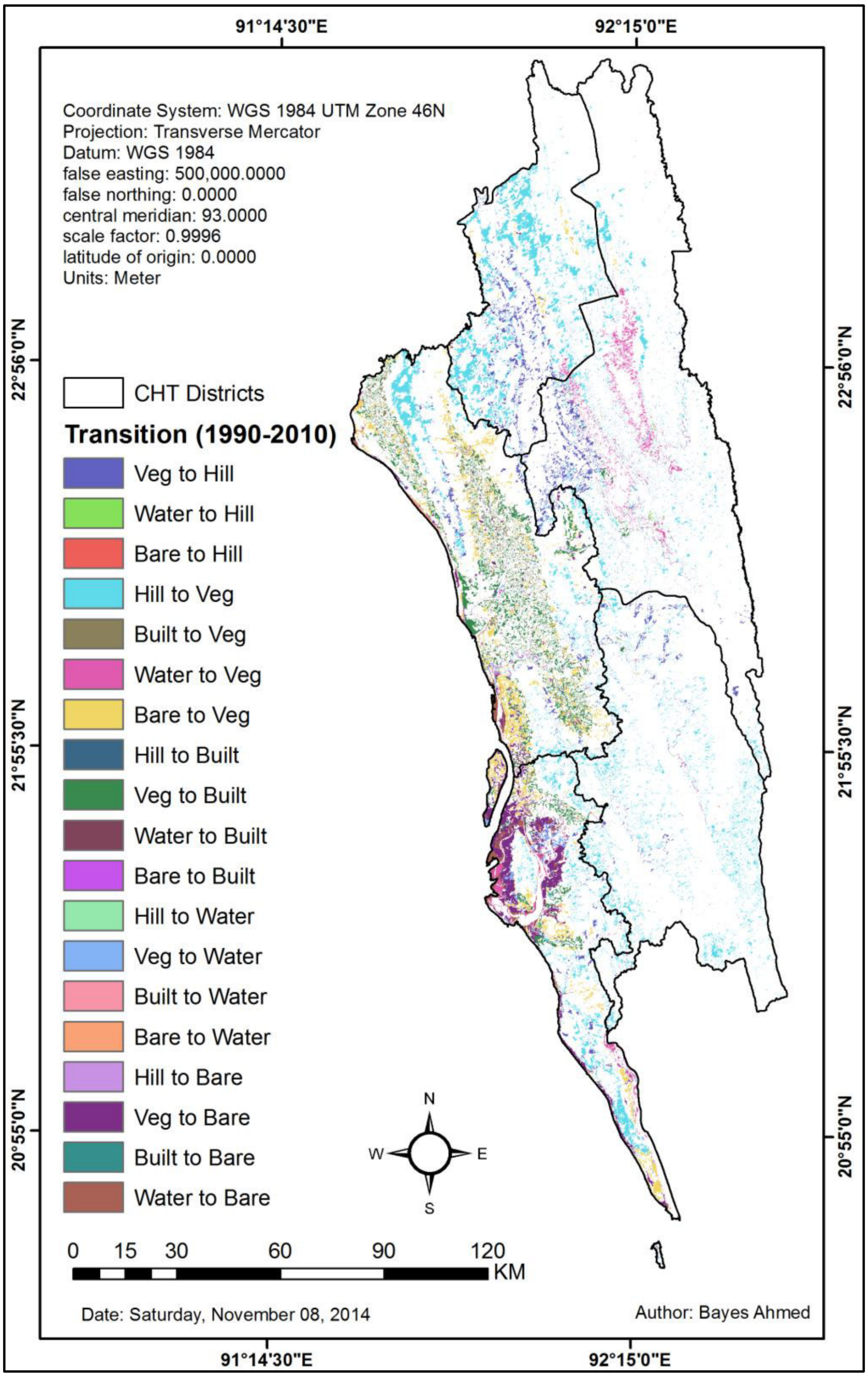


Figure 5.6: Gains and Losses in land cover between 1990-2010.

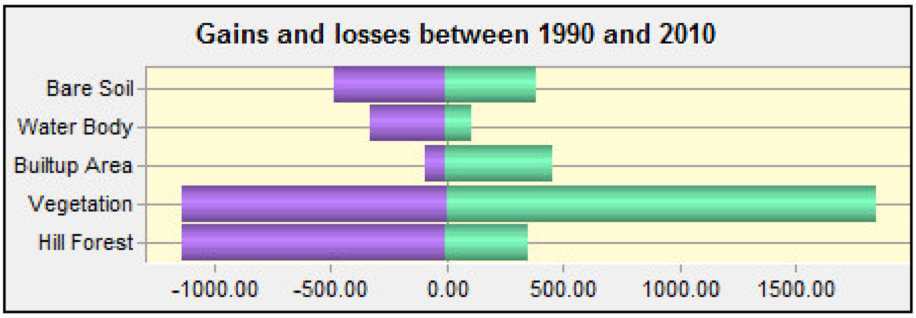
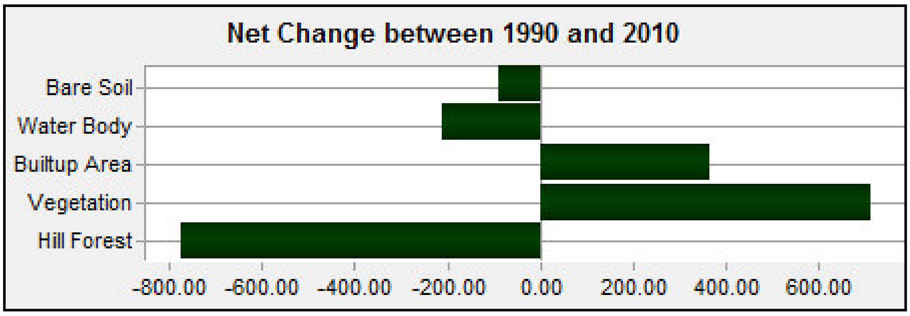


Figure 5.7: Net Change in land cover between 1990-2010.



5.5 LAND COVER MODELLING USING MULTI LAYER PERCEPTRON MARKOV MODEL

Multi Layer Perceptron (MLP) Markov Model is used to project the land cover map of CHT for 2030. This model combines both the Markov Chain and Artificial Neural Network (ANN) techniques [22, 23].

5.5.1 Markov Chain

A Markov chain is a stochastic process (based on probabilities) with discrete state space and discrete or continuous parameter space [24]. In this random process, the state of a system *s* at time *(t+1)*depends only on the state of the system at time *t*, not on the previous states.

5.5.1.1 Markov Property

In a Markov chain the probability of the next state is only dependent upon the current state. This is called Markov property and stated as [25]:

$$P\left(\xi_{t+1} = X_{i_{t+1}} \middle| \xi_1 = X_{i_1}, \ldots\ldots, \xi_t = X_{i_t}\right) = P\left(\xi_{t+1} = X_{i_{t+1}} \middle| \xi_t = X_{i_t}\right)$$

The probability of a Markov chain ξ_1, ξ_2,........can be calculated as [14]:

$$P(\xi_1 = X_{i_1}, \ldots, \xi_t = X_{i_t}) = P(\xi_1 = X_{i_1}) * P(\xi_2 = X_{i_2} | \xi_1 = X_{i_1}) * P(\xi_t = X_{i_t} | \xi_{t-1} = X_{i_{t-1}})$$

The conditional probabilities:

$$P(\xi_{t+1} = X_{i_{t+1}} | \xi_t = X_{i_t})$$

These are called the "Transition Probabilities" of the Markov chain [25].

5.5.1.2 Transition Matrix for a Markov Chain

Let's consider a Markov chain with n states s_1, s_2,.......,s_n. Let p_{ij} denote the transition probability from state s_i to state s_j, *i.e.*,

$$P(\xi_{t+1} = s_j | \xi_t = s_j)$$

The transition matrix (n×n) of this Markov process is then defined as [25]:

$$P = \begin{bmatrix} p_{11} & \ldots\ldots & p_{1n} \\ \ldots\ldots & \ldots\ldots & \ldots\ldots \\ p_{n1} & \ldots\ldots & p_{nn} \end{bmatrix}, \; p_{ij} \geq 0, \sum_{j=1}^{n} p_{ij} = 1, i = 1, \ldots\ldots, n$$

Predictions of the future state probabilities can be calculated by solving the matrix equation [19]:

$$p(t) = p(t-1).\, P$$

With increasing time steps, a Markov chain may approach to a constant state probability vector, which is called limiting distribution [19]:

$$p(\infty) = \lim_{t\to\infty} p(t) = \lim_{t\to\infty} p(0).\, P^t$$

5.5.2 Multi Layer Perceptron Markov Model

The term 'Artificial Neural Network (ANN)' has been inspired by human biological nervous system [26]. In a typical ANN model, simple nodes are connected together to form a network of nodes. Some of these nodes are called input nodes; some are output nodes and in between there are hidden nodes [27]. Multi Layer Perceptron (MLP) is a feed-forward Neural Network with one or more layers between input and output layers. The great advantage of using MLP perceptron neural network is that it gives the opportunity to model several or even all the transitions at once [23].

5.5.2.1 The Feed-Forward Concept of Multi Layer Perceptron Neural Network

MLP neural network uses the back propagation (BP) algorithm. The calculation is based on information from training sites [23]. Back propagation involves two major steps, forward and backward propagation. The input that a single node receives is weighted as:

$net_j = \sum \omega_{ji} O_i$

where, w_{ij}= the weights between node i and node j; O_i = the output from the node i

The output from a given node j is computed as [16]:

$O_i = f\ (net_j)$

f = a non-linear sigmoid function that is applied to the weighted sum of inputs before the signal passes to the next layer

This is known as "Forward Propagation". Once it is finished, the activities of the output nodes are compared with their expected activities. In normal circumstances, the network output differs from the desired output (a set of training data, e.g., known classes). The difference is termed as the error in the network [27]. The error is then back-propagated through the network. Now the weights of the connections are corrected as follows [23]:

$\Delta\omega_{ji}(n+1) = \eta(\delta_j O_i) + \alpha\Delta\omega_{ji}(n)$

η = the learning rate parameter; δ_j= an index of the rate of change of the error; α = the momentum parameter.

The process of the forward and backward propagation is repeated iteratively, until the errors of the network minimized or reaches an acceptable magnitude [27]. The purpose of training the network is to get proper weights both for the connection between the input and hidden layer, and between the hidden and the output layer for the classification of unknown pixels [23]. Several factors affect the capabilities of the neural network to generalize [27]. These include:

5.5.2.2 Number of Nodes

In general, the larger the number of nodes in the hidden layer, the better the neural network represents the training data [27]. The number of hidden layer nodes is estimated by the following equation [23]:

$N_h = INT\ (\sqrt{N_i * N_o})$

where, N_h = the number of hidden nodes; N_i = the number of input nodes; N_o = the number of output nodes.

5.5.2.3 Number of Training Samples and Iterations

The number of training sample also affects the training accuracy. Too few samples may not represent the pattern of each category while too many samples may cause overlap. Again too many iterations can cause over training that may cause poor generalization of the network

[23]. Over training can be prevented by early stopping of training [26]. The acceptable error rate is evaluated based on the Root Mean Square (RMS) Error [26]:

$$RMS = \sum(e_i)^2/_N = \sum(t_i - a_i)^2/_N$$

where, N = the number of elements; i = the index for elements; e_i= the error of the i^{th} element; t_i = the target value (measured) for i^{th} element; a_i = the calculated value for the i^{th} element.

5.5.2.4 Multi Layer Perceptron Markov Modeling

The basic concept of modeling with MLP neural network adopted in this research is the following two criteria (Appendix-E.3):

i. Changes from all land cover type to builtup area
ii. Changes from hill forest to all other land cover types

These two criteria have been selected based on the trends of change detection over the years and also giving priority on the issues related to landslide vulnerability. Therefore, the following 9 transitions were selected for the MLP_Markov modeling:

i. Hill Forest to Vegetation
ii. Hill Forest to Builtup Area
iii. Hill Forest to Water Body
iv. Hill Forest to Bare Soil
v. Vegetation to Builtup Area
vi. Vegetation to Bare Soil
vii. Water Body to Builtup Area
viii. Water Body to Bare Soil
ix. Bare Soil to Builtup Area

Next,three driver variables along with the Digital Elevation Model (DEM) are selected for MLP_Markov modeling (Appendix-E.4). The driving variables are (1990–2010): Distance from all land cover type to builtup area, Distance from Hill Forest to all other land cover types, and the Empirical likelihood image.

The empirical likelihood transformation is an effective means of incorporating categorical variables into the analysis (Appendix-E.4). It was produced by determining the relative frequency of different land cover types occurred within areas of transition (2000 to 2010). The numbers indicate the likelihood of changing into builtup area. The higher the value, the likeliness of the pixel to change into the builtup cover type is more [22].

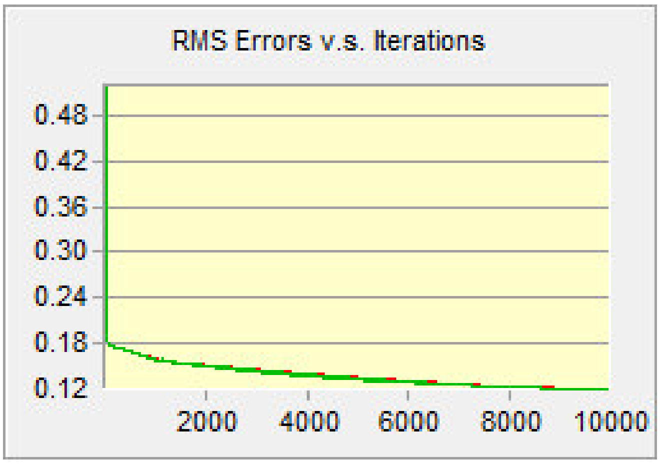
Now it is important to test the potential explanatory power of each variable. The quantitative measures of the variables have been tested through Cramer's V [28]. It is suggested that the variables that have a Cramer's V of about 0.15 or higher are useful while those with values of 0.4 or higher are good [23].In most of the cases, the Cramer's V were found statistically significant (Table 5.3).

Table 5.3: Cramer's V for the Driving Variable for Land Cover Modelling.

Land Cover Class	Cramer's V		
	Distance (All to Built)	Distance (Hill to All)	Empirical Likelihood Image
Overall V	0.3736	0.2268	0.3936
Hill Forest	0.5706	0.3466	0.7250
Builtup Area	0.5057	0.2365	0.6975
Vegetation	0.3658	0.2133	0.2345
Water Body	0.2033	0.1390	0.0808
Bare Soil	0.1993	0.0590	0.0752

After getting satisfactory Cramer's V values for all the driving variables, now the turn is to run MLP neural network model. For this purpose, 10,000 iterations were chosen. The minimum number of cells that transitioned from 1990 to 2010 is 1589. Therefore, the maximum sample size has been chosen as 1,589 (50% training/ 50% testing). For each principal transition particular weights has to be obtained. The RMS error curve has been found smooth and descent after running MLP neural network (Figure 5.8). After all these combinations, the MLP running statistics gives a very high accuracy rate of 89.60%.

Figure 5.8: RMS Error Curve for MLP_Markov Modelling.



Based on these running statistics the transition potential mapsare produced (Appendix-E.5). These maps depict, for each location, the potential it has for each of the modelled transitions [23]. These are not the probability maps where the sum of values for a particular pixel location will not be 1. The reason behind this is because the MLP neural network outputs are obtained by applying fuzzy set to the signals into values from 0 to 1 with activation function (sigmoid). Here the higher values represent a higher degree of membership for that corresponding land cover type [23].

5.5.2.5 Future Prediction Using Multi Layer Perceptron Markov Model

Using this kind of MLP neural network analysis, it is possible to determine the weights of the transitions that will be included in the matrix of probabilities of Markov Chain for future prediction [22]. The transition probabilities are shown in Table 5.4. Based on all these information from MLP neural network, the final land cover map of 2030 (Figure 5.9) is simulated through Markov chain analysis. The projected areas of the land cover types in 2030 will be as follows (Figure 5.9):

Hill Forest = Approx. 9753 sq. km

Vegetation = Approx. 7300 sq. km

Builtup Area = Approx. 1362 sq. km

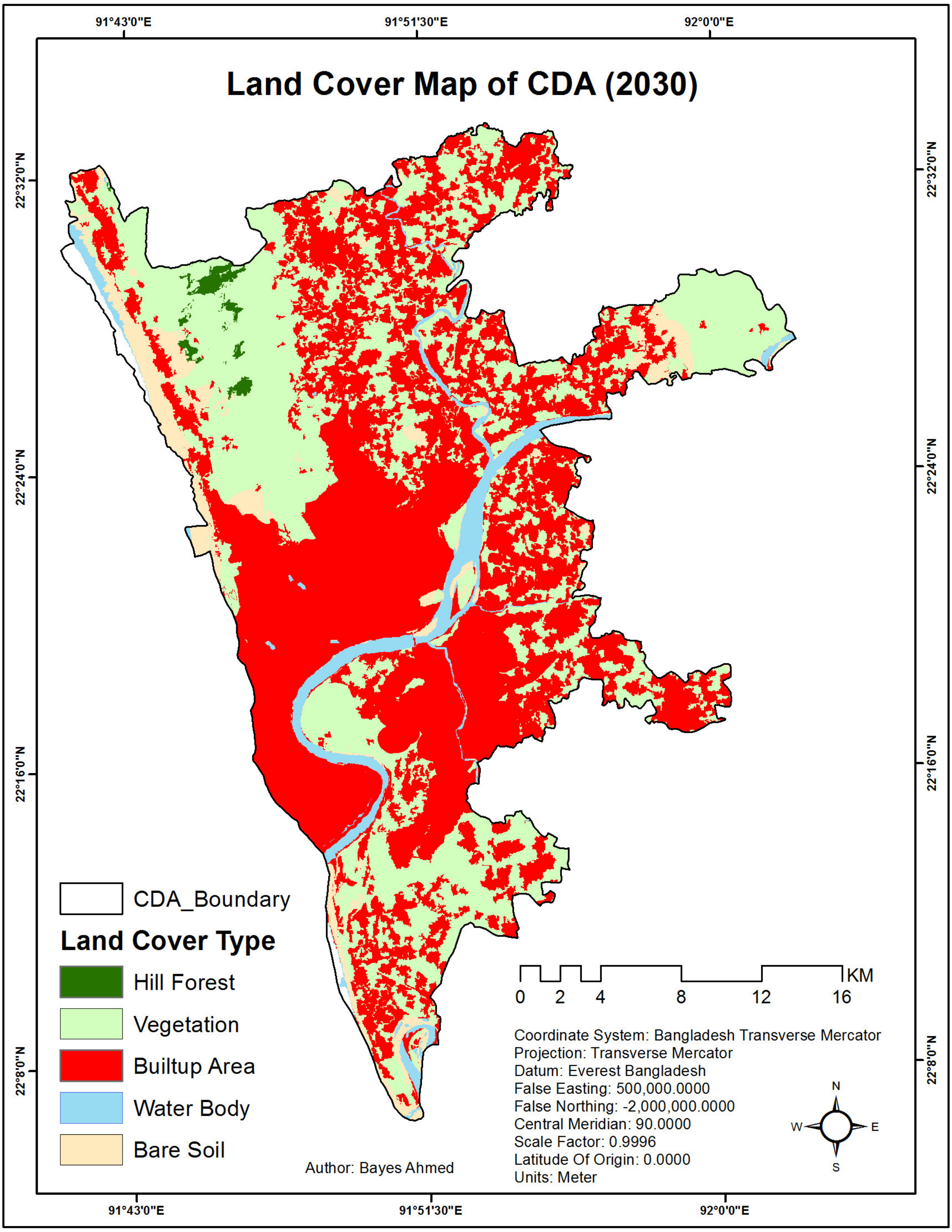
Water Body = Approx. 572 sq. km

Bare Soil = Approx. 893 sq. km

Table 5.4: Transition Probabilities Grid for Markov Chain for MLP_Markov Modelling.

Landcover Categories	Hill Forest	Vegetation	Builtup Area	Water Body	Bare Soil
Hill Forest	0.9020	0.0974	0.0001	0.0002	0.0002
Vegetation	0.0552	0.8204	0.0667	0.0133	0.0445
Builtup Area	0.0001	0.1892	0.8070	0.0020	0.0018
Water Body	0.0140	0.2345	0.0031	0.6233	0.1251
Bare Soil	0.0027	0.6816	0.0554	0.0447	0.2155

Figure 5.9: MLP_Markov Projected Land Cover Map of CDA (2030).



CHAPTER 6: RAINFALL PATTERN MODELING

6.1 BACKGROUND

The objective of rainfall modeling is to predict the future rainfall pattern of Chittagong Metropolitan Area. To perform this modeling, rainfall data (1950-2010) on daily basis is collected from the 'Bangladesh Meteorological Department (BMD)'. BMD collects daily basis precipitation data (unit: Millimetre) from 34 stations for all over Bangladesh. But there are only two stations that collect the precipitation data for Chittagong City. Moreover, approximately 2% data were found missing. The missing data were then adjusted based on the rainfall trend of the previous years.

6.2 METHODOLOGY

At first, the rainfall pattern based on the previous years is analysed using "RClimDex". The RClimDex is developed and maintained by Xuebin Zhang and Feng Yang at the Climate Research Branch of Meteorological Service of Canada. ClimDex is a Microsoft Excel based program that provides an easy-to-use software package for the calculation of indices of climate extremes for monitoring and detecting climate change. It runs on "R", which is free, robust and powerful software for statistical analysis and graphics [29]. In the later section, based on the past trend, the future rainfall pattern is predicted using 'IDRISI Selva' and 'ArcGIS 10.2' software.

6.2.1 Indices Used

The following indices are used to analyse the precipitation pattern [1]:

ID	Indicator Name	Definitions	UNITS
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
Rx5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as PRCP>=1.0mm) in the year	Mm/day

ID	Indicator Name	Definitions	UNITS
R10	Number of heavy precipitation days	Annual count of days when PRCP>=10mm	Days
R20	Number of very heavy precipitation days	Annual count of days when PRCP>=20mm	Days
Rnn	Number of days above nn mm	Annual count of days when PRCP>=nn mm, nn is user defined threshold	Days
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	Days
R95p	Very wet days	Annual total PRCP when RR>95th percentile	mm
R99p	Extremely wet days	Annual total PRCP when RR>99th percentile	mm
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1mm)	mm

The definitions of the climatic indices are as follows [29]:

1. RX1day

Let RR_{ij} be the daily precipitation amount on day i in period j. Then maximum 1-day values for period j are:

$$Rx1day_j = \max(RR_{ij})$$

2. Rx5day

Let RR_{kj} be the precipitation amount for the 5-day interval ending k, period j. Then maximum 5-day values for period j are:

$$Rx5day_j = \max(RR_{kj})$$

3. SDII

Let RR_{wj} be the daily precipitation amount on wet days, $w(RR \geq 1mm)$ in period j. If W represents number of wet days in j, then:

$$SDII_j = \frac{\sum_{w=1}^{W} RR_{wj}}{W}$$

4. R10

Let RR_{ij} be the daily precipitation amount on day i in period j. Count the number of days where:

$$RR_{ij} \geq 10mm$$

5. R20

Let RR_{ij} be the daily precipitation amount on day i in period j. Count the number of days where:

$RR_{ij} \geq 20mm$

6. Rnn

Let RR_{ij} be the daily precipitation amount on day i in period j. If nn represents any reasonable daily precipitation value then, count the number of days where:

$RR_{ij} \geq nnmm$

7. CDD

Let RR_{ij} be the daily precipitation amount on day i in period j. Count the largest number of consecutive days where:

$RR_{ij} < 1mm$

8. CWD

Let RR_{ij} be the daily precipitation amount on day i in period j. Count the largest number of consecutive days where:

$RR_{ij} \geq 1mm$

9. R95pTOT

Let RR_{wj} be the daily precipitation amount on a wet day $w(RR \geq 1.0mm)$ in period j and let $RR_{wn}95$ be the 95th percentile of precipitation on wet days in the 1950-2010period. If W represents the number of wet days in the period, then:

$$R95p_j = \sum_{w=1}^{W} RR_{wj} \text{ where } RR_{wj} > RR_{wn}95$$

10. R99p

Let RR_{wj} be the daily precipitation amount on a wet day $w(RR \geq 1.0mm)$ in period j and let $RR_{wn}99$ be the 99th percentile of precipitation on wet days in the 1950-2010 period. If W represents number of wet days in the period, then:

$$R99p_j = \sum_{w=1}^{W} RR_{wj} \text{ where } RR_{wj} > RR_{wn}99$$

11. PRCPTOT

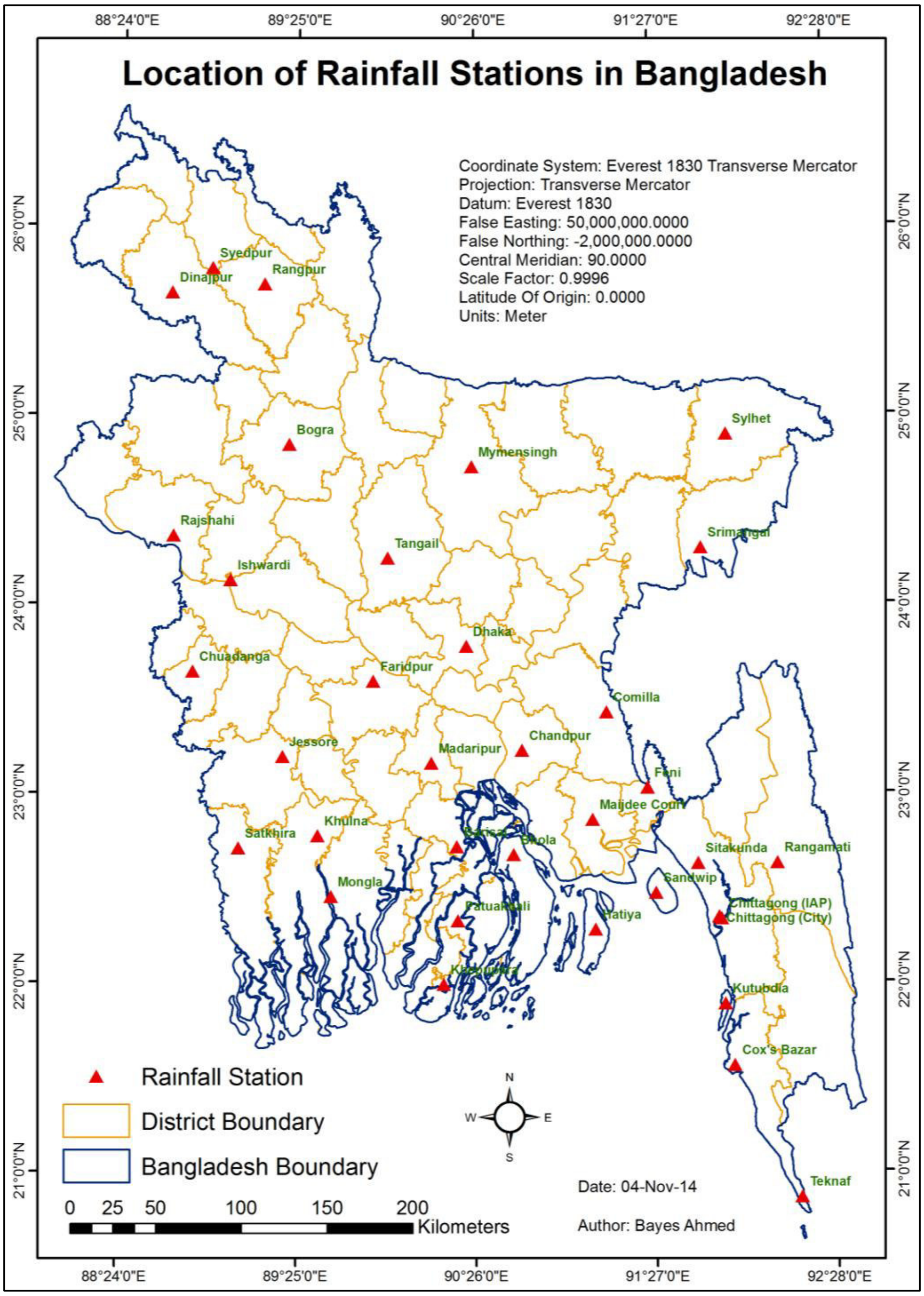
Let RR_{ij} be the daily precipitation amount on day i in period j. If I represents the number of days in j, then

$$PRCPTOT_j = \sum_{i=1}^{I} RR_{ij}$$

6.2.2 Identifying the Rainfall Pattern in Bangladesh

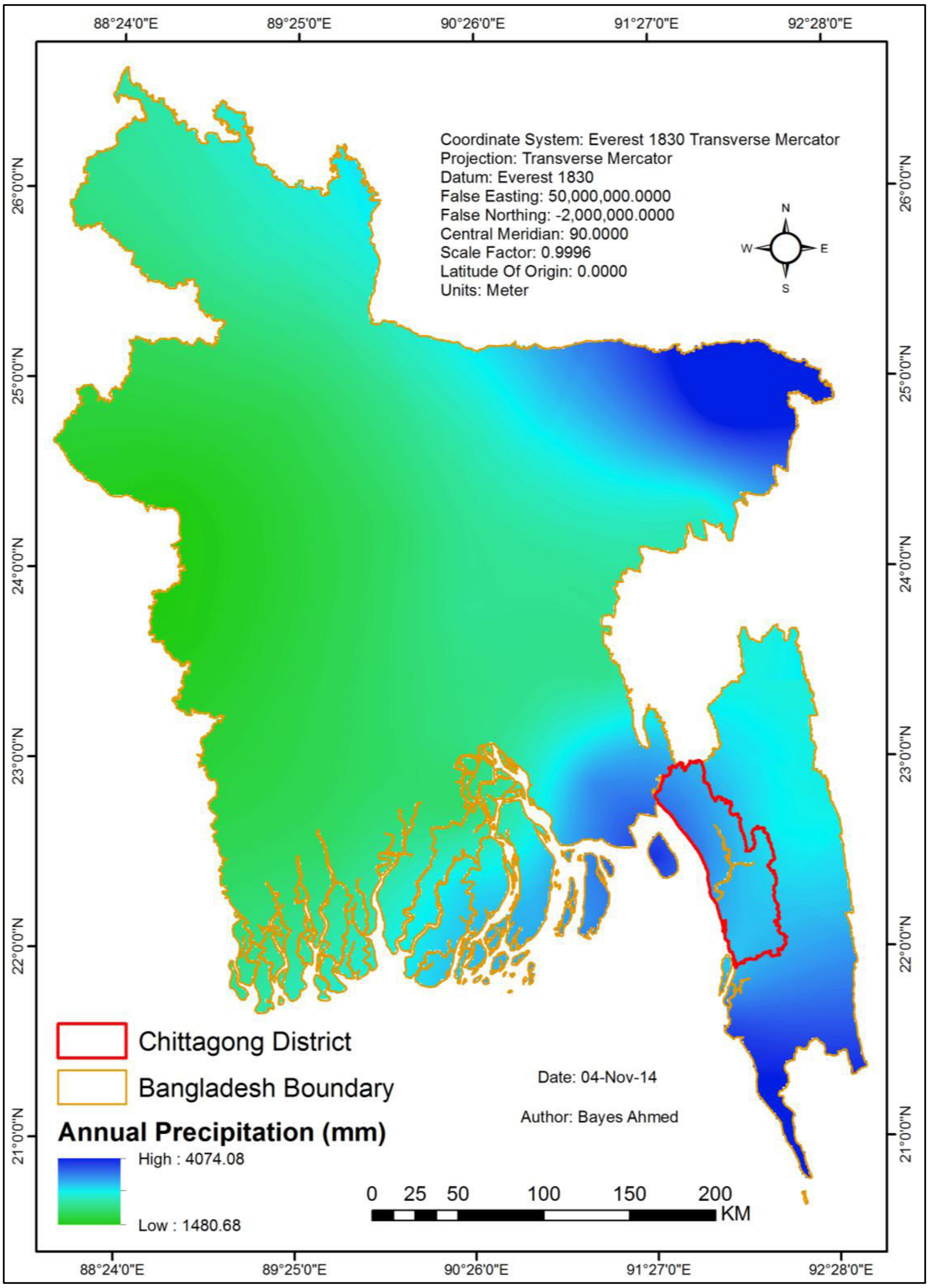
The daily rainfall data from 1950-2010 is collected from the Bangladesh Meteorological Department (BMD). There are in total 34 rainfall measuring stations in Bangladesh, as defined by BMD (Figure 6.1).All the maps are projected in 'Bangladesh Transverse Mercator (BTM)' projection system and the datum is used as 'Everest 1830'. The month and yearly precipitation (mm) graphsare attached in Appendix-E.6.

Figure 6.1: Locations of the Rainfall Gauges in Bangladesh.



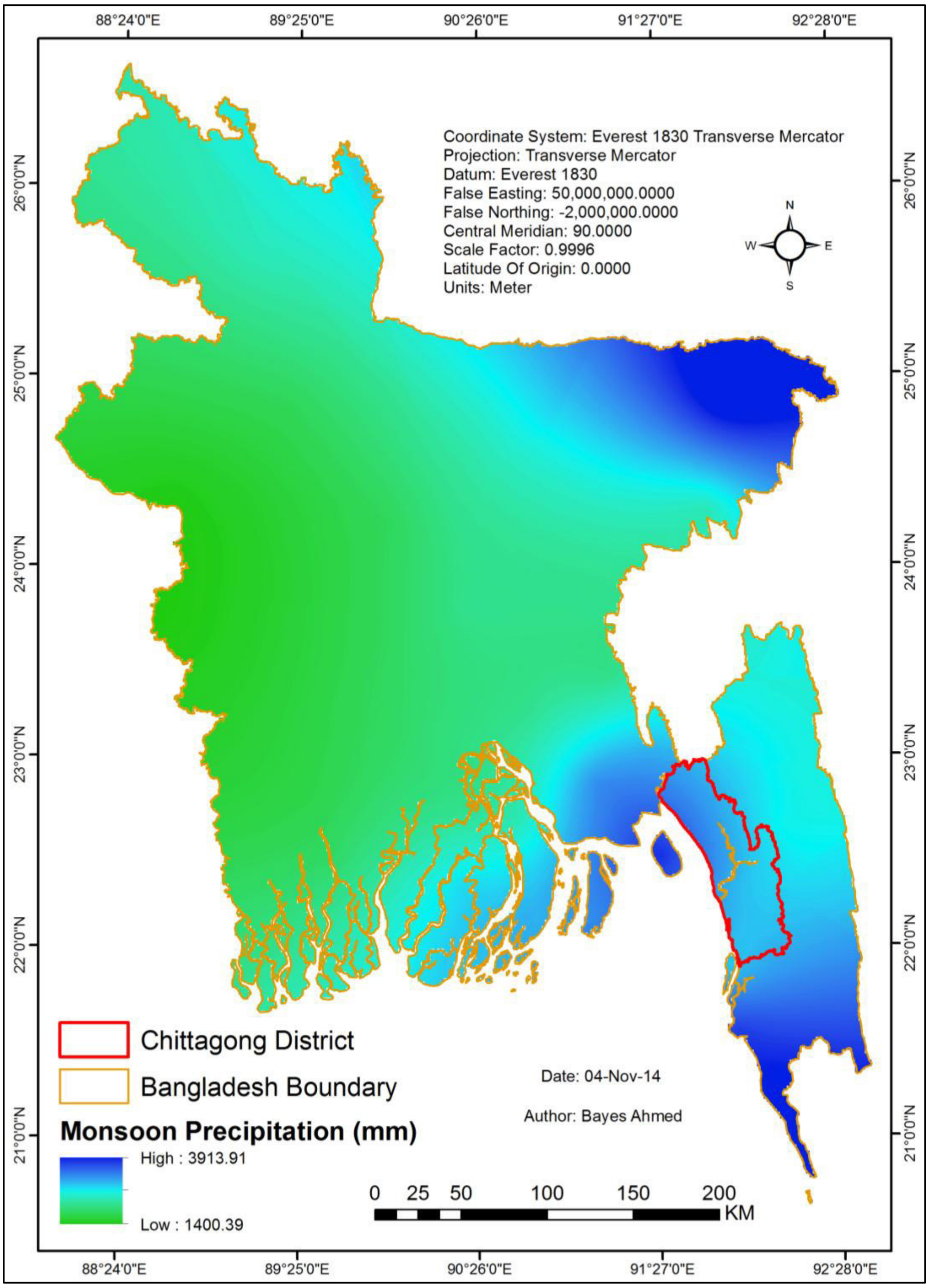
Later, based on the collected database, 'Krigging' interpolation method was implemented in 'ArcGIS 10.2' to generate the rainfall pattern map of Bangladesh. It is found that 'Chittagong District' is located within the 'very high' to 'moderately high' rainfall zone in Bangladesh (Figure 6.2).

Figure 6.2: Annual Rainfall Pattern Map of Bangladesh.



The scenario is found same for the Monsoon season.The north-east and south-east parts of Bangladesh face maximum rainfall during the monsoon (Figure 6.3). Here, the Monsoon season comprises of the months from April-October. It is also found that June and July are months when the intensity of rainfall is the highest (Appendix-E.7).The rainfall pattern maps of Bangladesh during the rainy season are attached in Appendix-E.7.

Figure 6.3: Monsoon Rainfall Pattern Map of Bangladesh.



6.2.3 Trend Analysis

'RClimdex (version 1.0)' is used to analyse the trends of the precipitation indices for Chittagong. All the generated plots and the indices are attached in Appendix-E.8-E.11. Moreover, the result of the numerical trend analysis is depicted in Table 1.'Rnn' is calculated using 50mm, 75mm and 100mm of rainfall values (Appendix-E.8, Appendix-E.9 and Table 6.1). But here the rainfall threshold limit is taken as 50mm [30].

Table 6.1: Trends of the Rainfall Indices (1950-2010).

Indices	Starting Year	End Year	Slope	Slope Error	P_Value
Rx1day	1950	2010	0.335	0.564	0.554
Rx5day	1950	2010	-0.030	1.189	0.980
SDII	1950	2010	0.001	0.032	0.969
R10mm	**1950**	**2010**	**0.053**	**0.062**	**0.394**
R20mm	**1950**	**2010**	**0.054**	**0.051**	**0.296**
R50mm	1950	2010	-0.005	0.033	0.883
CDD	1950	2010	0.045	0.187	0.809
CWD	1950	2010	-0.025	0.034	0.465
R95p	1950	2010	-2.552	3.486	0.467
R99p	1950	2010	-1.770	2.543	0.489
PrcpTot	1950	2010	0.763	4.071	0.852

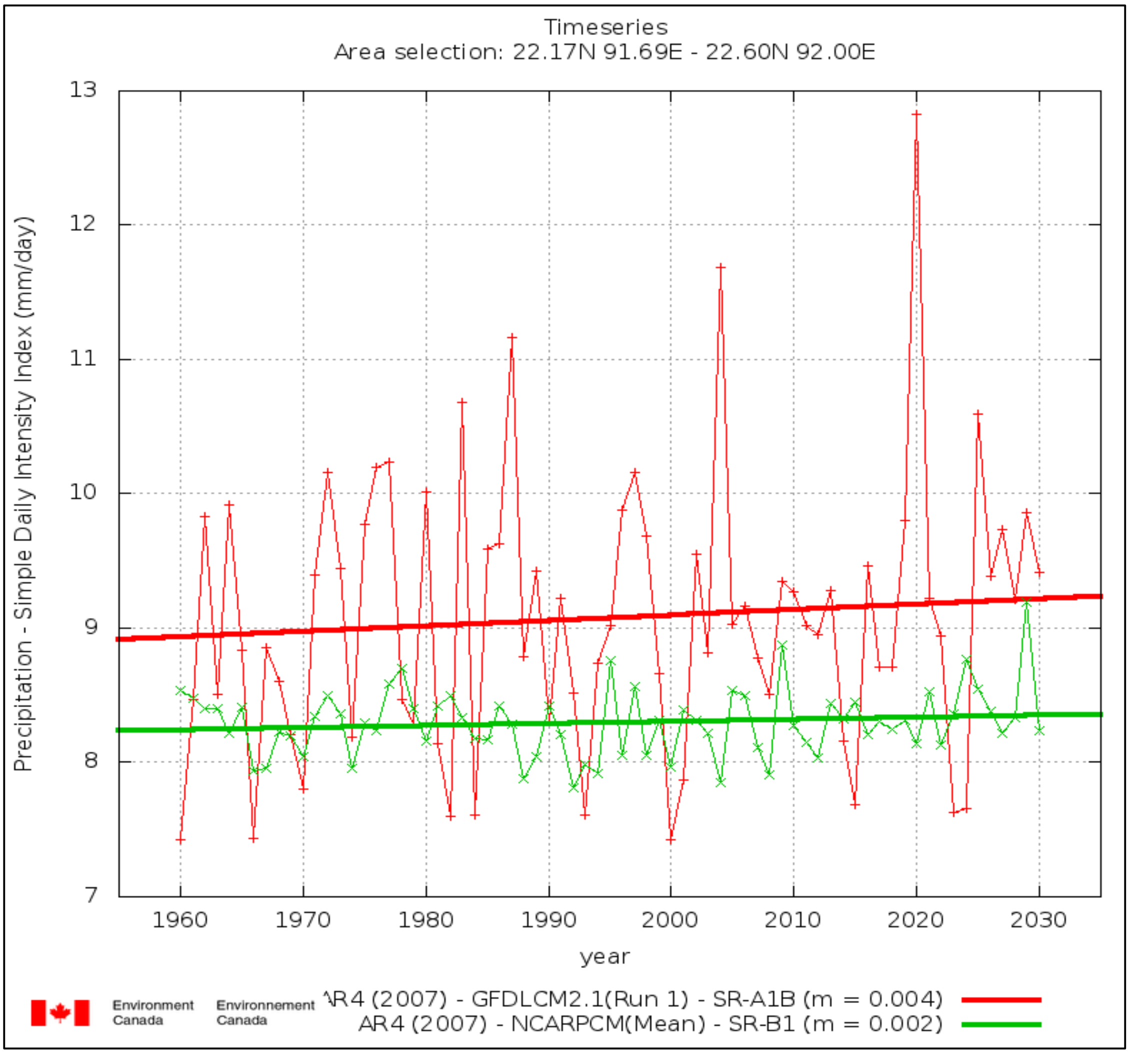
6.2.4 Generating Climate Scenarios

Climate change is defined as a difference over a period of time (with respect to a baseline or a reference period) and corresponds to a statistical significant trend of mean climate or its variability, persistent over a long period of time (e.g. decades or more). Climate change may be due to both natural (i.e. internal or external processes of the climate system) as well as anthropogenic forcing (ex. increase in concentrations of greenhouse gases) [31]. A climate change scenario is not a prediction of future climate. It is a plausible future climate that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change [31, 32]. Here:

CLIMATE SCENARIO = CURRENT CLIMATE + CLIMATE CHANGE SCENARIO [33].

In this section, the climate scenarios focusing on the rainfall pattern are generated from the Canadian Climate Data and Scenarios (CCDS). The CCDS is an interface for distributing climate data and climate change scenarios. Climate change scenarios are provided from numerous international research centres, in support of the Intergovernmental Panel for Climate Change (IPCC) assessments. Results from the fourth (AR4) assessments are used in this report [31].For selecting the scenarios, the guidelines from the CCDS are followed [31]. The ‘simple daily intensity index (mm/day)’, ‘total (mm/day)’, ‘days > 10 mm/d (day)’, and ‘5 day maximum (mm) precipitation’ variables are selected for analysing the rainfall trend in Chittagong Metropolitan Area (CMA). For each index, two different scenarios are generated (Figure 6.4-6.7). The projections (till 2030) of the precipitationtrends are performed based on the past database (from 1960).

Figure 6.4: Trend-line showing the Daily Precipitation Intensity Index (mm/day) of CMA from 1960-2030.



6.3 RESULTS AND DISCUSSIONS

The following results are achieved from the rainfall analysis (1950-2010):

i. The north-east and south-east hilly districts of Bangladesh counter heavy rainfall during the monsoon (Figure 6.2).

ii. **Chittagong City is located in high rainfall zone** (Figure 6.2).

iii. The trend of monthly maximum 1-day precipitation is increasing (Approx. 33%). It means the wet months are increasing in CMA.

iv. The number of monthly maximum consecutive 5-day precipitation is decreasing (Approx. 3%).

v. The simple daily intensity index (Precipitation>=1) is almost unchanged over the years.

vi. The number of heavy and very heavy precipitation days has increased (Approx. 5% for both R10 and R20).

vii. The number of days above 50mm precipitation (the threshold limit as defined in this project) is not changed in time.

viii. The number of consecutive dry days (rainfall<1mm) is increased by approx. 4.5%.

ix. The number of consecutive wet days (rainfall>=1mm) is decreased by approx. 2.5%.

x. The results obtained from RClimdex and CCDS are found the same.

Figure 6.5: Trend-line showing Total Precipitation (mm/day) of CMA (1960-2030).

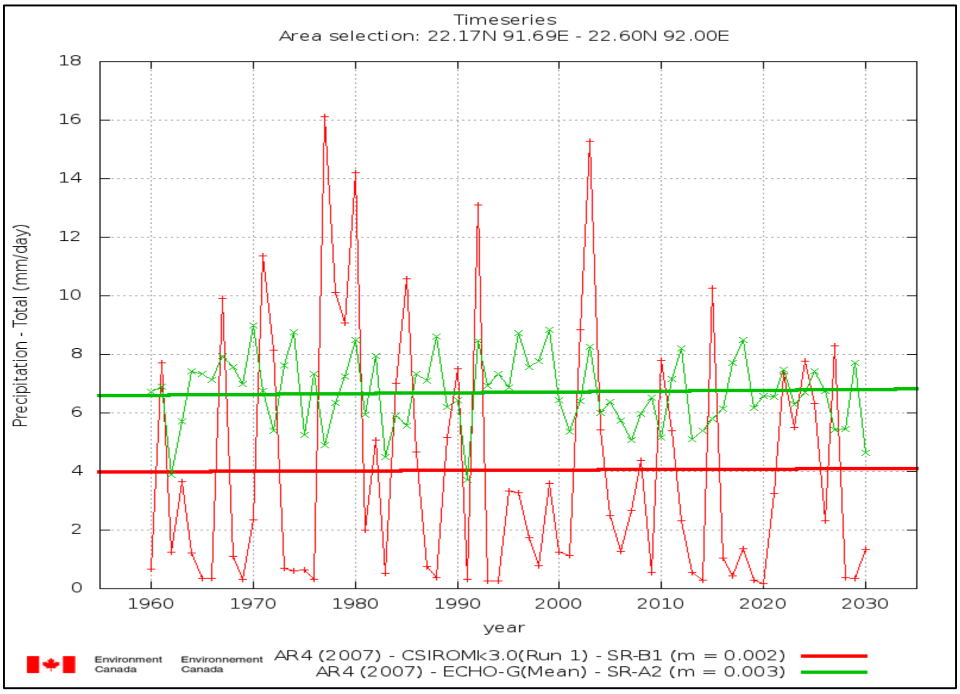


Figure 6.6: Trend-line showing Precipitation Greater 10mm/day from 1960-2030.

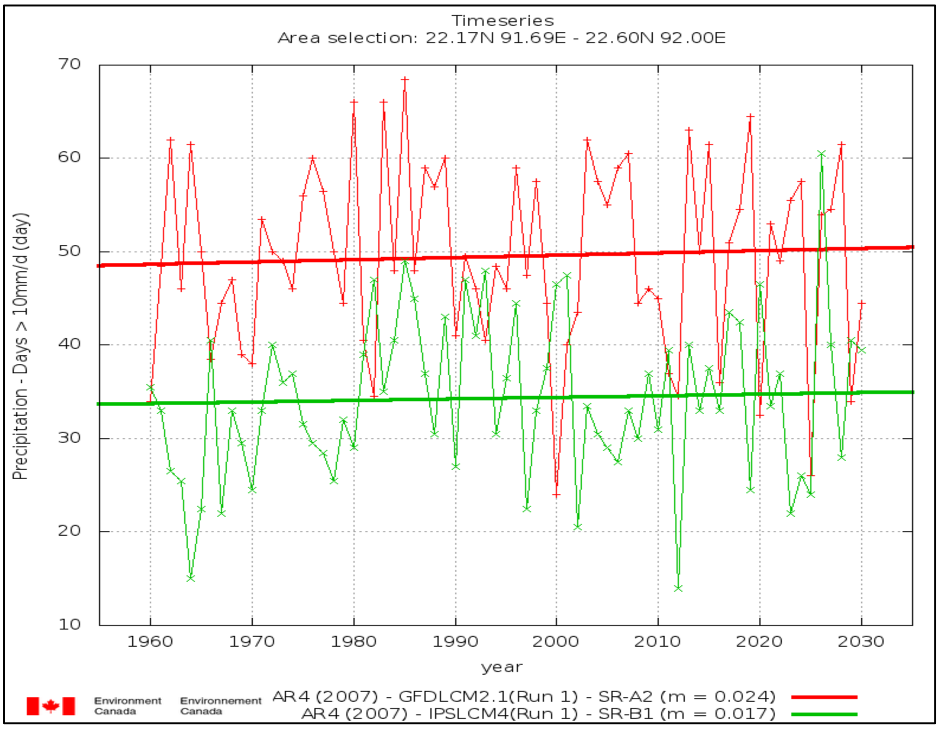
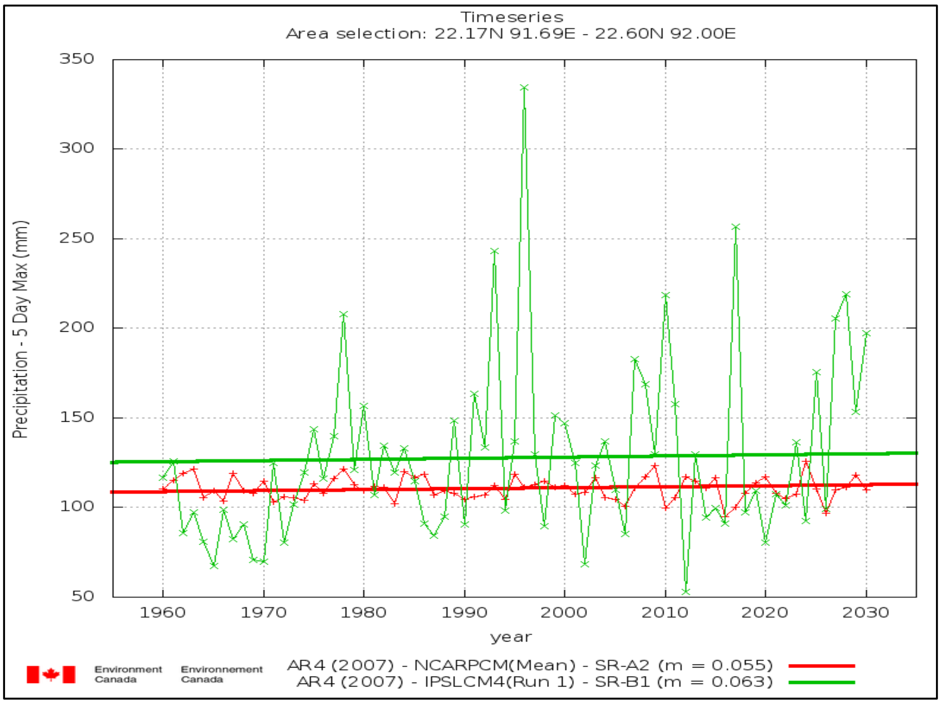


Figure 6.7: Trend-line showing the Precipitation of 5-Day Maximum (mm) of CMA from 1960-2030.



The projected future trends, as per the scenarios developed by IPCC and CCDS, are showing a slightly increasing trend for CMA (till 2030). This trend ranges from +0.1% - +0.4% (Figure 6.4-6.7).

CHAPTER 7
LANDSLIDE SUSCEPTIBILITY MAPPING

7.1 EXISTING LITERARY WORKS

Landslides are one of the most significant natural damaging disasters in hilly environments [34]. Social and economic losses due to landslides can be reduced by the means of effective planning and management [35]. Landslide hazard assessment is generally based on the concept that "the present and the past are keys to the future". This is why; most landslide hazard analyses take into account an up-to-date landslide inventory that represents the fundamental tool for identifying the hillslope instability factors in triggering landslides [36]. However, in spite of improvements in hazard recognition, prediction, mitigation measures, and warning systems, worldwide landslide activity is increasing [37]. This trend is expected to continue for the following reasons in the landslide prone areas [38, 39]:

a) Increased urbanization and illegal hill-cutting
b) Continued deforestation and agricultural activities
c) Increased regional precipitation (heavy rainfall) due to climate change

Various geo-structural as well as causative-factor based approaches have been proposed for landslide susceptibility zoning [40]. But GIS modeling of landslide phenomena has taken precedence in recent time. Geospatial technologies like 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. The GPS is a space-based global navigation satellite system which provides the information of position and time anywhere in the world in all weather conditions [41]. Previous studies showed the application of GPS for mapping and indentifying landslide zones. GIS is used for collection, storage, and analysis of processes where geographic information is involved [41]. The use of GIS for landslide mapping is very common in various studies. Remote sensing is the science in which information is acquired about the surface of earth without physically being in contact with it. RS is also used for monitoring and mapping of landslides in various studies [41].

Mapping the areas that are susceptible to landslides is essential for proper landuse planning and disaster management for a particular locality or region. Throughout the years different techniques and methods have been developed and applied in the literature for landslide susceptibility mapping. Landslide susceptibility maps can be produced using both the quantitative or qualitative approach [42].

Qualitative maps weight each factors affecting the landslides based on the practical experience and expertise of the researcher [42]. Qualitative methods simply portray the hazard zoning in descriptive terms [43]. The qualitative approaches were used by the scientists until the late 1970's [44]. But because of the developments in computer programming and geospatial technologies, qualitative techniques have become very popular in recent decades. Moreover, it incorporates the causes of landslides (instability factors) and probabilistic methods which give much better results than the quantitative methods [44].

Methods to map landslide susceptibility can be classified into four groups, namely landslide inventory based probabilistic, deterministic, heuristic, and statistical techniques [43]. Landslide inventory based probabilistic techniques involve the inventory of landslides, construction of databases, geomorphological analysis, and producing the susceptibility maps based on the collected data [45]. Deterministic techniques (quantitative methods) involve the estimation of quantitative values of stability variables and require the creation of a map that displays the spatial distribution of input data [46, 47]. Heuristic analysis (qualitative method) is based on the intrinsic properties of the geomorphologists to analyse aerial photographs or to conduct field surveying [48].

In this kind of analysis, the susceptibility is established by researchers and the analyst uses expert knowledge to assign weights to a series of parameters for preparing the qualitative map [47]. Statistical analysis is used to analyse factors affecting landslides in areas with environmental conditions similar to those where past landslides have been reported [42]. These methods use sample data based on the relationship between the dependent variable (the presence or absence of landslides), and the independent variables (landslides triggering/causative factors). Through these statistical techniques, quantitative predictions are possible to make for areas where there is no landslides and with similar conditions [47].

Within these techniques, the probabilistic and statistical methods have been most commonly used in recent years. These methods have become more popular, assisted by the geographic information system (GIS) and remote sensing (RS) techniques [36].

The probabilistic (non-deterministic) models like frequency ratio, bivariate analysis, multivariate analysis, and Poisson probability model [49] are more frequently used to determine landslide susceptibility zones [50]. Among the most widely used statistical method is the logistic regression [47]. Many researchers have used different techniques such as heuristic approach [47] and deterministic models [37].

Moreover, GIS based multi criteria decision analysis (MCDA) provides powerful techniques for the analysis and prediction of landslide hazards. These include the analytic hierarchy process (AHP) [51], the weighted linear combination (WLC), the ordered weighted average (OWA) [51] etc.

Most recently, new non-parametric techniques like cellular automata, fuzzy-logic, artificial neural networks (ANN) [52], support vector machines (SVM), and neuro-fuzzy models have been used for landslide modeling [42].

In most cases the researchers have used the following thematic layers for modelling or predicting landslide susceptibility maps [37, 41, 42, 52]:

1) Landslide Inventory
2) Precipitation Data/ Rainfall Intensity Map
3) Land Cover Maps
4) Digital Elevation Model (DEM)
5) Aspect
6) Elevation/ Internal Relief
7) Slope
8) Curvature (Plan & Profile)
9) Geology
10) Geomorphology
11) Soil/ Lithology
12) Lineaments/ Distance from Faults
13) Drainage Density
14) Distance to Road
15) Distance to Stream
16) Topographic Wetness Index (TWI)
17) Normalized Difference Vegetation Index (NDVI)
18) Stream Power Index (SPI)
19) Seismic Data
20) Surrounding Infrastructure (e.g. Buildings)

If the above mentioned 20 thematic layers/ variables are analysed, then it is clear that the land cover maps and precipitation data (rainfall pattern) can be changed markedly over time.

Similarly drainage density, distance to road/ stream, TWI, NDVI, SPI and surrounding infrastructure can change in course of time. Therefore, these variables can be considered as 'dynamic variables'. The rest of the layers can be termed as 'persistent variables'.

7.2 DATA COLLECTION

For landslide susceptibility mapping (LSM), it is very important to collect necessary data layers. For this research purpose, 9 different GIS layers have been produced for LSM. The details of the data collection technique and ways of preparing the thematic layers are described below:

7.2.1 Land Cover Mapping

Landsat Thematic Mapper (TM) satellite images were used for the land cover mapping (2010) of CHT area. This CHT base map was collected from International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal. But the procedure for preparing the map is described in brief. Initially four scenes were collected to cover the whole CHT area. TM sensor collects reflected energy in three visible bands (blue = 1, green = 2, and red = 3) and three infrared bands (two NIR = 4, 5 and one middle infrared = 7). The base year for this land cover mapping is selected as 2010.

Among the four scenes, three were acquired using the Global Visualization Viewer (GLOVIS) of United States Geological Survey (USGS) and the one was from GISTDA (Geo-Informatics and Space Technology Development Agency), Thailand. However, thermal band was not used in this particular study. The details of the scenes used are listed in Table 7.1. All the image-dates are of the dry season in Bangladesh.

The land cover classification methodology for this research is based on 'Object Based Image Analysis (OBIA)'. 'OBIA' is also called 'Geographic Object-Based Image Analysis (GEOBIA)'. 'OBIA' is a sub-discipline of geoinformation science devoted to partitioning remote sensing imagery into meaningful image objects, and assessing their characteristics through spatial, spectral and temporal scale. The fundamental step of any object based image analysis is a segmentation of a scene representing an image into image objects.

Table 7.1: Details of the Landsat 4-5 TM scenes of CHT.

Satellite	Sensor	Path	Row	Date (DD/MM/YY)	Source Agency
Landsat 4-5	TM	136	044	08/02/2010	USGS
		136	045	06/12/2009	
		135	045	01/02/2010	GISTDA
		135	046	01/02/2010	

The projection detail of all the raster images (cell size 30m × 30m)/ vector-shapefiles used in this research is as follows:

Projection: Bangladesh_Transverse_Mercator (BTM)
False_Easting: 500000.000000
False_Northing: -2000000.000000
Central_Meridian: 90.000000
Scale_Factor: 0.999600
Latitude_Of_Origin: 0.000000
Linear Unit: Meter (1.000000)

Geographic Coordinate System: GCS_Everest_Bangladesh
Angular Unit: Degree (0.017453292519943299)
Prime Meridian: Greenwich (0.000000000000000000)
Datum: D_Everest_Bangladesh
Spheroid: Everest_Adjustment_1937
Semimajor Axis: 6377276.344999999700000000
Semiminor Axis: 6356075.413140240100000000
Inverse Flattening: 300.801699999999980000

At first, the acquired Landsat TM images were inserted in 'eCognition Developer 64 8.7' software for processing. The ''multi-resolution segmentation'' algorithm was used which consecutively merges pixels or existing image objects that essentially identifies single image objects of one pixel in size and merges them with their neighbours, based on relative homogeneity criteria. Multi-resolution segmentations are those groups of similar pixel values which merges the homogeneous areas into larger objects and heterogeneous areas in smaller ones.

During the classification process, information on spectral values of image layers, vegetation indices like the Normalized Difference Vegetation Index (NDVI) and land water mask which were created through band rationing, slope and texture information were used. Image indices are very important during the image classification. Image rationing is a "synthetic image layer" created from the existing bands of a multispectral image. This new layer often provides unique and valuable information not found in any of the other individual bands. Image index is a calculated results or generated product from satellite band/channels. It is help to identify different land cover from mathematical definition.

NDVI: One of the commonly used indices and it is related to vegetation is that healthy vegetation reflects very well in the near infrared part of the spectrum. NDVI index values can range from -1.0 to 1.0. NDVI was calculated using the following formula:

NDVI = (NIR - red) / (NIR + red)

Land and water mask: Land and water mask indices values can range from 0 to 255, but water values typically range between 0 and 50. The land and water mask was created using the formula

Land and water mask: IR/Green*100

The next step is to code these image objects according to their attributes, such as NDVI, Land and water mask, layer value and colour and relative position to other objects using user-defined rules. In this process, selected object that represent patterns were recognize with the help from other sources namely already known Ground truthing information and high resolution Google earth images. Normally similar features observed similar spectral responses and unique with respect to all other image objects.

After that comparison, features using the '2D Feature Space Plot' were used for correlation of two features from the selected image objects. Developing rule sets investigated single image objects and generated land cover map. Image objects have spectral, shape, and hierarchical characteristics and these features are used as sources of information to define the inclusion-or-exclusion parameters used to classify image objects. Over each scene rules were generated for each land cover class and evaluated for their separation, tested for their visual assessment over Google earth images.

After ascertaining the class separation using segment based approach, classification is performed to get land cover classification map for each scene. Each scene thus prepared again evaluated with available field data and Google earth image over randomly selected points for accuracy assessment. After finalization of classification of each scene, all the scenes were gone through mosaic to obtain land cover map of CHT area (Figure 7.1).

Figure 7.1 consists of 14 land cover classes. But for this research purpose, only 5 broad land cover classes (urban area, semi-urban area, water body, vegetation and bare soil) were chosen by reclassification technique. Later the study area was extracted from the CHT land cover map using the CMA boundary. This is the final land cover map of the study area (Figure 7.2).

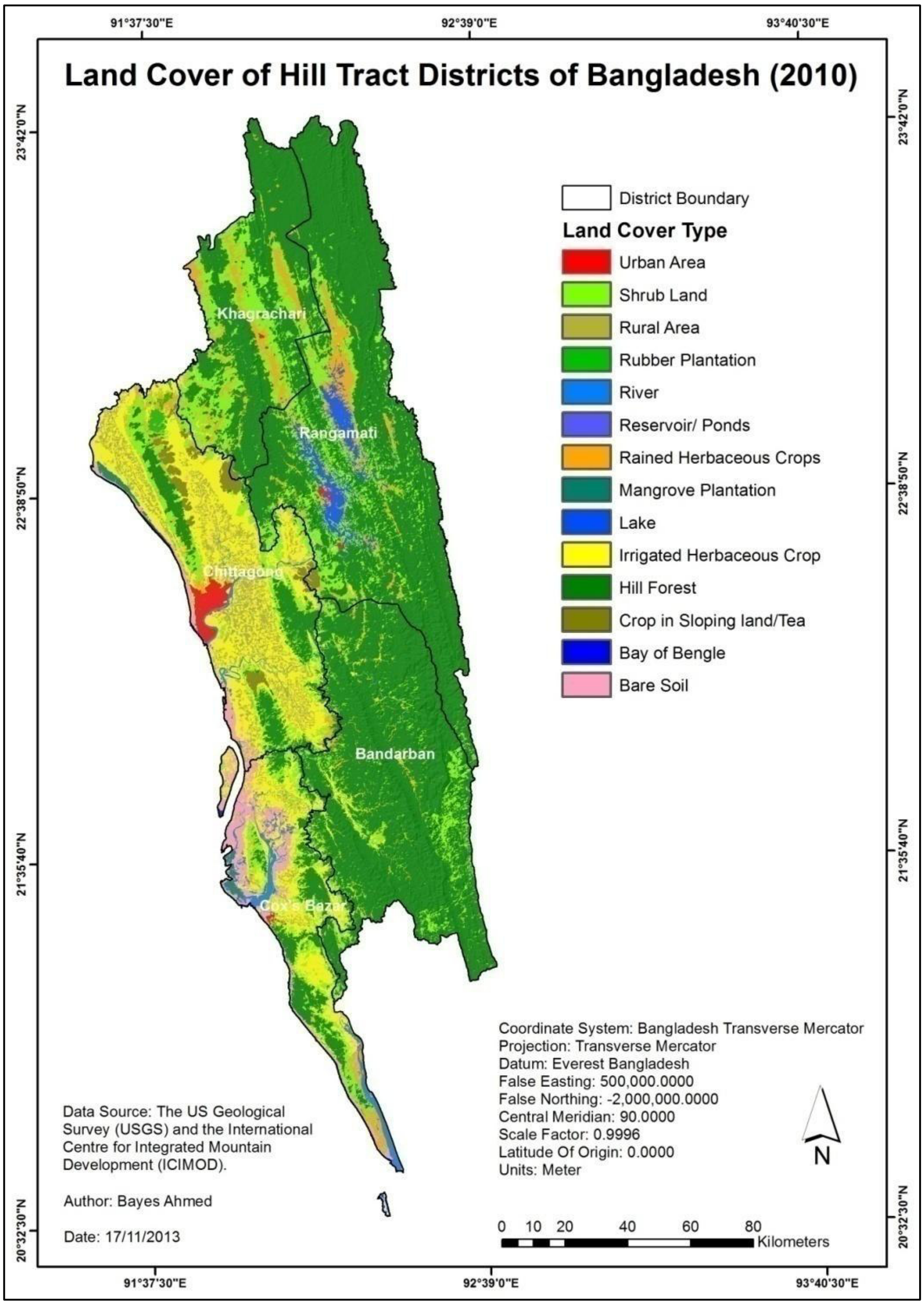
7.2.2. Precipitation Map

The daily observed precipitation data were collected from Bangladesh Meteorological Department (1950-2010). Based on the average annual precipitation, the final precipitation map of CMA was prepared using Kriging overlaying technique (Figure 7.3).

7.2.3. Landslide Inventory Map

A total of 20 landslide locations were identified in the study area through field visit. The latitude and longitude values were collected using a Global Positioning System (GPS) device. Moreover, the Digital Elevation Model (DEM) data were collected from the ASTER GDEM portal. The Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) was developed jointly by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). The ASTER GDEM was contributed by METI and NASA to the Global Earth Observation System of Systems (GEOSS) and is available at no charge to users via electronic download from the Earth Remote Sensing Data Analysis Center (ERSDAC) of Japan and NASA’s Land Processes Distributed Active Archive Center (LP DAAC) [56].

Figure 7.1: Land cover map of Chittagong Hill Tract (CHT) area.



The tiles of ASTGTM2_N20E092, ASTGTM2_N22E092, ASTGTM2_N21E092, ASTGTM2_N21E091, ASTGTM2_N22E091, ASTGTM2_N23E091 and ASTGTM2_N23E092 (acquired on 29 November 2013); cover the whole CHT area. The characteristics of the ASTER GDEM are listed in Table 7.2 [56]. Later the DEM map of CMA was extracted from CHT DEM. Finally the observed landslide locations of CMA were represented in Figure 7.4.

Figure 7.2: Land cover map.

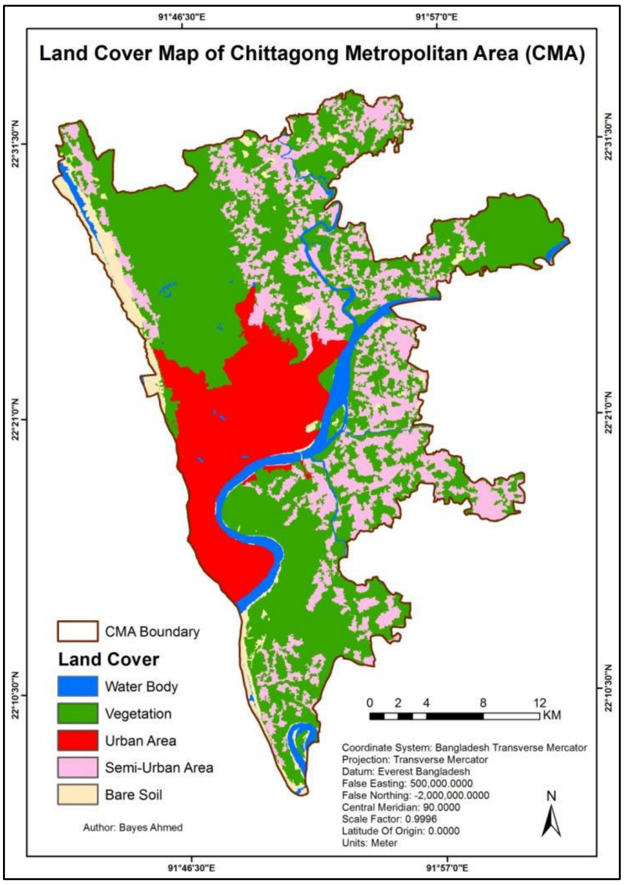


Figure 7.3: Precipitation map.

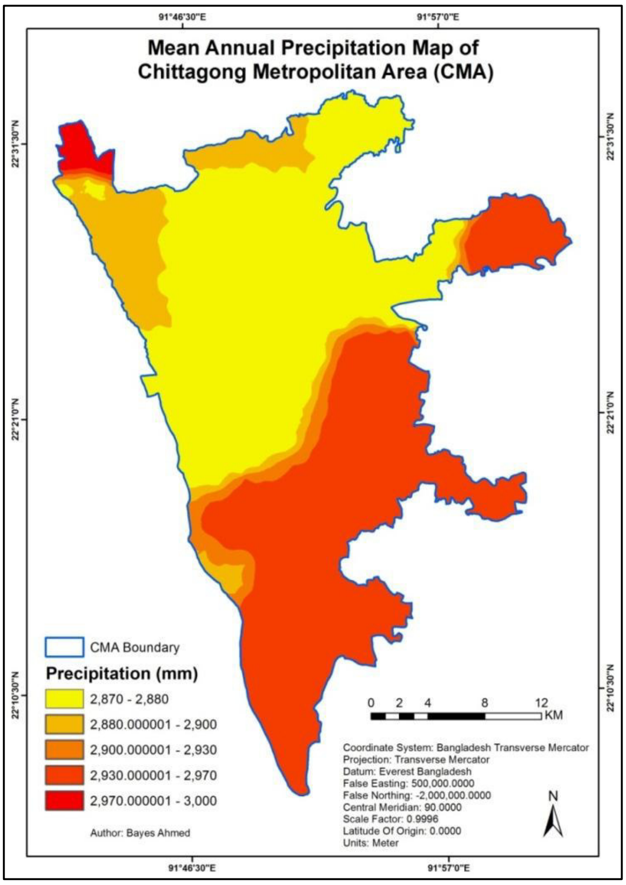
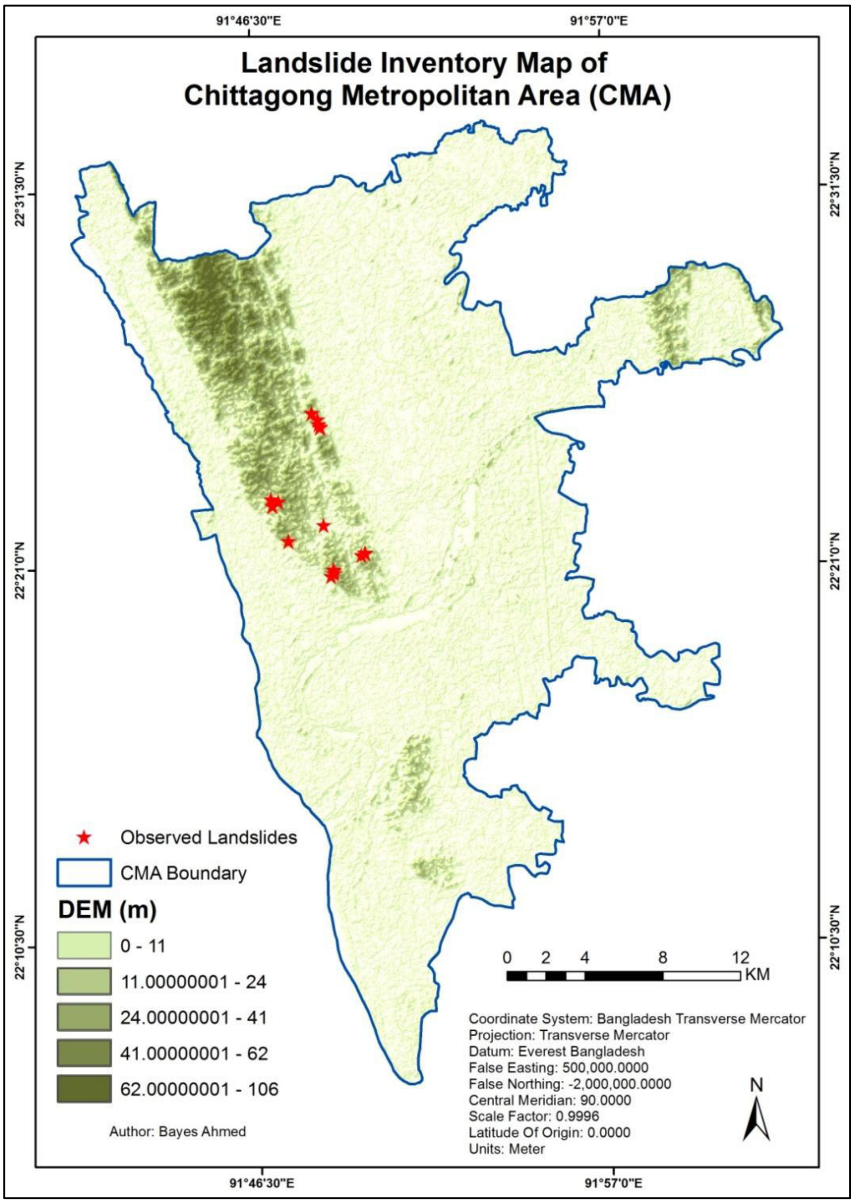


Table 7.2: ASTER GDEM raster image characteristics. [56]

Item	Description
Tile Size	3601-by-3601 pixels (1-by-1 degree)
Posting interval	1 arc-second
Geographic coordinates	Geographic latitude and longitude
Output format	GeoTIFF, signed 16 bits
DN values	1m/DN referenced to the WGS84/EGM96 geoid-9999 for void pixels, and 0 for sea water body
Coverage	North 83 degrees to south 83 degrees, 22,600 tiles
Posting interval	30m
DEM accuracy (stdev.)	7~14m

Figure 7.4: Observed landslide locations in CMA.



7.2.4. Elevation and Slope Map

Elevation and slope maps can be produced from DEM layer. The maps were then classified using Natural Breaks (Jenks) method with 5 classes (Figure 7.5 and Figure 7.6). Natural Breaks classes are based on natural groupings inherent in the data. Class breaks are identified that best group similar values and that maximize the differences between classes. The features are divided into classes whose boundaries are set where there are relatively big differences in the data values. Natural breaks are data-specific classifications and not useful for comparing multiple maps built from different underlying information [57].

Figure 7.5: Slope map.

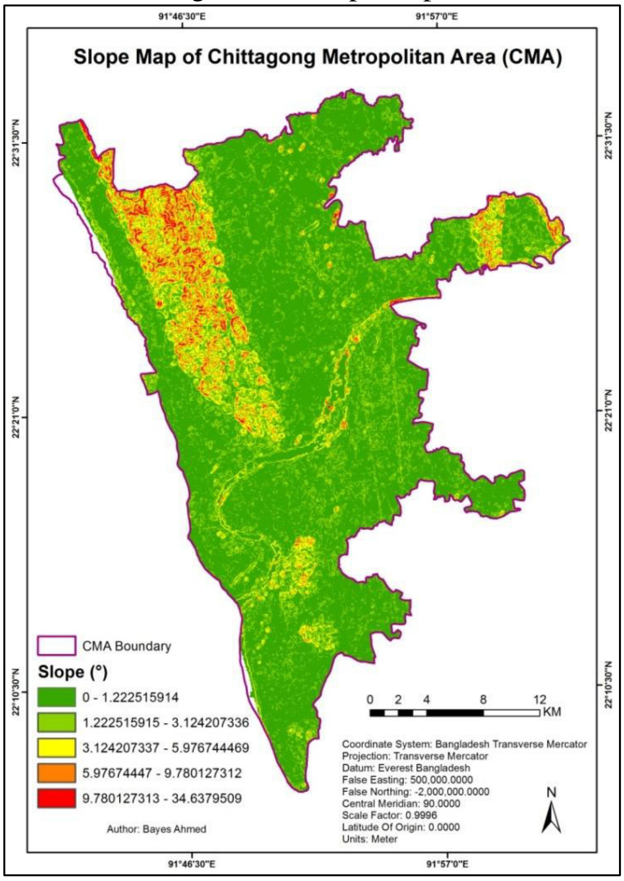
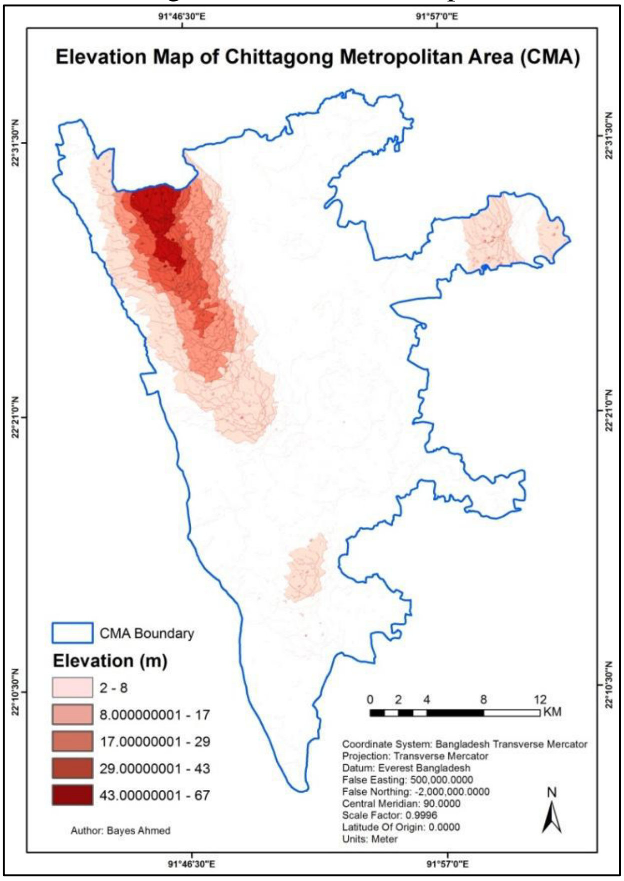


Figure 7.6: Elevation map.



7.2.5. NDVI Map

The Normalized Difference Vegetation Index (NDVI) is a standardized index allowing you to generate an image displaying greenness (relative biomass). This index takes advantage of the contrast of the characteristics of two bands from a multispectral raster dataset- the chlorophyll pigment absorptions in the red band and the high reflectivity of plant materials in the near-infrared (NIR) band [57]. The documented and default NDVI equation is as follows:

$$NDVI = ((IR - R)/(IR + R))$$

where, IR = pixel values from the infrared band (band 4)

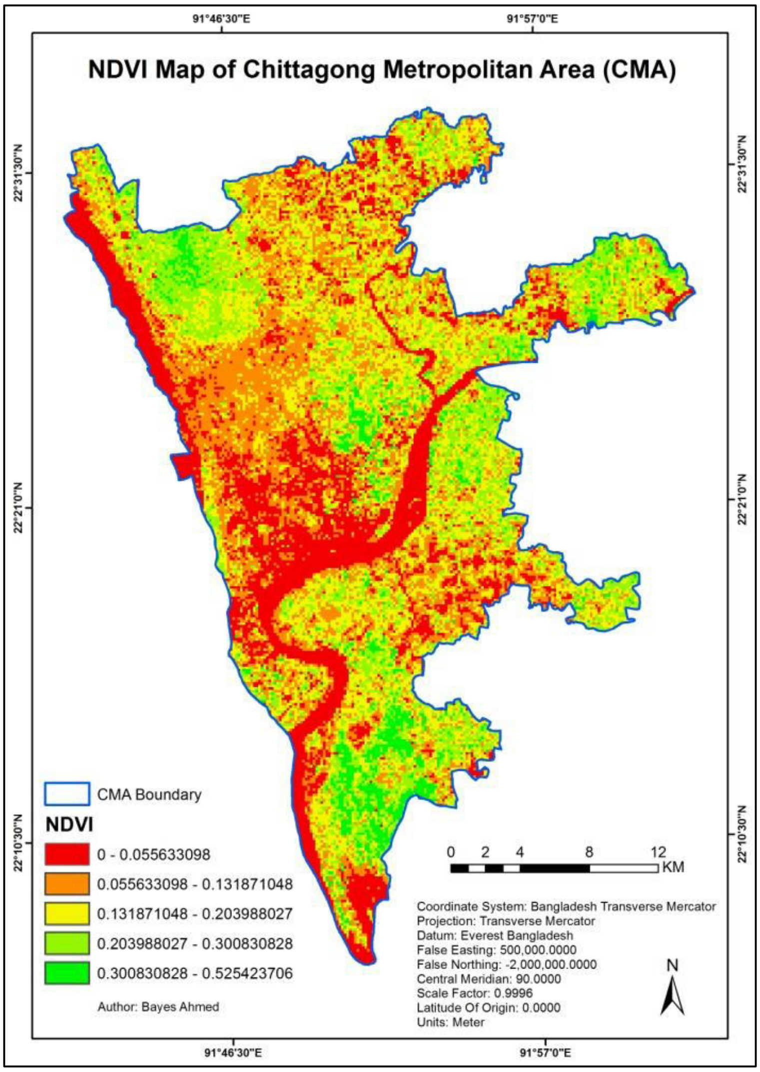
R = pixel values from the red band (band 3)

This index outputs values between -1.0 and 1.0, mostly representing greenness, where any negative values are mainly generated from clouds, water, and snow, and values near zero are mainly generated from rock and bare soil. Very low values of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8) [57]. In this research, the Landsat 4-5 TM images from the same season (dry and summer) were acquired from GLOVIS USGS website. The specifications of the collected satellite images are described in Table 7.3. Finally the NDVI map (Figure 7.7) of CMA was prepared by analysing band 3 and band 4.

Table 7.3: Details of the satellite images for NDVI analysis.

Satellite	Sensor	Path	Row	Date (DD/MM/YY)	Source Agency	Cloud Coverage	Quality
Landsat 4-5	TM	136	44	05/02/2009	USGS	0%	9
		136	45	09/03/2009			

Figure 7.7: NDVI map.



7.2.6 Other Layers

The road network, drainage network and water body layers were collected from the Chittagong Development Authority (CDA). The distance images from all these layers were prepared using 'Euclidean Distance' technique which gives the distance from each cell in the raster to the closest source (Figure 7.7-7.10). The Euclidean distance tools give you information according to Euclidean, or straight-line, distance. 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 tools [57].

The soil permeability map (Figure 7.11) was collected from Bangladesh Agricultural Research Council (BARC).

Figure 7.8: Distance to road map.

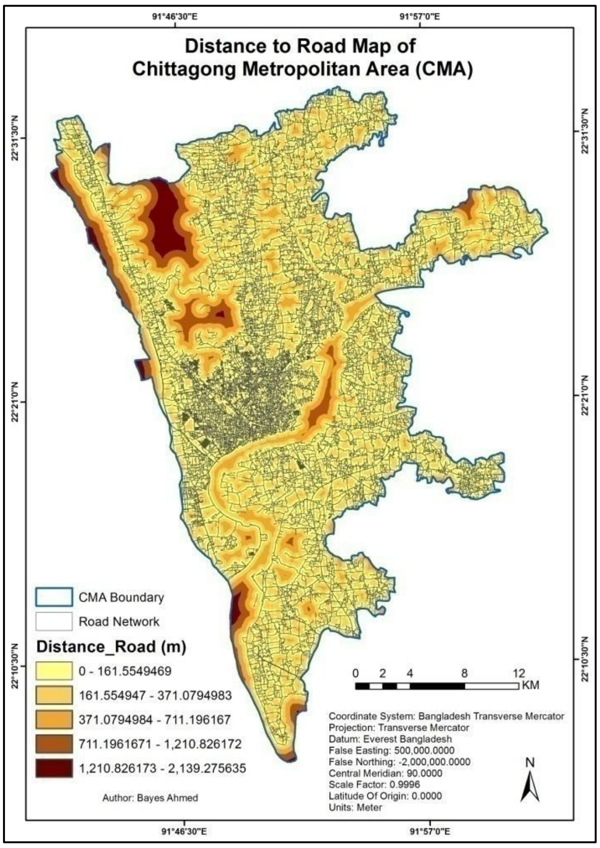


Figure 7.9: Distance to drain map.

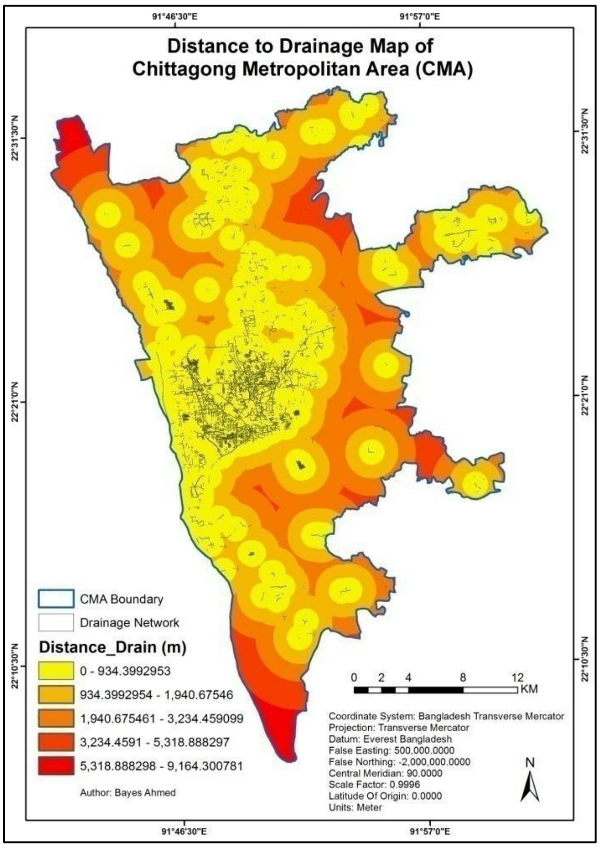


Figure 7.10: Distance to stream map.

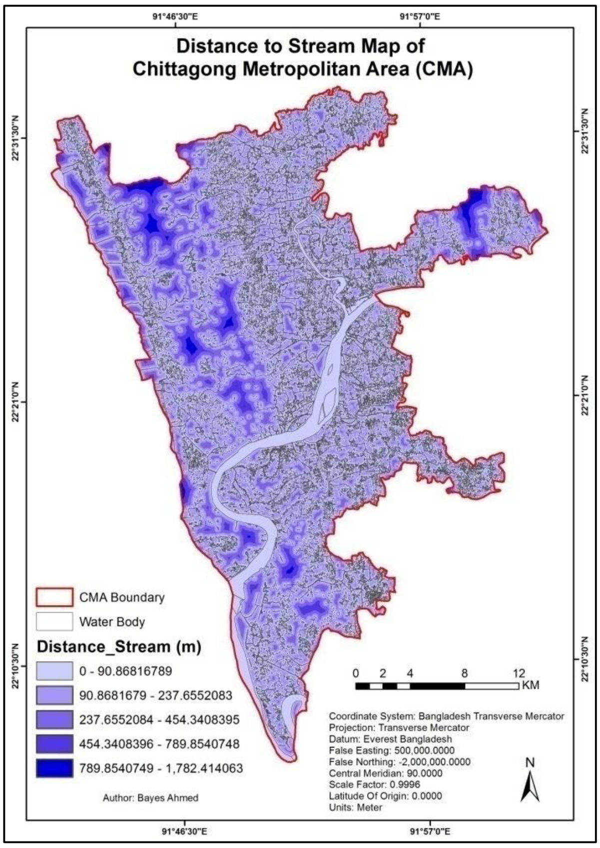
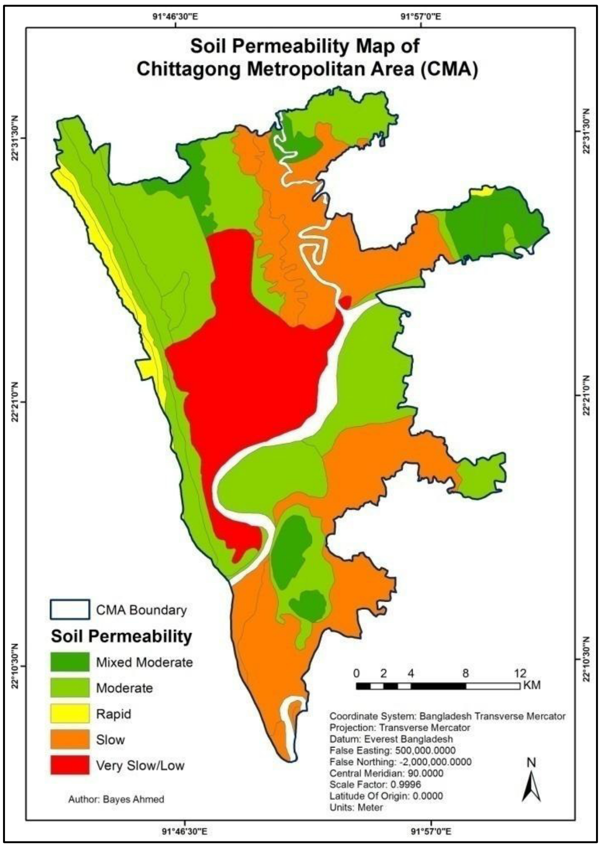


Figure 7.11: Soil permeability map.



For the predictive landslide susceptibility mapping of CMA, three different techniques have been implemented. These are:

a. Weighted Linear Combination
b. Logistic Regression
c. Multiple Regressions

7.3 WEIGHTED LINEAR COMBINATION (WLC)

The GIS-multicriteria decision analysis (GIS-MCDA) technique is increasingly used for landslide hazard mapping and zonation. It enables the integration of different data layers with different levels of uncertainty. The WLC method is one of the most commonly used GIS-MCDA [58]. The WLC technique is a popular method that is customized in many GIS and is applicable for the flexible combination of maps. The tables of scores and the map weights can be adjusted to reflect the judgment of an expert in the domain of the application being considered [51]. This method initially requires the standardization of the classes in each factor to a common numeric range. WLC can be considered as a hybrid between qualitative and quantitative methods. In the WLC method, each criterion is multiplied by its weight from the pair wise comparison and the results are summed:

$$S = \sum_i w_i \mu_i$$

In this formula, S represents the final score, w_i represents the weight of the criterion i, and μ_i represents the criterion standardized score [59]. Weights can have a tremendous influence on the solution. Due to the criterion weights being summed to one, the final scores of the combined solution are expressed on the same scale. Also, weights given to each criterion determine the trade-off level relative to the other criteria, which implies that high scores and weights from standardized criteria can compensate for low scores from other criteria. However, when scores from standardized criteria are low while the weights are high, they can only weakly compensate for the poor scores from other criteria [51, 59].

WLC (or simple additive weighting) is based on the concept of a weighted average. The decision-maker directly assigns the weights of 'relative importance' to each attribute map layer. A total score is then obtained for each alternative by multiplying the weight assigned to each attribute by the scaled value given to the alternative on that attribute, and summing the products of all attributes. When the overall scores are calculated for all of the alternatives, the alternative with the highest overall score is chosen. The method can be operationalized using any GIS system with overlay capabilities. The overlay techniques allow the evaluation criterion map layers (input maps) to be combined, in order to determine the composite map layer (output map) [51, 58].

In this method, criteria may include both weighted factors and constraints. WLC starts by multiplying each factor by its factor/trade-off weight and then adding the results; constraints are then applied by successive multiplication to "zero out" excluded areas. This procedure is characterized by full trade-off between factors and average risk. Factor weights, not used at all in the case of Boolean intersection (no trade-off), are very important in WLC because they determine how individual factors will trade-off relative to each other. In this case, the higher the factor weight the more influence that factor has on the final suitability map. (Contrast this with method 3 below where the importance of factor weights is variable). Along with full trade-off, an average level of risk characterizes this combination procedure, as it is exactly midway between the minimization (AND operation) and maximization (OR operation) of areas to be considered suitable in the final result [60].

The class rating within each factor was based on the relative importance of each class according to experts opinion, practical experience, field observations in the study area and existing literature, indicating certain conditions as the most favourable to slope failure. For this research purpose, some assumptions were undertaken for the factors. The susceptibility to landslides for a certain area increases:

1. The more the distance from drainage network
2. The higher the elevation
3. The closer to urban area land cover type
4. The lower the NDVI
5. The higher the precipitation
6. The farther the distance from road network
7. The steeper the slope
8. The slower the soil permeability
9. The closer to water body

Based on the above assumptions, three different combinations of factor weights (Table 7.4) were chosen for producing three different WLC maps. Finally the WLC maps were reclassified into low, medium and high landslide susceptibility zones (Figure 7.4-7.6).

Table 7.4: Factor weights for WLC analysis.

Factor	Factor Weight_1	Factor Weight_2	Factor Weight_3
Distance to Drain	0.05	0.10	0.10
Elevation	0.10	0.10	0.15
Land Cover	0.10	0.15	0.15
NDVI	0.10	0.10	0.10
Precipitation	0.05	0.05	0.05
Distance to Road	0.05	0.05	0.05
Slope	0.10	0.15	0.15
Soil Permeability	0.40	0.25	0.20
Distance to Stream	0.05	0.05	0.05
Total	**1.00**	**1.00**	**1.00**

Figure 7.12: WLC_1 map.

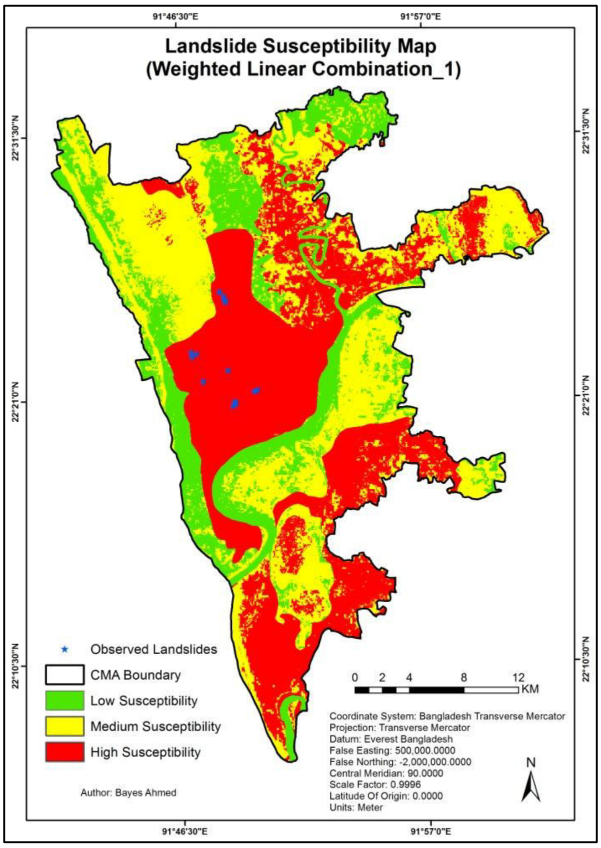


Figure 7.13: WLC_2 map.

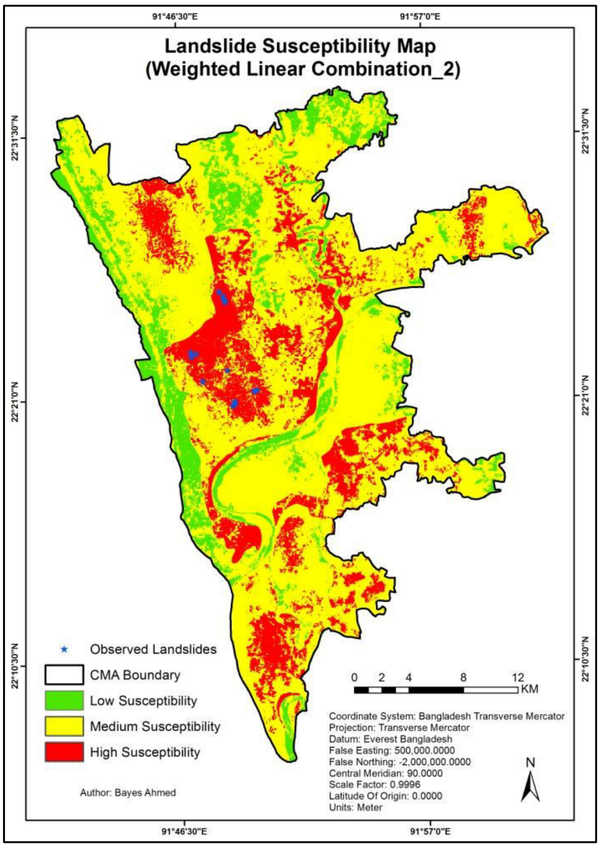
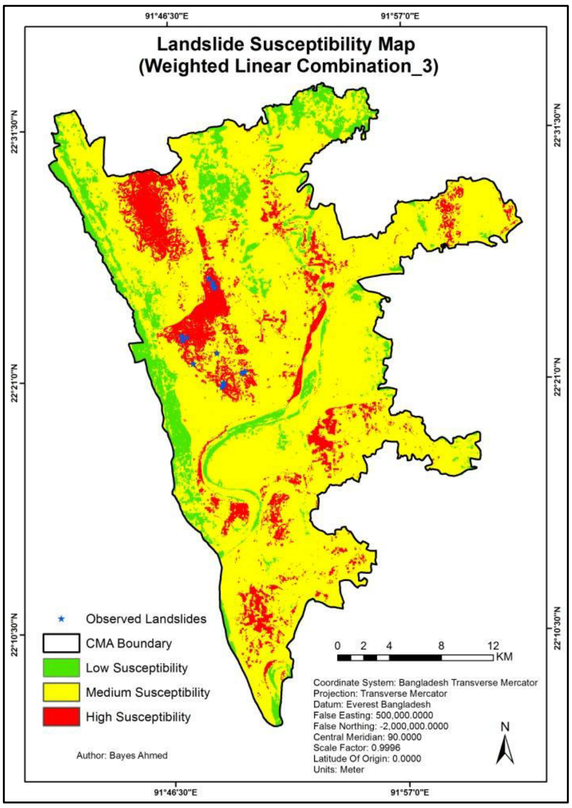


Figure 7.14: WLC_3 map.



7.4 LOGISTIC REGRESSION (LR)

Logistic regression (LR), a type of multivariate analysis, is useful for predicting the presence or absence of a characteristic or outcome based on the values of a set of predictor variables [61]. The LR model, which was developed by McFadden (1973), uses independent variables to create a mathematical formula for the probability that an event will occur on any given parcel of land [62].The key to LR is that the dependent variable is dichotomous [42]. The independent variables in this model are predictors of the dependent variable and can be measured on a nominal, ordinal, interval, or ratio scale. The relationship between the dependent and independent variables is nonlinear [42, 43].

For this research, the 'LOGISTICREG' tool of IDRISI Taiga software was used. LOGISTICREG performs binomial logistic regression, in which the input dependent variable must be binary in nature, that is, it can have only two possible values (0 and 1). Such regression analysis is usually employed in estimating a model that describes the relationship between one or more continuous independent variable (s) to the binary dependent variable. The basic assumption is that the probability of dependent variable takes the value of 1 (positive response) follows the logistic curve and its value can be estimated with the following formula [60, 64]:

$$P(y=1|X) = \frac{exp\,(\sum BX)}{1+exp\,(\sum BX)}$$

where, P = the probability of the dependent variable being 1; X is the independent variables,

$X = (x_0, x_1, x_2, \ldots x_k), x_0 = 1$

B is the estimated parameters

$B = (b_0, b_1, b_2, \ldots. b_k)$

To linearize the above model and to remove the 0/1 boundaries for the original dependent variable (probability), the following transformation are usually applied [60, 64]:

$P' = Ln(P/(1-P))$

This transformation is referred to as the logit or logistic transformation. Note that after the transformation P' can theoretically assume any value between minus and plus infinity. By performing the logit transformation on both sides of the above logit regression model, we obtain the standard linear regression model [60, 64]:

$Ln(p/(1-p)) = b_0 + b_1*x_1 + b_2*x_2 + \ldots\ldots + b_k*x_k + error\_term$

Notice that the logit transformation of dichotomous data ensures that the dependent variable of the regression is continuous, and the new dependent variable (logit transformation of the probability) is unbounded. Furthermore, it ensures that the predicted probability will be continuous within the range from 0-1.

Assumptions of the logistic regression model [60]:

- the dependent random variable, Y, is assumed to be binary, taking on only two values (0 and 1).
- the outcomes on Y are assumed to be mutually exclusive and exhaustive.
- Y is assumed to depend on K observable variables X_k and the relationship is non-linear and follows the logistic curve.
- the data are generated from a random sample of size N, with a sample point denoted by i, i = 1, ..., N.
- no restriction on the independent variables except that they cannot be linearly related; (implies that N>K).
- the error term of each observation is assumed to be independent of the error terms of all other observations.

LOGISTICREG employs Maximum Likelihood Estimation (MLE) procedure to find the best fitting set of parameters (coefficients). The maximum likelihood function used by LOGISTICREG is the following [60, 64]:

$L = \prod_{i}^{N} \mu * (1-\mu_1)^{(1-y_i)}$

where, L is the likelihood

μ_i is the predicted value of the dependent variable for sample i

$\mu_i = exp\ (\sum_{k=0}^{k} b_k\, x_{ik}) / (1 + exp \sum_{k=0}^{k} b_k x_{ik})$

y_i is the observed value of the dependent variable for sample i

To maximize the above likelihood function, it thus requires the solution for the following simultaneous nonlinear equations [60, 64]:

$\sum_{i=1}^{N} . (y_i - \mu_i) * x_{ij} = 0$

Where $x_{ij}$is the observed value of the independent variable j for sample i.

The rest is the same as for the likelihood function. In solving the above equations, LOGISTICREG uses the Newton-Raephson algorithm [60]. Moreover, the LOGISTICREG text output includes the following:

The regression equation and the individual regression coefficient;

In the Regression Statistics section [60]:

Number of Total Observations:	the number of observations used in study area
Number of 0s in Study Area:	the number of observations with dependent value as 0 in study area
Number of 1s in Study Area:	the number of observations with dependent value as 1 in study area
Percentage of 0s in Study Area:	equal to 100*(Number of 0s in study area / Number of observations in study area)
Percentage of 1s in Study Area:	equal to 100*(Number of 1s in study area / Number of observations in study area)
Number of Auto-sampled Observations	the number of observations sampled for analysis
Number of Os in Sampled Area:	the number of observations with dependent value as 0 in analysis
Number of 1s in Sampled Area:	the number of observations with dependent value as 1 in analysis
Percentage of 0s in Sampled Area:	actual percentage of 0s used in analysis
Percentage of 1s in Sampled Area;	actual percentage of 1s used in analysis

The basis for testing the goodness of fit in logistic regression is the likelihood ratio principle. The ratio is based on the following two statistics [60, 64]:

-2log(L0)

where L0 is the value of the likelihood function if all coefficients except the intercept are 0;

-2log(Likelihood)

where Likelihood is the value of the likelihood function for the full model as fitted;

Based on the above two statistics, the following two are calculated [60]:

Pseudo R_square = 1- (log(Likelihood)/log(L0);

Thus, pseudo R_square = 1 indicates a perfect fit, where as pseudo R_square = 0 indicates no relationship.

Pseudo R_square greater than 0.2 is considered a relatively good fit [65].

ChiSquare(k) = -2(log(likelihood) –log(L0));

This is also known as the likelihood ratio statistic which follows, approximately, a chi-square distribution when the null hypothesis is true. This statistic tests the hypothesis that all coefficients except the intercept are 0. Thus, it is a similar test as the F statistic in liner regression analysis. The degrees of freedom for this chi-square statistic is K (the number of the independent variables included) [60].

The last statistic in this group that bears some measure of goodness of fit is calculated based on the difference between the observed and the predicted values of the dependent variable [60]:

$$Goodess\_of\_fit = \sum_{i=1}^{N}.(y_i-\mu_i)^2/\mu_i*(1-\mu_i)$$

Thus, the smaller of this statistic, the better fit it indicates.The classification is based on the predicted probability with 0.5 as the dividing point, i.e., classify a case as 0 if its predicted probability is less than 0.5 and as 1 otherwise. The odds ratio is calculated from the classification table with the following formula [60]:

$$Odds\_ratio = (f_{11} * f_{22})/(f_{12} * f_{21})$$

where,

Observed	Pred_0	Pred_1
0	f_{11}	f_{12}
1	f_{21}	f_{22}

In the last section, this version of LOGISTICREG offers two additional statistics [60]:

(1) Instead of reclassifying the case using the probability of 0.5 as the cutting point, it offers an alternative classification of cases based on a new cutting point, which is determined by matching the quantity of the number of 1s in the observed values of the dependent variable. Accordingly, an Adjusted Odds Ratio is calculated. In addition, as a transition to the ROC statistic that follows, True and False Positive are also calculated based on this new classification, where [60]:

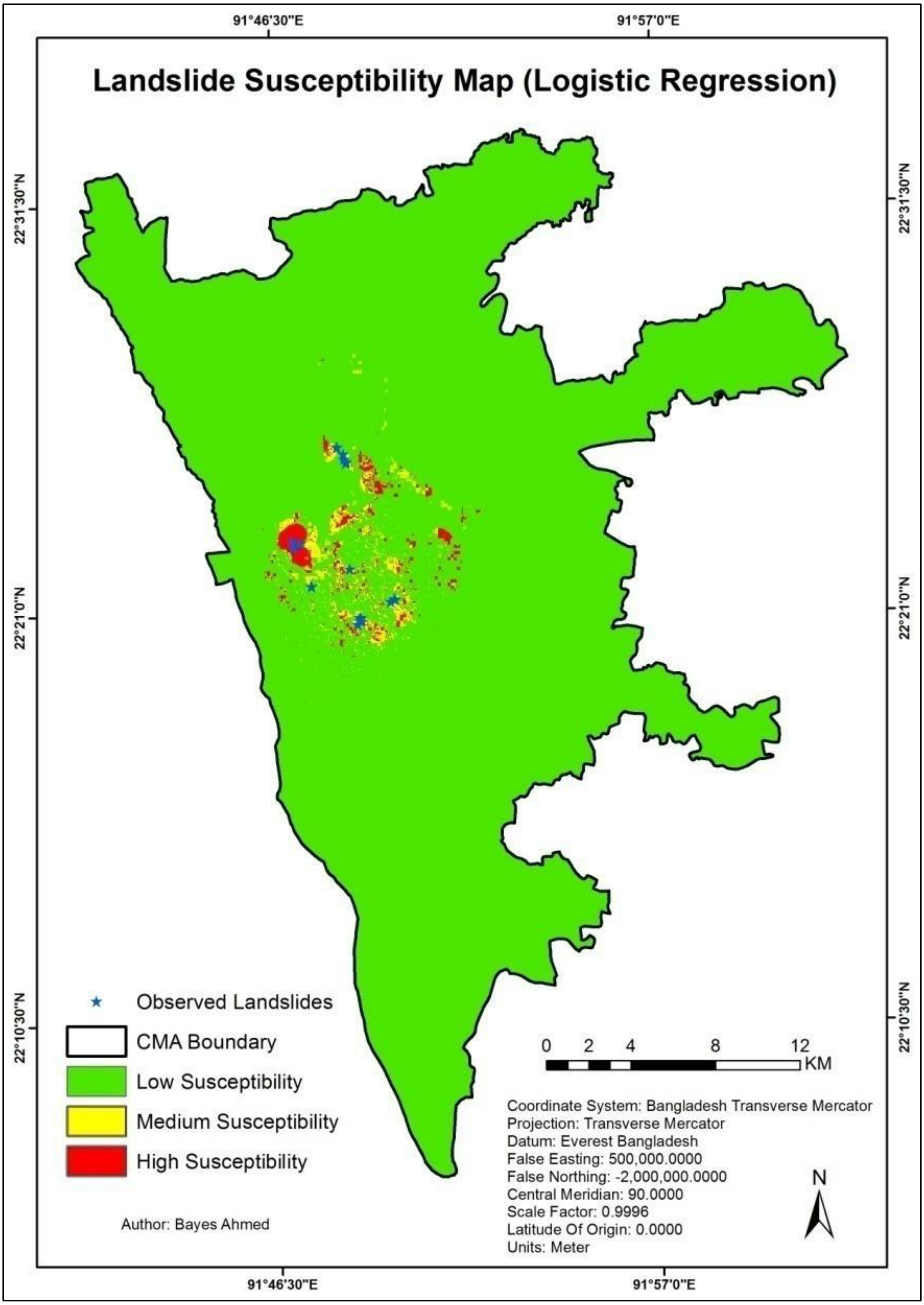
$True\_Positive = f_{22} / (f_{21} + f_{22})$ *and*

$False\_Positive = f_{12} / (f_{11} + f_{12})$

(2) ROC (Relative Operating Characteristic) ROC is an excellent method to compare a Boolean map of "reality" versus a suitability map (for detailed explanation, see help for the ROC module). Thus, ROC is included here as an excellent statistic for measuring the goodness of fit of logistic regression. The ROC value ranges from 0 to 1, where 1 indicates a perfect fit and 0.5 indicates a random fit. A ROC value between 0.5 and 1 indicates some association between the X variables and Y. The larger the ROC, the better the fit [60, 66].

Now applying the above mentioned method, the landslide susceptibility map of CMA was produced (Figure 7.15). The detailed statistical output of this LR analysis is attached in Appendix-E.12.

Figure 7.15: Landslide susceptibility map derived from LR model.



7.5 MULTIPLE REGRESSIONS (MR)

For this research, the 'MULTIREG' tool of IDRISI Taiga software was used. MULTIREG undertakes a multiple linear regression to analyze the relationship of one or more independent variables to a single dependent variable. The regression can be conducted for image files or attribute values files. MULTIREG adopts a least-squares approach to multiple regressions [68, 69].

In multiple regressions, a linear relationship is assumed between the dependent variable and the independent variables. For example, in the case of three independent variables, the multiple linear regression equation can be written as [60]:

$Y=a+b1*x1+b2*x2+b3*x3$

where Y is the dependent variable, $x1$, $x2$, and $x3$ are the independent variables, a is the intercept, and $b1$, $b2$ and $b3$ are the coefficients of the independent variables $x1$, $x2$, and $x3$ respectively. The intercept represents the value of Y when values of the independent variables are zero, and the coefficient indicates unit change of Y with a one-unit increase in the corresponding independent variable.

The independent variables can be continuous (e.g., interval, ratio, or ordinal) or discrete (dummy variable), but the dependent variable should be continuous and unbounded. Some assumptions underlie the use of multiple linear regressions, such as [60]:

(1) The observations are drawn independently from the population, and the dependent variable is normally distributed;

(2) The number of observations are larger than number of independent variables; and

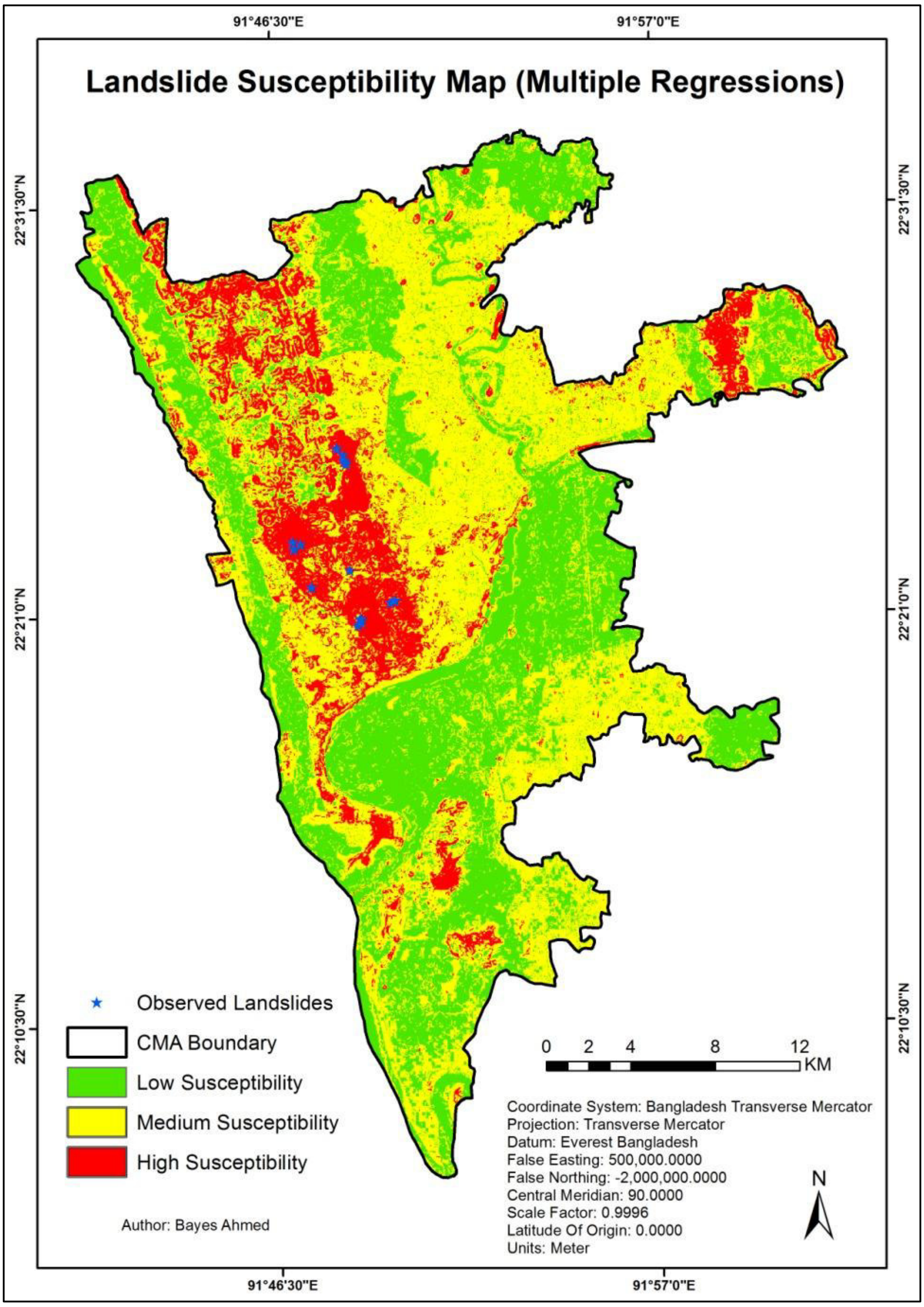
(3) No exact or near-linear relationship exists among independent variables.

The susceptibility map derived from MR approach is depicted in Figure 7.16. Moreover, the detailed statistical output of this MR model is attached in Appendix-E.13.

7.6 MODEL VALIDATION AND COMPARISON

To evaluate the performances of the models in analyzing landslide susceptibility, it is important to validate the models or techniques. To do this validation Relative Operating Characteristic (ROC) method is used in this research. The ROC module employs an excellent method to assess the validity of a model that predicts the location of the occurrence of a class by comparing a suitability image depicting the likelihood of that class occurring (i.e., the input image) and a Boolean image showing where that class actually exists (i.e., the reference image). For example, the ROC could be used to compare an image of modelled probability for landslides against an image of actual observed landslides [60].

Figure 7.16: Landslide susceptibility map derived from MR model.



The ROC module offers a statistical analysis that answers one important question: "How well is the category of interest concentrated at the locations of relatively high suitability for that category?" The answer to this question allows the scientist to answer the general question, "How well do the pair of maps agree in terms of the *location* of cells in a category?" while not being forced to answer the question "How well do the pair of maps agree in terms of the *quantity* of cells in each category?" Thus the ROC analysis is useful for cases in which the scientist wants to see how well the suitability map portrays the location of a particular category but does not have an estimate of the quantity of the category [6].

ROC is a summary statistic derived from several two-by-two contingency tables (Table 7.5), based on a comparison of the simulated image with the reference image. Each table corresponds to a different threshold in the suitability map [66, 70].

Table 7.5: Contingency table for ROC.

		Reference Image	
		In class of interest (1)	Not in class of interest (0)
Simulated Image	In class of interest (within threshold)	A (true positive)	B (false positive)
	Not in class of interest (not within threshold)	C (false negative)	D (true negative)

The true positive % value is derived from A/(A+C) while the false positive % value is derived from B/(B+D), where A, B, C, D are pixel counts in the contingency table for each threshold [66, 70].

Figure 7.17: ROC graph for three input images. [60]

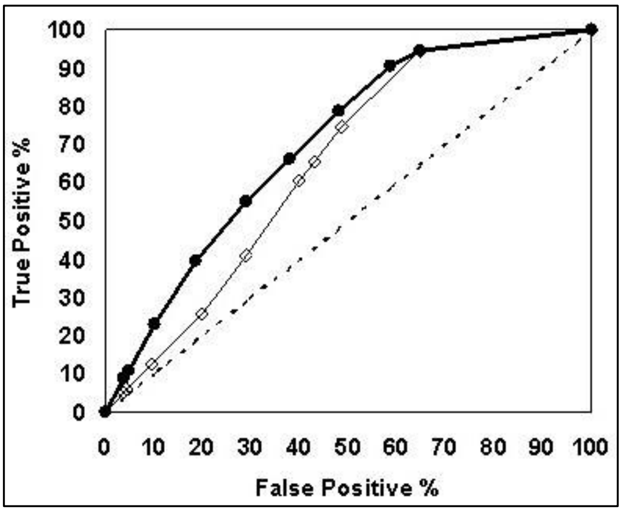


Figure 7.17 shows the ROC graph for three input images. A point for each threshold is plotted with the percentage of true positives on the vertical axis and the percentage of false positives on the horizontal axis [60, 66, 70].

The ROC statistic is the area under the curve that connects the plotted points. IDRISI uses the trapezoidal rule from integral calculus to compute the area, where x_i is the rate of false positives for threshold i, y_i is the rate of true positives for threshold i, and n+1 is the number of thresholds [66, 70].

$$AreaUnderCurve = \sum_{i=1}^{n}[x_{i+1} - X_i] \times [y_i + (y_{i+1} - y_i)/2]$$

The dashed diagonal line derives (Figure 7.17) from an input image in which the locations of the image values were assigned at random (AUC=0.50). The other two lines derive from different models. The model that produced the thin line with open squares (AUC=0.65) is shown to be performing more poorly than the model that produced the thin line with closed circles (AUC=0.70).

7.6.1 Comparison of Models

To assess the spatial effectiveness of the susceptibility maps using ROC curves were also constructed in this research. The landslide-susceptibility analysis results were verified using the landslide location sites for CMA. The verification method was then performed by comparing the landslide test data and landslide-susceptibility analysis results for each of the models. Two basic assumptions are then needed to verify the landslide susceptibility calculation methods. One is that landslides are related to spatial information, such astopography, land cover, soil, and geology; the other is that future landslides will be precipitated by a specific impact factor, such as rainfall [71]. In this research, both the two assumptions were satisfied because the landslides were shown to be related to the spatial information (Figure 7.18), and the landslides were precipitated by heavy rainfall (Figure 7.19).

The area under ROC curves (AUC) constitutes one of the most common used accuracy statistics for the prediction models in natural hazard assessments [72]. The minimum value of AUC is 0.5 means no improvement over random assignment while the maximum value of that is 1denotes perfect discrimination [73]. The comparison results are shown in Figure 4.7 as a line graph (threshold type is equal interval and number of thresholds is 25%). The AUC values are indicating the accuracy of the models for landslide prediction. The WLC_1, WLC_2, WLC_3, LR and MR models had AUC values of 0.839, 0.911, 0.885, 0.767 and 0.967, respectively. Generally, the verification results showed satisfactory agreement between the susceptibility map and the existing data on the landslide location (AUC values from 0.767-0.967). The MR model fits best for this research area (Figure 7.18).

Figure 7.18: Assessment of the model performance based on the ROC curves.

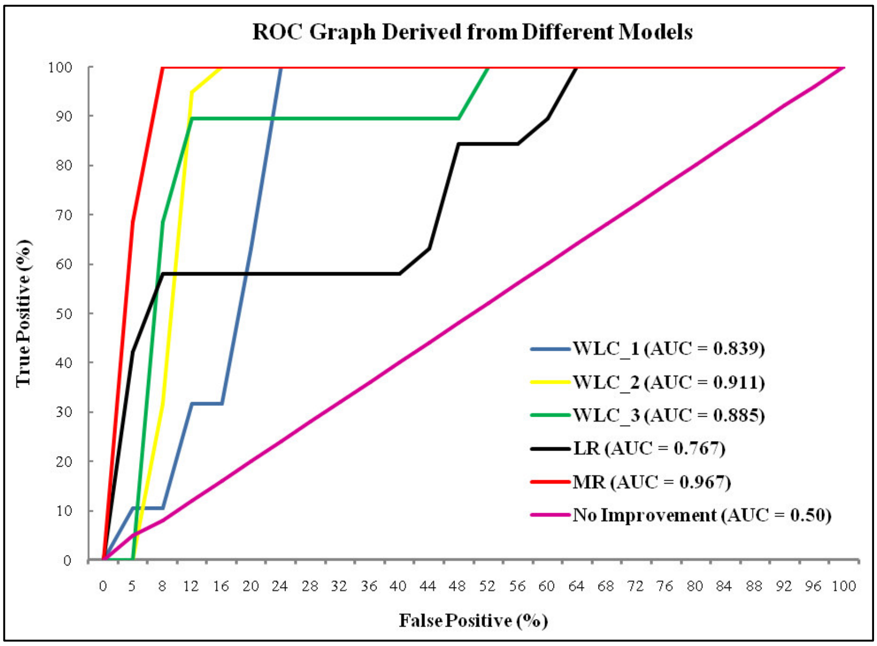
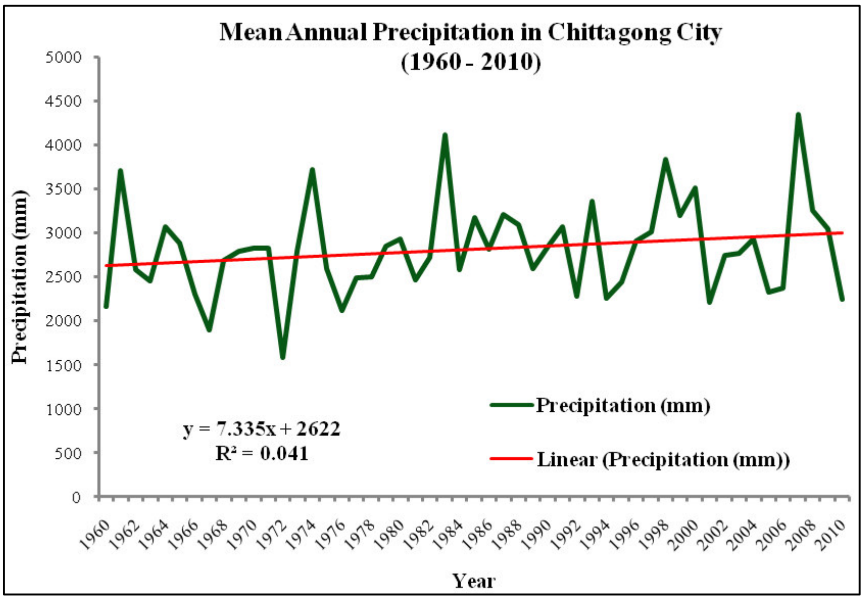


Figure 7.19 Annual rainfall patter in Chittagong City from 1960-2010



The detailed statistics of the ROC results for all the models are attached in Appendix-E.14. Moreover it has already been stated that, due to climate change, Chittagong City is experiencing high intensity of rainfall in recent years which is making the landslide situation worse. Existing evidences to date also justify the above argument because of a gradual upward shift in precipitation has been noted for the last five decades (1960-2010), with an abrupt fluctuation in the mean annual precipitation levels (Figure 7.19).

CHAPTER 8: SLOPE STABILITY MAPPING FOR CHITTAGONG METROPOLITAN AREA (CMA) OF BANGLADESH

8.1 BACKGROUND

Landslide is the hazard significant for most casualties and damages on this earth. The damages in a landslide depend on the type, speed and volume of the soil movement. Hydrology is a major determinant of many natural hazards. Landslide occurs mainly due to slope instability of hilly areas. Slopes may become instable because of ground water fluctuation due to heavy rainfall for some consecutive days, typhoon, hurricanes, earthquake, human activity etc. So, it is very necessary to know about the stability of slope i.e, susceptible areas in a hilly and mountainous region before taking any measure to prevent or manage the devastating disaster and thus reduce the losses.

At inventory stage, we found 57 locations in Chittagong Metropolitan Area (CMA), Bangladesh (field survey, August, 2014) where landslide has already been occurred for several years. But we found no prepared map or information on the stability of slope in any organization related to landslide. It is the scope of this project to prepare a slope stability map of Chittagong Metropolitan Area (CMA) in a scientific way and through it the locations vulnerable to slope failure and landslide can easily be determined.

The climate change is responsible for the slope failure and the ultimate result is slope instability. Surface runoff calculation and ground water movement is important factor in slope instability. Digital Elevation Model (DEM), land cover map, plant cover and plant height; daily rainfall data, evapotranspiration; soil type map with soil properties like hydraulic conductivity of the soil at saturation level, porosity of the soil, internal friction of the soil; field capacity of the soil, wilting point of the soil, angle of internal friction, soil cohesion, specific density regolith, splash detachment erodibility; and soil depth datasets will be used for slope stability mapping.

It is must to know the physical characteristics of soil for making a water balance model. The variation of soil moisture and different processes (infiltration, evapotranspiration, percolation and groundwater flow) in soil layers depend on soil properties. The soil hydraulic properties are determined by two main characteristics of soil named texture and structure. The characteristics of soil are found in soil investigation part of this project.

Land cover change is an important issue in soil failure. Vegetation intercepts rainfall directly in the canopy (overlay) and decrease the amount of rain water reaching to the soil surface. A projected land cover map has prepared earlier during land cover modeling using satellite images (year: 1990, 2000 and 2010) from the United States Geological Survey (USGS).

The average annual rainfall is not same in each year. Excessive rainfall causes lose of soil and landslide in hilly areas. As a result, there is a huge loss of properties and lives in every year. To prepare for the preparedness and mitigation program it is necessary to know the return period of these devastating events calculating the long term rainfall data. From rainfall pattern modeling we have found the pattern of rainfall in the study area.

When groundwater in a slope rises up, the pressure in soil-pore-system is increased and as a result, the slope loses its resistance forces to hold its mass and it fails. The slope may move in different ways like falling, toppling, rotational slipping, sliding, translational slipping, spreading, creeping, or as block slip, avalanche, lahar, mudflow etc. [74] In this study, the driving force (mass of the slope) and resisting forces (for slope failure) will be compared through 'Infinite Slope Model'. The ratio of these two forces is called 'Factor of Safety (FS)'.

$$\text{FS} = \frac{\text{Resisting force}}{\text{Driving force}} = \frac{\text{Share strength of matrial (soil)}}{\text{Share stress required for equilibrium}}$$

Where, FS > 1.0 represents a stable situation and FS < 1.0 denotes failure of soil (soil instability). [75]

To find out the location of unstable slope and time of slope failure, the groundwater movement will be combined with the Infinite Slope Model. A sensitivity analysis will be done to know which combination of parameters will cause the slope instability in a particular area. The output of this portion will be a series map of slope stability factor maps for 365 days of the year. This mapping is expected to be very helpful to identify the endangered area where it is necessary to warn the people through web-GIS based early warning system.

8.2 DATA SOURCE

Table 8.1: Detail of the inputs used for natural hazards modeling/spatial dynamic modeling.

Sl. No.	Input	Description	Source
1.	Digital Elevation Model	ASTER GDEM 30m× 30 m resolution	USGLOVIS
2.	Rainfall station	Point location of rainfall station	
3.	Mask	Definition of Boundary Extent of the study area	Prepared
4.	LDD	Local Drainage Direction	Derived from DEM
5.	Outlet	Outlet of the catchment	Derived from DEM
6.	Soil texture class unit	Derived from geological map	Geological survey of Bangladesh
7.	Rainfall data (mm/day)	Rainfall data of 2008 for Chittagong City	Meteorological Department of Bangladesh
8.	Potential evapotranspiration	Standard Value from literature	Jetten and Shrestha
9.	Soil data	Engineering properties of the soil	Laboratory test and literature
10.	Saturated hydraulic conductivity (mm/h)	Calculated from soil particle ratio	SPAW Model
11.	Soil depth (mm)	Interpolated value from 18 borehole location	Civil Department , Southern University, Chittagong
12.	Stream channel width	Width of stream and river	Derived from LDD
13.	Landcover Map	Classification of Landcover	Classified from Landsat TM image

8.3 METHODOLOGY

8.3.1 Preparation of Input Data

Digital Elevation Model (DEM) is the basic data for any slope modeling. DEM is extracted from ASTER global DEM with 30m spatial resolution (Figure 8.1). Coordinate of rainfall station has been collected from Bangladesh Metrological Department (BMD). Then a raster map rainfall station is prepared with rainfall station location. An area map called mask is prepared for Chittagong Metropolitan Area to define the study area (Figure 8.2). Local Drainage Direction (LDD) map is calculated from DEM (Figure 8.3). The stream network created from a map with surface drainage directions. This is a map with a network connecting all cells according to the steepest slope. A subset of this map is the stream channel network. Therefore, a continuous network is being created that connects every cell to the outlet of the catchment. From this LDD map an outlet map has been prepared to define the outlet point of the catchment. Soil unit map has been prepared based on geological unit map available from Geological Survey of Bangladesh (GSB). Engineering properties of soil units such as hydraulic conductivity of the soil, porosity, internal angle of friction, cohesion has been collected through lab testing and available literature. Soil depth map has been prepared by inverse distance weight (IDW) interpolation of borehole location (Figure 8.4). Depth of top soil class layers has been considered as soil depth of 18 borehole locations.

Figure 8.1: Digital Elevation Model (DEM) of Chittagong Metropolitan Area (CMA).

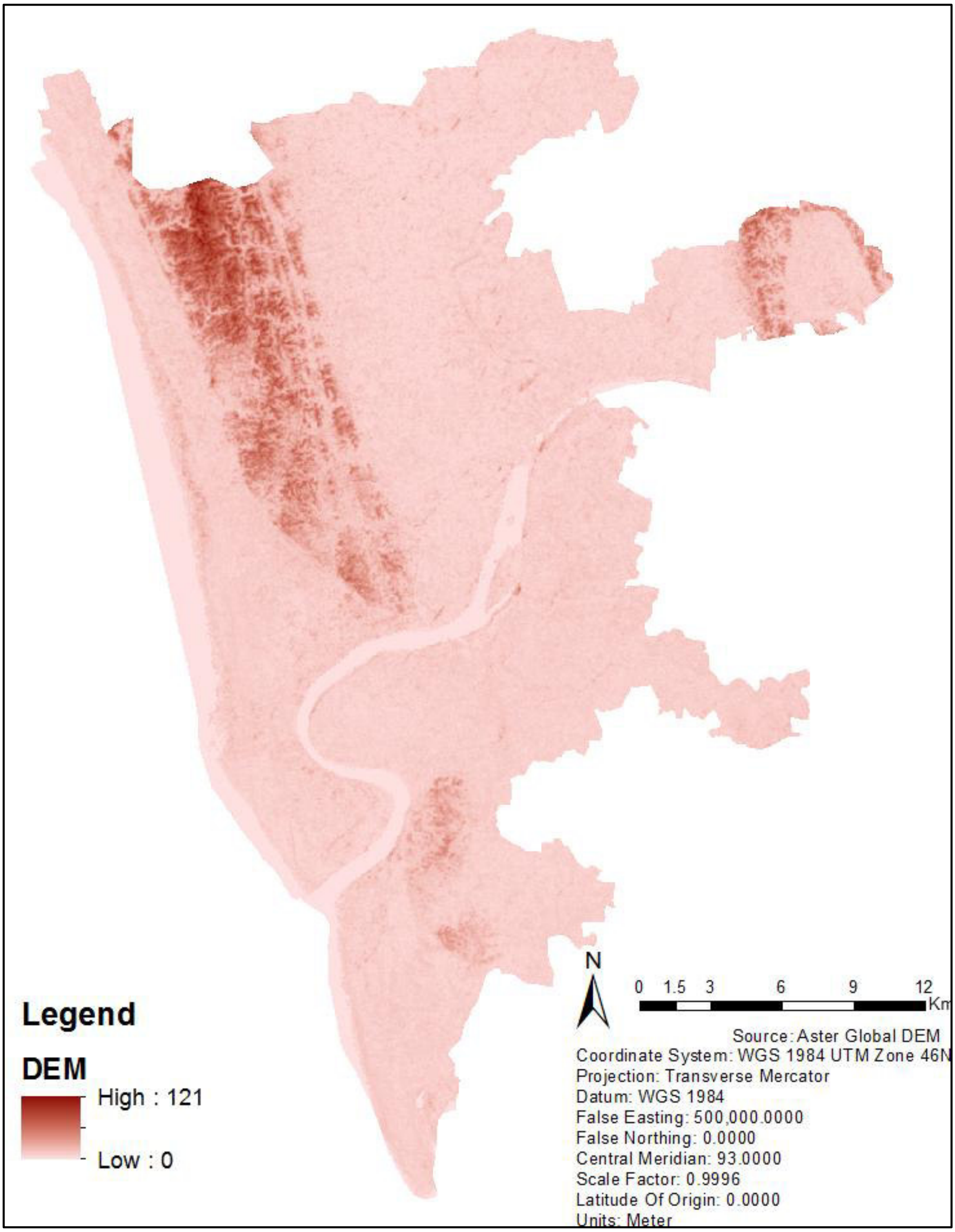


Figure 8.2: Saturated Hydrouclic Conductivity Map of Chittagong Metropolitan Area.

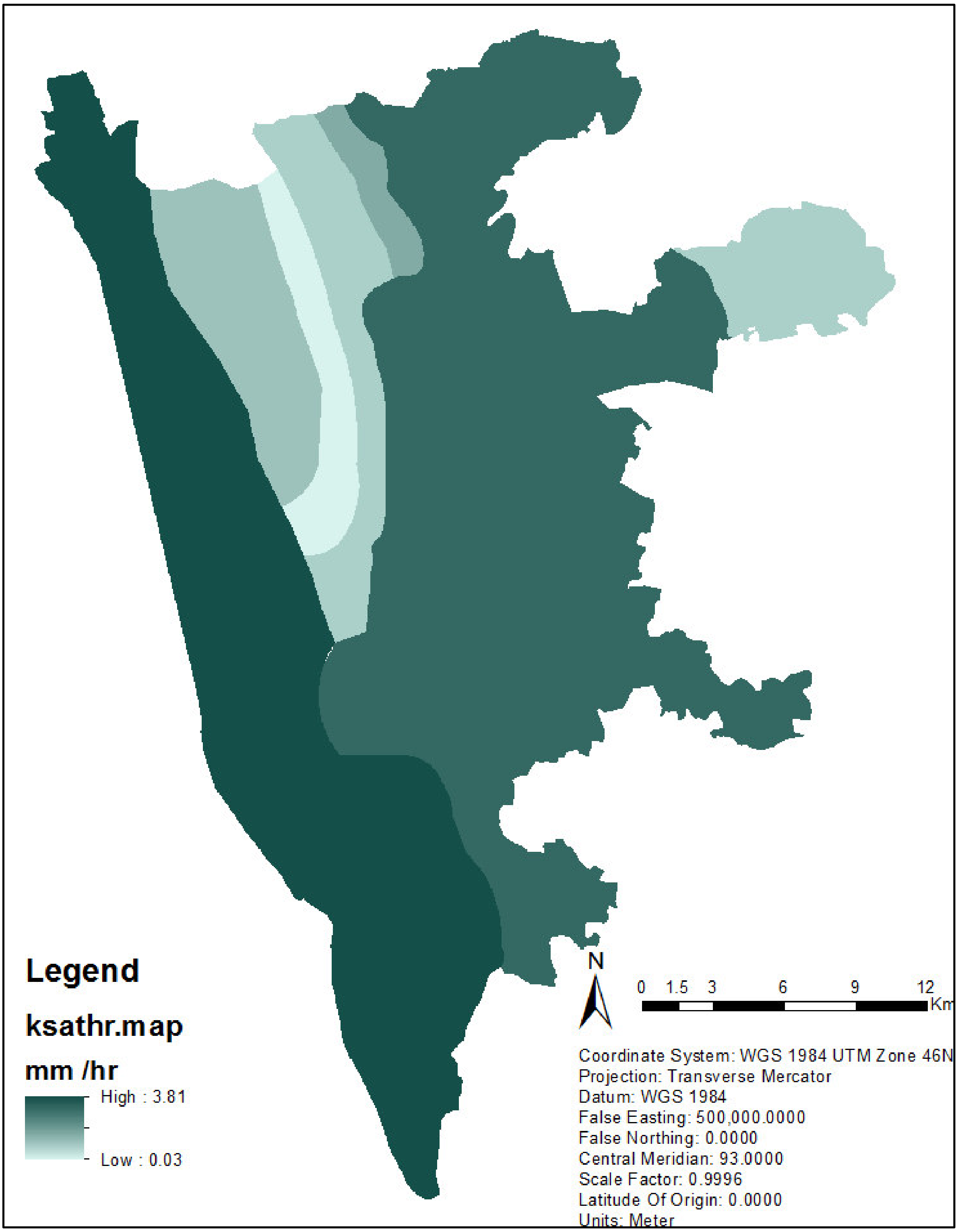


Figure 8.3: Local Drainage Direction (LDD) Map of Chittagong Metropolitan Area.

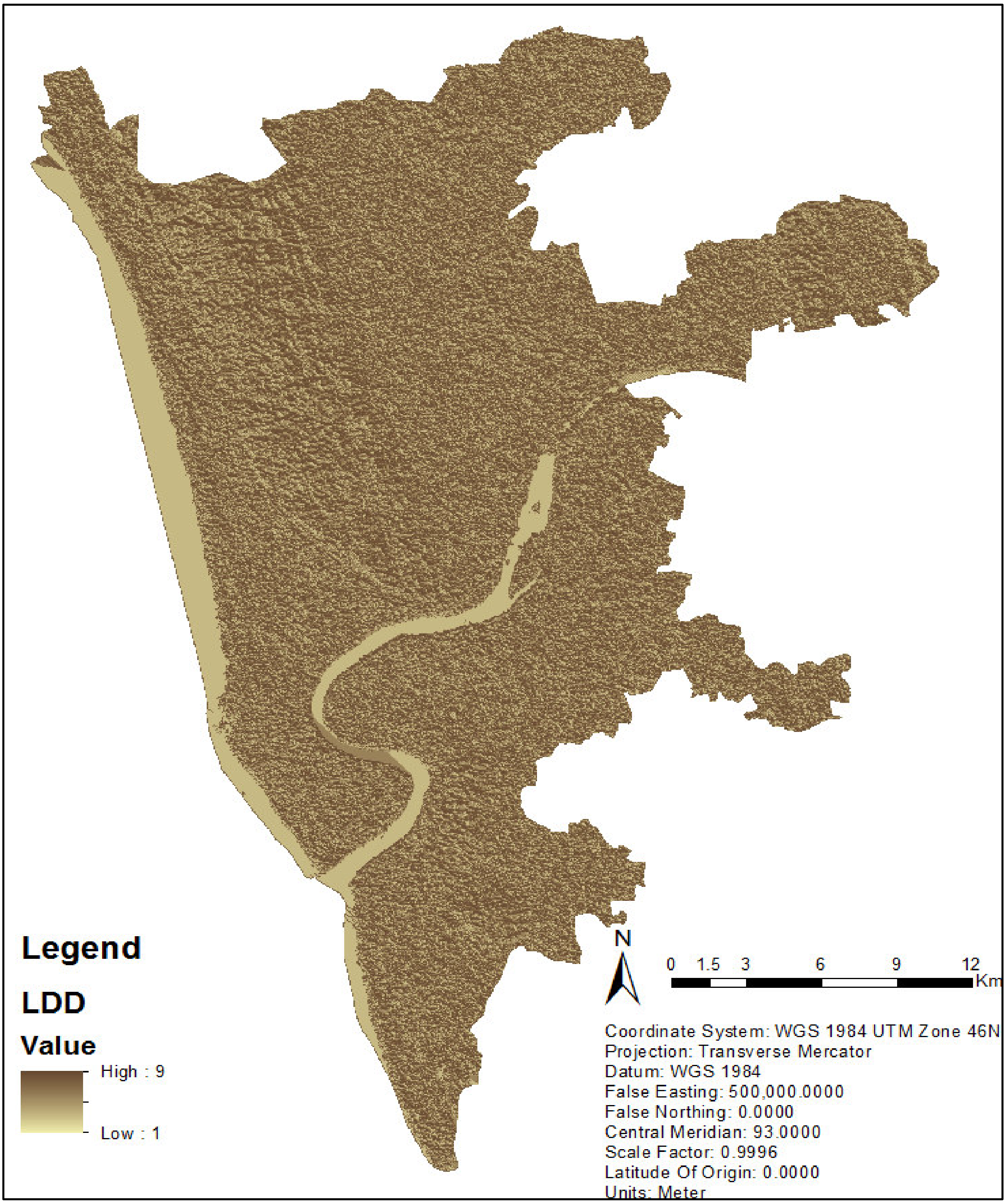
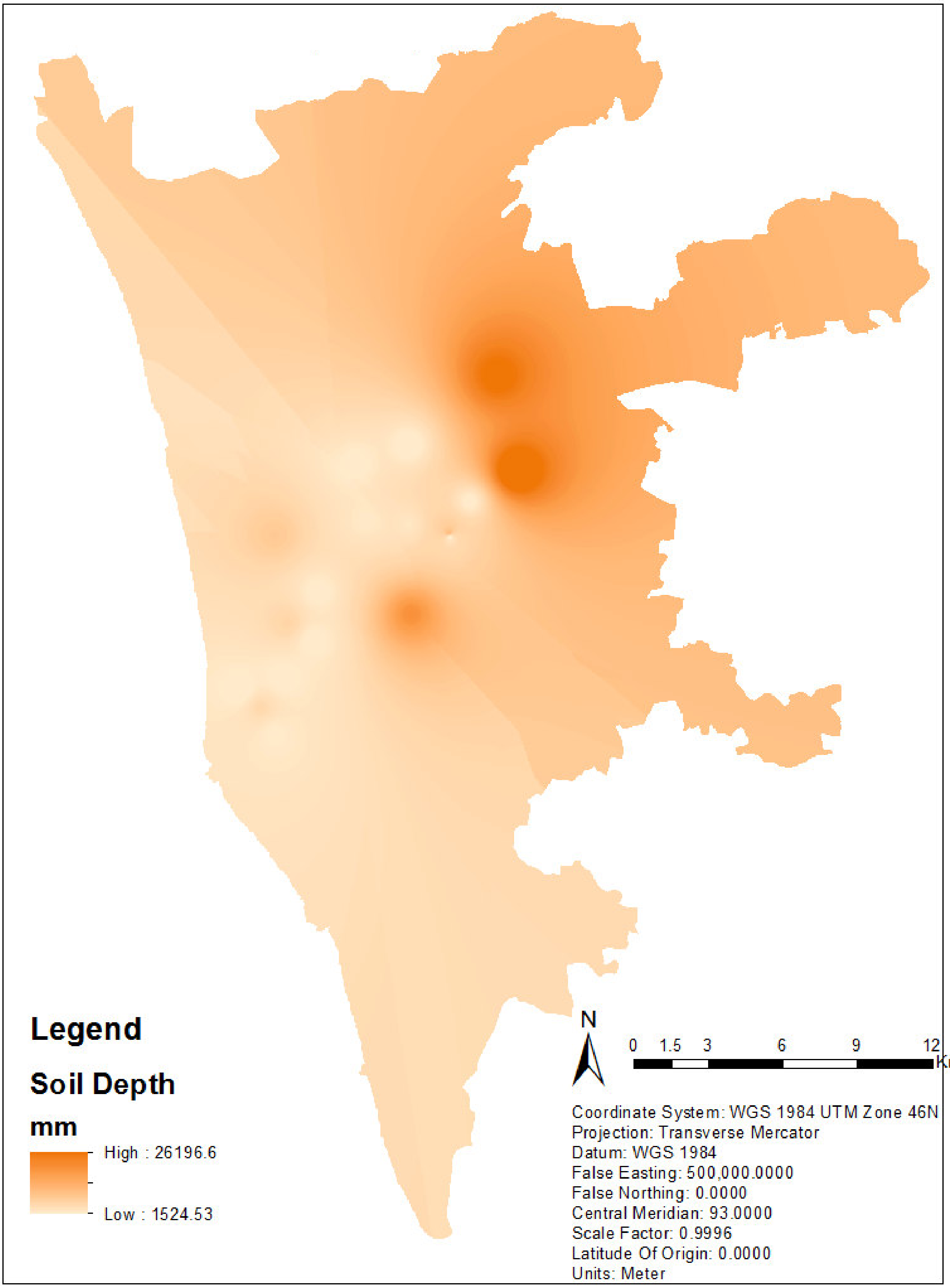


Figure 8.4: Soil Depth Map of Chittagong Metropolitan Area.



8.3.2 Land Cover Mapping

Landsat Thematic Mapper (TM) satellite images were used for the land cover mapping (2010) of Chittagong Hill Tracks (CHT) area. Initially four scenes were collected to cover the whole CHT area. TM sensor collects reflected energy in three visible bands (blue = 1, green = 2, and red = 3) and three infrared bands (two NIR = 4, 5 and one middle infrared = 7). The base year for this land cover mapping is selected as 2010.

Among the four scenes, three were acquired using the Global Visualization Viewer (GLOVIS) of United States Geological Survey (USGS) and the one was from GISTDA (Geo-Informatics and Space Technology Development Agency), Thailand. However, thermal band was not used in this particular study. The details of the scenes used are listed in Table 1.2. All the image-dates are of the dry season in Bangladesh.

The land cover classification methodology for this research is based on 'Object Based Image Analysis (OBIA)'. 'OBIA' is also called 'Geographic Object-Based Image Analysis (GEOBIA)'. 'OBIA' is a sub-discipline of geoinformation science devoted to partitioning remote sensing imagery into meaningful image objects and assessing their characteristics through spatial, spectral and temporal scale. The fundamental step of any object based image analysis is a segmentation of a scene representing an image into image objects. [76, 77]

Table 8.2: Details of the Landsat 4-5 TM scenes of CHT.

Satellite	Sensor	Path	Row	Date (DD/MM/YY)	Source Agency
Landsat 4-5	TM	136	044	08/02/2010	USGS
		136	045	06/12/2009	
		135	045	01/02/2010	GISTDA
		135	046	01/02/2010	

At first, the acquired Landsat TM images were inserted in 'eCognition Developer 64 8.7' software for processing. The ''multi-resolution segmentation'' algorithm was used which consecutively merges pixels or existing image objects that essentially identifies single image objects of one pixel in size and merges them with their neighbours, based on relative homogeneity criteria. Multi-resolution segmentations are those groups of similar pixel values which merges the homogeneous areas into larger objects and heterogeneous areas in smaller ones. [77, 78]

During the classification process, information on spectral values of image layers, vegetation indices like the Normalized Difference Vegetation Index (NDVI) and land water mask which were created through band rationing, slope and texture information were used. Image indices are very important during the image classification. Image rationing is a “synthetic image layer” created from the existing bands of a multispectral image. This new layer often provides unique and valuable information not found in any of the other individual bands. Image index is a calculated results or generated product from satellite band/channels. It is helpful to identify different land cover from mathematical definition [77, 78].

NDVI: One of the commonly used indices and it is related to vegetation is that healthy vegetation reflects very well in the near infrared part of the spectrum. NDVI index values can range from -1.0 to 1.0. NDVI was calculated using the following formula:

$$NDVI = (NIR - red) / (NIR + red) \quad [78]$$

Land and water mask: Land and water mask indices values can range from 0 to 255, but water values typically range between 0 and 50. The land and water mask was created using the formula:

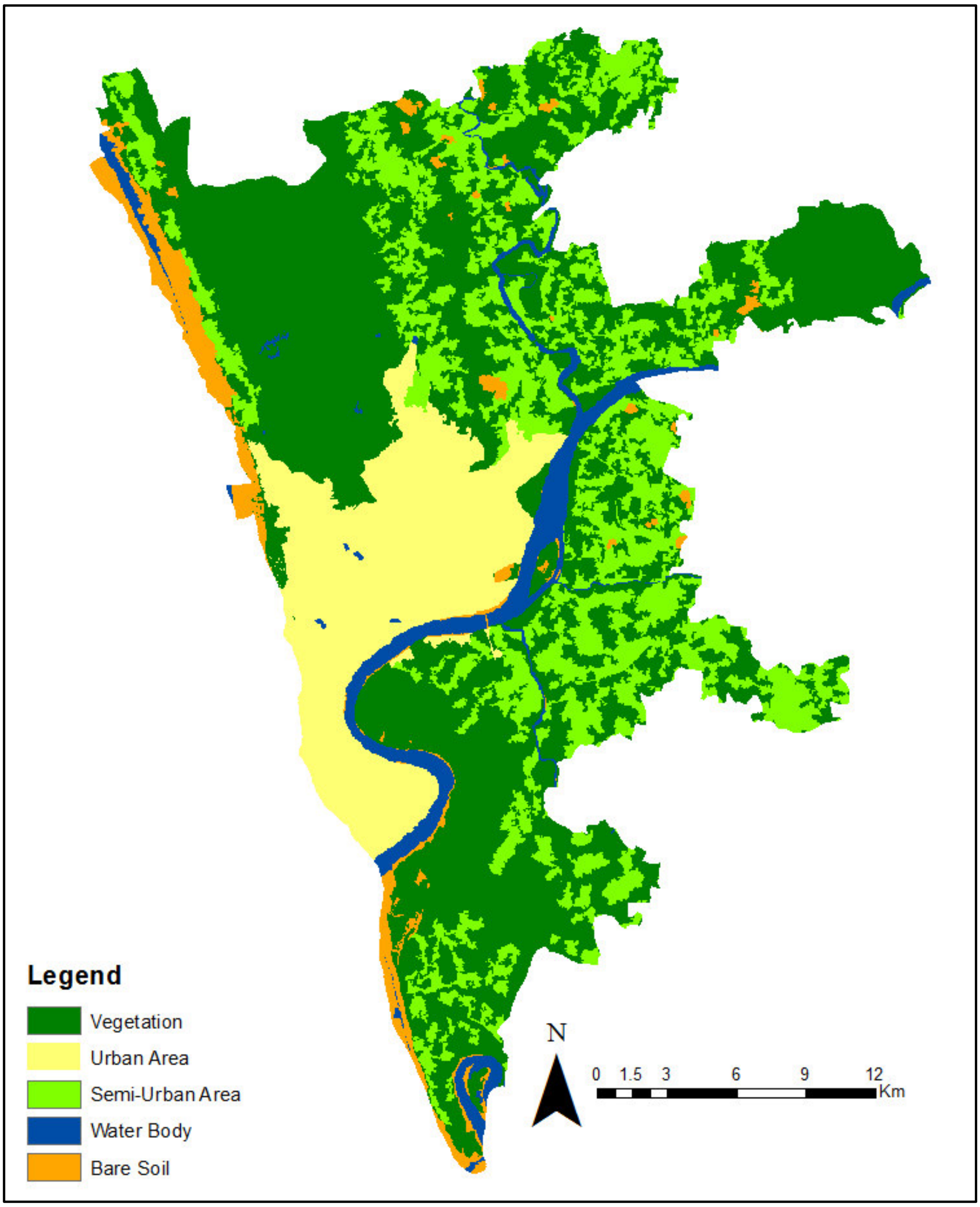
$$Land\ and\ water\ mask: IR/Green*100 \quad [77]$$

The next step is to code these image objects according to their attributes, such as NDVI, Land and water mask, layer value and colour and relative position to other objects using user-defined rules. In this process, selected object that represent patterns were recognized with the help from other sources namely already known ground truthing information and high resolution Google earth images. Normally similar features observed similar spectral responses and unique with respect to all other image objects [78].

After that comparison, features using the ‘2D Feature Space Plot’ were used for correlation of two features from the selected image objects. Developing rule sets investigated single image objects and generated land cover map. Image objects have spectral, shape and hierarchical characteristics and these features are used as sources of information to define the inclusion-or-exclusion parameters used to classify image objects. Over each scene rules were generated for each land cover class and evaluated for their separation, tested for their visual assessment over Google earth images [78].

After ascertaining the class separation using segment based approach, classification is performed to get land cover classification map for each scene. Each scene thus prepared again evaluated with available field data and Google earth image over randomly selected points for accuracy assessment. After finalization of classification of each scene, all the scenes were gone through mosaic to obtain land cover map of CMA. For this research purpose, only 5 broad land cover classes (urban area, semi-urban area, water body, vegetation and bare soil) were chosen (Figure 8.5).

Figure 8.5: Landcover Map of Chittagong Metropolitan Area (CMA).



8.3.3 Preparation of Soil Related Map

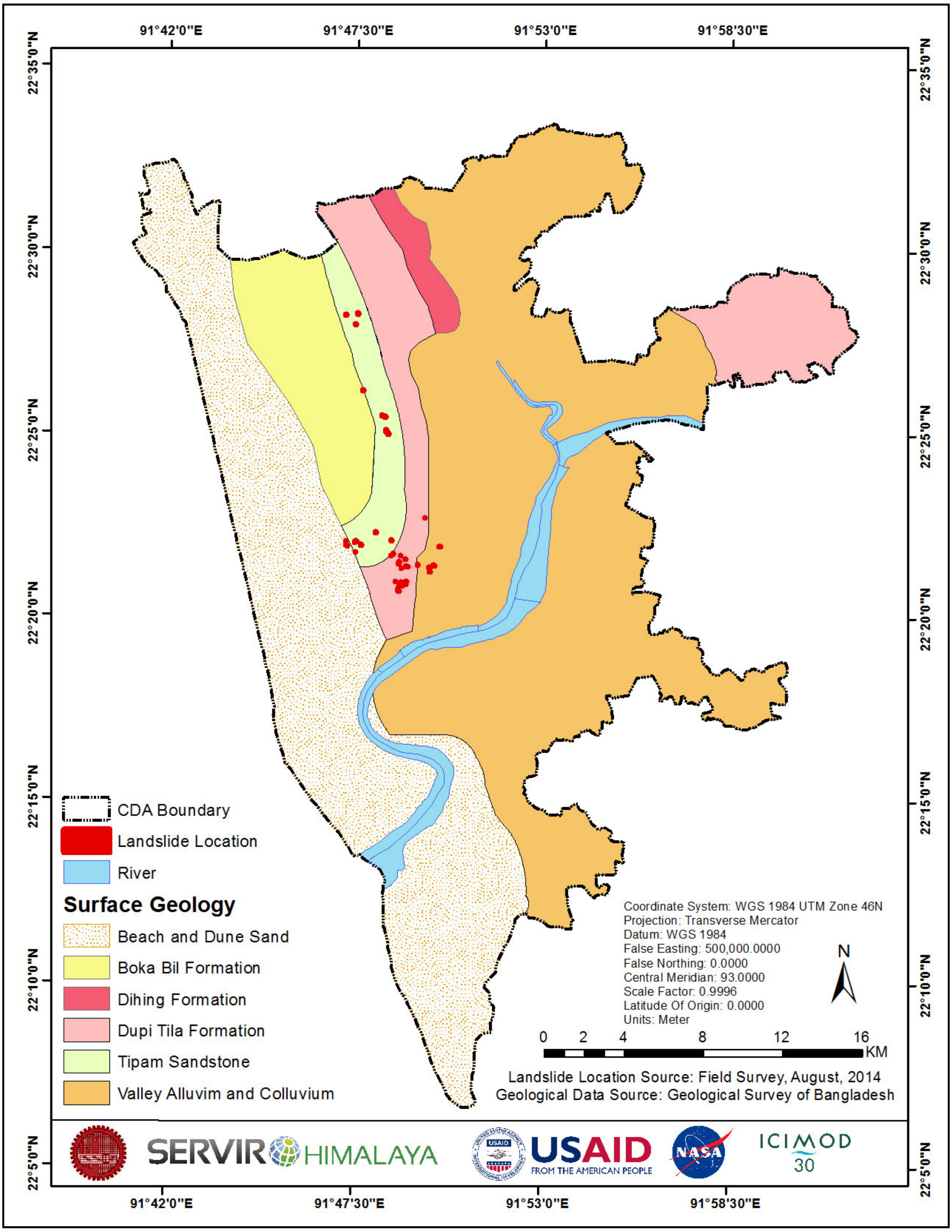
Soil physical characteristics is very much important for this kind of modeling, because soil moisture variations and other processes related to soil layer are strongly related to soil engineering properties. These processes are infiltration, percolation and groundwater flow and slope stability. The soil map of Chittagong Metropolitan Area has six units. Analyzing landslide location with respect to geology it is seen that most of the landslide locations are located in Dulphi tila formation and Tipam sandstone geological class (Figure 8.6). Many soil properties are important in geotechnical discussion. In this study, only the soil properties are considered which is related to hydrology. Only few soil samples were collected from the site and classified them based on the grain size distribution. The texture of the soil depends on the particle size distribution. The soil hydraulic properties are not directly measured. In this case we used Soil Plat Atmosphere and Water (SPAW) model to get some properties such as porosity, saturated hydraulic conductivity, field capacity and wilting point of the soil units. Other properties are collected from laboratory test and available literature (Table 8.3).

Table 8.3: Soil Engineering Properties.

Name of the Unit	Porosity	Field Capacity	Wilting Point	Van Genuchten n-param	Angle of internal friction (radian)	soil cohesion (Kpa)	Specific density regolith kN/m3	Erodi-bility (g/J)
csd	0.53	0.41	0.05	0.19	0.47	2.4	16	2.6
Tbb	0.43	0.35	0.08	0.3	0.67	3.6	16	2
Tt	0.49	0.47	0.08	0.1	0.84	4.2	16	1.7
QTdt	0.52	0.45	0.07	0.1	0.6	4	16	2.2
ava	0.42	0.31	0.09	0.22	0.7	2.7	16	2.1
Qtdi	0.44	0.35	0.06	0.2	0.6	3	16	2.3

Raster map of saturated hydraulic conductivity, map of soil porosity, map of wilting point, map of field capacity, map of internal angle of friction, map of soil specific density and map of soil erodibility have been prepared as attribute map based on soil unit and soil engineering properties. All raster layers have been prepared with 30 m resolution. Each soil unit has related property value in raster cell.

Figure 8.6: Landslide locations in different soil classes of Chittagong Metropolitan Area.



8.3.4 Input of Meteorological Data

At this stage, model will get rainfall value (in mm) as input in rainfall station location. Raster IDW interpolation with power 2 is applied to get the rainfall map for the whole study area. Therefore each cell of raster map gets a rainfall value. As this is a very small area and elevation difference is not too high, the orographic effect is ignored. Only one rainfall data from one station has been considered to run this model. Standard potential evapotranspiration value is considered for this model.

8.3.5 Interception

When rain falls from the sky, some part of the rainfall directly fall on the ground, some part is intercepted by the canopy of natural vegetation and crop. The later part of the rainfall is evaporated directly from the canopy and therefore this is not available for the runoff or groundwater recharge. It can be assumed that the storage capacity of the canopy is related to the total surface area of the leaf [75]. For this kind of area especially where grass and shrubs are dominating, De long and Jetten (2007) established an equation to calculate storage capacity which is Smax=0.912 ln (LAI) +0.703 [79]. Leave area index (LAI) can be calculated from the following equation $C=1-e^{-0.4LAI}$ [80]. This interception of rainfall is used as a storage function which is filling by rainfall and emptying by evaporation. The other part of rainfall which goes directly to the ground contributes to runoff and infiltration.

8.3.6 Infiltration

In this flux of the model some initial value has been considered as arbitrary. Initial soil moisture is considered as half of the wilting point of the soil and one-tenth of soil depth is considered as initial ground water depth to run the model. Residual moisture content (Θr) is considered as 25% of wilting point. Unsaturated soil depth is the soil depth which is not saturated by ground water. Every time step, some part of the rainfall will be infiltrated to the soil which will change the soil moisture and ground water depth. Some part of the rainfall will go to stream as surface runoff. At this stage, soil water storage is calculated from the multiplication of unsaturated depth with the difference of soil porosity (volume of void space) and the initial moisture [75].

8.3.7 Percolation

The remaining water from rainfall after runoff and interception will go downward from surface to groundwater through soil is known as percolation. Percolation is a process to recharge groundwater which is passes through soil layer. The rate of percolation depends upon soil characteristics and soil moisture. Capillary force is responsible to hold water near to pore walls. However, water in the pores can move freely depending on the grain size of the soil. Hydraulic conductivity, the permeability of the soil depends on moisture content and pore size of the soil. Permeability of dry soil is higher than the wet soil. Hydraulic conductivity of fully saturated soil is the maximum value. Following the above concept of flow in the soil, the conductivity of the unsaturated soil is a fraction of the saturated conductivity, but the fraction is a highly non-linear function of the saturated conductivity. This fraction depends on the dimensionless relative degree of saturation (θE) which can be expressed by

$$\theta_E = \frac{\theta - \theta_r}{\theta_s - \theta_r} \sim \frac{\theta}{\theta_E} \quad [75]$$

Where θ (theta) is the volumetric moisture content, θr the residual moisture content (a very small value that is set equal to 25% of the wilting point), and θs is the saturated moisture content, which equals the porosity.

Normally in the soil, water moves under the influence of gravity and differences in suction (capillary forces). The flux is calculated as the unsaturated conductivity K(θE) (in m/s) multiplied by differences in potential dH (suction + gravity) over a given distance in the soil

dz (in m/m): $Q=K(\theta E)*dH/dz$ [75]

This is a form of Darcy equation for vertical flow in a soil column. For simplicity, Jetten and Shrestha (2014) assumed that there are no suction differences acting on the lower boundary of the soil and that the flux downward, the percolation is driven by gravity only. Since gravity changes linearly with depth the total difference in potential simplifies to unity: dH/dz = 1. Therefore, they also assume that the percolation flux equals K(θE). The following equation for of Van Genuchten (1980), is used for the model.

$$K(\theta_E) = Ksat * f(\theta_E) = \mathrm{Ksat}\sqrt{\theta_E}\left[1-(1-\theta_E{}^{\frac{1}{m}})^{\mathrm{m}}\right]^2 \quad [75]$$

Where m is the texture depended parameter with guideline value from Van Genuchten curve.

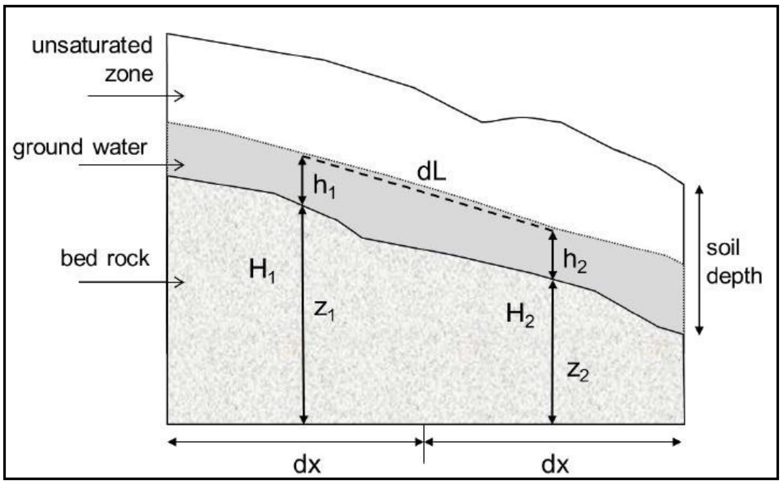
8.3.8 Ground Water Balance

Only top layer property of the soil is considered the property of whole soil. The ground water balance is also a flux where incoming is percolation from the soil layer above and outgoing is flow to neighboring cell. In hydrology, the law of Darcy (1856) is one of the main laws which can be used to calculate water fluxes in the soil. It states that groundwater moves through the soil as a result of differences in hydraulic potential H (in m), caused by gravity. The hydraulic potential H is the sum of the groundwater level h and the absolute elevation at a location z (H=h+z) (Jetten and Shrestha). Below the groundwater table the soil is fully saturated, so the saturated hydraulic conductivity, K(sat) can be used. When there is a difference in hydraulic potential dH between two points (over a distance dL) water will flow from the higher to the lower potential.

$$Q_{GW} = qA = Ksat\left(\frac{dH}{dL}\right)h\,dx = Ksat\left(\frac{dh+dz}{dL}\right)h\,dx \qquad [75]$$

Where QGW is the groundwater flow in m3/s, q is the one dimensional flux in m/s and A is the cross section of flow (m2), which is the product of the cell width dx and the water height h. Ksat is the saturated hydraulic conductivity.

Figure 8.7: Principles of groundwater flow used in our PCRaster model: h1 and h2 are groundwater levels, z1 and z2 absolute elevation above a given datum, dL is the distance between two points along the water surface. [74]



The groundwater flow is based on the difference in hydraulic potential dH (H2-H1) between two points that are spaced dL apart. This is the sum of groundwater layer heights (h2 and h1) and the elevations (z2 and z1) (Figure 8.7).

8.3.9 The Infinite Slope Model

A slope stability map of the Chittagong Metropolitan Area (CMA) can be made based on the "infinite slope" model. There are two forces on a given slope, one is driving force for slope movement and the other is resistance force that holds the slope in position. Here driving force is gravitational force of the slope mass. The driving force is gravity on the mass of the slope. Here, the specific weight of an object is its weight per volume in kN/m3. The value for the specific weight γ is depended on soil type. The weight of a slope element can be decomposed in a vector along the slope, the shear stress τ, and a vector perpendicular to the slope, the normal stress σ. Stress is the term used for force per surface area or F/A (dimension is N/m2). It has the same dimension as pressure. Using the slope angle Θ and material depth h these vectors are defined (Figure 8.8).

Figure 8.8: (a) weight W of a slope segment divided in a normal stress vector σ and shear stress vector τ. (b) Definition of shear stress and normal stress (N/m2) on a slope with a given angle Θ and regolith depth h (m). x = the regolith depth perpendicular to the slope (m) and γ (gamma) is the specific weight (see table 4.1, in kN/m3). [75]

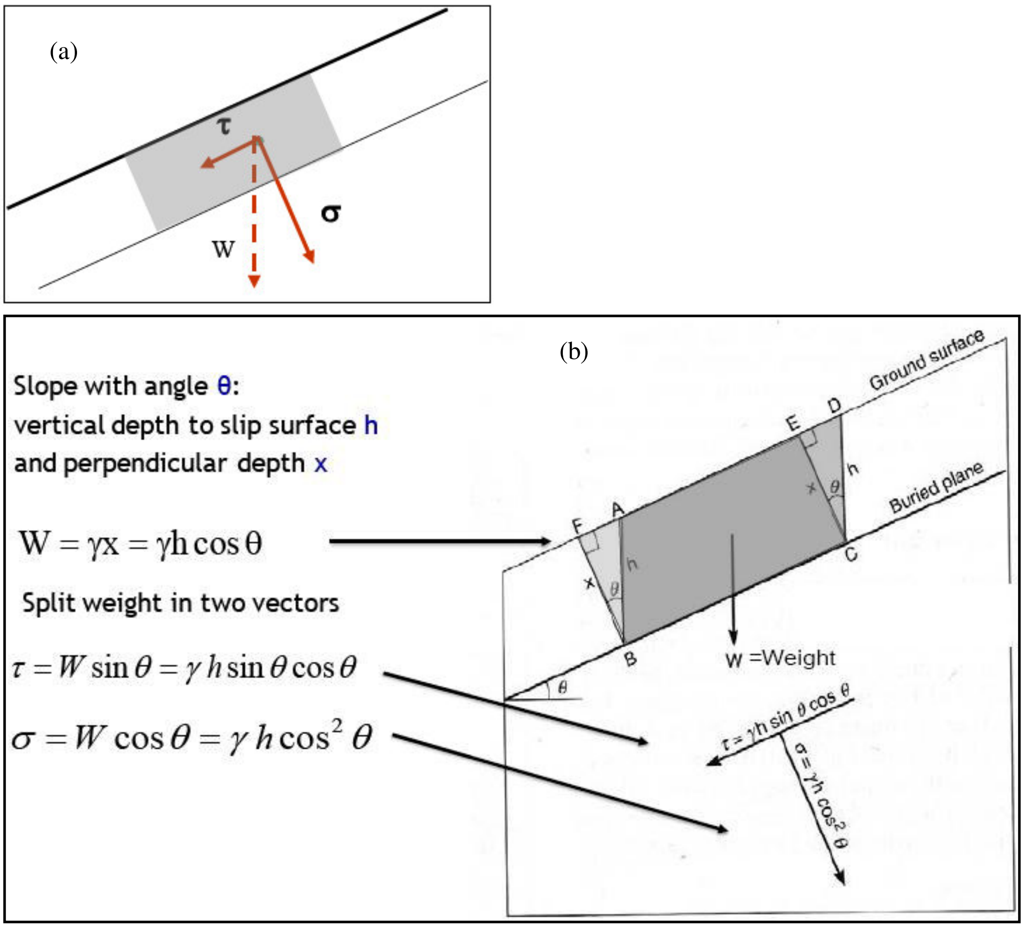


Figure 8.8 shows how the vectors τ and σ are related to the slope angle Θ: the shear stress vector τ = W sin(Θ) while the normal stress vector σ = W cos(Θ). For simplicity, it is assumed here that the potential sliding surface is parallel to the slope surface. Because the soil depth h is measured vertically, while the moving block is perpendicular to a sliding surface the slope with a thickness x, the shear stress is τ = γhsin(Θ)cos(Θ), and the normal stress is σ = γhcos2(Θ).

While shear stress acts on the block to move it downward, it is kept in place by a number of forces that are combined in the shear strength S (the strength of the segment parallel to a potential sliding surface). The shear strength is composed of direct friction caused by weight, which equals the normal stress σ but points in the opposite direction, and other material properties related to strength factors. These are summarized in the law of Mohr-Coulomb, which relates the shear strength S to material properties:

$$S = c + \sigma' \tan(\varphi) \text{.......................i} \quad [75]$$

c=cohesion ()kpa, φ angle of internal friction 'phi' (-), σ'=effective normal stress (kpa).

The effective normal stress $\sigma'$is the normal stress σ decreased by pressure exerted by ground water if that is present in the slope segment.

$$\sigma' = (\gamma - \gamma_w n) h cos^2(\theta) \text{...........ii} \quad [75]$$

Here n= fraction of the segment with thickness h that is saturated with ground water: n=0 means a completely dry segment and n=1 means groundwater reaching the surface.

Combining the equations i and ii we get Factor of Safety (FS)

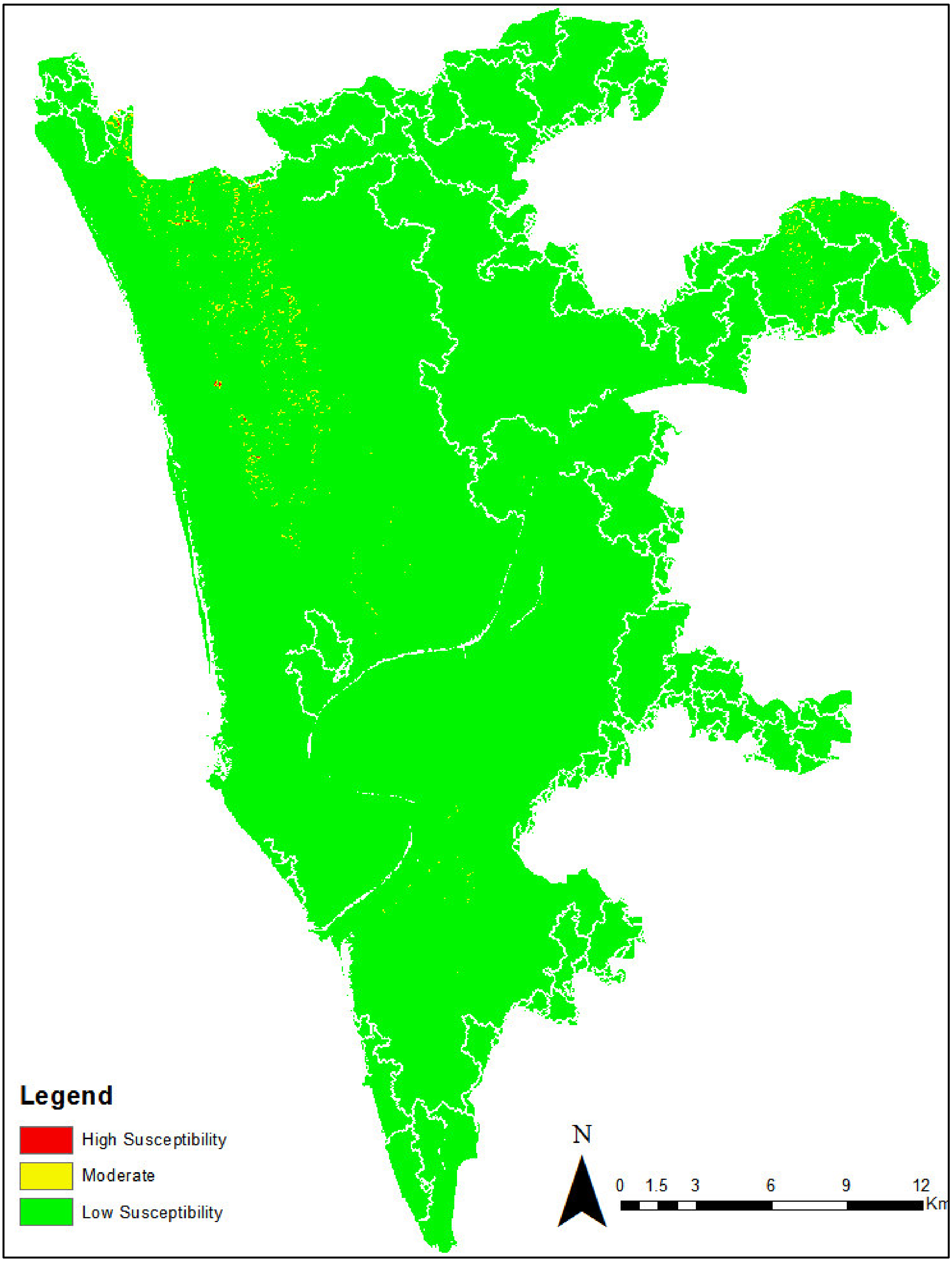
$$\mathrm{FS} = \frac{c + (\gamma - \gamma_w n) h cos^2(\theta) \tan(\varphi)}{\gamma \cos(\Theta) h \sin(\Theta)} \quad [75]$$

Where, FS > 1.0 represents a stable situation and FS < 1.0 denotes failure of soil (soil instability).

8.4 CONCLUSION

Finally through Infinite Slope Model a slope stability map of the study area (CMA) is prepared where the total area is divided into three categories as low, moderate and high susceptible to landslide. From Figure 8.9 we see that highly and moderately susceptible places are in northern-west part in CMA where landslide occurred mostly in previous years (Figure 8.6).

Figure 8.9: Slope Stability Map of Chittagong Metropolitan Area (CMA).



CHAPTER 9: CONCLUSION

Landslide is a common natural damaging disaster occurs in every monsoon in Chittagong Metropolitan Area. The people residing at the hill sides are most vulnerable. It is an urgent necessity of these people to have a scientific early warning before the disaster occurs, so that the people at risks can save their valuable lives and properties. Through this project this need will hopefully be filled by developing dynamic web-GIS based early warning system.

In this report there are descriptions of the step by step research works for the project purpose. The Inventory phase, Social and Community Survey, Soil Investigation, Landcover Modelling, Rainfall Pattern Modelling, Landslide Susceptibility Modelling, Slope Stability Modelling are described in each different chapters.

Firstly, the landslide locations were found out through inventory survey. The social and community study helped to know about the community people and their needs well. Through the soil investigation the types of the soil was known which were helpful in identifying the landslide susceptible locations of CMA. From landcover modeling the change of landcover has been detected from 1990 to 2010. The projected landcover map is produced for 2030. From the rainfall data of Bangladesh Meteorological Department rainfall pattern modeling is done. The slope stability mapping is also a useful part of this project.

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APPENDIX-A

Landslide Investigation Report- 2014

[Modified from- Multinational Andean Project (2009), Landslide Classification System by Cruden and Varnes (1996); and Intensity Scales for Urban Landslide Damage developed by David E. Alexander (1989)]

Basic Information

1. Address/Location:
2. North/Latitude:
3. East/Longitude:
4. Datum:
5. Altitude (MASL):
6. Date(s) of Movement:
7. Rainfall on that day/ week (mm):
8. Area of displaced Mass (m):

Landslide Characteristics

9. Type of Movement
   - Fall
   - Topple
   - Slide
   - Spread
   - Flow
   - Creep

10. State
    - Active
    - Reactivated
    - Suspended
    - Inactive
    - Dormant
    - Abandoned
    - Stabilized
    - Relict

11. Distribution
    - Advancing
    - Retrogressive
    - Widening
    - Confined
    - Diminishing
    - Moving

12. Style
    - Complex
    - Composite
    - Multiple
    - Successive
    - Single

13. Water Content
- Dry
- Moist/ Wet
- Muddy
- Very wet

14. Material
- Rock
- Soil/Earth
- Debris
- Mixture

15. Land Cover Type (%)
- Herbaceous vegetation
- Forest/woodland
- Built over
- Water body
- Bare soil
- Others

16. Land Use Type (%)
- Protected area
- Residential
- Road way
- Vegetation
- Plantation/Forest
- Commercial
- Hills
- Agriculture/grazing
- Barren land
- Others

17. Causes of Movement
- Collapse of slope
- Improper construction work
- Weak/sensitive/weathered material
- Deposition of load on the slope
- Vegetation removal
- Intense rainfall
- Prolonged exceptional rainfall
- Earthquake or tectonic uplift
- Rapid drawdown of floods
- Excavation of slope
- Deforestation
- Irrigation
- Water leakage from utilities
- Artificial vibration
- Natural subterranean erosion
- Improper disposal of debris
- Poor maintenance of drainage
- Others

Damage Assessment

18. Number of Death:

19. Number of Injury:

20. Number of buildings damaged/ destroyed

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21. Buildings/Infrastructure- Damage Intensity

- None
- Negligible
- Light
- Moderate
- Serious
- Very serious
- Partial collapse
- Total collapse

22. Electricity, Gas, Water and Sewer Mains-Damage Intensity

- None
- Light
- Moderate
- Serious
- Destruction I
- Destruction II

23. Roads- Damage Intensity

- None
- Negligible
- Light
- Moderate
- Serious
- Destruction I
- Destruction II

24. Economic Activity- Damage Intensity

- Light damage
- Moderate damage
- Severe damage
- Total destruction
- Not quantifiable

25. Additional Comments (Landslide History, Surrounding Settlement Pattern, People's Socio-Economic Condition, Geology, Slope Characteristics, Drainage System, Soil Characteristics, Land Use, and Future Risks etc.)

Questionnaire for Human Ecology to Landslide Risks Surveying - 2014

BASIC INFORMATION

Serial No:
Date:…………………………, Time:
Interviewee Details:
Present Address (street level): ………………………………………………………………
Previous Address (street level): ……………………………………………………………..

PHYSICAL ASPECTS

1. Have you come to live here because of
   - Flood
   - Drought/ Famine
   - Eviction/ Relocation by force
   - Employment/ Business
   - Cyclone
   - River erosion
   - Sea level rise
   - Others………..
2. When and why have you settled in this area?
3. How old is this settlement (surrounding neighbourhood)? If possible please tell in brief the land-use change of this area?
4. Do you own this property? If not, who is the owner?
5. Did you build your own house (number of storeys)? If not, who built it?
6. What is your house made of?
   - Bamboo
   - Brick/ Concrete/ Cement
   - Wood
   - Clay/ Thatch
   - Tin
   - Others…………….
7. For what purpose do you use the hill or its surrounding area?
   - Housing
   - Agriculture
   - Recreation
   - Commercial activity
   - Tree plantation/ Forestry
   - Others……………………
8. Do you need to travel to your place of work? How far?

9. What is the distance to your nearest community facilities (e.g. School, Market, Bank, Playground; Health Care Centre etc.)?

10. Are the roads adequate in this area?

11. Is there necessary drainage facility in this area?

12. Do you have water, electricity; sanitation and gas facilities in this house? *(Please circle)*

SOCIO-ECONOMIC ASPECTS

13. What is the main source of your household income?
    - Garment worker
    - Rickshaw puller
    - Office work
    - Day labour
    - House maid
    - Others.......................

14. Please give details of the household members: (Indicate the household head by a tick-mark and interviewee with a star-mark)

Relation	Sex	Age (Years)	Level of Education	Occupation	Avg. Monthly Income (Taka)	Avg. Monthly Expenditure (Taka)

15. Do you pay rent for this land/ house/ property? If yes, how much?

16. Do you get any sort of financial help from any of your family member(s) living or working in another place in Bangladesh? If yes, from where, how frequently and how much?

17. Do you get remittance from any of your family member(s) living or working in abroad? If yes, from which country, how frequently and how much?

18. Do you borrow micro-credit/ loan? If yes, from which micro-finance institution(s) (MFI)/ Bank? For what purpose you use it? Please give details.

Name of MFI/Bank	Target Group	Issuing of Membership	Admission Fees	Load Detail	Interest Rate	Payback Rules	Insurance/ Other Facilities

19. Do you face any other threats living in this area?
- Terrorism
- Social insecurity
- Political violence
- Theft/ Robbery
- Water Logging
- Lack of Utility Facilities
- Drugs or illegal business
- Eviction for illegal occupancy
- Inadequate Road/Drain
- Others...
...

20. What are the advantages of living here?
- Better job/ business opportunity
- Less living expenses
- Close to city centre
- Nearer to community facilities
- Higher living standard
- Others...

21. Do you think that you will be in a more problematic situation if you are relocated or evicted from here? If yes, what problems you will face?

22. How can you improve your living standard if you stay here?

REAL LIFE EXPERIENCE

23. Are landslides a problem here?
- Very serious
- Serious
- Moderate
- No

24. If yes, who are vulnerable to landslide hazards? (Community/Gender/Age)

25. How frequently do landslides occur in this area?

26. What are the triggering factors of landslides?
- Hill cutting
- Deforestation
- High precipitation
- Agricultural activities
- Residential use
- Supernatural event
- God/ Religious belief
- Earthquakes/ Flash flood
- Construction of road/ structure
- Others...........................

27. What are the negative impacts of landslides?

- Houses destroyed
- Property damaged
- Road blocked
- People died
- People injured/stranded
- Loss of economy
- Loss of job
- Mental disorder
- Damage of utility facilities
- Relocation
- Low living standard
- Others.................................

28. When was the last landslide you observed? Where you were then? What was your immediate response?

29. Are you a victim of landslide? If yes- when (date and time), where, how many of your family members/ others were injured or died; and how many houses were destroyed or damaged?

30. Do you think you remain vulnerable to landslide risks? Why or why not?

LANDSLIDE RISK MANAGEMENT

31. What are the positive impacts of monsoon rains in this area?

32. What are the negative impacts of monsoon rains in this area?

33. Do you relocate somewhere else in the time of monsoon rains? If yes please give details- [Where, how far, who provide the facility; do you need to pay any rent, what benefits you get or problems you face there, how long you can stay there etc.]

34. Is there any (landslide related) voluntary committee/ NGO located near to you?

35. Who offers the emergency services during landslides?

- Family members
- Friends
- Neighbours
- Community groups
- Volunteers/ rescue team
- Police/ army
- Fire service
- City corporation officials
- NGOs/ other agencies
- Others....................

36. Was the rescue effort good enough? If not, why?

37. Do the victims get any help or compensation? If yes; what and from whom? If not, why?

38. Have you ever participated in any disaster preparedness training/drill/workshop? If yes, explain.

39. Is there any early (landslide/flooding) warning system in this area?

40. How do you get the meteorological news/ warning/ information related to landslides?

- Radio
- Television
- Local agencies/ volunteers
- Newspaper/ press
- Announcement through Mike
- Others.............................

41. What do you do after getting an early warning?

42. Do you have the contact number of the nearest fire service/ police station/ volunteer groups/ emergency services/ relevant agencies? If not, why?

43. How the landslide risks can be reduced in this area?

44. Do you and your family, or does the local community, have any plans to reduce the risk of landslides in the future?

45. Is there anything you would like to add that might be of interest? (e.g. ethical, religious, myth or cultural issues; capacity building/ resilience, what Govt. can do for you; facing other disasters, how community can help providing safer housing, good governance etc.)?

Key Informant Survey Questionnaire- 2014

Serial No:

Designation: ....

1. Do you think the urbanized hilly areas are vulnerable to landslides?

2. If yes, who are vulnerable to landslides?

3. What are the causative factors of landslides (Please Rank)? Please explain.
    - Hill cutting
    - Deforestation
    - High precipitation
    - Govt. policies
    - No landuse zoning
    - Not implementing master plan
    - Lack of good governance
    - Lack of coordination
    - Political unrest
    - Corruption
    - Agricultural activities
    - Residential use
    - Earthquakes
    - Lack of manpower
    - No early warning system
    - No proper monitoring
    - Illegal occupation of land
    - Poorly constructed houses
    - Construction of road/ structure
    - Others.......................

4. Is there any early warning system for the people at risk? If not, why?

5. What steps are taken/ can be taken in case of landslide hazards-

   Preparedness-

   Response-

   Recovery-

Mitigation-

6. Please explain, what measures can be taken to reduce landslide vulnerability at-

Individual/ Household Level-

Community Level-

Government Level-

International Level-

7. Do you think a balance between the general people's opinion and policy makers decision is needed for a better outcome? If yes, how it can be achieved? If no, why?

8. What are the main things that stop landslides from being brought under control?

9. What is the future plan of your organization/ yourself to reduce landslide risks?

10. Is there anything you would like to share that may be of interest?

APPENDIX B

FIELD PHOTOGRAPHS

Figure 1. : Measuring displacement of mass.

Figure 2. : Taking Photographs.

Figure 3 : Taking GPS value

Figure 4: Taking GPS value

Figure 5: Discussion on Project activities

Figure 6: A victim describing landslide event occurred in 2007 at Motijharna Area

Figure 7: A victim describing landslide event occurred in 2007 at Lebu Bagan Area

Figure 8: Discussion with local child

Figure 9 and10: Interviewing Key Informant

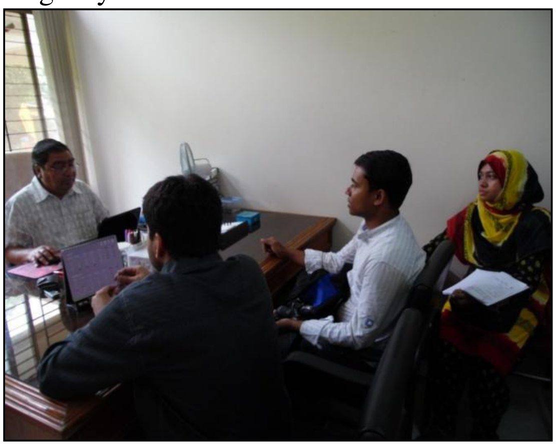


Figure 11 : Interviewing the people

Figure 12: Interviewing the people in Batali Hill area

Figure 13 : Interviewing the people

Figure 14: Interviewing people in Golpahar area

Figure 15: Interviewing people in Moti Jharna

Figure 16: Community survey in Moti Jharna

Figure 17: View exchange meeting among ICIMOD, CDA and BUET-JIDPUS project team. Organized by Chittagong Development Authority (CDA) on September, 2014

APPENDIX C

SATELLITE IMAGES OF THE LOCATIONS OF CLUSTER

Figure 1: Cluster- 1 (Moti Jharna Area)

Source: *Google earth and field survey August, 2014*

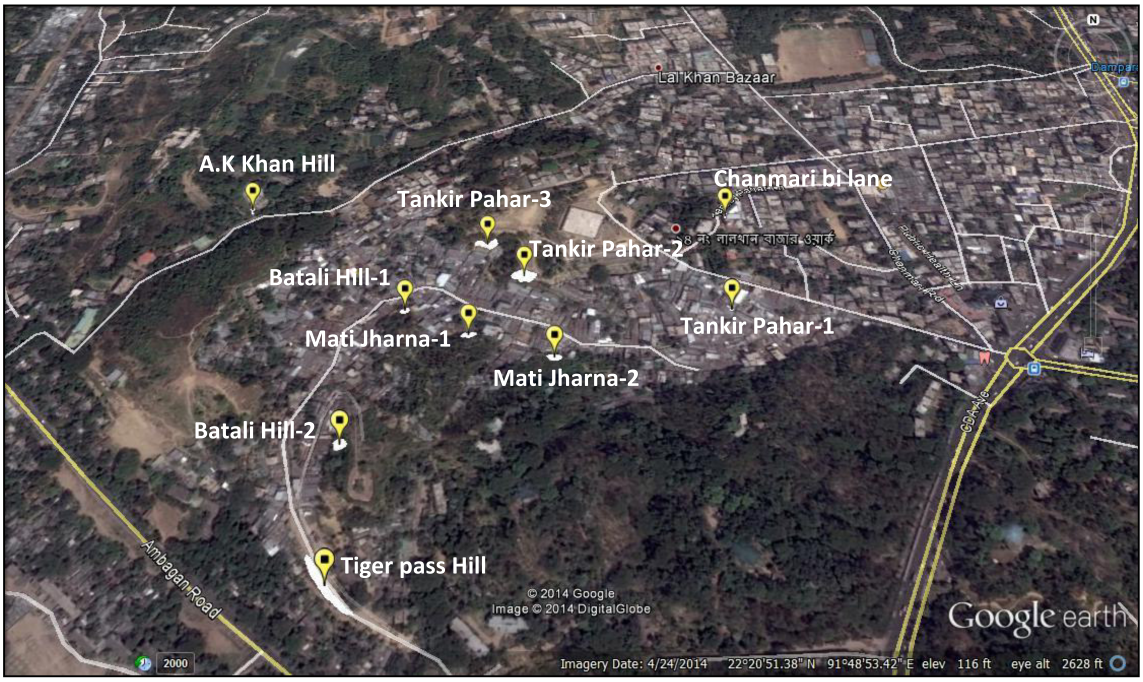


Figure 2: Cluster- 2 (Chittagong Cantonment Area)

Source: *Google earth and field survey August, 2014*

Figure 3: Cluster- 3 (Kushumbagh Area)
Source: *Google earth and field survey August, 2014*

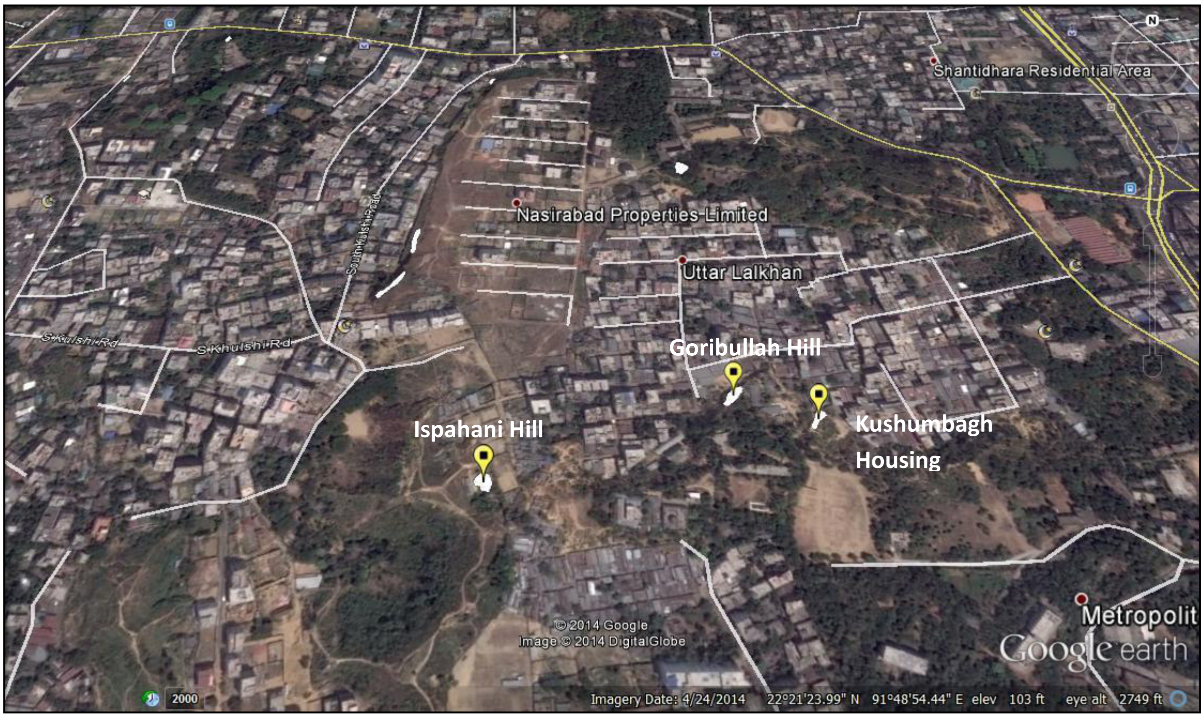


Figure 4: Cluster- 4 (Chittagong University Campus Area)
Source: *Google earth and field survey August, 2014*

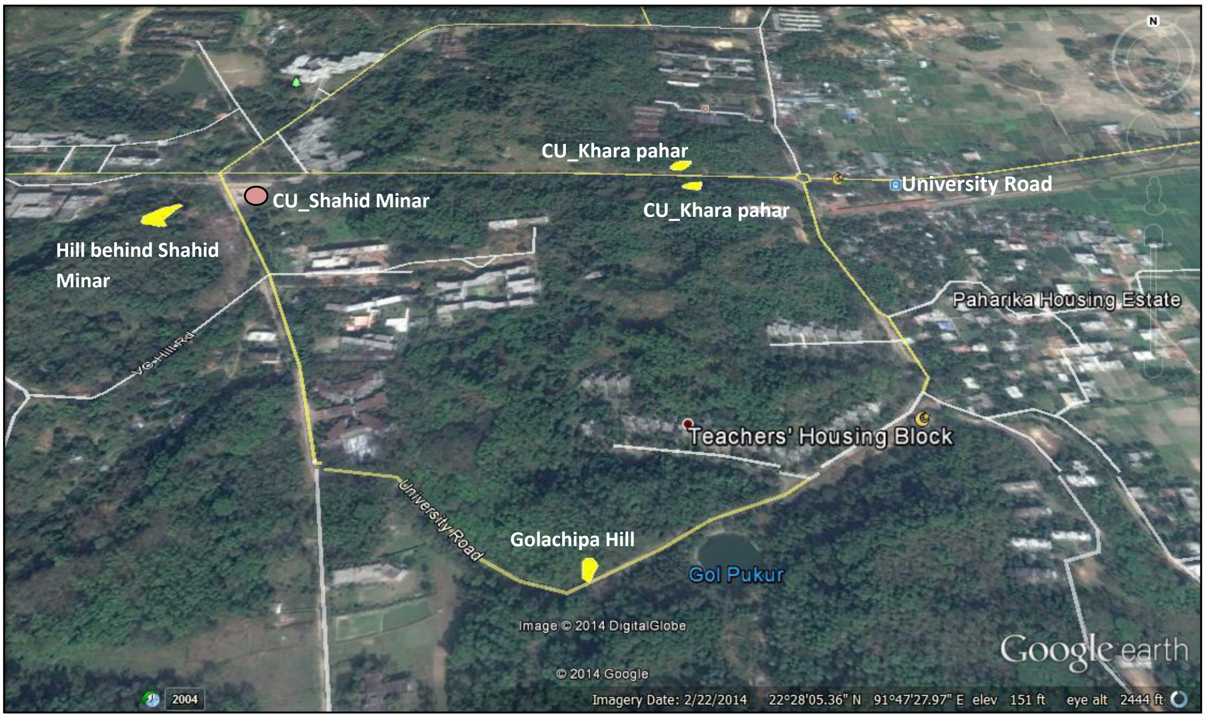


Figure 5: Cluster-5 (Akbar Shah Mazar Area)
Source: *Google earth and field survey August, 2014*

Figure 6: Cluster- 6 (Foy's Lake Area)
Source: *Google earth and field survey August, 2014*

Figure 7: Cluster- 7 (Khulshi Area)
Source: *Google earth and field survey August, 2014*

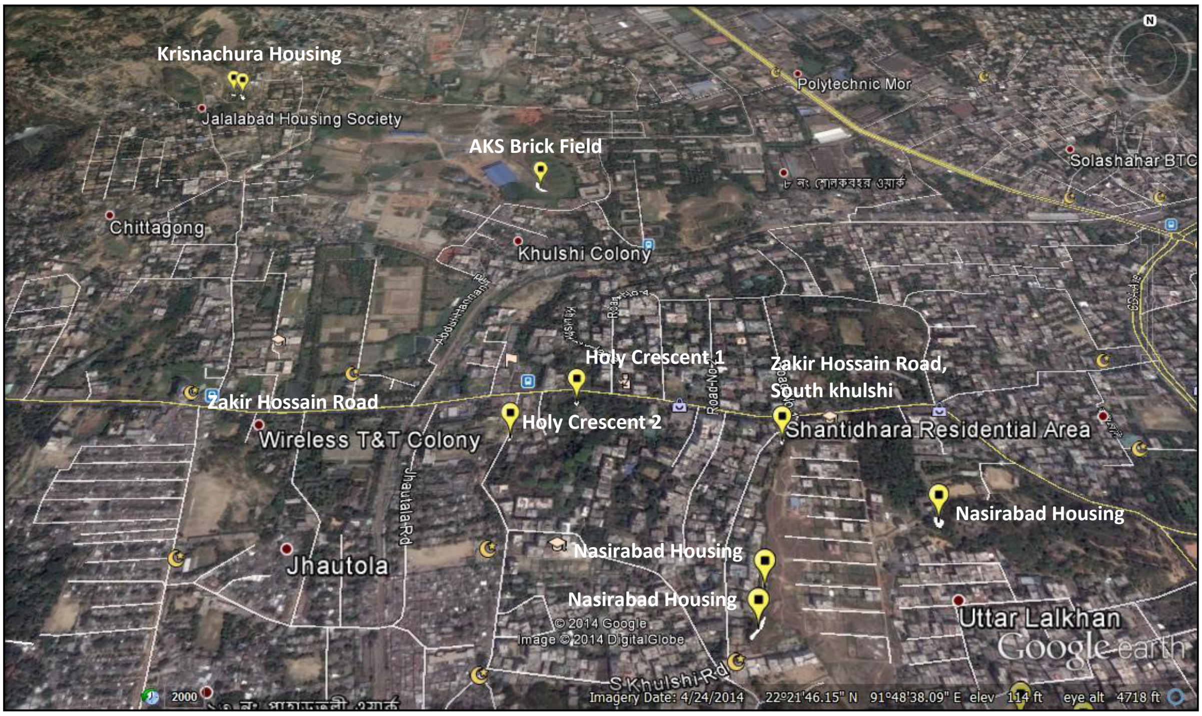


Figure 8: Cluster- 8 (Chatteswari Area)
Source: *Google earth and field survey August, 2014*

Figure 9: Cluster- 9 (Pachlaish Area)
Source: *Google earth and field survey August, 2014*

APPENDIX-D

DATA FROM SOCIAL SURVEY

STUDY AREA: CHITTAGONG METROPOLITAN AREA.

Figure 1: Gender of the respondents

Source: Field Survey, September, 2014

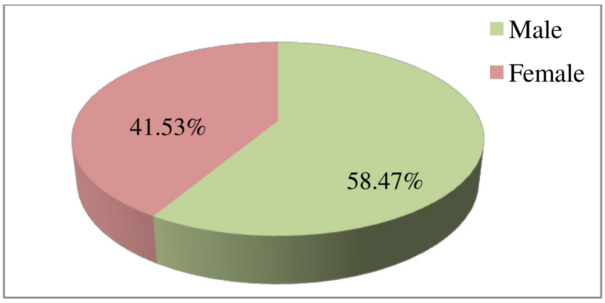


Figure 2: Age of the respondents.

Source: Field Survey, September, 2014

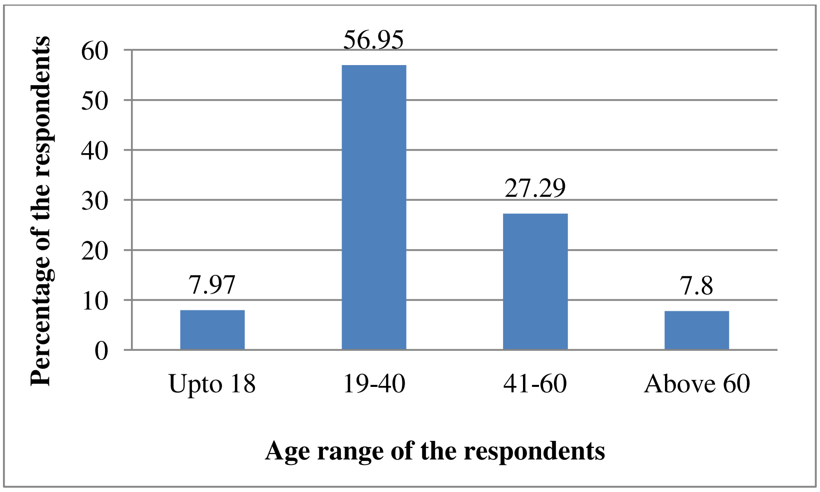


Table 1: Migration status of the inhabitants of Moti Jharna area.

Source: Field Survey, August, 2014

Previous address	Number of respondents	Percentage
Barisal	29	4.9
Bhola	4	0.7
Brahmanbaria	13	2.2
Chandpur	24	4.1
Chittagong	235	39.8
Comilla	83	14.1
Cox's Bazar	5	0.8
Dhaka	7	1.2
Faridpur	3	0.5
Feni	6	1.0
Gaibandha	4	0.7
Gopalganj	2	0.3
Jessore	2	0.3
Khagrachari	3	0.5
Khulna	3	0.5
Kishoreganj	3	0.5
Kushtia	1	0.2
Lakshmipur	2	0.3
Madaripur	1	0.2
Munshiganj	1	0.2
Mymensingh	2	0.3
Narayanganj	2	0.3
Narsingdi	3	0.5
Nepal	1	0.2
Noakhali	53	9.0
Other Area	83	14.1
Pirojpur	1	0.2
Rangamati	1	0.2
Rangpur	3	0.5
Shariatpur	2	0.3
Sylhet	6	1.0
Tangail	2	0.3
Total	**590**	**100**

Figure 3: Respondents' duration to reside in the study area.

Source: Field Survey, September, 2014

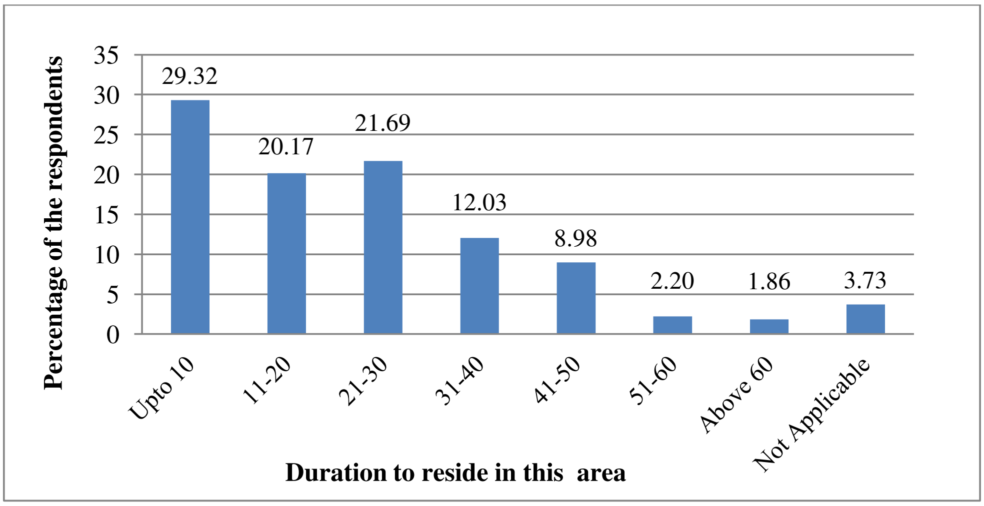


Figure 4: Respondents' opinion about the establishment of the settlement in Moti Jharna area.

Source: Field Survey, September, 2014

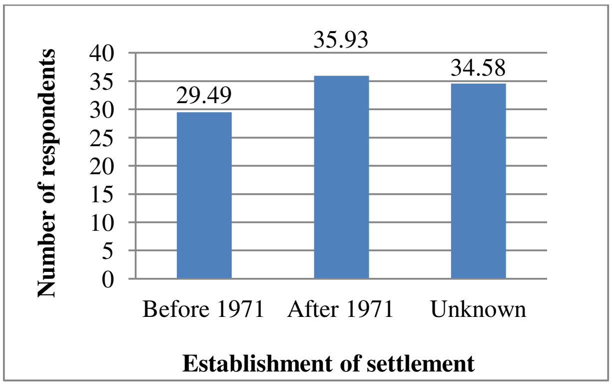


Table 2: Respondents' opinion about land ownership, house builders and rent payment.

Source: Field Survey, September, 2014

Respondents' opinion	Ownership of the land		Builders of the houses		Status of rent payment	
	Number	%	Number	%	Number	%
Yes	152	25.76	271	45.93	315	53.39
No	438	74.24	319	54.07	275	46.61
Total	**590**	**100**	**590**	**100**	**590**	**100**

Table 3: Respondents' opinion regarding financial help.

Source: Field Survey, September, 2014

Respondents' opinion	Financial help within Bangladesh		Financial help from Abroad		Help from micro-credit/ loan	
	Number	%	Number	%	Number	%
Yes	20	3.39	23	3.90	142	24.07
No	570	96.61	567	96.10	448	75.93
Total	**590**	**100**	**590**	**100**	**590**	**100**

Table 4: Interval of landslide occurrence in CMA.

Source: Field Survey, September, 2014

Interval of landslide occurrence	Number of respondents	Percentage
Once per year	254	43.05
Twice a year	5	0.85
Thrice a year	2	0.34
2 years' interval	19	3.22
3 years' interval	30	5.08
4 years' interval	8	1.36
5 years' & above interval	18	3.05
Sometimes	27	4.58
No idea	33	5.59
No answer	194	32.88
Total	**590**	**100**

Table 5: Respondents' opinion regarding last landslide observance, remain vulnerable to landslide risk and relocation during monsoon rain.

Source: Field Survey, September, 2014

Respondents' opinion	Last landslide observed		Remain in vulnerable to landslide risk		Relocation during monsoon rain	
	Number	Percentage	Number	Percentage	Number	Percentage
Yes	352	59.66	140	23.73	66	11.19
No	238	40.34	450	76.27	524	88.81
Total	**590**	**100**	**590**	**100**	**590**	**100**

Figure 5: Relocation during monsoon rain

Source: Field Survey, September, 2014

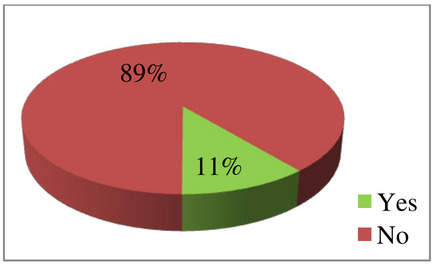


Table 6: Duration of stay in the relocation place.

Source: Field Survey, September, 2014

Duration of stay in relocation place	**Number of respondents**	**Percentage**
2-3 days	14	21.21
3-4 days	2	3.03
7 days	6	9.09
10-15 days	5	7.58
2 months	4	6.06
3 months	2	3.03
4-5 months	1	1.52
As wish	1	1.52
Heavy rainfall time	9	13.64
No answer	11	33.33
Total	**66**	**100**

Table 7: Existence of landslide voluntary committee, early warning system for landslide, contact number of emergency services.

Source: Field Survey, September, 2014

Respondents' opinion	**Existence of landslide voluntary committee**		**Existence of early warning system for landslide**		**If have the contact number of the nearest fire service/ police station/ volunteer groups/ emergency services/ relevant agencies**	
	Number	**Percentage**	**Number**	**Percentage**	**Number**	**Percentage**
Yes	41	6.95	545	92.37	92	15.59
No	549	93.05	45	7.63	498	84.41
Total	**590**	**100**	**590**	**100**	**590**	**100**

Table 8: Satisfactory level of rescue effort and status of victims' getting compensation.

Source: Field Survey, September, 2014

Respondents' opinion	Respondents' satisfactory level of the rescue effort		Victims' compensation getting status	
	Number	Percentage	Number	Percentage
Yes	320	54.24	182	30.85
No	118	20.00	240	40.68
No answer/ Unknown	152	25.76	168	28.47
Total	**590**	**100**	**590**	**100**

Table 9: Respondents' suggestion.

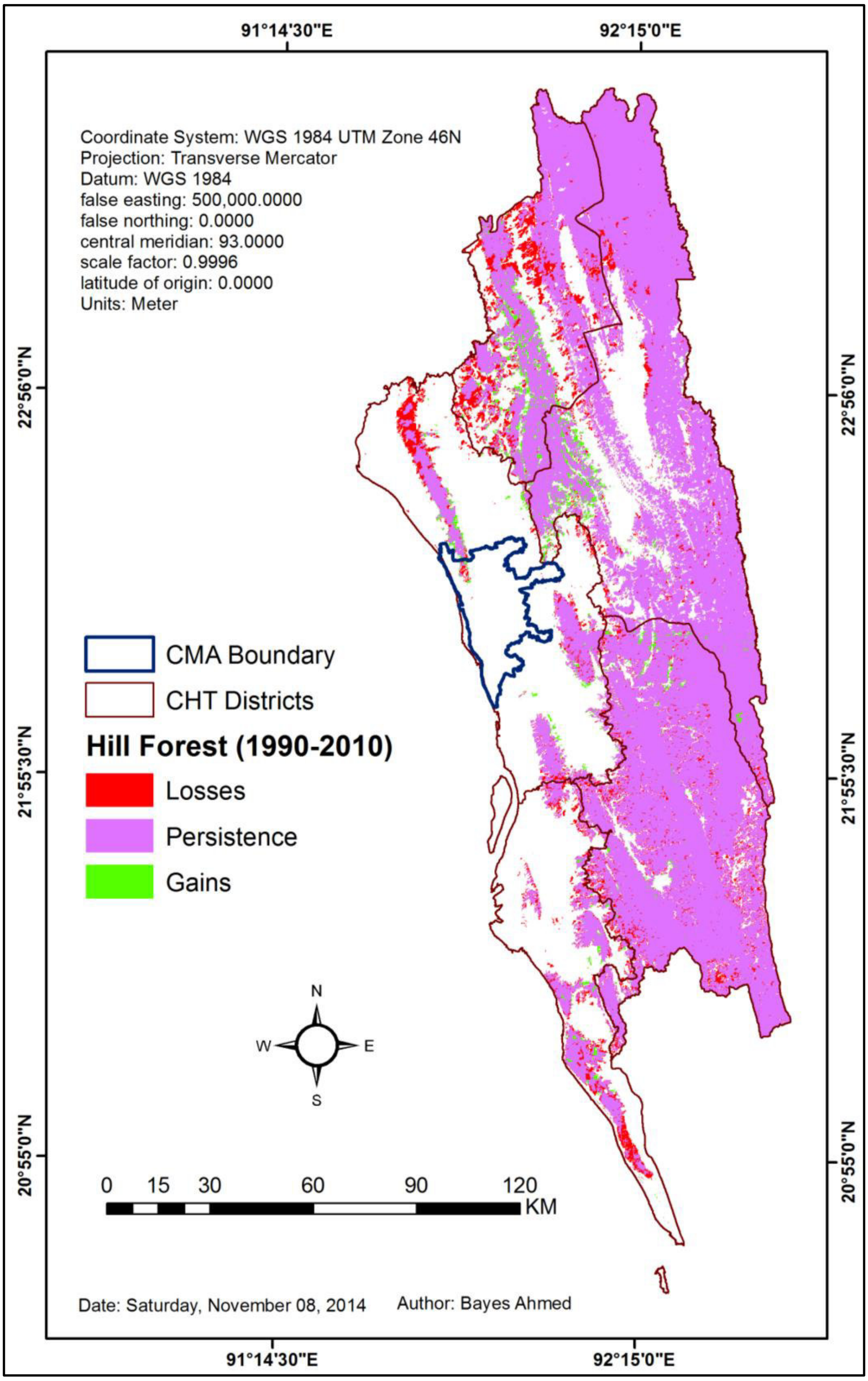
Source: Field Survey, September, 2014

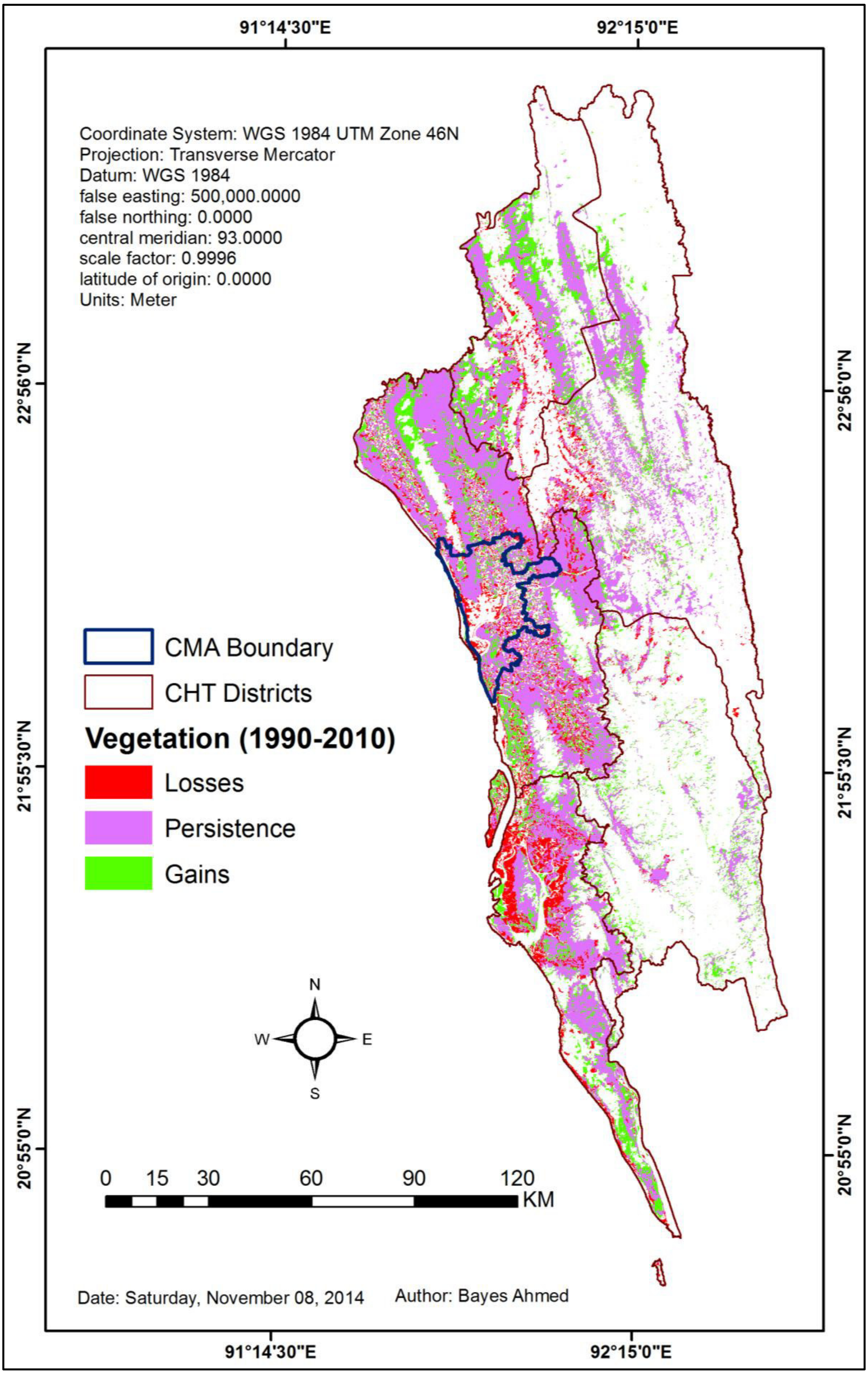
Suggestion	Number of respondents	Percentage
Job security for women and establish a school	1	0.17
Planned administration needed, commissioner is corrupted, encroach land	1	0.17
Police disturbance to victim	1	0.17
Relocate the vulnerable people	4	0.68
No suggestion	583	98.81
Total	**590**	**100**

APPENDIX E: OUTCOME FROM DIFFERENT MODELING

LAND COVER MODELLING

Appendix-E.1: Maps Showing the Transitions of Land Cover Types (1990-2010)

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92°15'0"E
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Projection: Transverse Mercator
Datum: WGS 1984
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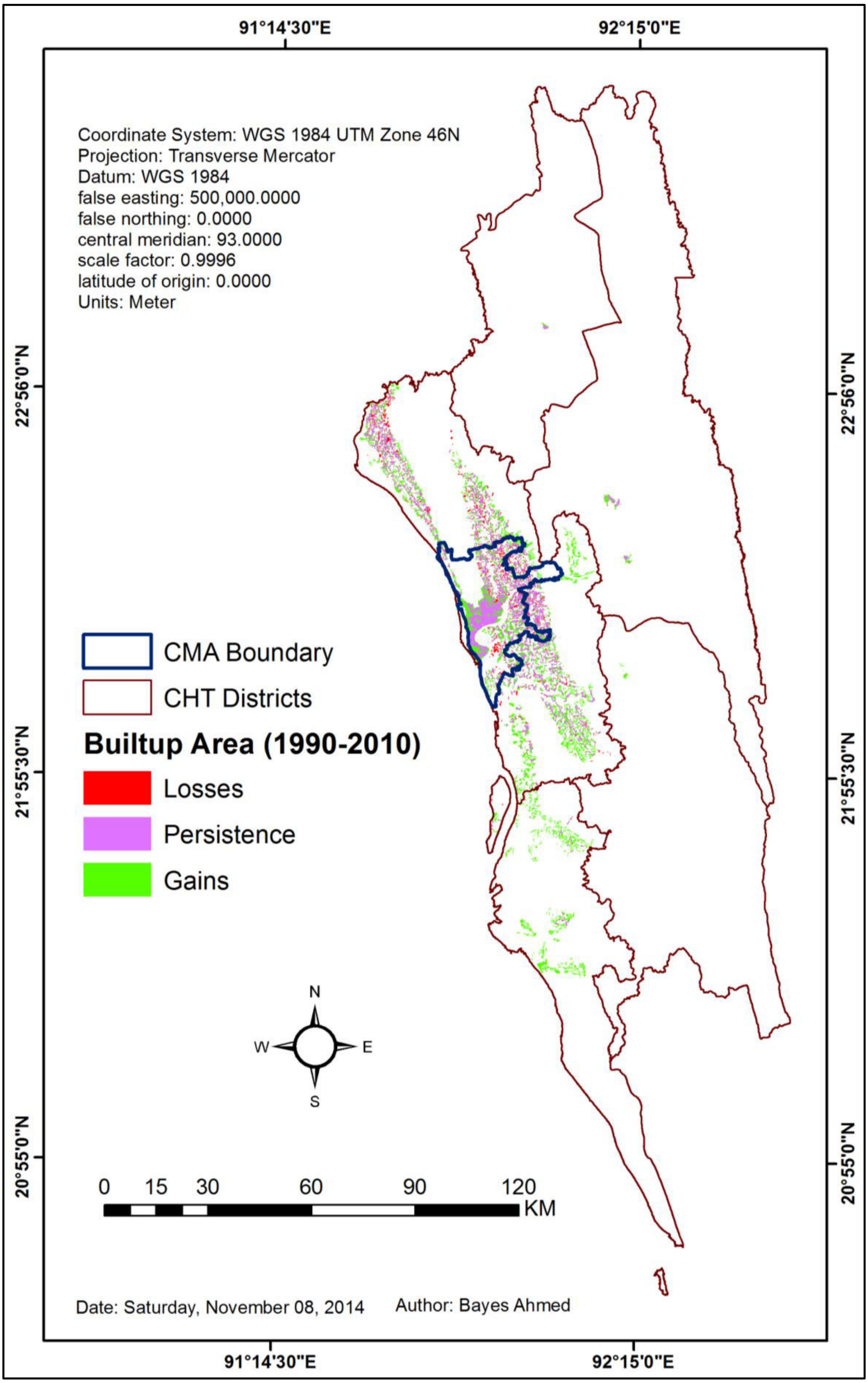
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
22°56'0"N
21°55'30"N
20°55'0"N
CMA Boundary
CHT Districts
Vegetation (1990-2010)
Losses
Persistence
Gains
N
W
E
S
0 15 30 60 90 120
KM
Date: Saturday, November 08, 2014
Author: Bayes Ahmed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92°15'0"E
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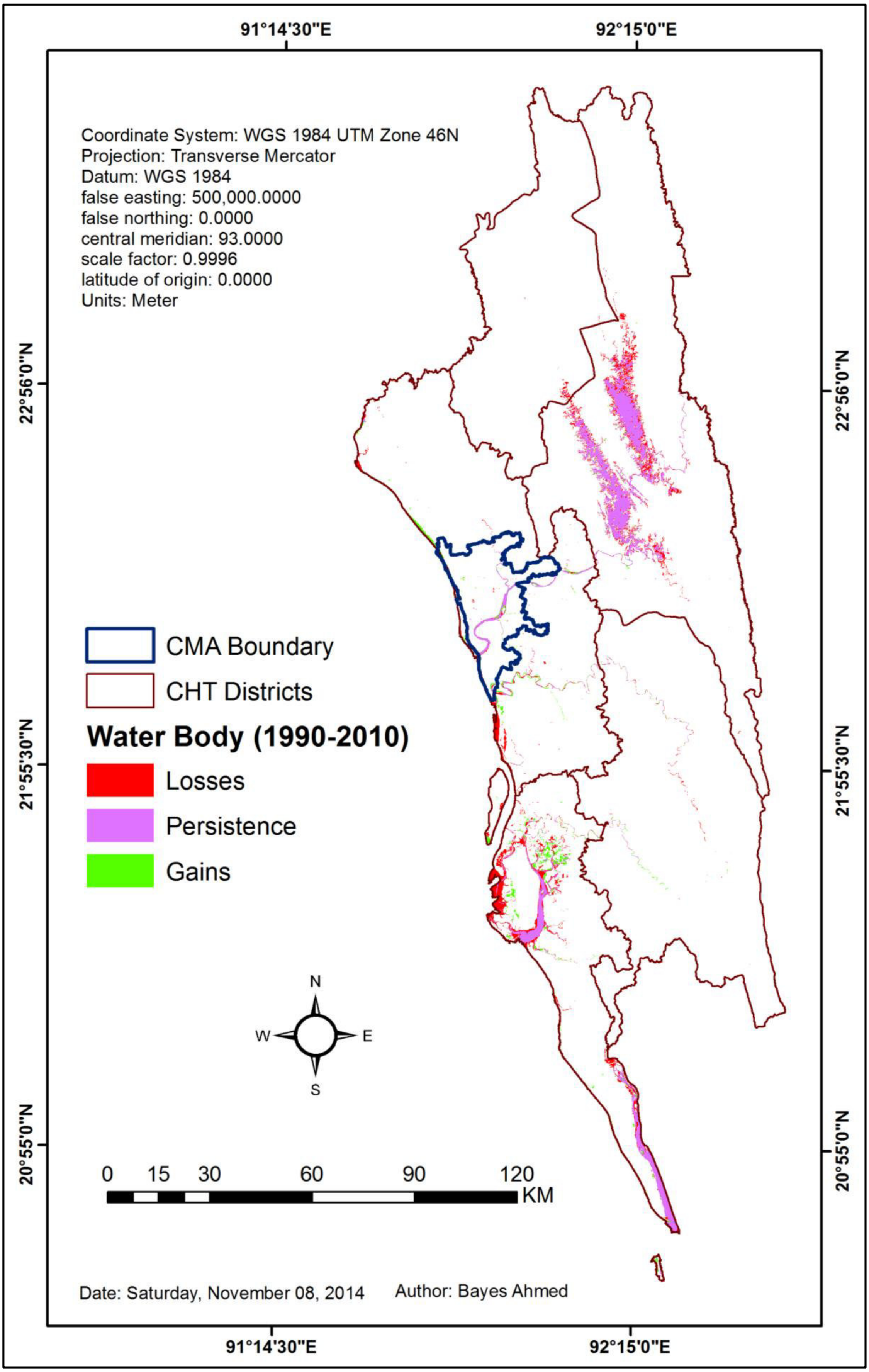
Projection: Transverse Mercator
Datum: WGS 1984
false easting: 500,000.0000
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
22°56'0"N
21°55'30"N
20°55'0"N
CMA Boundary
CHT Districts
Builtup Area (1990-2010)
Losses
Persistence
Gains
N
W
E
S
0 15 30 60 90 120
KM
Date: Saturday, November 08, 2014
Author: Bayes Ahmed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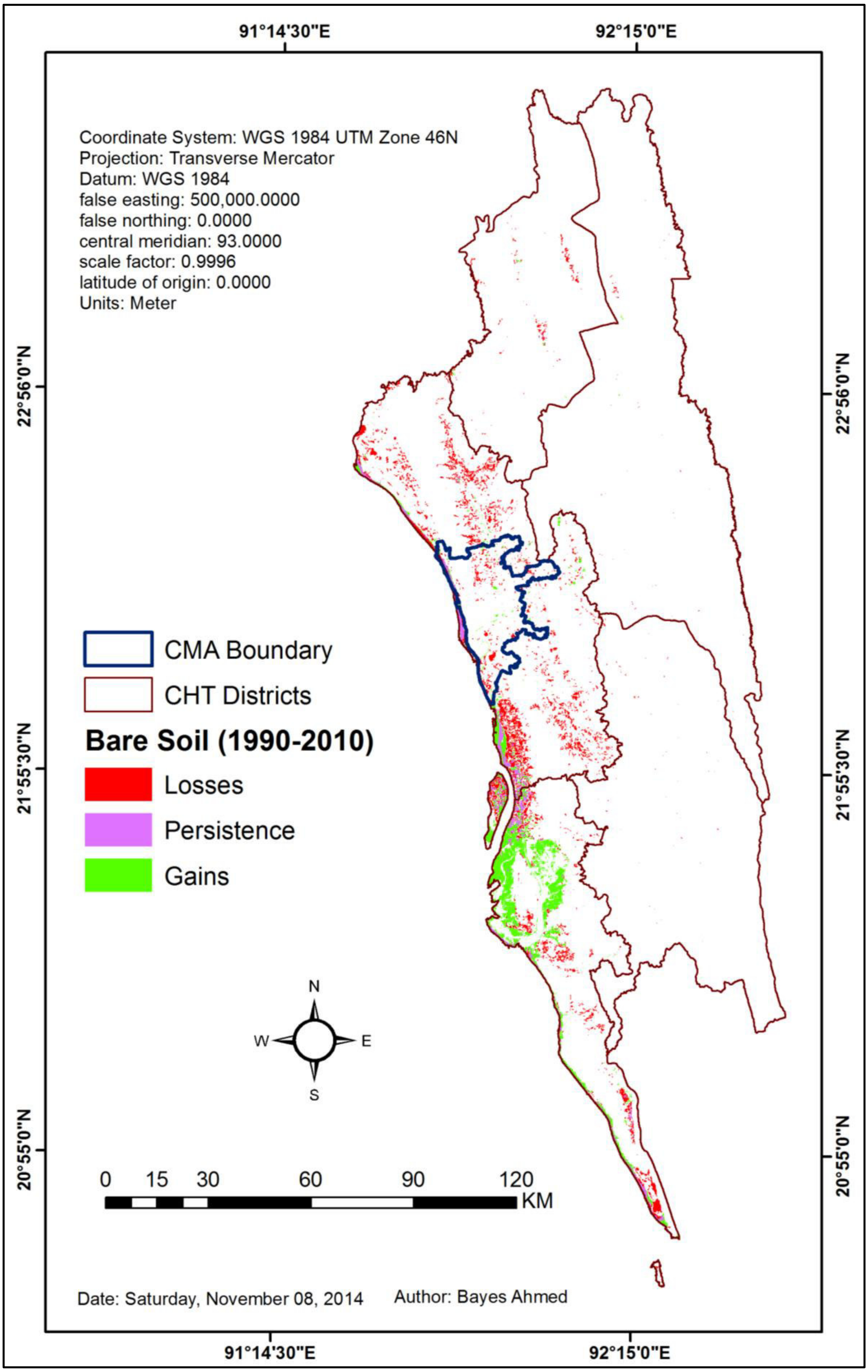
92°15'0"E
Coordinate System: WGS 1984 UTM Zone 46N
Projection: Transverse Mercator
Datum: WGS 1984
false easting: 500,000.0000
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
22°56'0"N
21°55'30"N
20°55'0"N
CMA Boundary
CHT Districts
Water Body (1990-2010)
Losses
Persistence
Gains
N
W
E
S
0 15 30 60 90 120
KM
Date: Saturday, November 08, 2014
Author: Bayes Ahmed



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92°15'0"E
Coordinate System: WGS 1984 UTM Zone 46N
Projection: Transverse Mercator
Datum: WGS 1984
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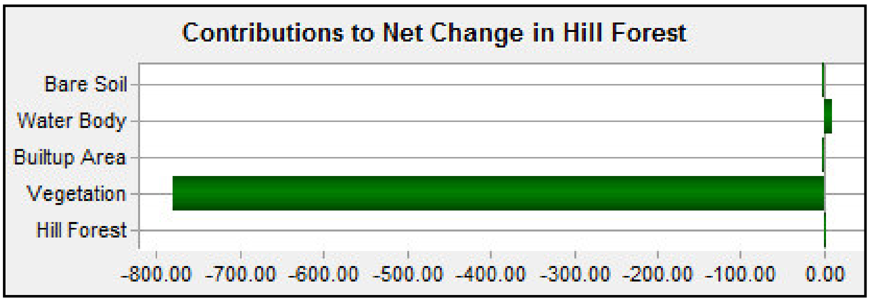
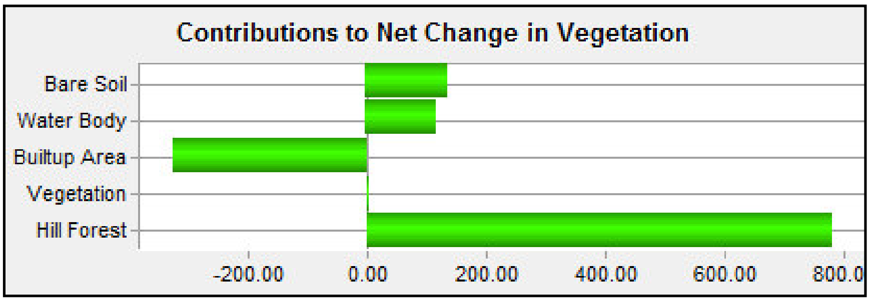
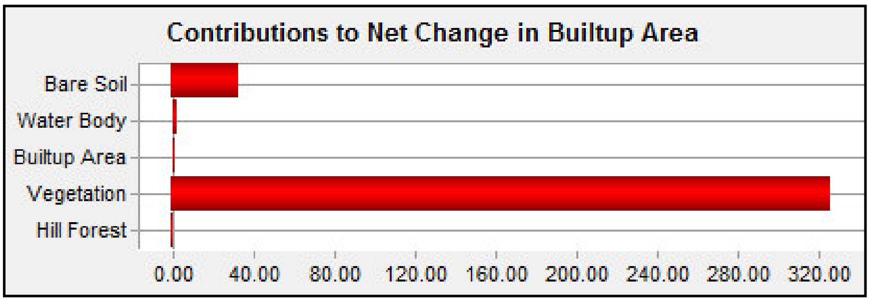
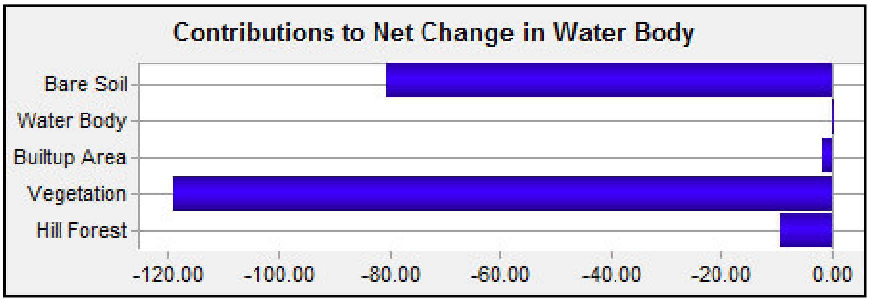
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
22°56'0"N
21°55'30"N
20°55'0"N
CMA Boundary
CHT Districts
Bare Soil (1990-2010)
Losses
Persistence
Gains
N
W
E
S
0 15 30 60 90 120
KM
Date: Saturday, November 08, 2014
Author: Bayes Ahmed

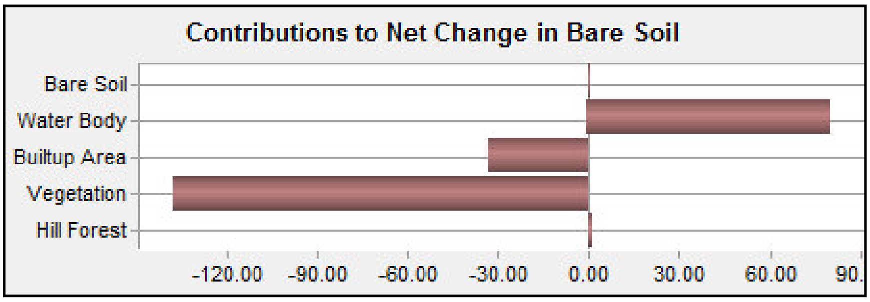
Appendix-E.2: Contributions to Different Land Cover Types in CHT (1990-2010).



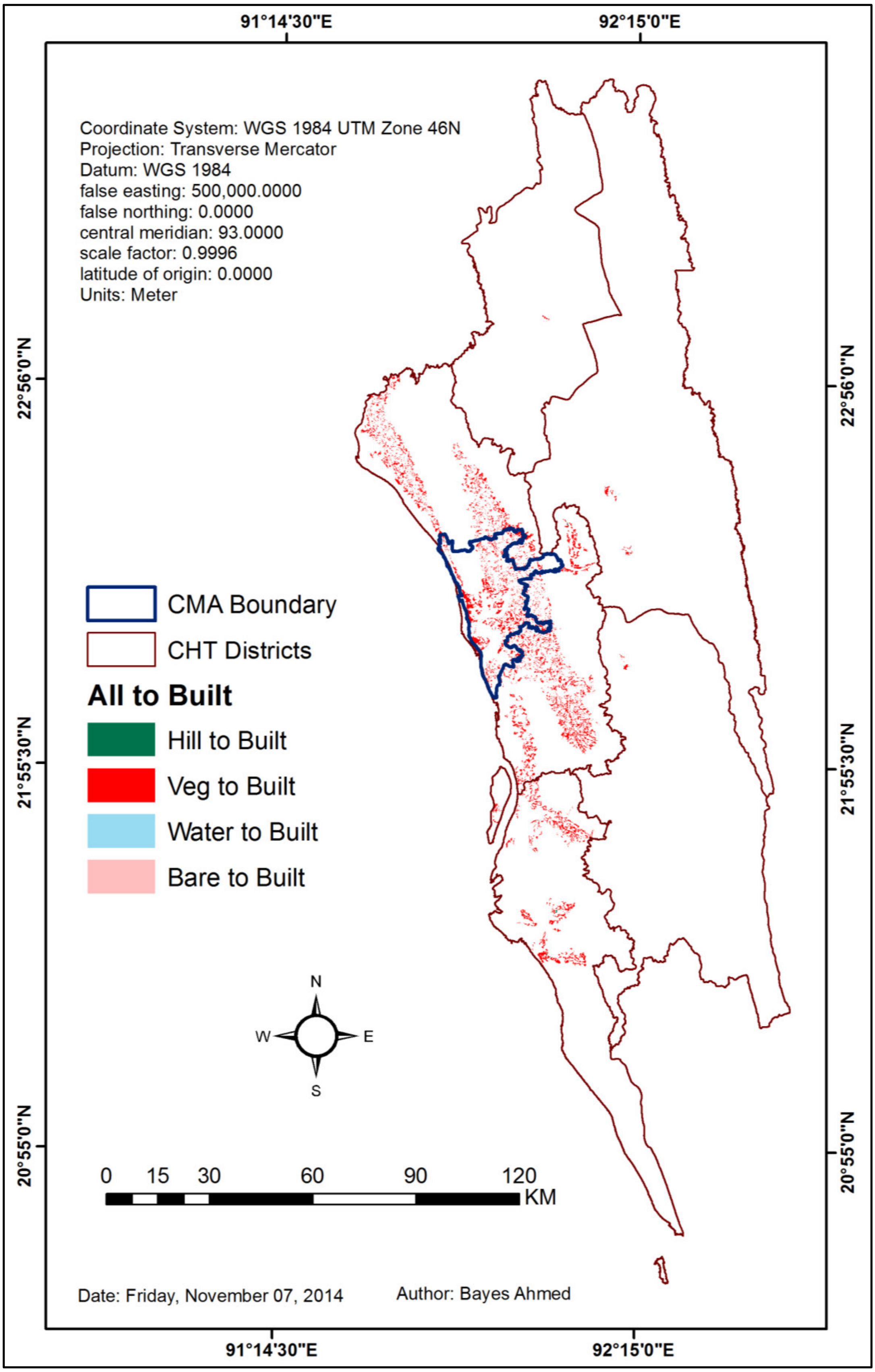


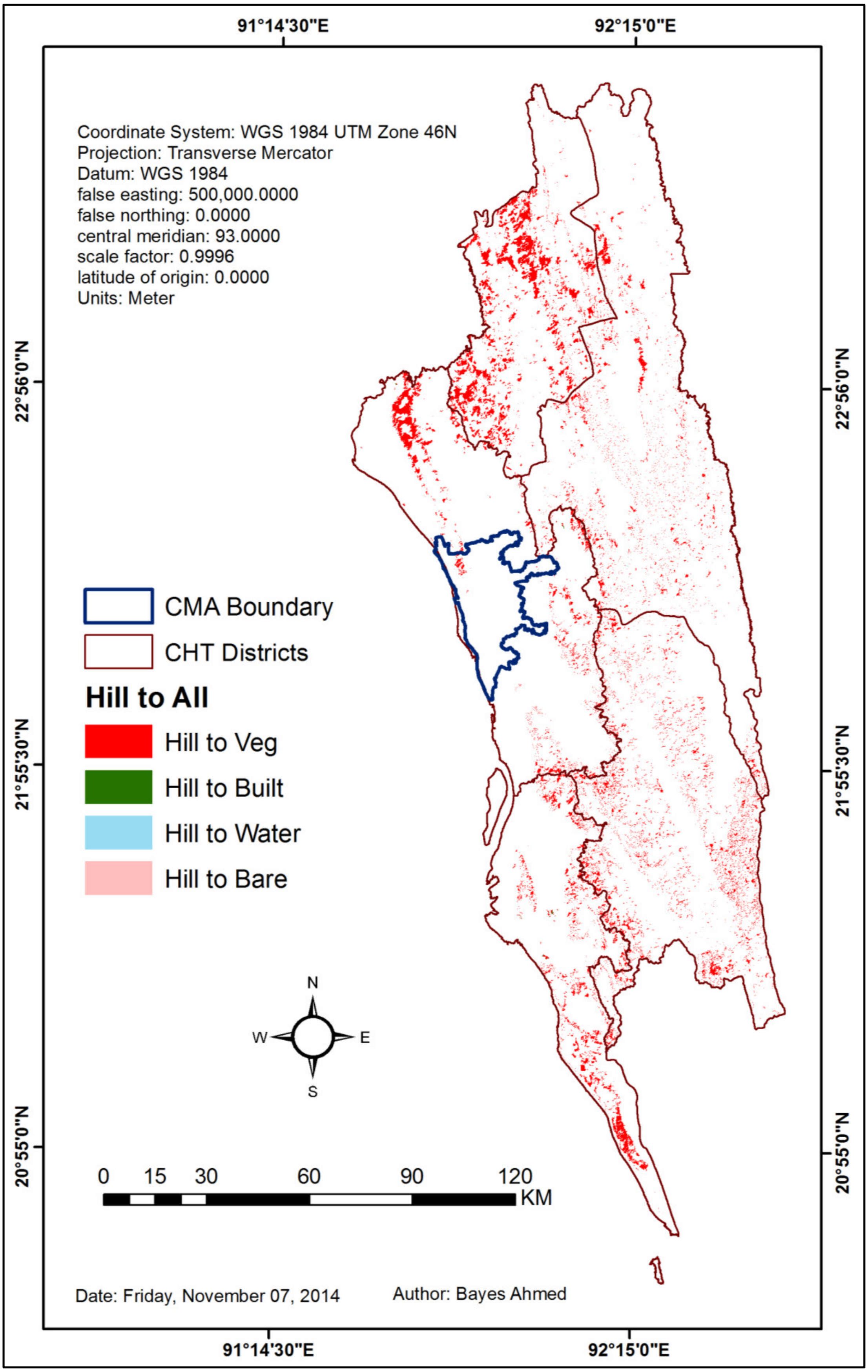






Appendix-E.3: Criteria Images for Land Cover Modelling

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92°15'0"E
Coordinate System: WGS 1984 UTM Zone 46N
Projection: Transverse Mercator
Datum: WGS 1984
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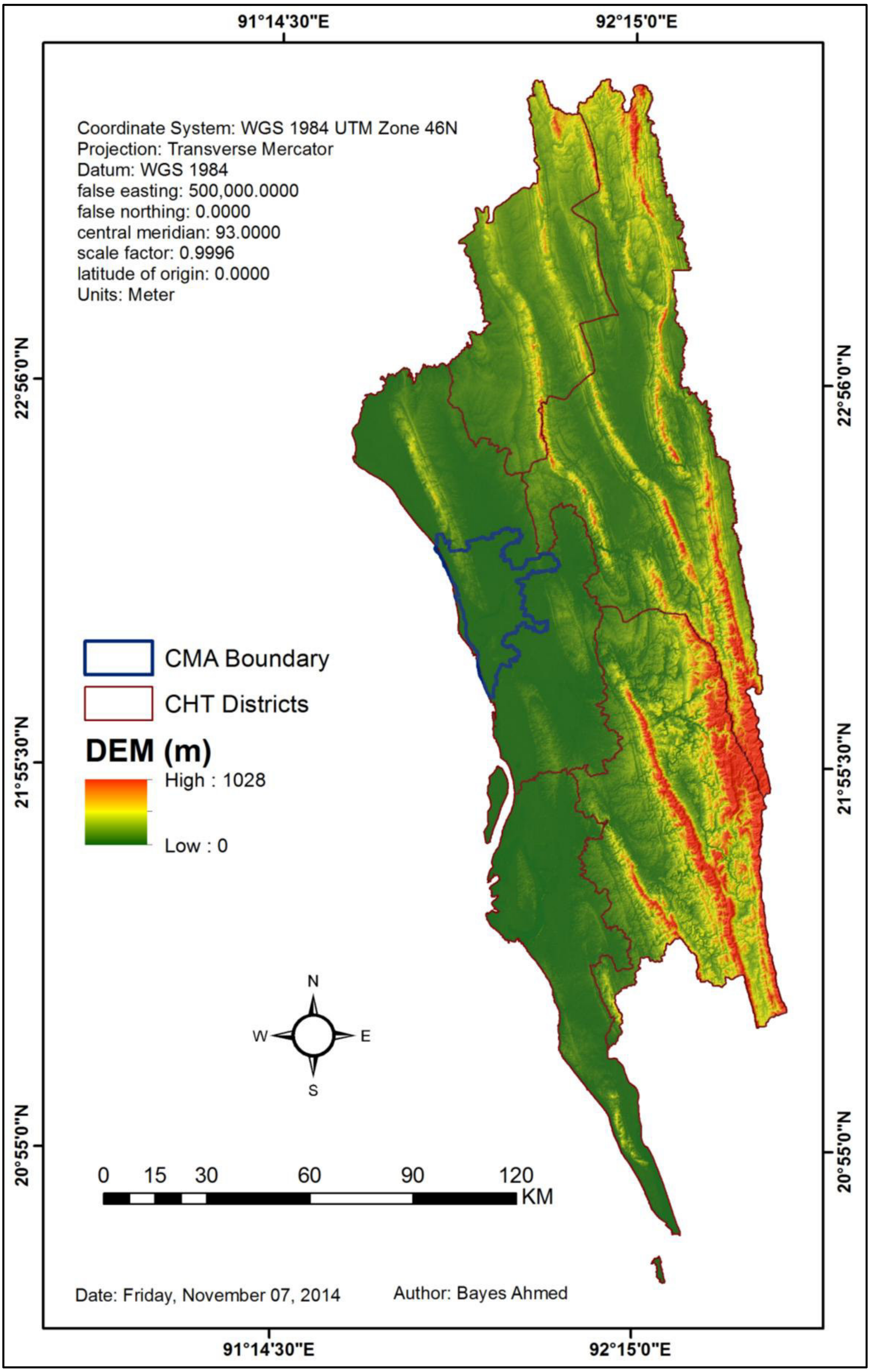
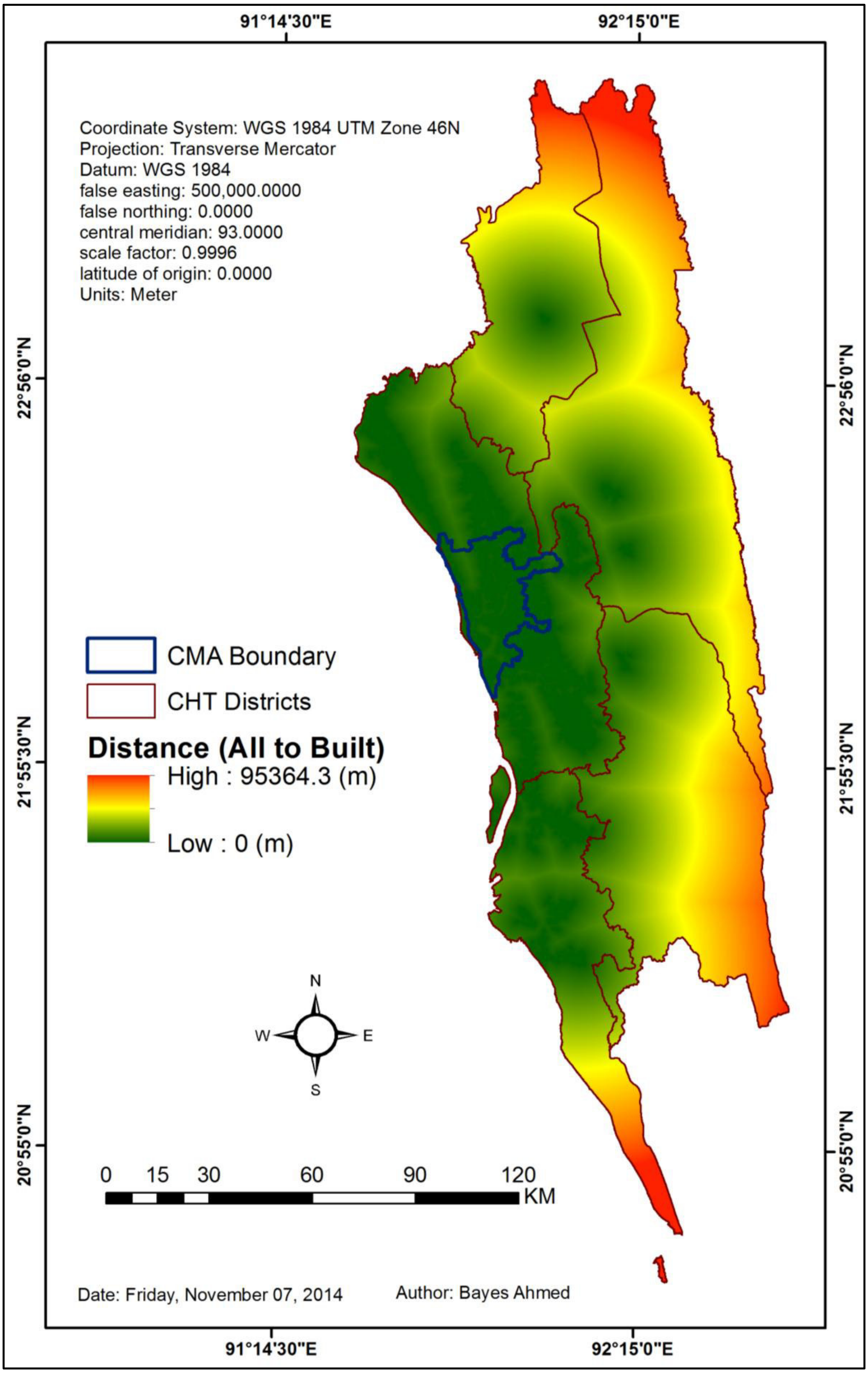
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
22°56'0"N
CMA Boundary
CHT Districts
Hill to All
Hill to Veg
Hill to Built
Hill to Water
Hill to Bare
21°55'30"N
N
W
E
S
20°55'0"N
0 15 30 60 90 120
KM
Date: Friday, November 07, 2014
Author: Bayes Ahmed
91°14'30"E
92°15'0"E

Appendix-E.4: DEM and the Driving Variables for MLP_Markov Modelling

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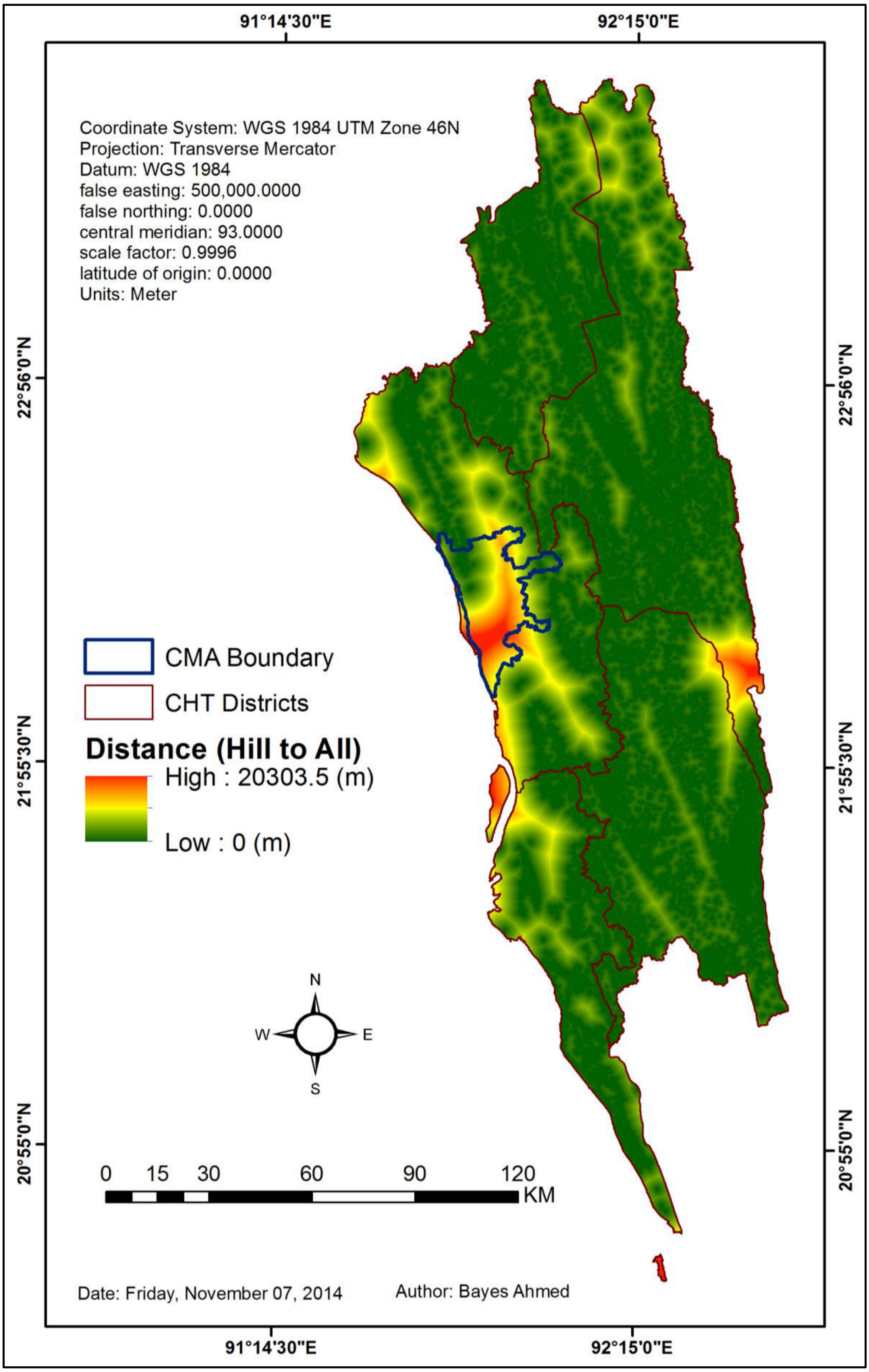
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
22°56'0"N
21°55'30"N
20°55'0"N
CMA Boundary
CHT Districts
Distance (All to Built)
High : 95364.3 (m)
Low : 0 (m)
N
W
E
S
0 15 30 60 90 120
KM
Date: Friday, November 07, 2014
Author: Bayes Ahmed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Projection: Transverse Mercator
Datum: WGS 1984
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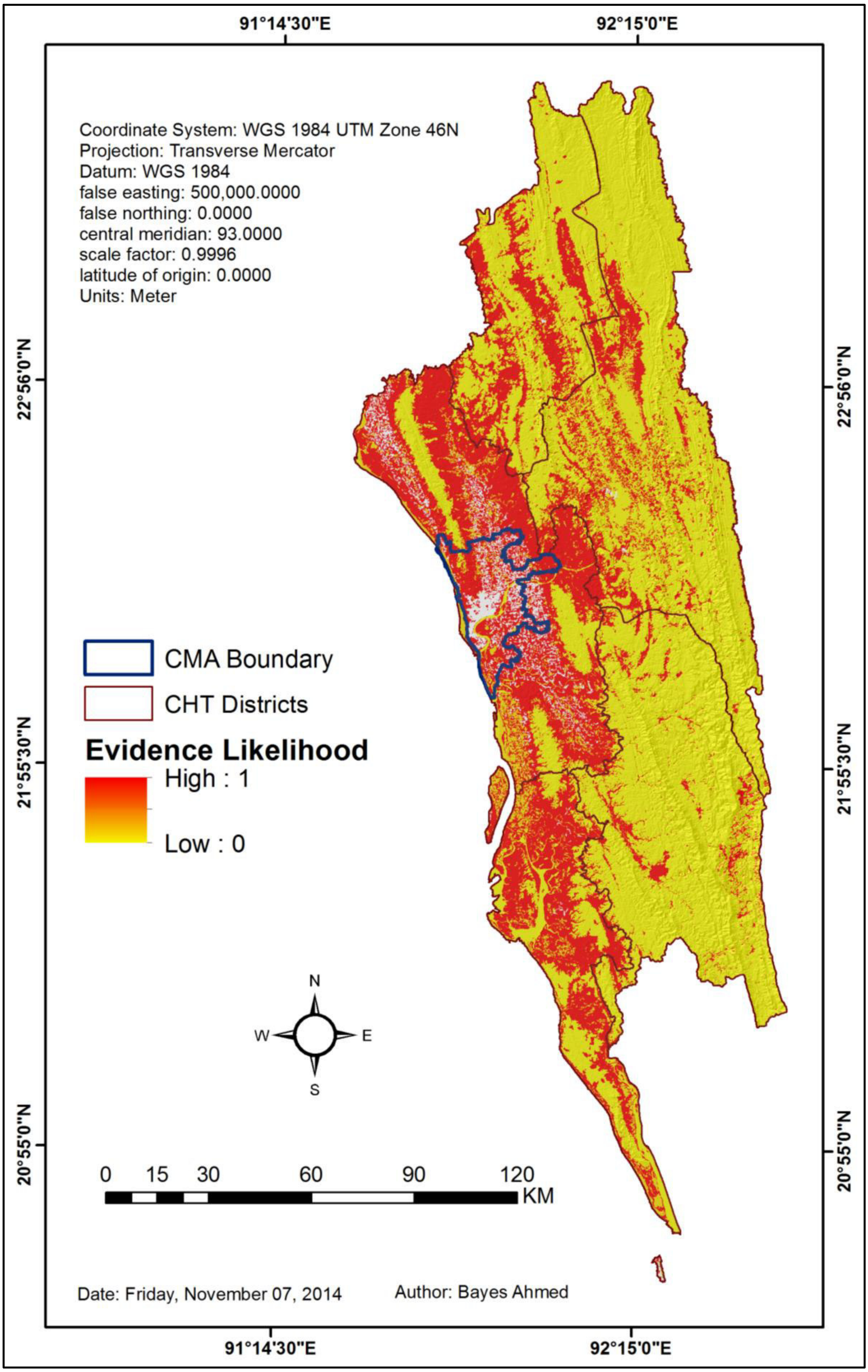
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
22°56'0"N
CMA Boundary
CHT Districts
Distance (Hill to All)
High : 20303.5 (m)
Low : 0 (m)
21°55'30"N
N
W
E
S
20°55'0"N
0 15 30 60 90 120
KM
Date: Friday, November 07, 2014
Author: Bayes Ahmed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92°15'0"E
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Projection: Transverse Mercator
Datum: WGS 1984
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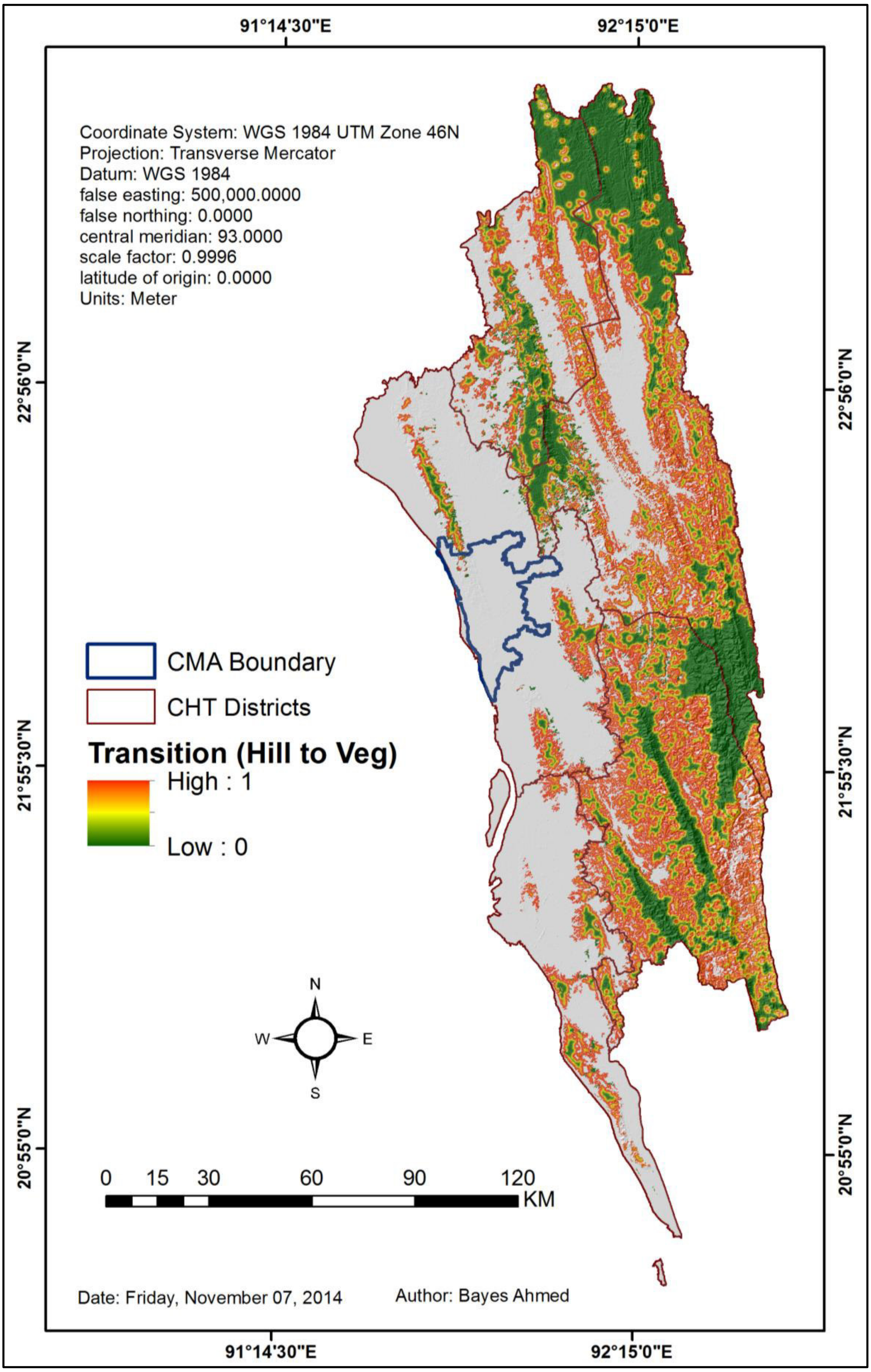
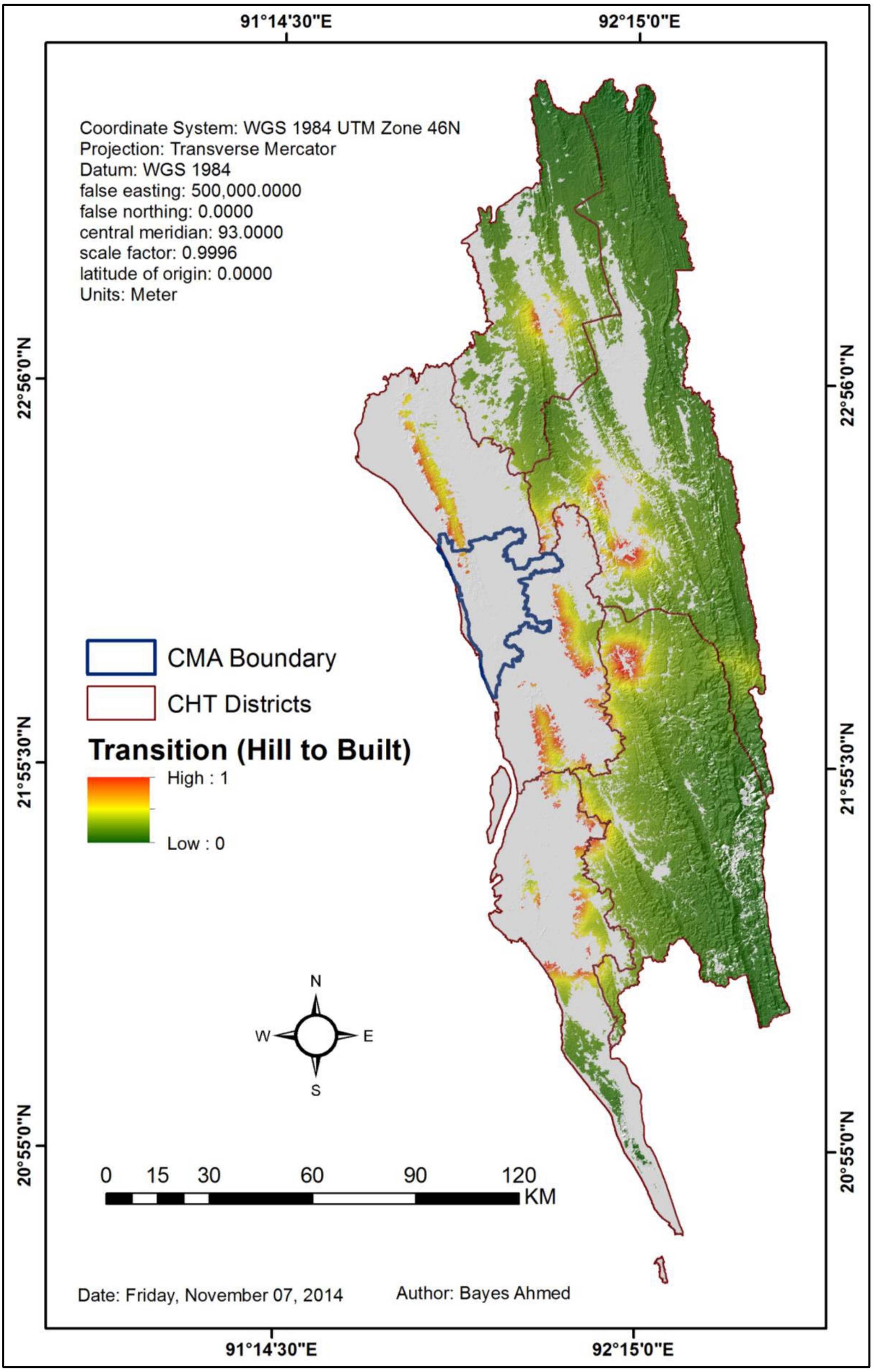
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
22°56'0"N
21°55'30"N
20°55'0"N
CMA Boundary
CHT Districts
Evidence Likelihood
High : 1
Low : 0
N
W
E
S
0 15 30 60 90 120
KM
Date: Friday, November 07, 2014
Author: Bayes Ahmed

Appendix-E.5: Transition Potential Maps for Land Cover Modelling

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92°15'0"E
22°56'0"N
21°55'30"N
20°55'0"N
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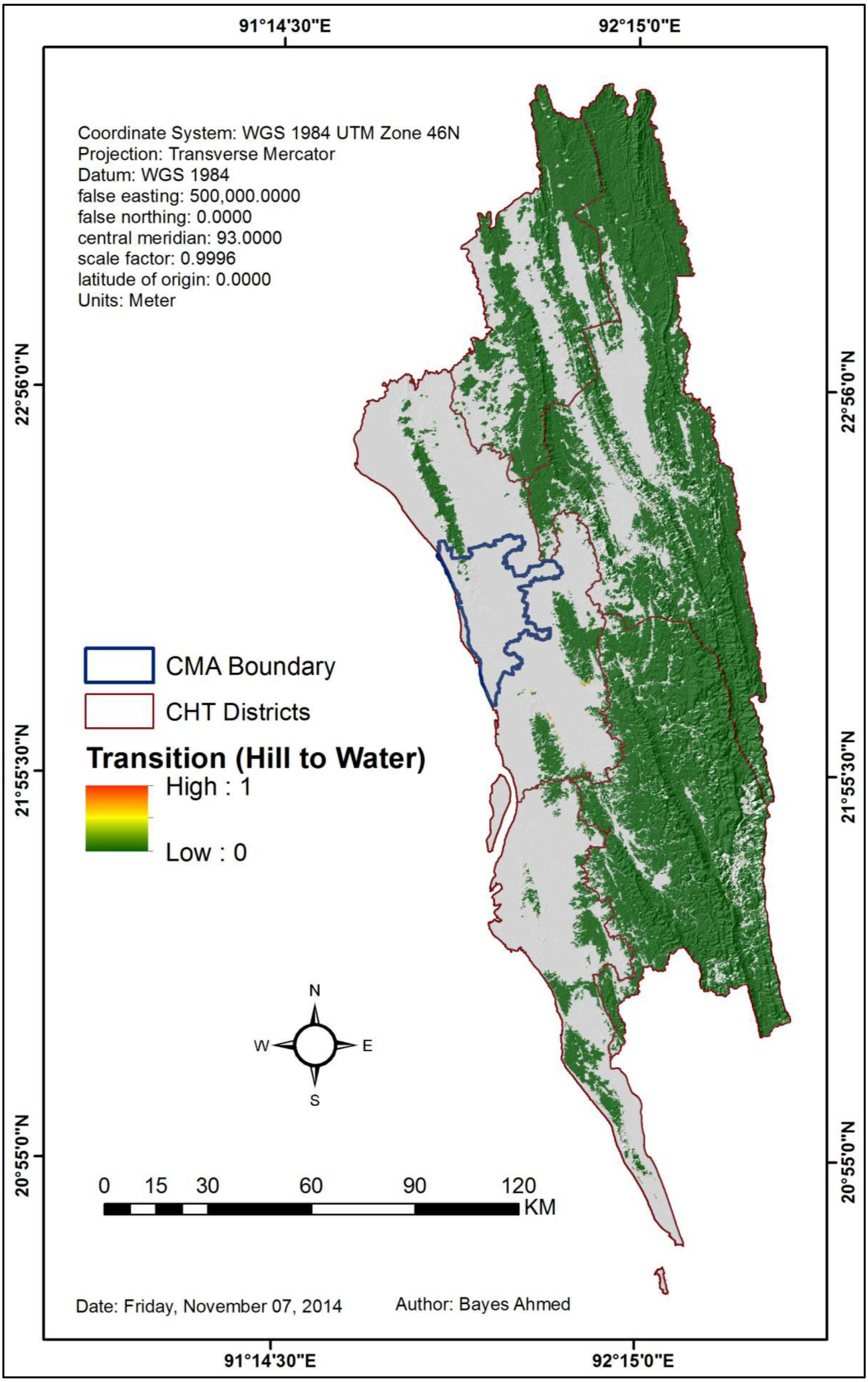
Projection: Transverse Mercator
Datum: WGS 1984
false easting: 500,000.0000
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
CMA Boundary
CHT Districts
Transition (Hill to Built)
High : 1
Low : 0
N
W
E
S
0 15 30 60 90 120
KM
Date: Friday, November 07, 2014
Author: Bayes Ahmed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Projection: Transverse Mercator
Datum: WGS 1984
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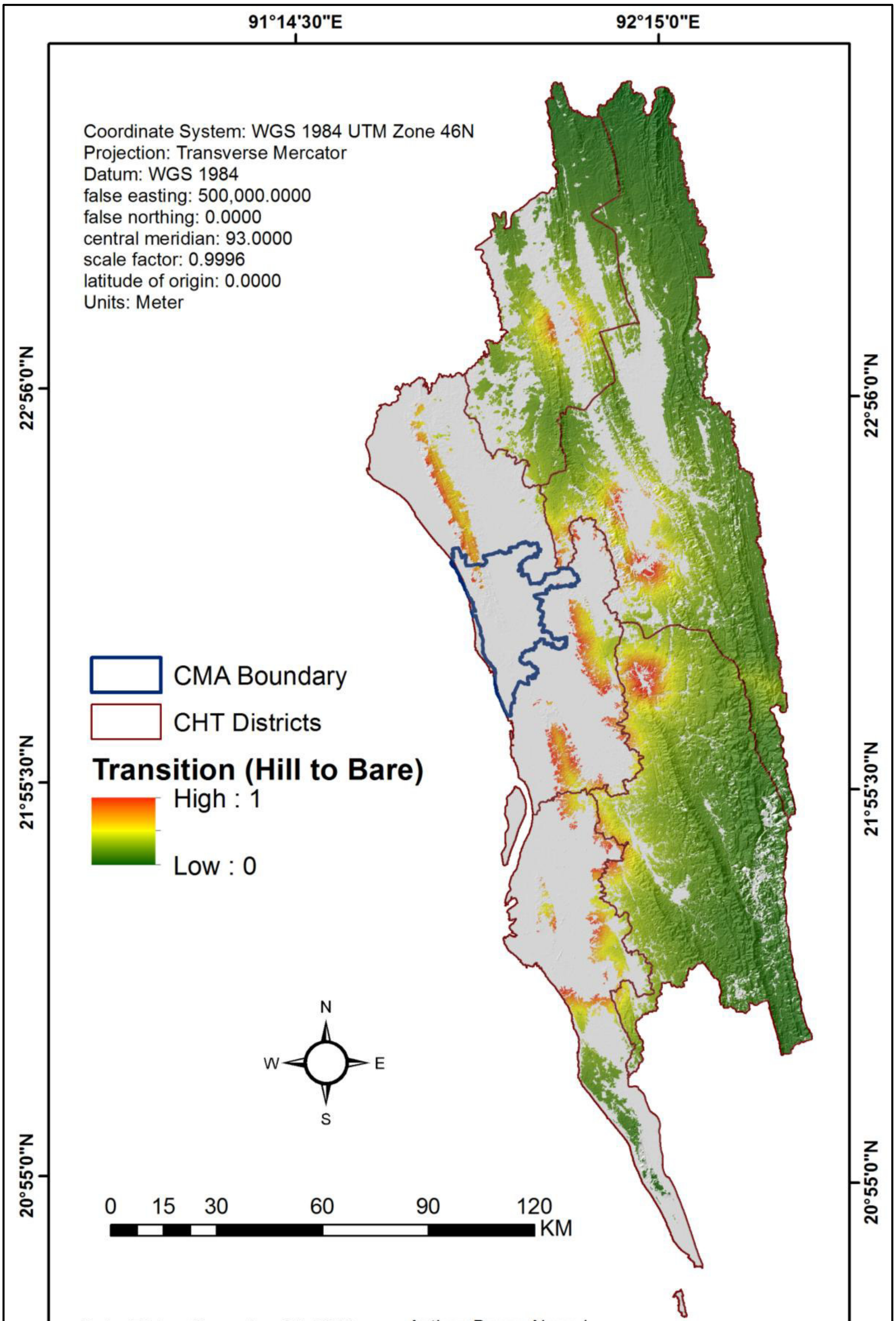
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
22°56'0"N
CMA Boundary
CHT Districts
Transition (Hill to Water)
High : 1
Low : 0
21°55'30"N
N
W
E
S
20°55'0"N
0 15 30 60 90 120
KM
Date: Friday, November 07, 2014
Author: Bayes Ahmed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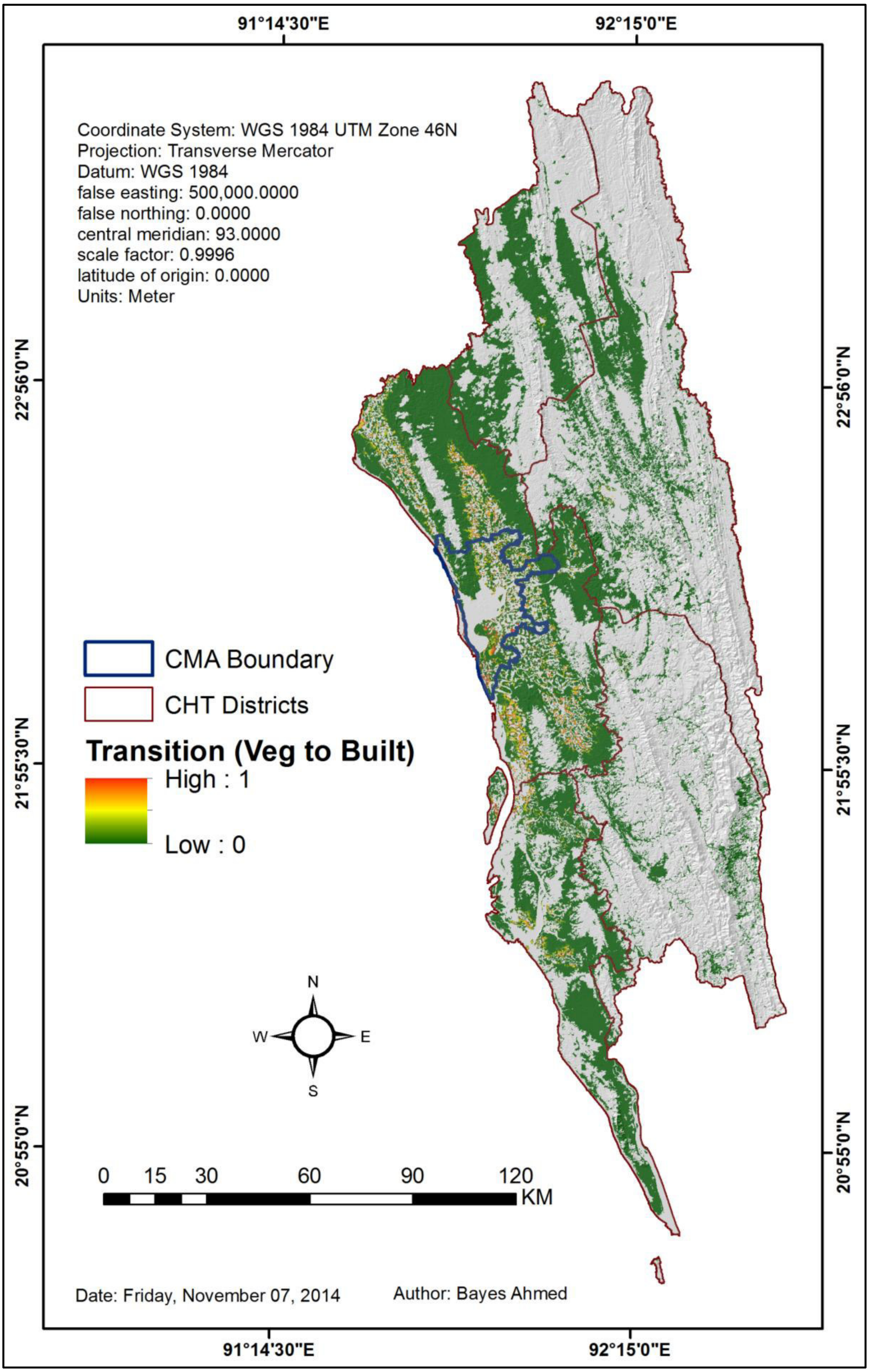
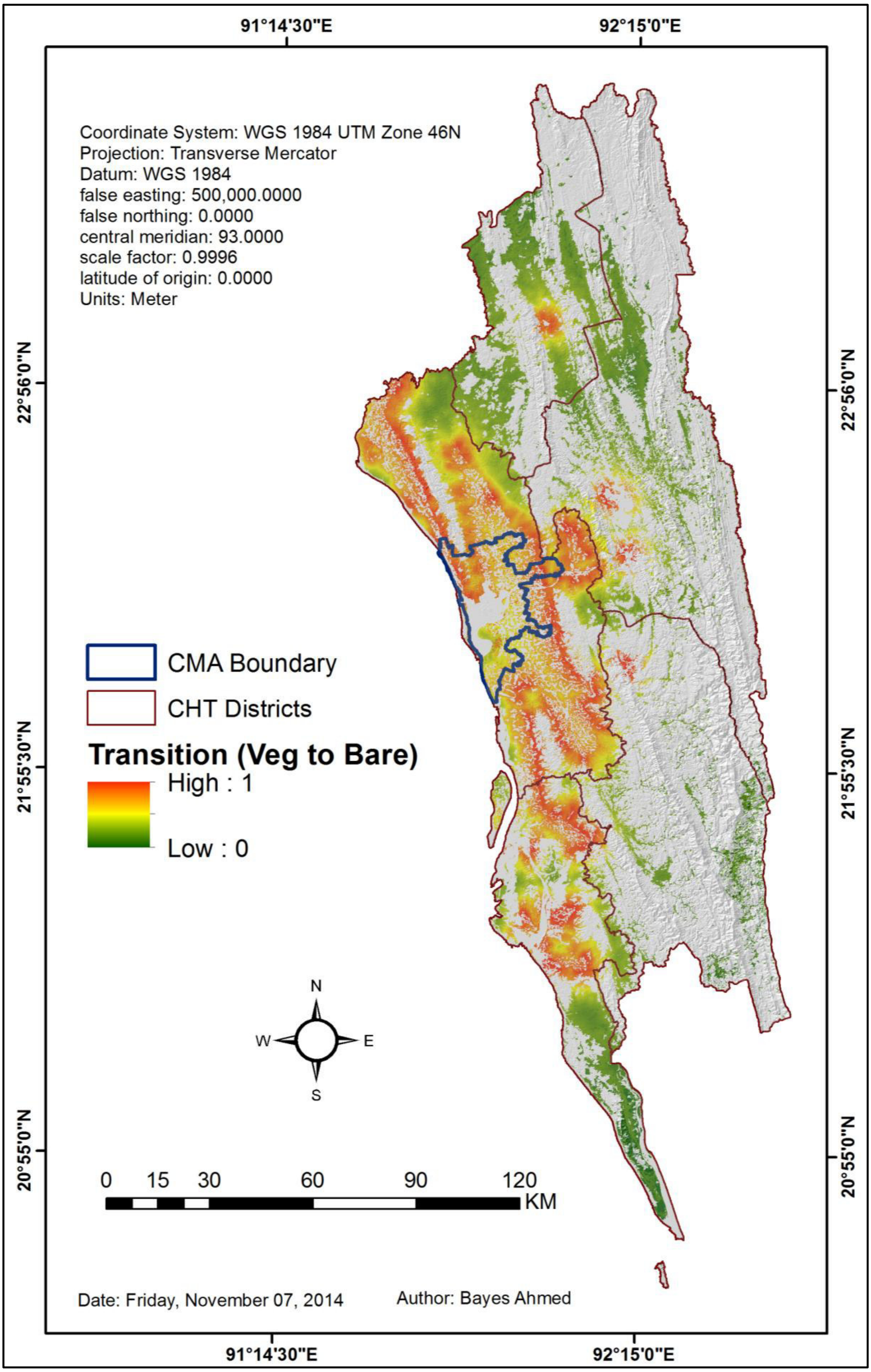
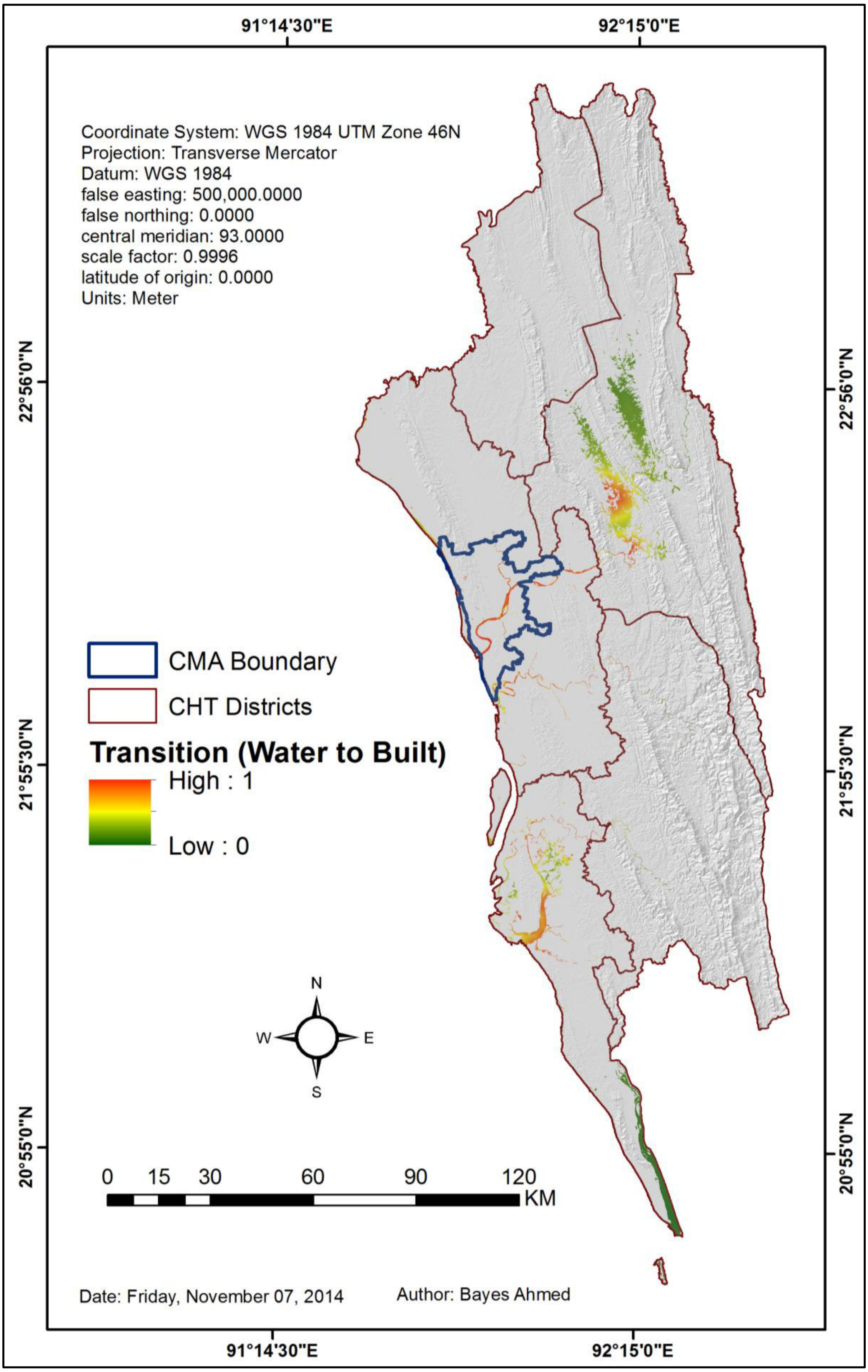
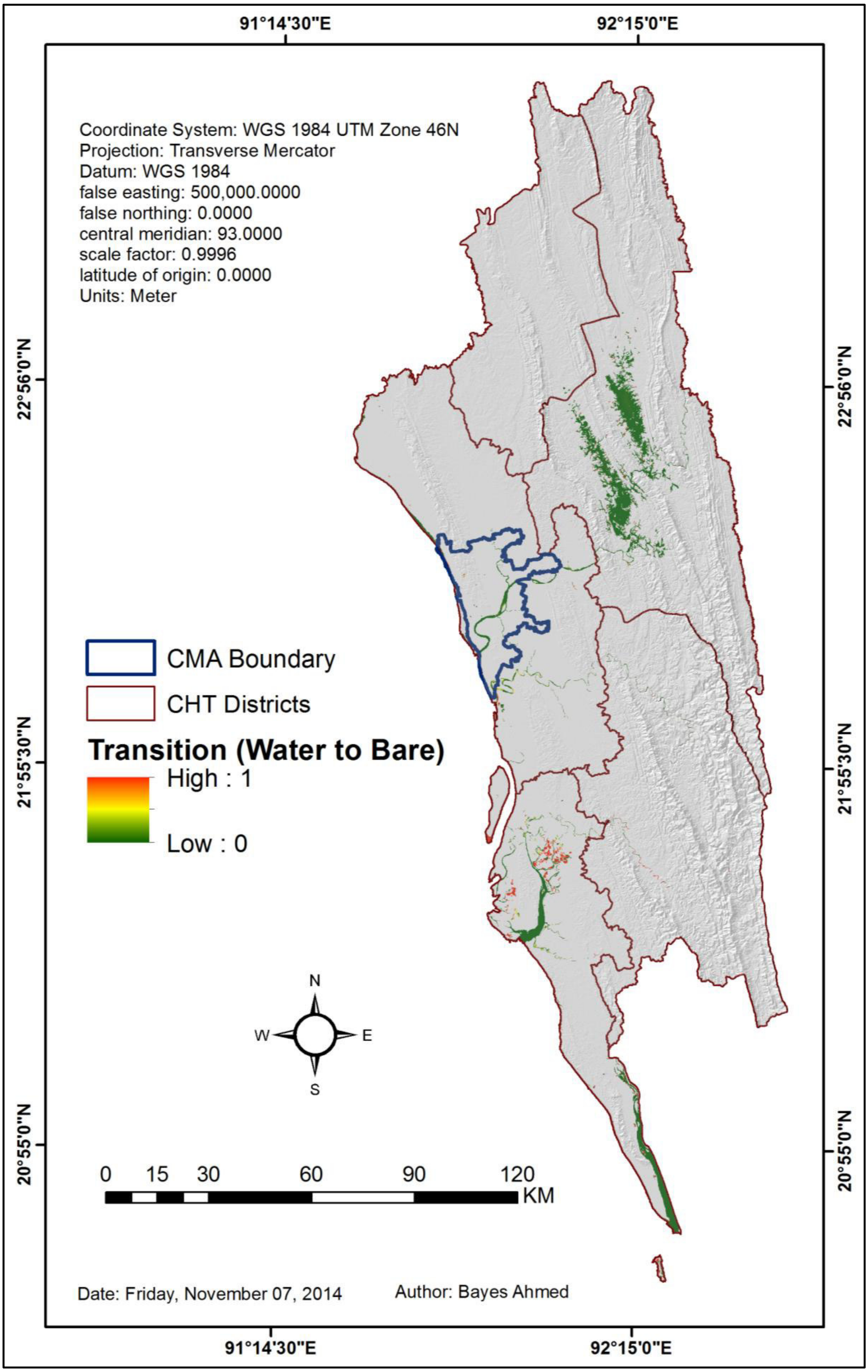
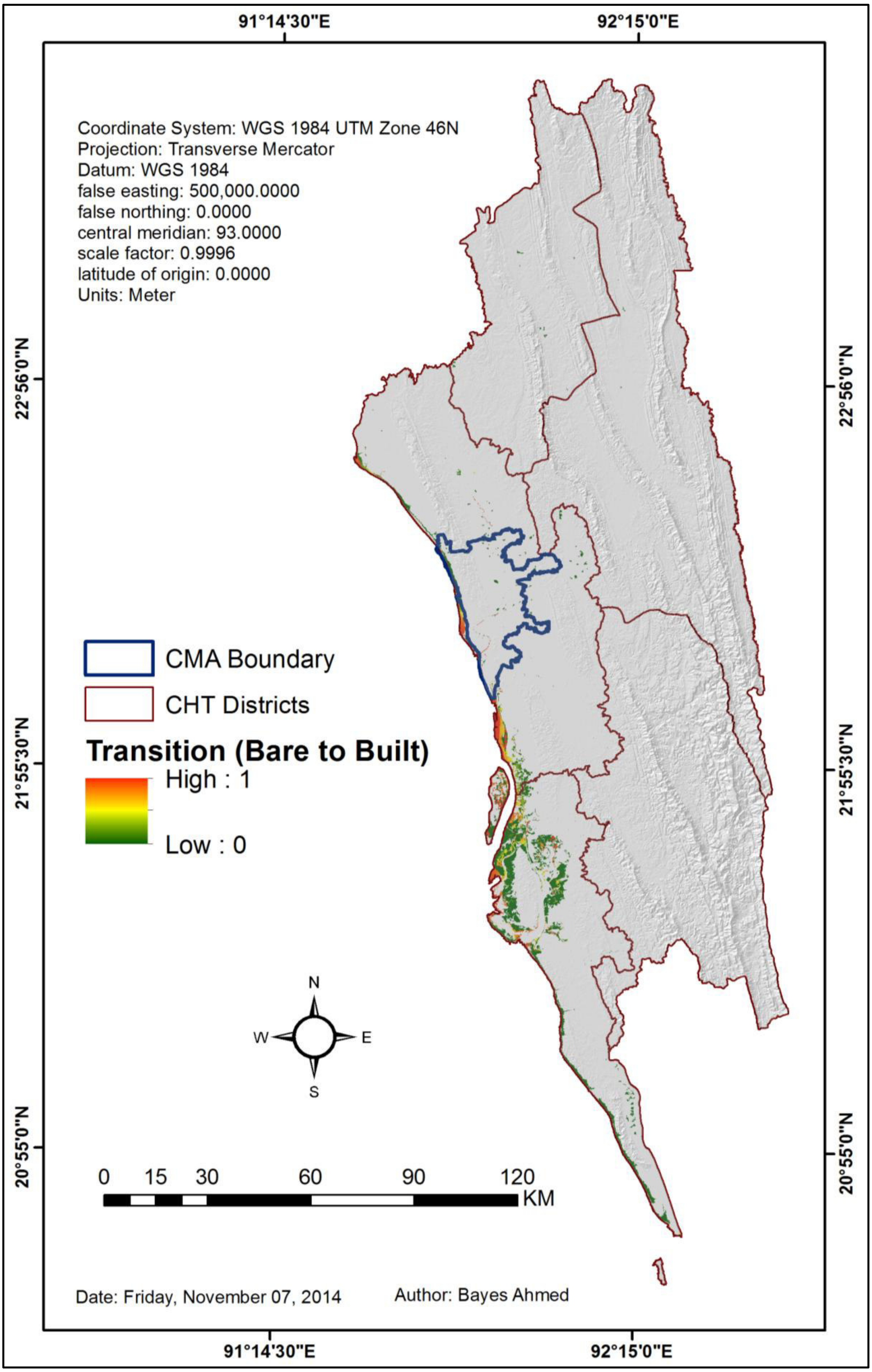
92°15'0"E
22°56'0"N
21°55'30"N
20°55'0"N
Coordinate System: WGS 1984 UTM Zone 46N
Projection: Transverse Mercator
Datum: WGS 1984
false easting: 500,000.0000
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
CMA Boundary
CHT Districts
Transition (Hill to Bare)
High : 1
Low : 0
N
W
E
S
0 15 30 60 90 120
KM
Date: Friday, November 07, 2014
Author: Bayes Ahmed


91°14'30"E
92°15'0"E
Coordinate System: WGS 1984 UTM Zone 46N
Projection: Transverse Mercator
Datum: WGS 1984
false easting: 500,000.0000
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
22°56'0"N
21°55'30"N
20°55'0"N
CMA Boundary
CHT Districts
Transition (Veg to Built)
High : 1
Low : 0
N
W
E
S
0 15 30 60 90 120
KM
Date: Friday, November 07, 2014
Author: Bayes Ahmed


91°14'30"E
92°15'0"E
Coordinate System: WGS 1984 UTM Zone 46N
Projection: Transverse Mercator
Datum: WGS 1984
false easting: 500,000.0000
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
22°56'0"N
21°55'30"N
20°55'0"N
CMA Boundary
CHT Districts
Transition (Veg to Bare)
High : 1
Low : 0
N
W
E
S
0 15 30 60 90 120
KM
Date: Friday, November 07, 2014
Author: Bayes Ahmed

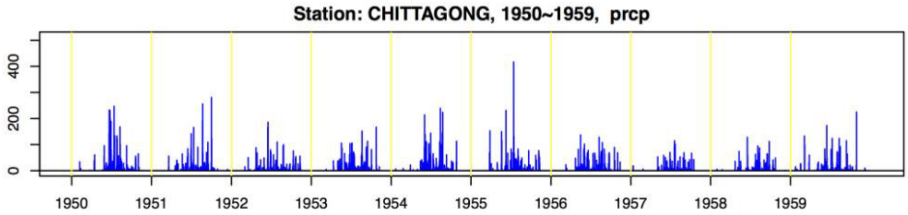

91°14'30"E
92°15'0"E
22°56'0"N
21°55'30"N
20°55'0"N
Coordinate System: WGS 1984 UTM Zone 46N
Projection: Transverse Mercator
Datum: WGS 1984
false easting: 500,000.0000
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
CMA Boundary
CHT Districts
Transition (Water to Built)
High : 1
Low : 0
N
W
E
S
0 15 30 60 90 120
KM
Date: Friday, November 07, 2014
Author: Bayes Ahmed

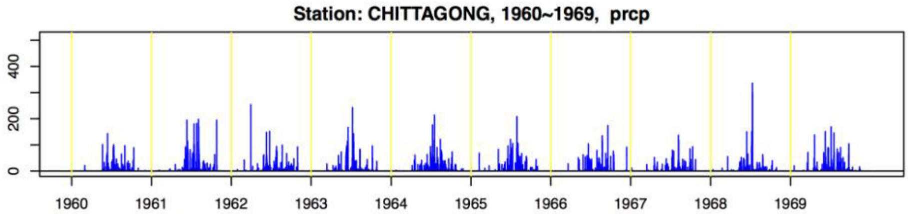

91°14'30"E
92°15'0"E
Coordinate System: WGS 1984 UTM Zone 46N
Projection: Transverse Mercator
Datum: WGS 1984
false easting: 500,000.0000
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
22°56'0"N
CMA Boundary
CHT Districts
Transition (Water to Bare)
High : 1
Low : 0
21°55'30"N
N
W
E
S
20°55'0"N
0 15 30 60 90 120 KM
Date: Friday, November 07, 2014
Author: Bayes Ahmed

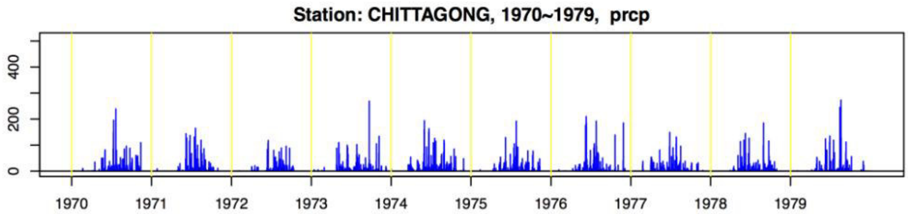

91°14'30"E
92°15'0"E
Coordinate System: WGS 1984 UTM Zone 46N
Projection: Transverse Mercator
Datum: WGS 1984
false easting: 500,000.0000
false northing: 0.0000
central meridian: 93.0000
scale factor: 0.9996
latitude of origin: 0.0000
Units: Meter
22°56'0"N
CMA Boundary
CHT Districts
Transition (Bare to Built)
High : 1
Low : 0
21°55'30"N
N
W
E
S
20°55'0"N
0 15 30 60 90 120 KM
Date: Friday, November 07, 2014
Author: Bayes Ahmed

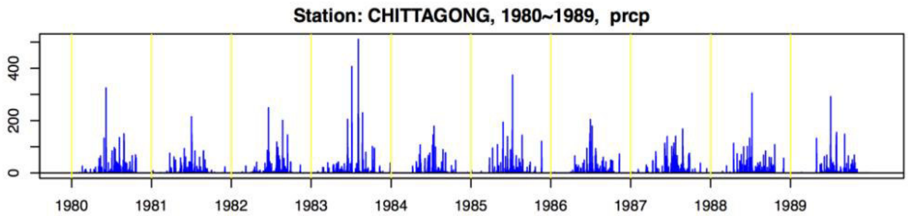
RAINFALL PATTERN MODELLING

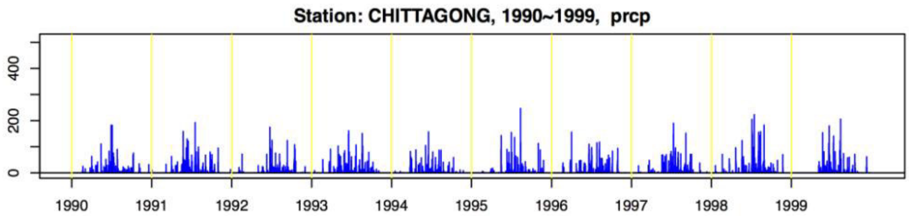
Appendix-E.6: Rainfall Pattern (mm) of Chittagong, Bangladesh (1950-2010).

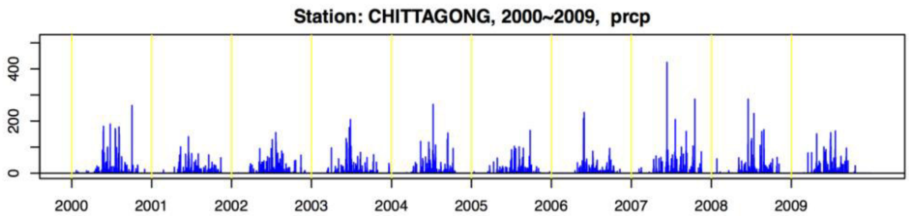


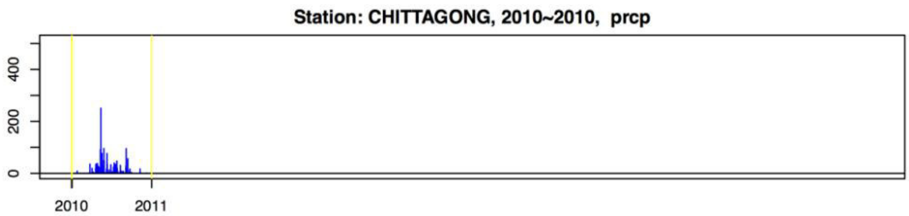




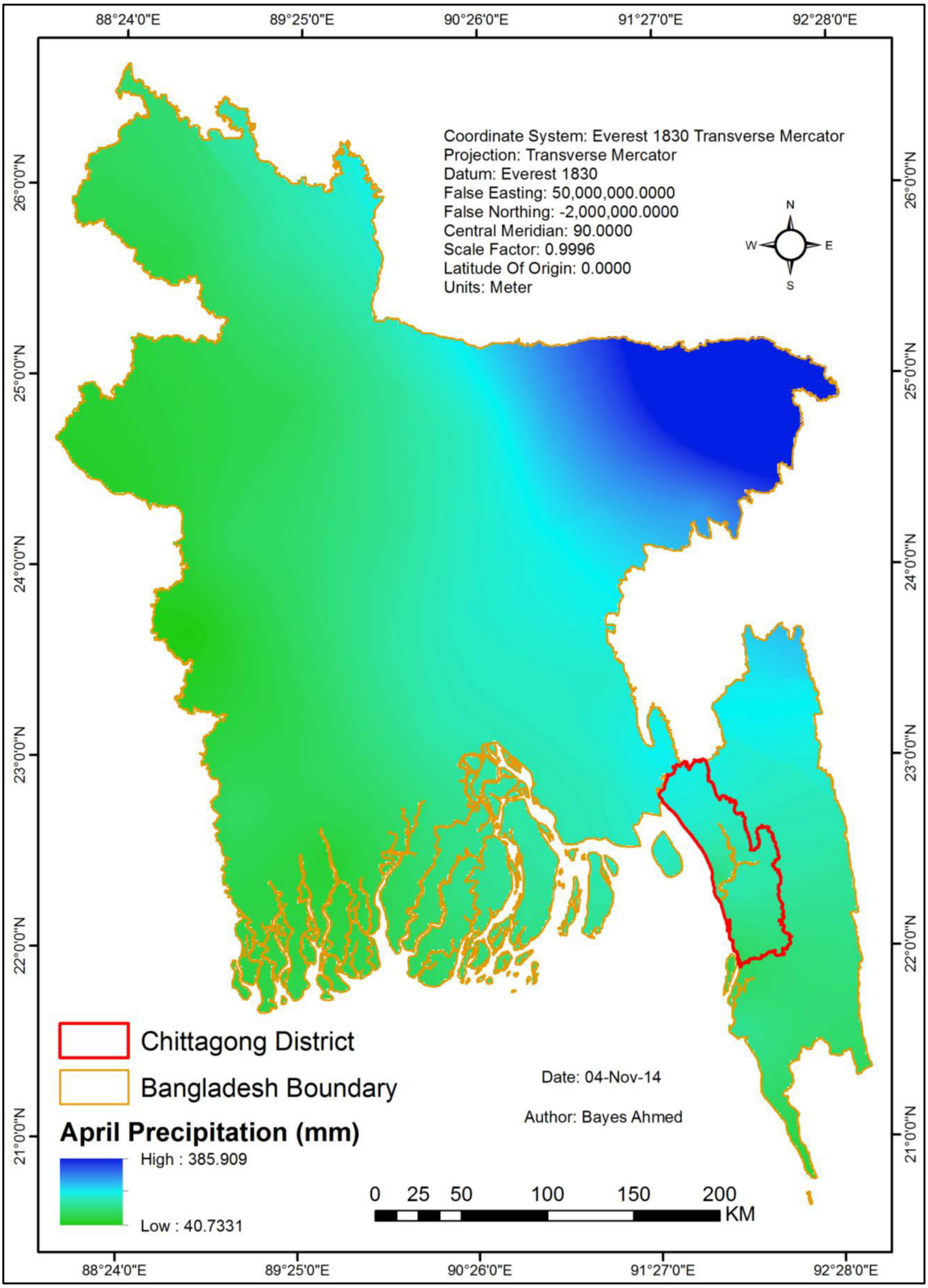


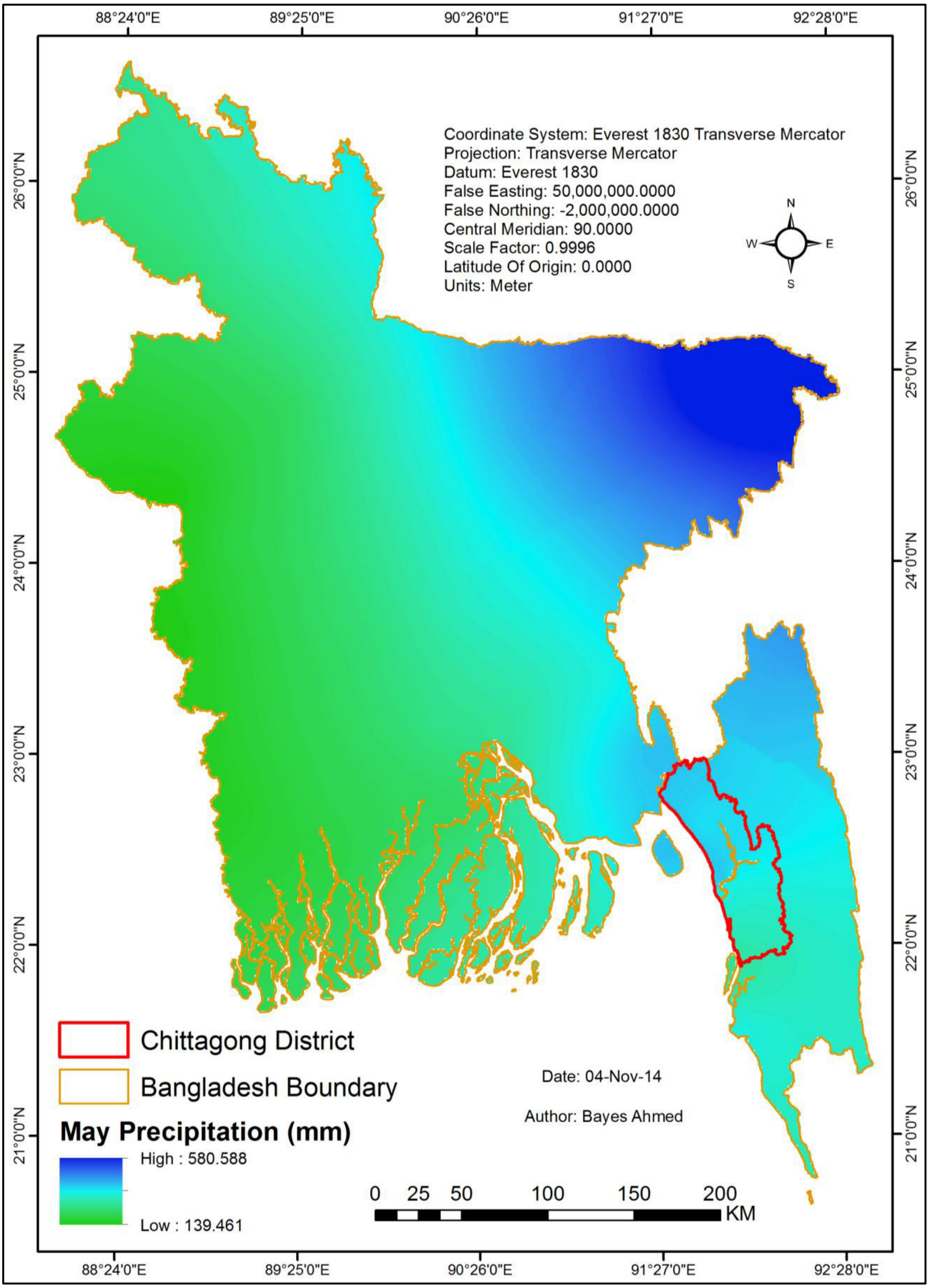


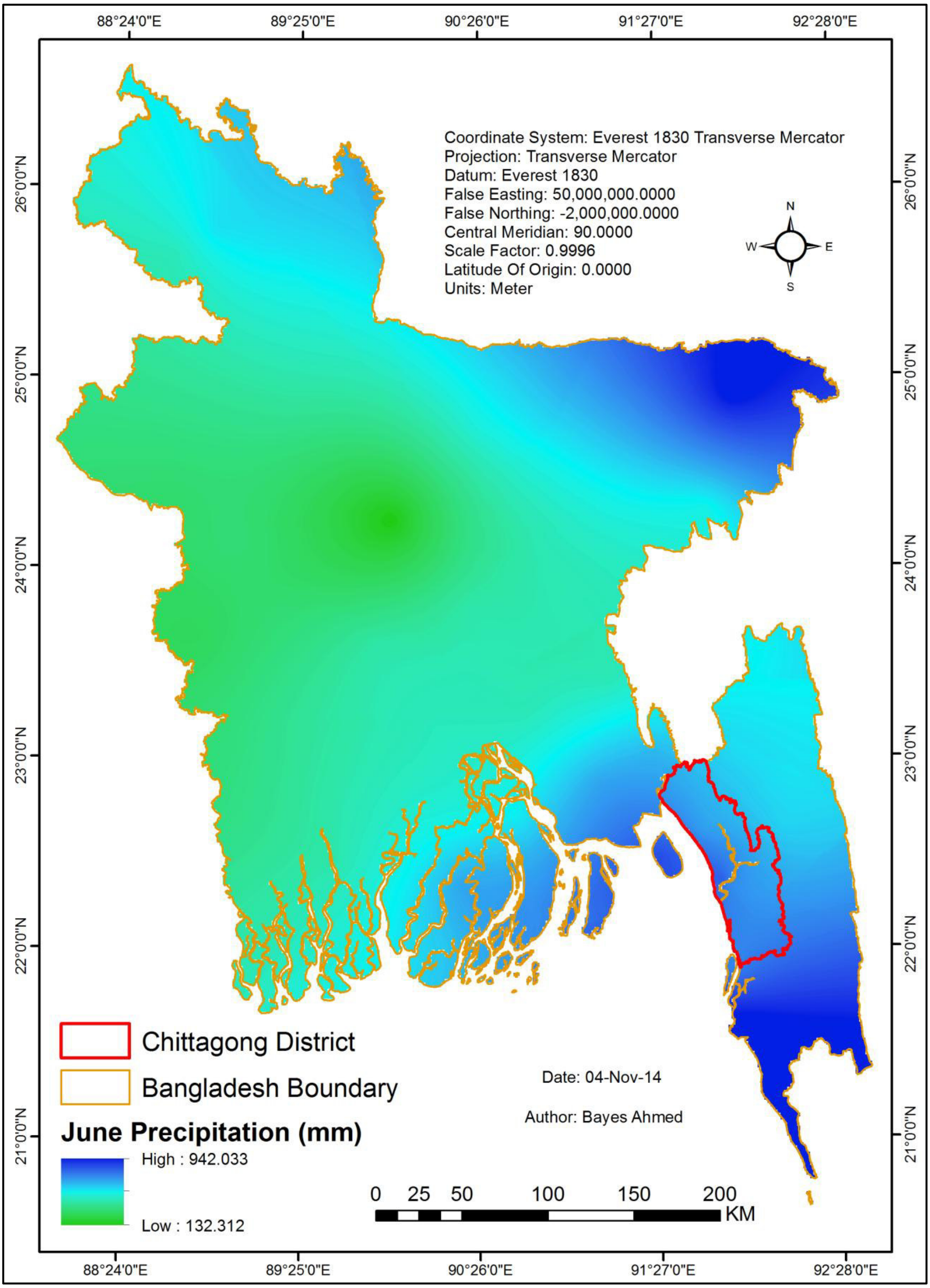


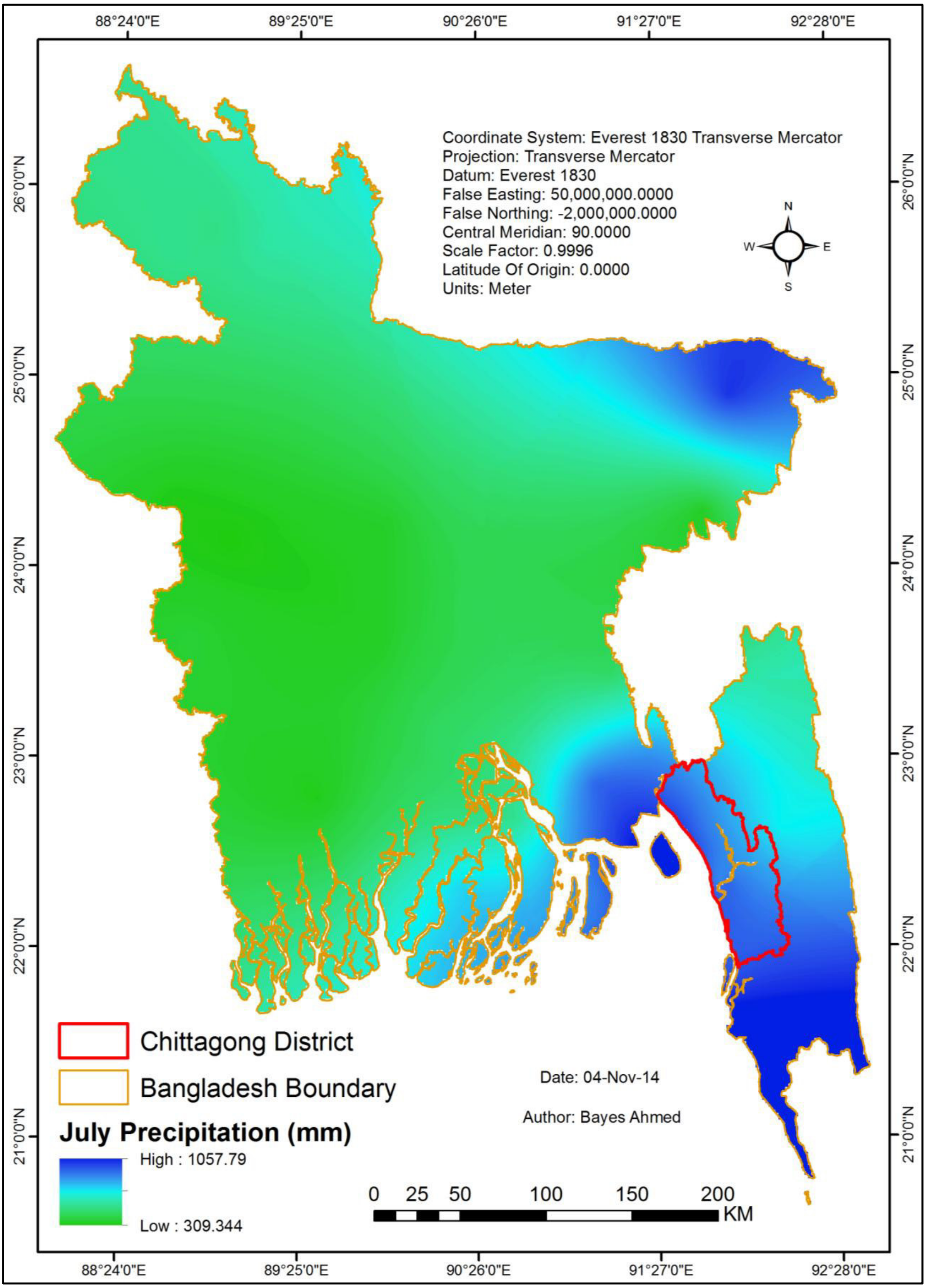


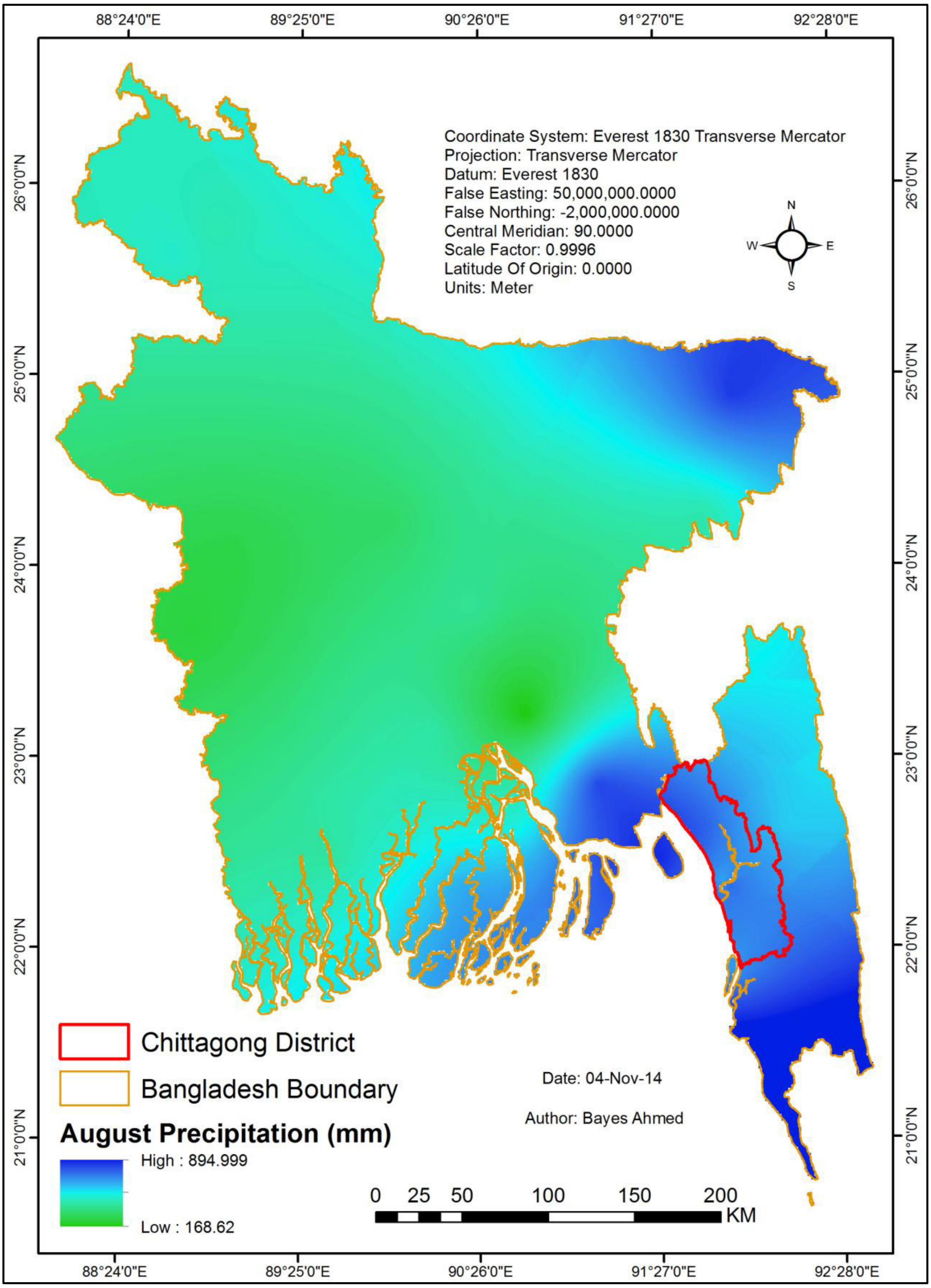
Appendix-E.7: Rainfall Pattern Maps of Bangladesh during the Rainy Season.

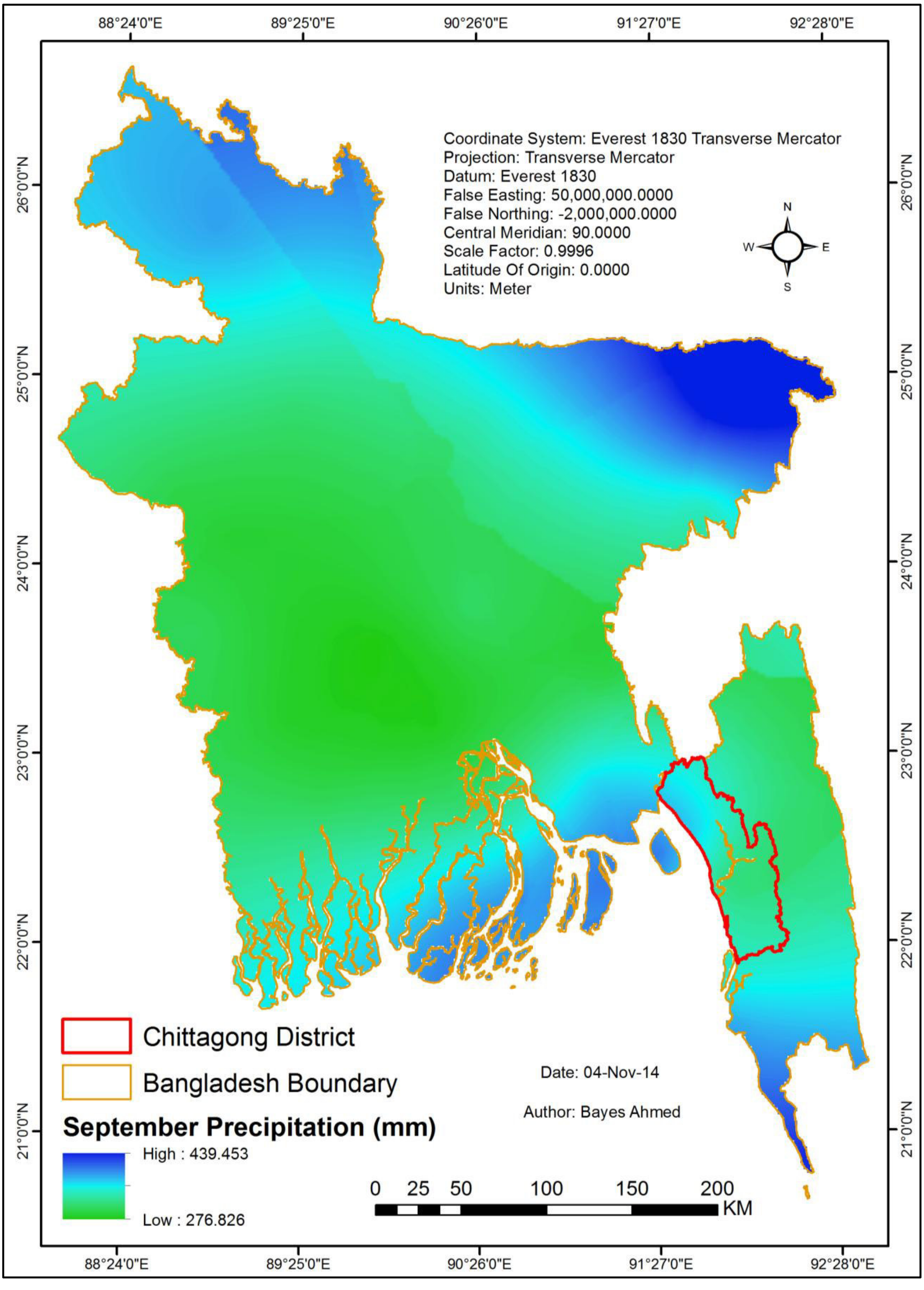



88°24'0"E
89°25'0"E
90°26'0"E
91°27'0"E
92°28'0"E
26°0'0"N
25°0'0"N
24°0'0"N
23°0'0"N
22°0'0"N
21°0'0"N
Coordinate System: Everest 1830 Transverse Mercator
Projection: Transverse Mercator
Datum: Everest 1830
False Easting: 50,000,000.0000
False Northing: -2,000,000.0000
Central Meridian: 90.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
N
W
E
S
Chittagong District
Bangladesh Boundary
May Precipitation (mm)
High : 580.588
Low : 139.461
Date: 04-Nov-14
Author: Bayes Ahmed
0 25 50 100 150 200
KM

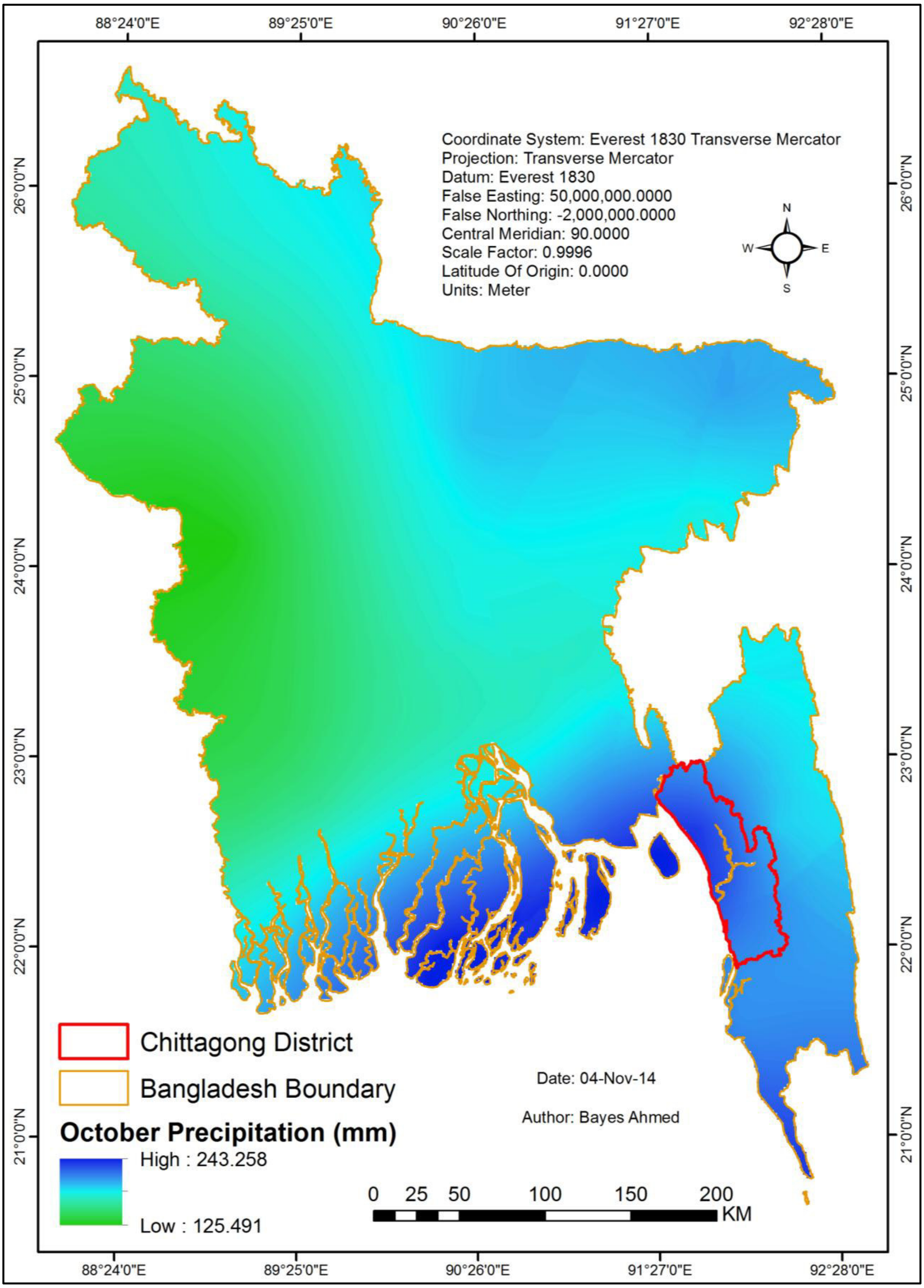

88°24'0"E
89°25'0"E
90°26'0"E
91°27'0"E
92°28'0"E
26°0'0"N
25°0'0"N
24°0'0"N
23°0'0"N
22°0'0"N
21°0'0"N
Coordinate System: Everest 1830 Transverse Mercator
Projection: Transverse Mercator
Datum: Everest 1830
False Easting: 50,000,000.0000
False Northing: -2,000,000.0000
Central Meridian: 90.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
N
W
E
S
Chittagong District
Bangladesh Boundary
June Precipitation (mm)
High : 942.033
Low : 132.312
Date: 04-Nov-14
Author: Bayes Ahmed
0 25 50 100 150 200
KM


Coordinate System: Everest 1830 Transverse Mercator
Projection: Transverse Mercator
Datum: Everest 1830
False Easting: 50,000,000.0000
False Northing: -2,000,000.0000
Central Meridian: 90.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
N
W
E
S
88°24'0"E
89°25'0"E
90°26'0"E
91°27'0"E
92°28'0"E
26°0'0"N
25°0'0"N
24°0'0"N
23°0'0"N
22°0'0"N
21°0'0"N
Chittagong District
Bangladesh Boundary
July Precipitation (mm)
High : 1057.79
Low : 309.344
Date: 04-Nov-14
Author: Bayes Ahmed
0 25 50 100 150 200
KM

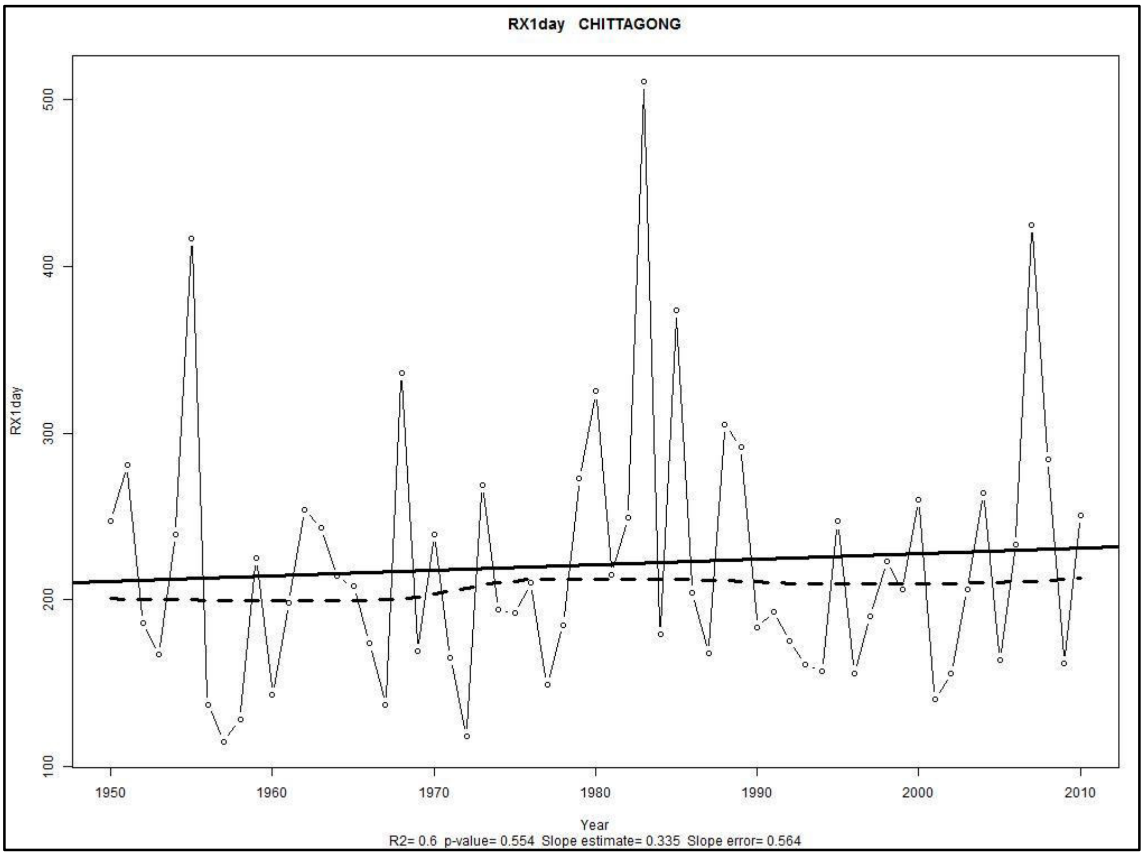

88°24'0"E
89°25'0"E
90°26'0"E
91°27'0"E
92°28'0"E
26°0'0"N
25°0'0"N
24°0'0"N
23°0'0"N
22°0'0"N
21°0'0"N
Coordinate System: Everest 1830 Transverse Mercator
Projection: Transverse Mercator
Datum: Everest 1830
False Easting: 50,000,000.0000
False Northing: -2,000,000.0000
Central Meridian: 90.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
N
W
E
S
Chittagong District
Bangladesh Boundary
August Precipitation (mm)
High : 894.999
Low : 168.62
Date: 04-Nov-14
Author: Bayes Ahmed
0 25 50 100 150 200
KM

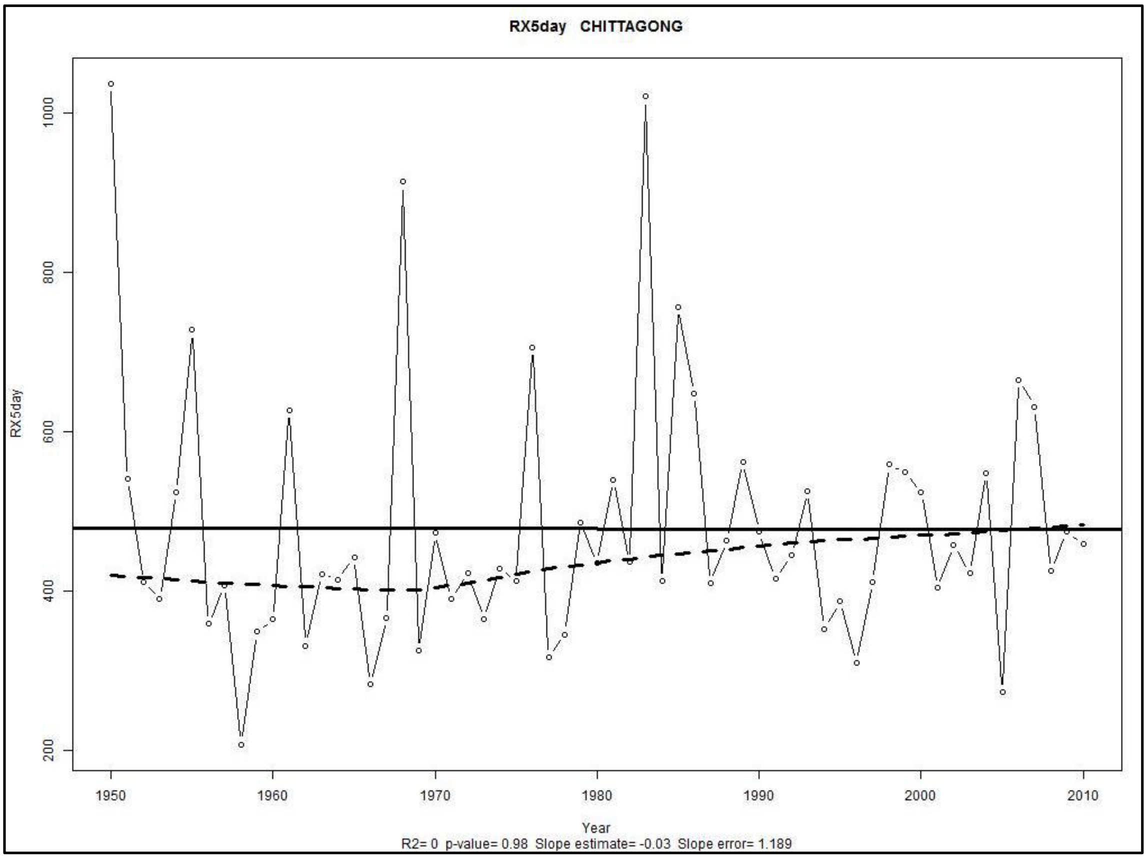


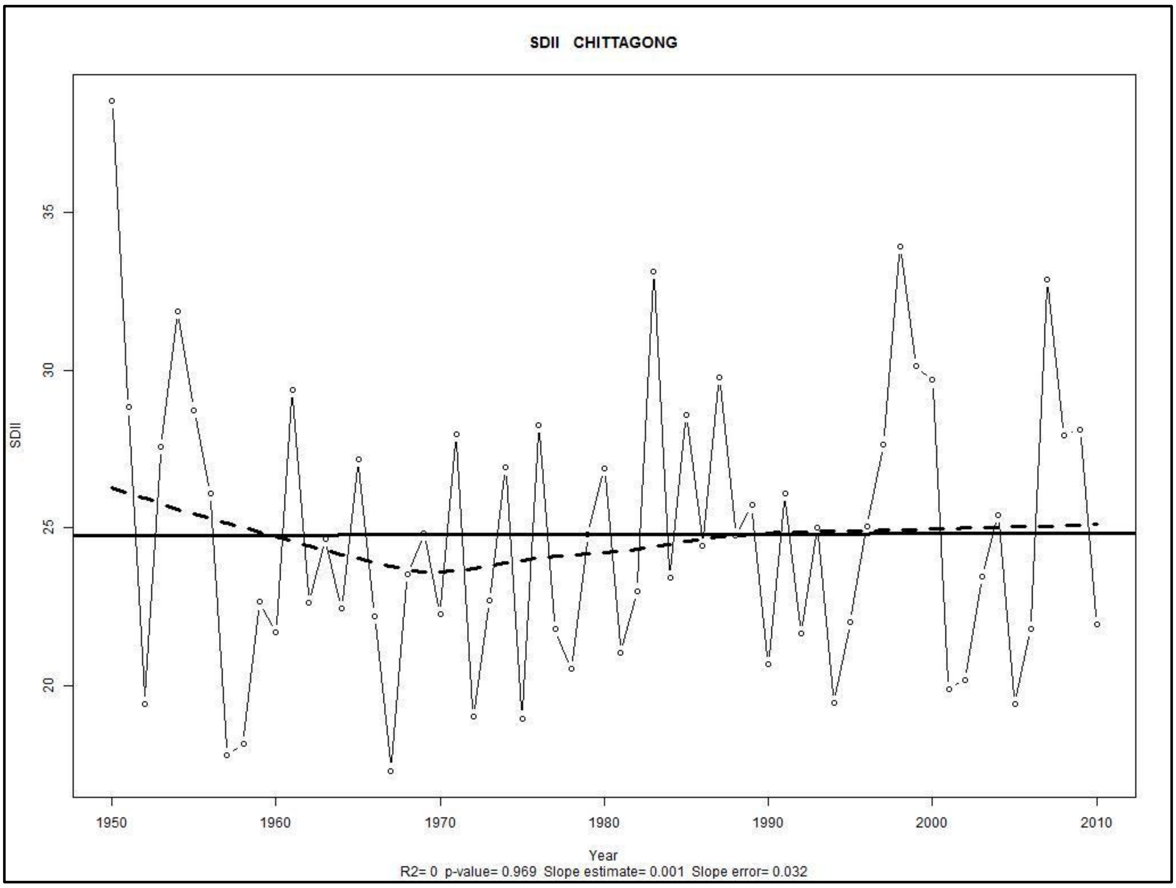
88°24'0"E
89°25'0"E
90°26'0"E
91°27'0"E
92°28'0"E
26°0'0"N
25°0'0"N
24°0'0"N
23°0'0"N
22°0'0"N
21°0'0"N
Coordinate System: Everest 1830 Transverse Mercator
Projection: Transverse Mercator
Datum: Everest 1830
False Easting: 50,000,000.0000
False Northing: -2,000,000.0000
Central Meridian: 90.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
N
W
E
S
Chittagong District
Bangladesh Boundary
September Precipitation (mm)
High : 439.453
Low : 276.826
Date: 04-Nov-14
Author: Bayes Ahmed
0 25 50 100 150 200
KM

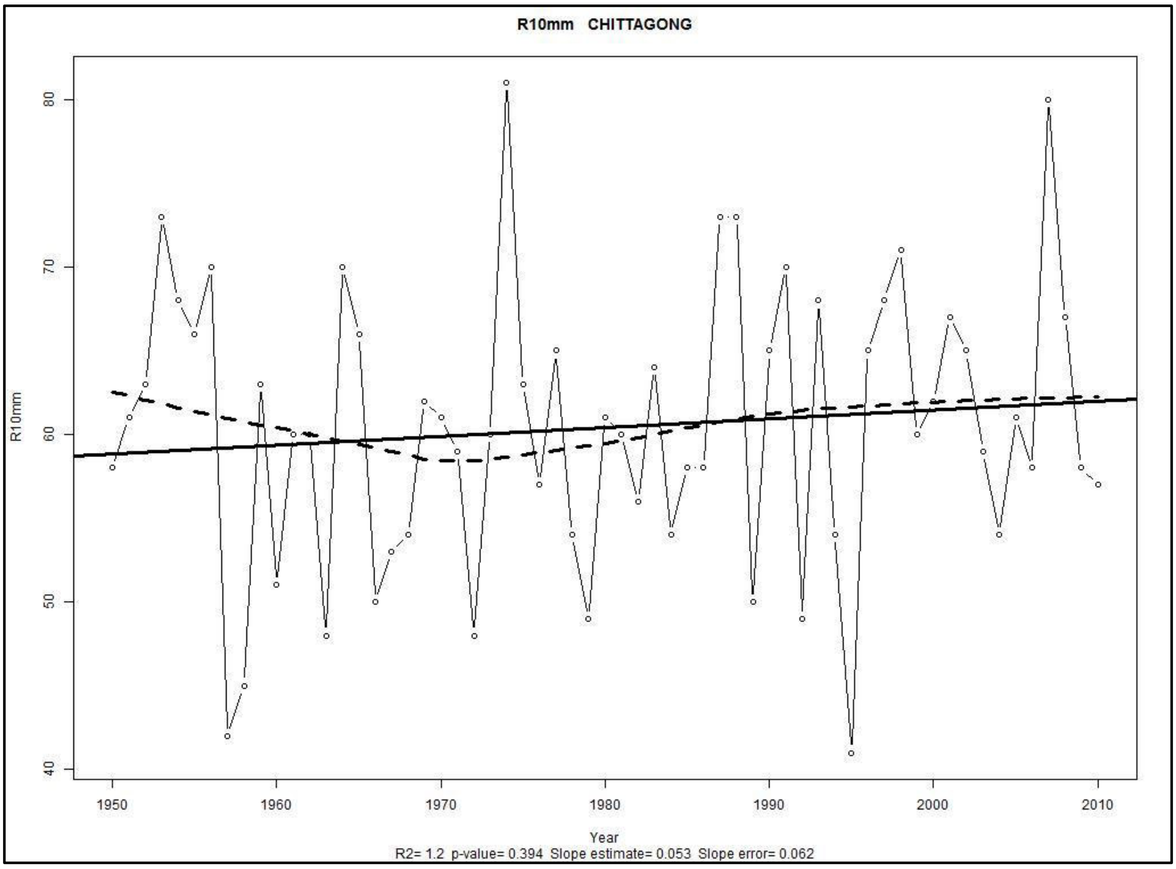

88°24'0"E
89°25'0"E
90°26'0"E
91°27'0"E
92°28'0"E
26°0'0"N
25°0'0"N
24°0'0"N
23°0'0"N
22°0'0"N
21°0'0"N
Coordinate System: Everest 1830 Transverse Mercator
Projection: Transverse Mercator
Datum: Everest 1830
False Easting: 50,000,000.0000
False Northing: -2,000,000.0000
Central Meridian: 90.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
N
W
E
S
Chittagong District
Bangladesh Boundary
October Precipitation (mm)
High : 243.258
Low : 125.491
Date: 04-Nov-14
Author: Bayes Ahmed
0 25 50 100 150 200
KM

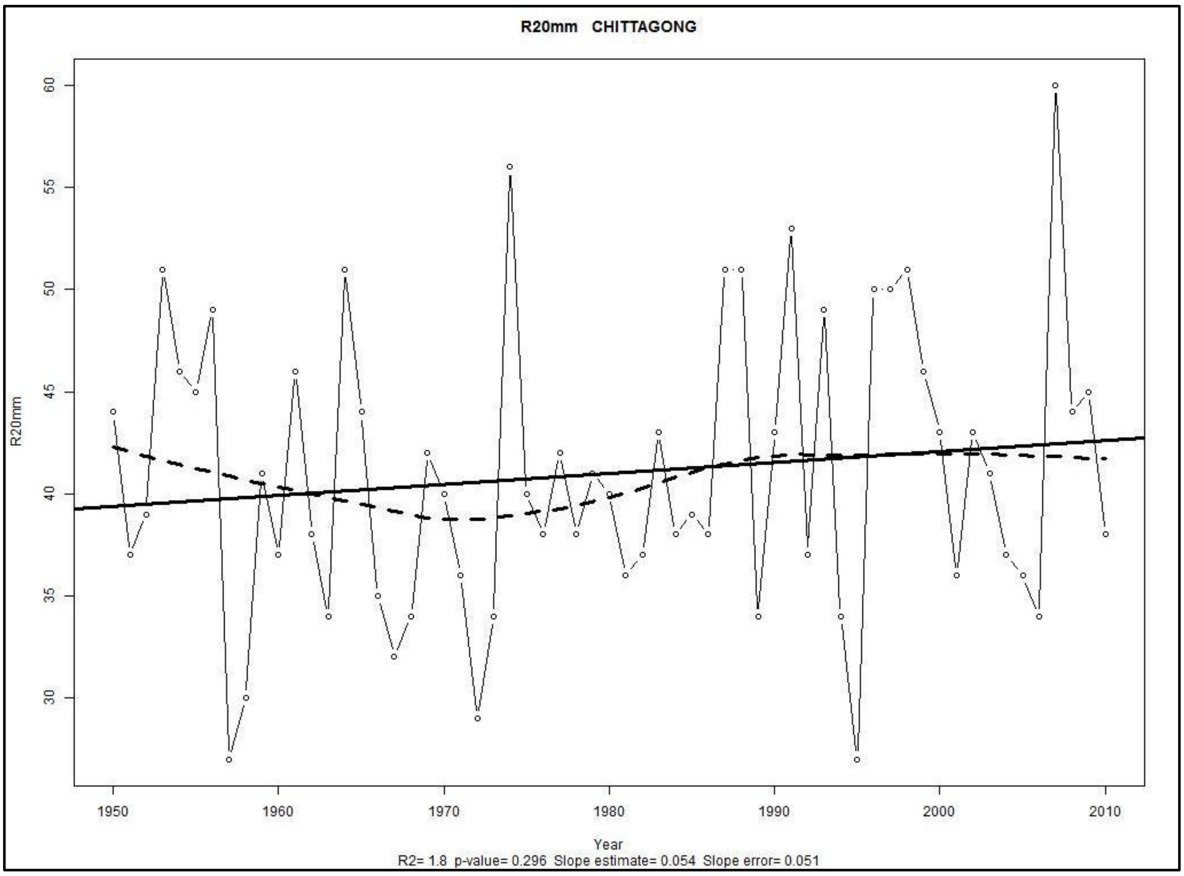
Appendix-E.8: Plots Generated for the Rainfall Indices

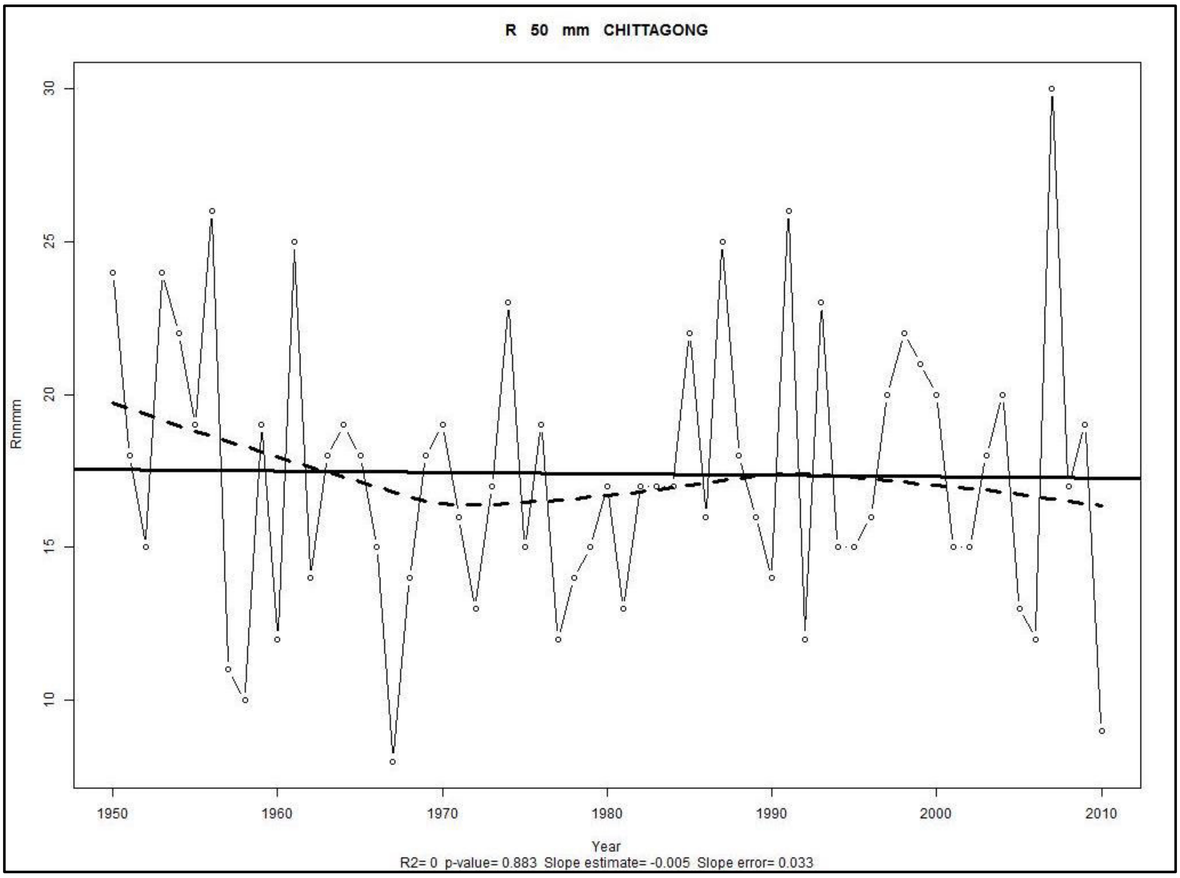


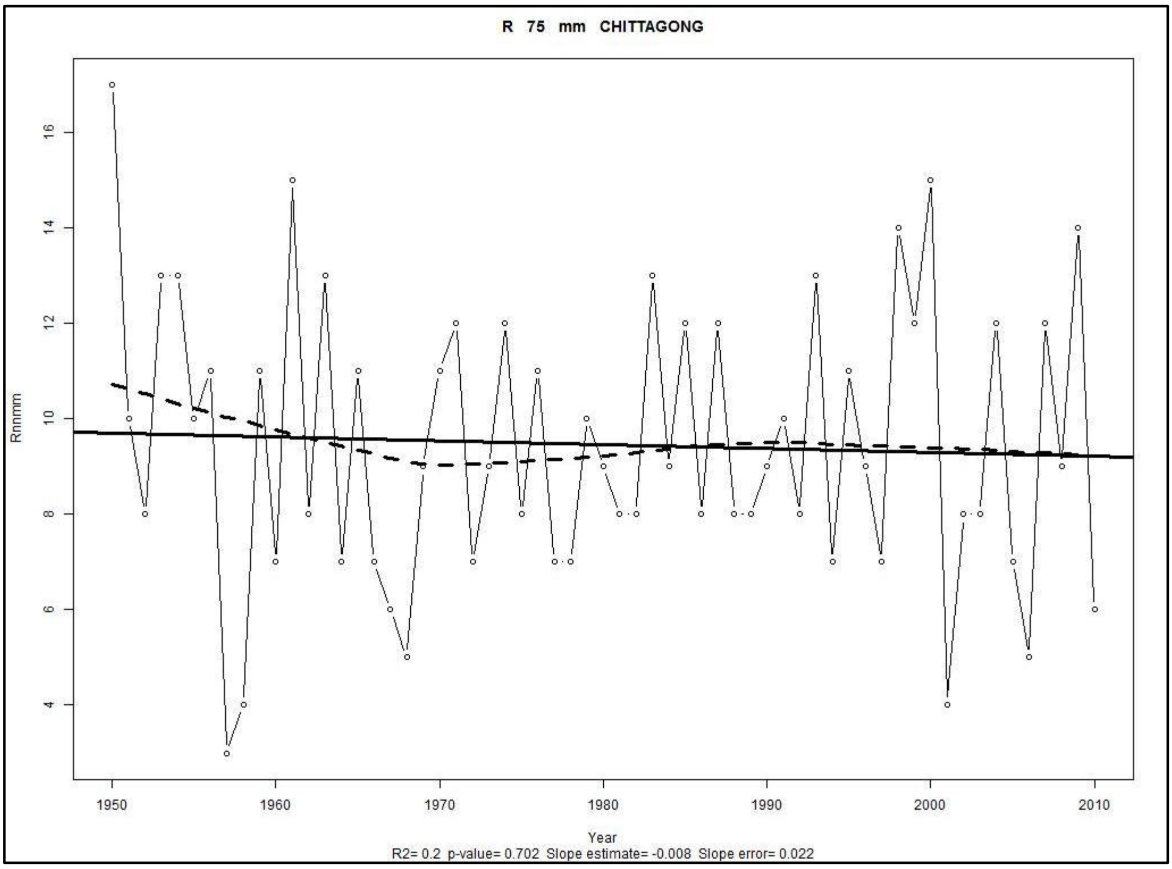


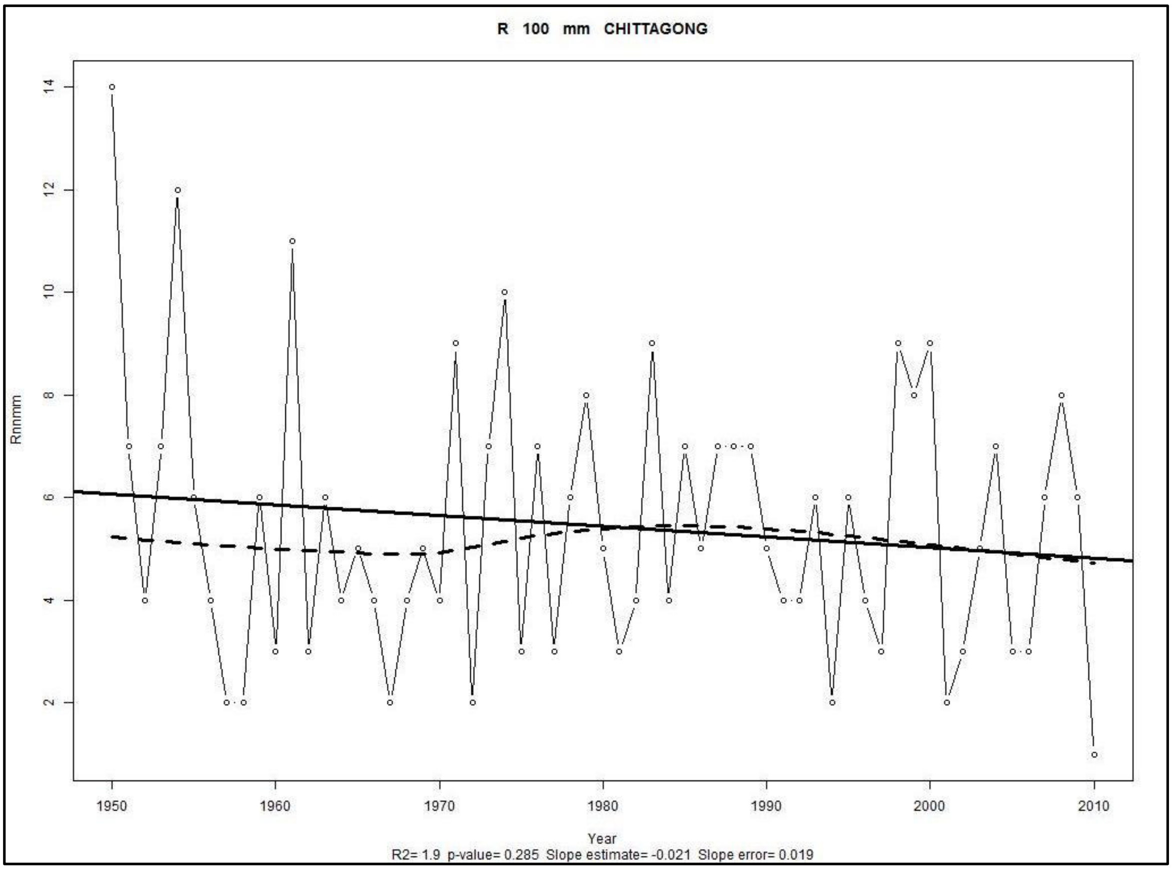

SDII CHITTAGONG
SDII
20
25
30
35
1950
1960
1970
1980
1990
2000
2010
Year
R2= 0 p-value= 0.969 Slope estimate= 0.001 Slope error= 0.032

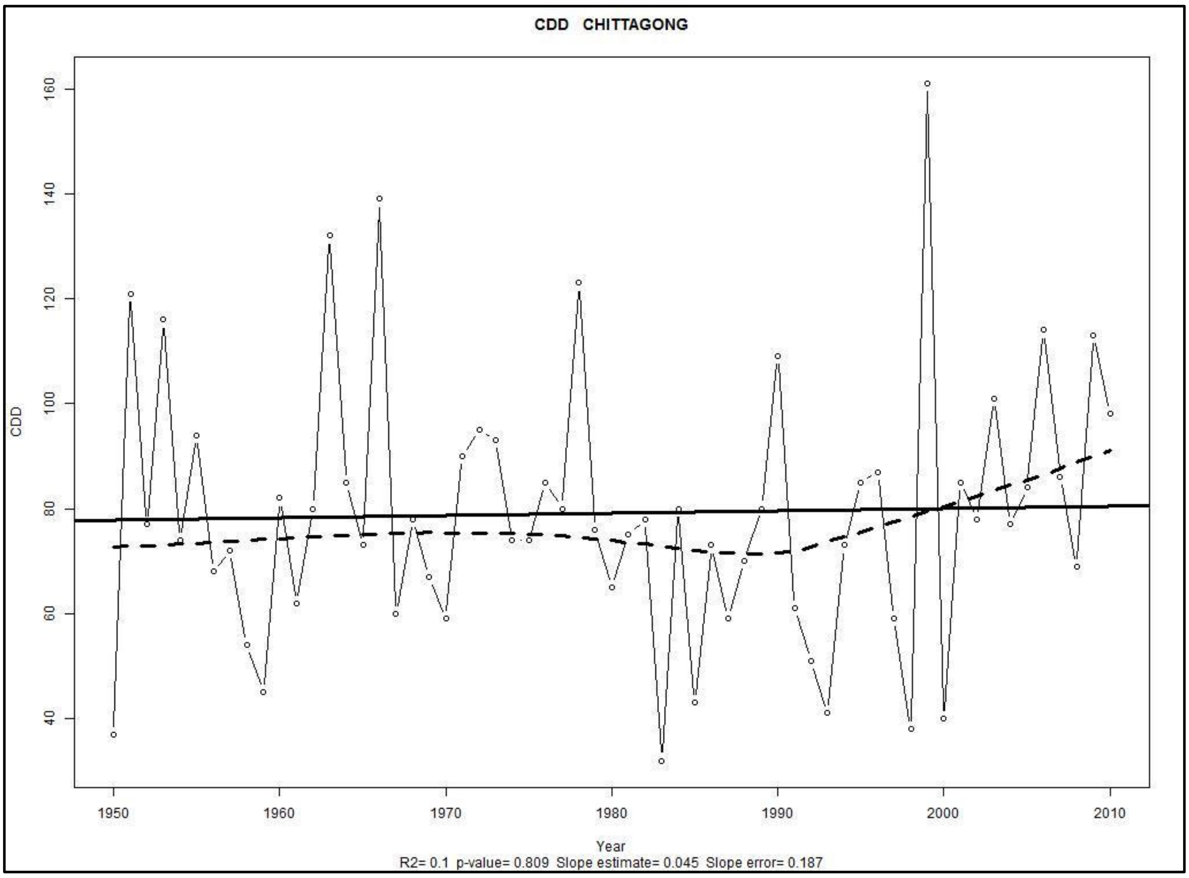

R10mm CHITTAGONG
R10mm
40
50
60
70
80
1950
1960
1970
1980
1990
2000
2010
Year
R2= 1.2 p-value= 0.394 Slope estimate= 0.053 Slope error= 0.062

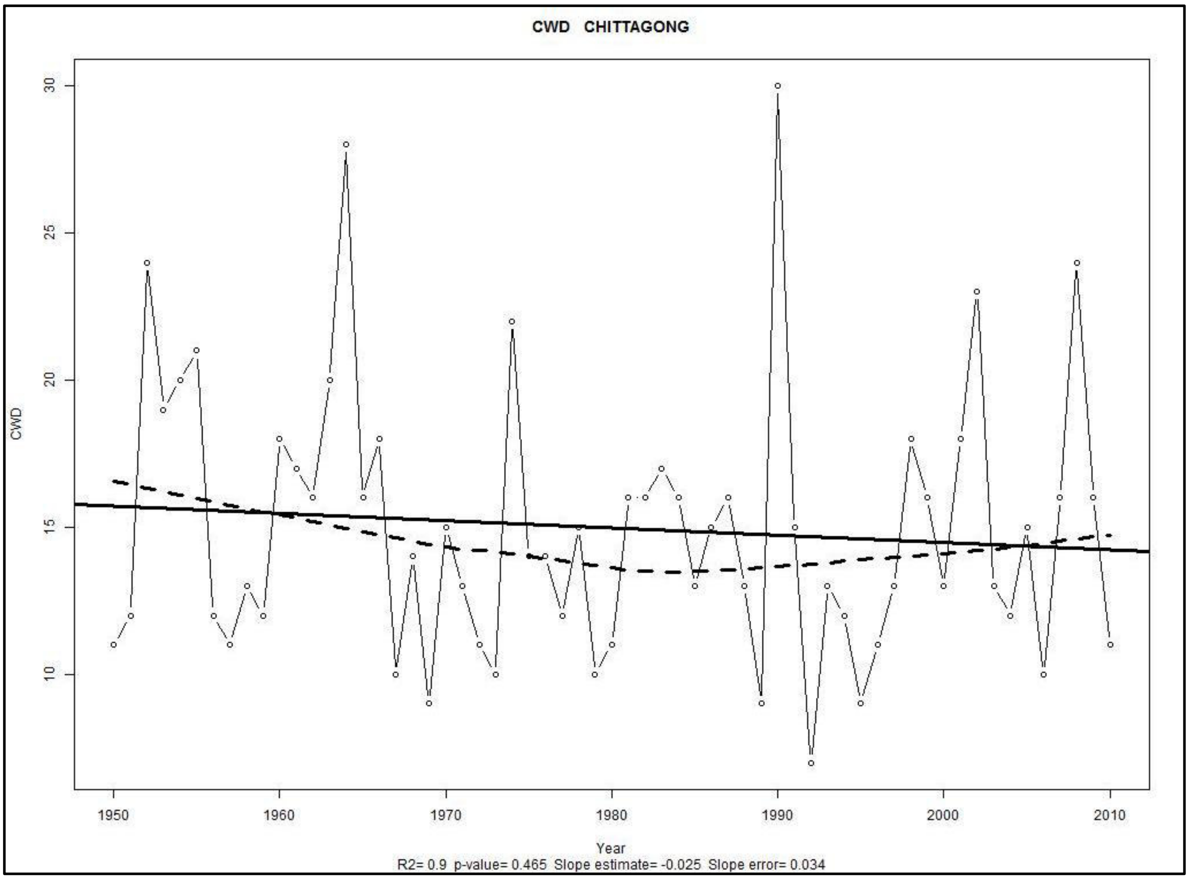

R20mm CHITTAGONG
R20mm
Year
R2= 1.8 p-value= 0.296 Slope estimate= 0.054 Slope error= 0.051

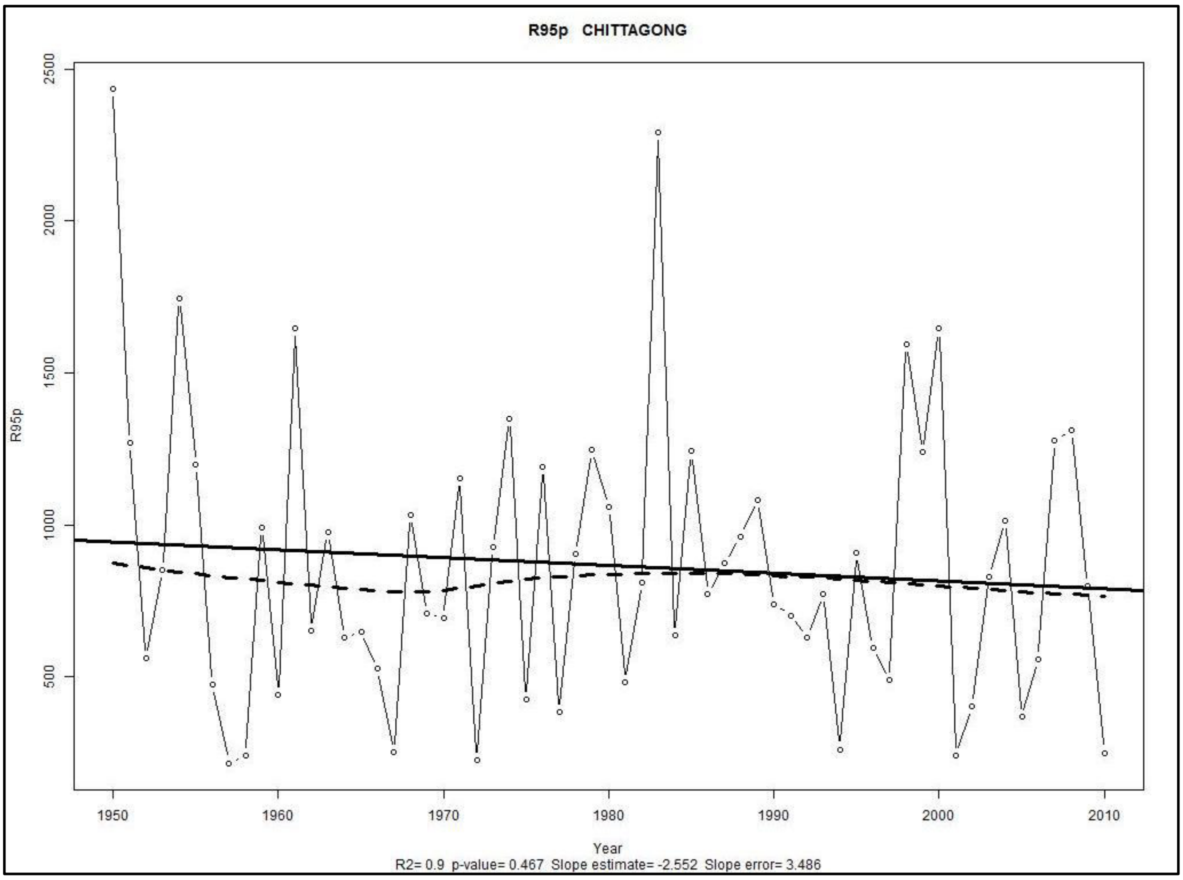

R 50 mm CHITTAGONG
Rnnmm
Year
R2= 0 p-value= 0.883 Slope estimate= -0.005 Slope error= 0.033

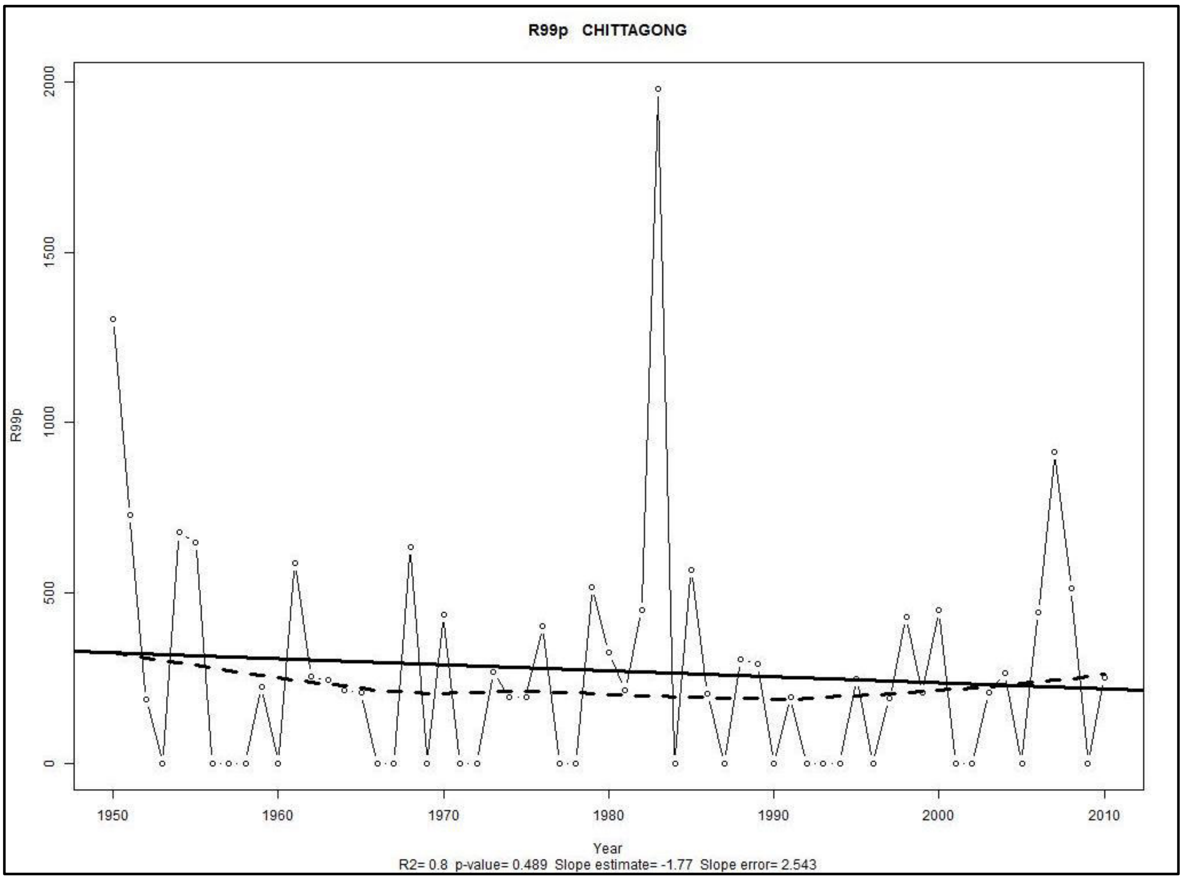

R 75 mm CHITTAGONG
Rnnmm
Year
R2= 0.2 p-value= 0.702 Slope estimate= -0.008 Slope error= 0.022

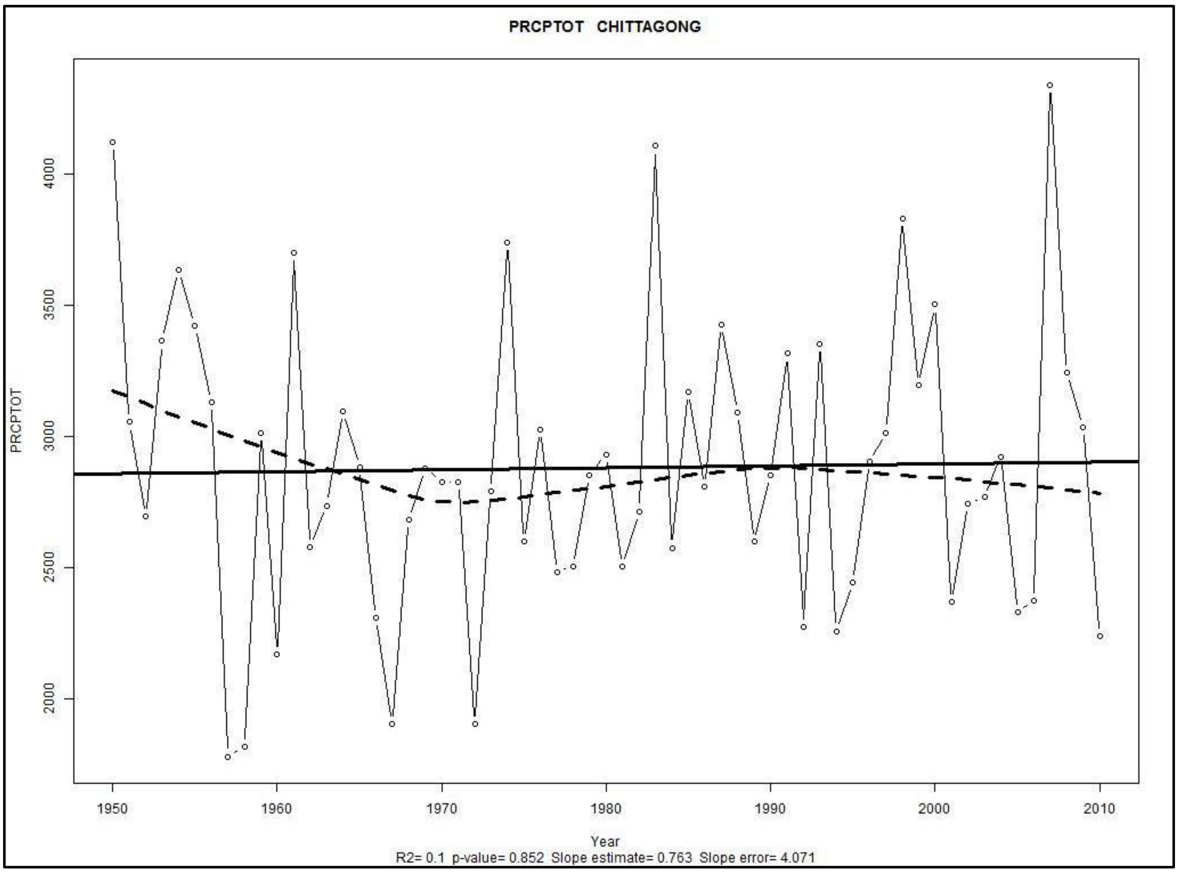

R 100 mm CHITTAGONG
Rnnmm
Year
R2= 1.9 p-value= 0.285 Slope estimate= -0.021 Slope error= 0.019


CDD CHITTAGONG
CDD
Year
R2= 0.1 p-value= 0.809 Slope estimate= 0.045 Slope error= 0.187


CWD CHITTAGONG
CWD
Year
R2= 0.9 p-value= 0.465 Slope estimate= -0.025 Slope error= 0.034


R95p CHITTAGONG
R95p
2500
2000
1500
1000
500
1950
1960
1970
1980
1990
2000
2010
Year
R2= 0.9 p-value= 0.467 Slope estimate= -2.552 Slope error= 3.486


R99p CHITTAGONG
R99p
2000
1500
1000
500
0
1950
1960
1970
1980
1990
2000
2010
Year
R2= 0.8 p-value= 0.489 Slope estimate= -1.77 Slope error= 2.543



Appendix-E.9: Year-wise Rainfall Indices of Chittagong (1950-2010)

Year	CDD	CWD	PrcpTot	R10	R20	R50	R75	R100	R95p	R99p	SDII
1950	37	11	4124	58	44	24	17	14	2434	1304	38.5
1951	121	12	3055	61	37	18	10	7	1269	728	28.8
1952	77	24	2697	63	39	15	8	4	562	186	19.4
1953	116	19	3364	73	51	24	13	7	852	0	27.6
1954	74	20	3635	68	46	22	13	12	1746	677	31.9
1955	94	21	3421	66	45	19	10	6	1199	648	28.7
1956	68	12	3132	70	49	26	11	4	475	0	26.1
1957	72	11	1780	42	27	11	3	2	217	0	17.8
1958	54	13	1817	45	30	10	4	2	240	0	18.2
1959	45	12	3013	63	41	19	11	6	993	225	22.7
1960	82	18	2169	51	37	12	7	3	442	0	21.7
1961	62	17	3702	60	46	25	15	11	1646	588	29.4
1962	80	16	2579	60	38	14	8	3	653	254	22.6
1963	132	20	2737	48	34	18	13	6	975	243	24.7
1964	85	28	3096	70	51	19	7	4	630	214	22.4
1965	73	16	2882	66	44	18	11	5	649	208	27.2
1966	139	18	2310	50	35	15	7	4	527	0	22.2
1967	60	10	1904	53	32	8	6	2	253	0	17.3
1968	78	14	2683	54	34	14	5	4	1032	634	23.5

Year	CDD	CWD	PrcpTot	R10	R20	R50	R75	R100	R95p	R99p	SDII
1969	67	9	2879	62	42	18	9	5	708	0	24.8
1970	59	15	2828	61	40	19	11	4	694	435	22.3
1971	90	13	2827	59	36	16	12	9	1153	0	28
1972	95	11	1903	48	29	13	7	2	225	0	19
1973	93	10	2791	60	34	17	9	7	927	269	22.7
1974	74	22	3741	81	56	23	12	10	1350	194	26.9
1975	74	14	2598	63	40	15	8	3	426	192	19
1976	85	14	3025	57	38	19	11	7	1192	402	28.3
1977	80	12	2484	65	42	12	7	3	384	0	21.8
1978	123	15	2505	54	38	14	7	6	904	0	20.5
1979	76	10	2851	49	41	15	10	8	1246	518	24.8
1980	65	11	2932	61	40	17	9	5	1058	325	26.9
1981	75	16	2505	60	36	13	8	3	481	215	21.1
1982	78	16	2715	56	37	17	8	4	810	450	23
1983	32	17	4108	64	43	17	13	9	2293	1980	33.1
1984	80	16	2576	54	38	17	9	4	636	0	23.4
1985	43	13	3172	58	39	22	12	7	1242	568	28.6
1986	73	15	2810	58	38	16	8	5	773	204	24.4
1987	59	16	3426	73	51	25	12	7	876	0	29.8
1988	70	13	3093	73	51	18	8	7	962	305	24.7
1989	80	9	2598	50	34	16	8	7	1083	292	25.7
1990	109	30	2852	65	43	14	9	5	740	0	20.7
1991	61	15	3316	70	53	26	10	4	703	193	26.1
1992	51	7	2275	49	37	12	8	4	629	0	21.7
1993	41	13	3352	68	49	23	13	6	773	0	25
1994	73	12	2258	54	34	15	7	2	262	0	19.5
1995	85	9	2444	41	27	15	11	6	910	247	22
1996	87	11	2904	65	50	16	9	4	596	0	25
1997	59	13	3015	68	50	20	7	3	490	190	27.7
1998	38	18	3833	71	51	22	14	9	1596	428	33.9
1999	161	16	3194	60	46	21	12	8	1241	206	30.1
2000	40	13	3503	62	43	20	15	9	1645	448	29.7
2001	85	18	2368	67	36	15	4	2	241	0	19.9
2002	78	23	2745	65	43	15	8	3	404	0	20.2
2003	101	13	2769	59	41	18	8	5	830	206	23.5
2004	77	12	2924	54	37	20	12	7	1013	264	25.4
2005	84	15	2331	61	36	13	7	3	368	0	19.4
2006	114	10	2375	58	34	12	5	3	559	443	21.8
2007	86	16	4340	80	60	30	12	6	1279	915	32.9
2008	69	24	3241.9	67	44	17	9	8	1311.2	513.1	27.9
2009	113	16	3037.3	58	45	19	14	6	799.4	0	28.1
2010	98	11	2238.7	57	38	9	6	1	250.9	250.9	21.9

Appendix-E.10: Year and Month-wise 'Rx1 Day' Index Values of Chittagong (1950-2010).

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1950	0	34	2	61	96	233	247	168	96	56	65	0	247
1951	0	0	56	40	64	84	166	256	109	281	0	5	281
1952	0	0	50	88	49	186	110	100	26	76	56	0	186
1953	0	0	5	38	106	104	106	152	113	167	15	0	167
1954	7	8	22	4	42	214	144	239	61	113	0	1	239
1955	0	0	153	27	150	231	417	83	77	59	77	0	417
1956	1	0	23	48	137	102	67	128	83	89	69	0	137
1957	19	6	0	0	59	70	115	53	69	67	0	1	115
1958	6	4	0	36	74	128	63	95	112	49	0	1	128
1959	15	27	133	1	33	173	124	124	115	225	0	10	225
1960	0	0	21	0	101	143	101	97	38	89	0	2	143
1961	0	3	8	25	44	195	182	198	30	195	1	0	198
1962	6	42	254	28	62	152	94	99	67	92	0	0	254
1963	0	0	27	21	73	167	243	83	44	96	0	0	243
1964	3	1	0	61	41	94	214	121	47	73	9	0	214
1965	0	68	20	5	83	121	208	105	56	44	0	0	208
1966	0	0	28	0	62	104	79	135	174	76	0	91	174
1967	12	0	25	52	34	47	80	137	85	93	0	0	137
1968	5	11	55	5	52	150	336	63	16	39	0	0	336
1969	20	0	71	138	34	151	169	90	104	15	16	0	169
1970	1	10	1	35	50	82	239	85	96	61	110	0	239
1971	9	0	0	2	29	144	165	119	43	16	0	0	165
1972	0	1	0	21	15	118	80	89	96	20	0	0	118
1973	5	5	14	88	110	100	102	63	269	105	134	18	269
1974	7	0	54	25	68	194	126	119	109	85	48	0	194
1975	0	5	0	28	54	129	192	92	78	77	47	0	192
1976	0	5	1	22	26	210	192	71	27	139	185	10	210
1977	0	38	0	54	81	149	131	96	38	31	32	0	149
1978	0	0	1	18	114	145	33	185	116	39	0	0	185
1979	1	1	1	27	53	135	119	273	112	56	38	23	273
1980	0	26	14	22	133	325	97	150	42	69	0	0	325
1981	8	2	75	61	93	61	215	85	50	10	1	23	215
1982	0	4	26	41	10	249	118	201	145	2	30	1	249
1983	5	21	39	35	41	205	407	511	79	101	26	38	511
1984	1	0	0	43	107	76	179	89	77	48	0	2	179
1985	10	6	57	95	194	139	374	144	41	23	121	2	374
1986	2	0	0	65	37	204	179	60	43	49	72	0	204
1987	3	13	30	81	26	139	140	168	75	16	37	16	168
1988	0	6	27	113	100	133	305	68	84	108	56	1	305
1989	0	2	0	132	35	68	292	23	148	68	14	0	292
1990	0	25	19	63	111	183	182	23	25	76	35	32	183
1991	12	0	33	63	159	130	193	99	80	70	95	13	193

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1992	0	72	0	1	28	175	125	72	124	108	3	24	175
1993	9	51	91	24	103	161	107	151	79	41	8	0	161
1994	7	6	82	88	58	157	80	87	41	59	11	0	157
1995	0	6	8	18	143	90	155	247	43	16	113	0	247
1996	0	38	49	156	48	110	115	118	68	94	3	1	156
1997	0	27	48	16	69	71	190	79	152	71	38	4	190
1998	28	71	54	96	124	37	223	183	38	48	70	0	223
1999	0	0	0	0	154	180	141	206	60	71	2	62	206
2000	10	0	9	27	180	188	171	177	33	260	15	0	260
2001	0	12	1	23	101	140	75	74	70	42	59	0	140
2002	1	0	36	31	94	94	156	85	36	49	69	10	156
2003	0	0	20	97	55	206	64	80	60	71	0	37	206
2004	0	0	3	41	122	119	264	41	154	95	0	0	264
2005	5	0	29	58	26	50	103	101	164	31	18	5	164
2006	0	0	0	40	233	54	84	23	95	28	15	0	233
2007	0	21	4	66	61	425	206	100	160	284	82	0	425
2008	54.7	4.8	9.5	1.1	58.8	284.1	229	167.2	39	60.4	34.8	0	284.1
2009	0	1.8	77.7	151.1	100.4	155.2	162	64.8	96	28.6	0	0	162
2010	8.8	0	36	38.2	250.9	76.6	47.4	31	95.4	3.6	17.3	1	250.9

Appendix-E.11: Year and Month-wise 'Rx5 Day' Index Values of Chittagong (1950-2010)

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1950	0	43	2	101	172	1037	504	384	142	130	92	0	1037
1951	0	0	69	127	103	264	361	541	144	455	7	7	541
1952	0	0	50	157	80	412	246	272	69	184	118	0	412
1953	0	0	5	57	241	213	313	390	302	198	17	0	390
1954	7	14	26	26	110	524	224	472	93	146	0	1	524
1955	0	0	254	184	300	310	728	175	84	145	223	0	728
1956	1	0	32	72	208	359	132	290	244	137	88	0	359
1957	35	6	6	0	76	92	407	116	125	86	0	1	407
1958	6	6	0	37	85	203	181	198	208	87	0	1	208
1959	18	52	236	60	82	264	349	323	184	249	249	17	349
1960	0	0	23	0	114	346	365	146	147	172	11	2	365
1961	0	5	12	35	82	519	481	627	76	217	2	0	627
1962	6	42	254	254	171	332	300	168	118	133	130	0	332
1963	0	0	27	23	96	422	420	193	66	157	3	0	422
1964	3	2	1	166	76	191	415	243	154	147	10	0	415
1965	0	71	20	5	100	262	440	443	150	83	17	0	443
1966	0	0	28	0	99	203	137	280	283	177	0	99	283
1967	14	0	25	99	77	89	158	366	173	156	0	0	366
1968	7	11	58	5	138	344	914	143	52	65	16	0	914
1969	20	0	113	224	62	278	325	237	189	22	31	0	325
1970	1	20	1	35	80	176	473	140	168	156	125	0	473

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1971	10	1	0	2	39	379	391	271	171	47	11	0	391
1972	0	2	0	36	15	423	200	166	136	60	0	0	423
1973	5	5	14	142	302	276	305	296	365	159	212	40	365
1974	7	0	85	107	163	429	287	250	361	133	61	61	429
1975	0	5	0	43	170	210	413	164	129	206	86	0	413
1976	0	6	1	28	71	706	413	228	43	160	228	228	706
1977	0	71	46	170	93	279	317	226	56	82	41	0	317
1978	0	0	2	34	151	346	100	284	335	72	8	0	346
1979	1	2	1	27	128	259	325	486	255	59	47	81	486
1980	0	26	25	32	170	435	277	324	138	179	0	0	435
1981	15	2	118	170	158	145	540	186	93	21	1	36	540
1982	0	7	52	73	25	437	255	334	241	85	43	1	437
1983	5	42	55	141	120	439	684	1021	94	193	45	52	1021
1984	38	0	0	82	251	273	413	129	159	63	0	2	413
1985	17	6	88	95	294	224	757	256	91	50	198	2	757
1986	2	0	0	81	60	560	648	118	94	99	122	0	648
1987	3	20	52	182	29	225	393	410	271	63	49	17	410
1988	0	11	30	178	131	285	464	137	167	169	72	73	464
1989	0	2	0	220	220	144	562	439	181	147	18	0	562
1990	0	37	28	100	161	318	475	177	43	202	64	36	475
1991	19	0	40	103	254	381	416	311	226	88	139	13	416
1992	0	79	0	1	78	445	148	168	177	321	3	34	445
1993	9	71	144	91	236	526	246	428	87	66	14	0	526
1994	7	7	174	156	80	353	153	167	55	67	11	0	353
1995	0	8	18	34	263	144	280	387	84	33	127	0	387
1996	0	85	91	168	109	310	240	251	109	189	186	1	310
1997	0	29	102	20	145	158	412	204	240	159	49	4	412
1998	37	89	87	175	179	68	559	437	315	57	93	0	559
1999	0	0	0	0	179	530	263	549	99	128	7	107	549
2000	12	5	9	57	524	280	438	460	103	286	57	15	524
2001	0	12	1	23	307	404	146	138	125	93	77	0	404
2002	1	1	69	37	188	102	458	140	56	71	113	23	458
2003	0	0	45	97	67	423	382	175	83	162	11	66	423
2004	0	0	3	67	158	364	548	74	447	162	0	0	548
2005	5	0	51	78	73	141	273	261	244	57	20	8	273
2006	0	0	0	40	665	468	228	70	251	64	16	0	665
2007	0	30	4	110	127	632	446	305	410	353	118	0	632
2008	55.7	7.6	14.1	1.1	103	425.8	395.5	318.2	267	117.1	42.6	0	425.8
2009	0	1.8	79.3	233.8	231.5	474.3	472.5	113.4	160.5	38.2	0	0	474.3
2010	8.8	0	38.1	135.3	459.2	144.7	118.8	40.6	198.7	3.6	22.3	1.8	459.2

Appendix-E.12 (LOGISTIC REGRESSION RESULTS)

Regression Equation:

logit(LS_locations) = -66.6424 - 3.118817*Drain_final + 2.958392*elevation_final- 0.151729*lc_final + 1.500556*NDVI_final - 13.020611*precipitation - 0.536982*Road_final - 0.291650*slope_final + 13.450597*soil_final + 0.138068*Water_final

Individual Regression Coefficient

Variables	*Coefficient*
Intercept	-66.64235202
Drain_Final	-3.1188169
Elevation_final	2.95839199
lc_final	-0.15172865
NDVI_final	1.50055576
Precipitation	-13.02061117
Road_final	-0.53698236
Slope_final	-0.29165029
soil_final	13.45059725
water_final	0.13806842

Regression Statistics:

Number of total observations = 800166

Number of 0s in study area = 800147

Number of 1s in study area = 19

Percentage of 0s in study area= 99.9976

Percentage of 1s in study area= 0.0024

Number of auto-sampled observations = 77021

Number of 0s in sampled area = 77019

Number of 1s in sampled area = 2

Percentage of 0s in sampled area = 99.9974

Percentage of 1s in sampled area = 0.0026

-2logL0 = 46.2347

-2log(likelihood) = 29.1549

Pseudo R_square = 0.3694

Goodness of Fit = 4258.7533

ChiSquare(9) = 17.0798

Means and Standard Deviations:

Variables	*Mean*	*Standard Deviation*
Drain_Final	2.305514	1.31106
Elevation_final	1.420807	0.858763
lc_final	2.717324	1.022174
NDVI_final	1.826593	1.094401
Precipitation	2.449202	1.411487
Road_final	1.073876	0.407564
Slope_final	1.507861	0.891945
soil_final	2.737565	1.690229
water_final	1.102089	0.714889
LS_locations	0.000026	0.005096

Classification of cases & odds ratio:

Observed	*Fitted_0*	*Fitted_1*	*Percent Correct*
0	77019	0	100
1	2	0	0

Odds Ratio = Not Applicable

Reclassification of cases & ROC (Sample-based computation when applicable):

(1) Select a new threshold value such that, after reclassification, the number of fitted 1s matches the number of observed 1s in the dependent variable

New cutting threshold = 0.0164

Classification of cases & odds ratio by using the new threshold

Observed	*Fitted_0*	*Fitted_1*	*Percent Correct*
0	77016	3	99.9961
1	2	0	0

Adjusted Odds Ratio = 0.0000

True Positive = 0.0000%

False Positive = 0.0039%

(2) ROC* Result with 100 thresholds (Sample-based computation when applicable):

ROC = 0.9900

* ROC=1 indicates a perfect fit; and ROC=0.5 indicates a random fit.

Appendix-E.13 (MULTIPLE REGRESSIONS RESULTS)

Regression Equation:

LS_locations = -0.0001 - 0.0000*Drain_final - 0.0000*elevation_final + 0.0000*lc_final - 0.0000*NDVI_final - 0.0000*precipitation- 0.0000*Road_final + 0.0001*slope_final + 0.0000*soil_final+ 0.0000*Water_final

Regression Statistics:

Apparent R = 0.014615

Apparent R square = 0.000214

Adjusted R = 0.014269

Adjusted R square = 0.000204

F (9, 800156) = 18.995455

ANOVA Regression Table:

	Apparent Degrees of Freedom	Sum of Squares	Mean Square
Source			
Regression	9	0	0
Residual	800156	19	0
Total	800165	19	0

Individual Regression Coefficients:

	Coefficient	t_test(800156)
Intercept	-0.000086	-2.66416
Drain_final	-0.000007	-1.48423
Elevation_final	-0.000013	-1.32267
lc_final	0.000004	0.636121
NDVI_final	-0.000008	-1.56341
precipitation	-0.000007	-1.62925
Road_final	-0.000016	-1.0048
Slope_final	0.000059	7.487095
Soil_final	0.000015	4.367872
Water_final	0.000047	5.389963

Appendix-E.14

RESULTS OF THE RELATIVE OPERATING CHARACTERISTIC (ROC)

1. Result of ROC for Weighted Linear Combination (1)

AUC = 0.839
The following section list detailed statistics for each threshold.
With each threshold, the following 2x2 contingency table is calculated

Reality (reference image)

Simulated by threshold 1 0

1	A(number of cells)	B(number of cells)
0	C	D

For the given reference image: A+C=19 B+D=800147

For the given reference image: A+C=19 B+D=800147

No.	Exp. Thrhlds(%)	Act. Thrhlds(%)	Act. raw cuts	A	True posi.(%)	B	False posi.(%)
1	0	0	0	0	0	0	0
2	4	4.0002	3	2	10.5263	32006	4
3	8	8.0001	3	2	10.5263	64012	8
4	12	12.0001	3	6	31.5789	96015	11.9997
5	16	16.002	3	6	31.5789	128022	15.9998
6	20	20.0001	3	12	63.1579	160022	19.9991
7	24	24.0001	3	19	100	192022	23.9983
8	28	28.0001	3	19	100	224028	27.9984
9	32	32.0001	3	19	100	256035	31.9985
10	36	36.0002	3	19	100	288042	35.9986
11	40	40.0001	3	19	100	320048	39.9986
12	44	44.0001	2	19	100	352055	43.9988
13	48	48.0002	2	19	100	384062	47.9989
14	52	52.0001	2	19	100	416068	51.9989
15	56	56.0001	2	19	100	448075	55.9991
16	60	60.0002	2	19	100	480082	59.9992
17	64	64.001	2	19	100	512088	63.9992
18	68	68.0001	2	19	100	544095	67.9994
19	72	72.0002	2	19	100	576102	71.9995
20	76	76.0001	2	19	100	608108	75.9995
21	80	80.0001	1	19	100	640115	79.9995
22	84	84.0001	1	19	100	672121	83.9997
23	88	88.0001	1	19	100	704128	87.9998
24	92	92.0002	1	19	100	736135	92
25	96	96.0001	1	19	100	768141	96
26	100	100	0	19	100	800147	100

For the given reference image, the following seven statistics are the same for all thresholds. The unit of each statistic is the proportion correct attributable to a combination of information of location and quantity.

No info of location and no info of quantity: N(n) = 0.5000
Perfect info of location and perfect info of quantity: P(p) = 1.0000
Perfect info of location and no info of quantity: P(n) = 0.5000
No info of location and perfect info of quantity: N(p) = 1.0000

No info of location and no info of quantity: Perfect Chance = 0.5000
No info of location and perfect info of quantity: Perfect Quantity = 0.5000
Perfect info of location given no info of quantity: Perfect Location = 0.0000

No.	M(m)	N(m)	P(m)	M(p)	M(n)
1	1	1	1	1	0.5
2	0.96	0.96	0.96	1	0.5
3	0.92	0.92	0.92	1	0.5
4	0.88	0.88	0.88	1	0.5
5	0.84	0.84	0.84	1	0.5
6	0.8	0.8	0.8	1	0.5
7	0.76	0.76	0.76	1	0.5
8	0.72	0.72	0.72	1	0.5
9	0.68	0.68	0.68	1	0.5
10	0.64	0.64	0.64	1	0.5
11	0.6	0.6	0.6	1	0.5
12	0.56	0.56	0.56	1	0.5
13	0.54	0.54	0.54	1	0.5
14	0.48	0.48	0.48	1	0.5
15	0.44	0.44	0.44	1	0.5
16	0.4	0.4	0.4	1	0.5
17	0.36	0.36	0.36	1	0.5
18	0.32	0.32	0.32	1	0.5
19	0.28	0.28	0.28	1	0.5
20	0.24	0.24	0.24	1	0.5
21	0.2	0.2	0.2	1	0.5
22	0.16	0.16	0.16	1	0.5
23	0.12	0.12	0.12	1	0.5
24	0.08	0.08	0.5	1	0.5
25	0.04	0.04	0.04	1	0.5
26	0	0	0	1	0.5

No.	Kno.	Klocation	Kquantity	Kstandard
1	1	0	1	0
2	0.92	0	0.92	0
3	0.84	0	0.84	0
4	0.76	0	0.76	0
5	0.68	0	0.68	0
6	0.6	0	0.6	0
7	0.52	1	0.52	0
8	0.44	1	0.44	0
9	0.36	1	0.36	0
10	0.28	1	0.28	0
11	0.2	1	0.2	0
12	0.12	1	0.12	0
13	0.04	1	0.04	0
14	-0.04	1	-0.04	0
15	-0.12	1	-0.12	0
16	-0.2	1	-0.2	0
17	-0.28	0.998	-0.28	0
18	-0.36	1	-0.36	0
19	-0.44	1	-0.44	0
20	-0.52	0.999	-0.52	0
21	-0.6	0	-0.6	0
22	-0.68	0	-0.68	0
23	-0.76	0	-0.76	0
24	-0.84	0	-0.84	0
25	-0.92	0	-0.92	0
26	-1	0	-1	0

No.	Correct Chance	Correct Quantity	Correct Location	Error Location	Error Quantity
1	0.5	0.5	0	0	0
2	0.5	0.46	0	0	0.04
3	0.5	0.42	0	0	0.08
4	0.5	0.38	0	0	0.12
5	0.5	0.34	0	0	0.16
6	0.5	0.3	0	0	0.2
7	0.5	0.26	0	0	0.24
8	0.5	0.22	0	0	0.28
9	0.5	0.18	0	0	0.32
10	0.5	0.14	0	0	0.36
11	0.5	0.1	0	0	0.4
12	0.5	0.06	0	0	0.44
13	0.5	0.02	0	0	0.48
14	0.48	0	0	0	0.52
15	0.44	0	0	0	0.56

No.	Correct Chance	Correct Quantity	Correct Location	Error Location	Error Quantity
16	0.4	0	0	0	0.6
17	0.36	0	0	0	0.64
18	0.32	0	0	0	0.68
19	0.28	0	0	0	0.72
20	0.24	0	0	0	0.76
21	0.2	0	0	0	0.8
22	0.16	0	0	0	0.84
23	0.12	0	0	0	0.88
24	0.08	0	0	0	0.92
25	0.04	0	0	0	0.96
26	0	0	0	0	1

2. Result of ROC for Weighted Linear Combination (2)

AUC = 0.911
The following section list detailed statistics for each threshold.
With each threshold, the following 2x2 contingency table is calculated

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Reality (reference image)

Simulated by threshold 1 0

----

1 A(number of cells) B(number of cells)
0 C D
For the given reference image: A+C=19 B+D=800147

No.	Exp. Thrhlds (%)	Act. Thrhlds (%)	Act. raw cuts	A	True posi. (%)	B	False posi. (%)
1	0	0	0	0	0	0	0
2	4	4.0002	3	0	0	32008	4.0003
3	8	8.0001	3	6	31.5789	64008	7.9995
4	12	12.0001	3	18	94.7368	96003	11.9982
5	16	16.002	3	19	100	128009	15.9982
6	20	20.0001	3	19	100	160015	19.9982
7	24	24.0001	3	19	100	192022	23.9983
8	28	28.0001	3	19	100	224028	27.9984
9	32	32.0001	3	19	100	256035	31.9985
10	36	36.0002	3	19	100	288042	35.9986
11	40	40.0001	3	19	100	320048	39.9986
12	44	44.0001	2	19	100	352055	43.9988
13	48	48.0002	2	19	100	384062	47.9989
14	52	52.0001	2	19	100	416068	51.9989
15	56	56.0001	2	19	100	448075	55.9991

No.	Exp. Thrhlds (%)	Act. Thrhlds (%)	Act. raw cuts	A	True posi. (%)	B	False posi. (%)
16	60	60.0002	2	19	100	480082	59.9992
17	64	64.001	2	19	100	512088	63.9992
18	68	68.0001	2	19	100	544095	67.9994
19	72	72.0002	2	19	100	576102	71.9995
20	76	76.0001	2	19	100	608108	75.9995
21	80	80.0001	1	19	100	640115	79.9997
22	84	84.0001	1	19	100	672121	83.9997
23	88	88.0001	1	19	100	704128	87.9998
24	92	92.0002	1	19	100	736135	92
25	96	96.0001	1	19	100	768141	96
26	100	100	0	19	100	800147	100

For the given reference image, the following seven statistics are the same for all thresholds. The unit of each statistic is the proportion correct attributable to a combination of information of location and quantity.

No info of location and no info of quantity: N(n) = 0.5000
Perfect info of location and perfect info of quantity: P(p) = 1.0000
Perfect info of location and no info of quantity: P(n) = 0.5000
No info of location and perfect info of quantity: N(p) = 1.0000

No info of location and no info of quantity: PerfectChance = 0.5000
No info of location and perfect info of quantity: PerfectQuantity = 0.5000
Perfect info of location given no info of quantity:PerfectLocation = 0.0000

No.	M(m)	N(m)	P(m)	M(p)	M(n)
1	1	1	1	1	0.5
2	0.96	0.96	0.96	1	0.5
3	0.92	0.92	0.92	1	0.5
4	0.88	0.88	0.88	1	0.5
5	0.84	0.84	0.84	1	0.5
6	0.8	0.8	0.8	1	0.5
7	0.76	0.76	0.76	1	0.5
8	0.72	0.72	0.72	1	0.5
9	0.68	0.68	0.68	1	0.5
10	0.64	0.64	0.64	1	0.5
11	0.6	0.6	0.6	1	0.5
12	0.56	0.56	0.56	1	0.5
13	0.54	0.54	0.54	1	0.5
14	0.48	0.48	0.48	1	0.5
15	0.44	0.44	0.44	1	0.5
16	0.4	0.4	0.4	1	0.5
17	0.36	0.36	0.36	1	0.5

No.	M(m)	N(m)	P(m)	M(p)	M(n)
18	0.32	0.32	0.32	1	0.5
19	0.28	0.28	0.28	1	0.5
20	0.24	0.24	0.24	1	0.5
21	0.2	0.2	0.2	1	0.5
22	0.16	0.16	0.16	1	0.5
23	0.12	0.12	0.12	1	0.5
24	0.08	0.08	0.5	1	0.5
25	0.04	0.04	0.04	1	0.5
26	0	0	0	1	0.5

No.	Kno	Klocation	Kquantity	Kstandard
1	1	0	1	0
2	0.92	-0.043	0.92	0
3	0.84	0.255	0.84	0
4	0.76	0.941	0.76	0
5	0.68	1	0.68	0
6	0.6	1	0.6	0
7	0.52	1	0.52	0
8	0.44	1	0.44	0
9	0.36	1	0.36	0
10	0.28	1	0.28	0
11	0.2	1	0.2	0
12	0.12	1	0.12	0
13	0.04	1	0.04	0
14	-0.04	1	-0.04	0
15	-0.12	1	-0.12	0
16	-0.2	1	-0.2	0
17	-0.28	0.998	-0.28	0
18	-0.36	1	-0.36	0
19	-0.44	1	-0.44	0
20	-0.52	0.999	-0.52	0
21	-0.6	0	-0.6	0
22	-0.68	0	-0.68	0
23	-0.76	0	-0.76	0
24	-0.84	0	-0.84	0
25	-0.92	0	-0.92	0
26	-1	0	-1	0

No.	Correct Chance	Correct Quantity	Correct Location	Error Location	Error Quantity
1	0.5	0.5	0	0	0
2	0.5	0.46	0	0	0.04
3	0.5	0.42	0	0	0.08
4	0.5	0.38	0	0	0.12
5	0.5	0.34	0	0	0.16
6	0.5	0.3	0	0	0.2
7	0.5	0.26	0	0	0.24
8	0.5	0.22	0	0	0.28
9	0.5	0.18	0	0	0.32
10	0.5	0.14	0	0	0.36
11	0.5	0.1	0	0	0.4
12	0.5	0.06	0	0	0.44
13	0.5	0.02	0	0	0.48
14	0.48	0	0	0	0.52
15	0.44	0	0	0	0.56
16	0.4	0	0	0	0.6
17	0.36	0	0	0	0.64
18	0.32	0	0	0	0.68
19	0.28	0	0	0	0.72
20	0.24	0	0	0	0.76
21	0.2	0	0	0	0.8
22	0.16	0	0	0	0.84
23	0.12	0	0	0	0.88
24	0.08	0	0	0	0.92
25	0.04	0	0	0	0.96
26	0	0	0	0	1

3. Result of ROC for Weighted Linear Combination (3)

AUC = 0.885
The following section list detailed statistics for each threshold.
With each threshold, the following 2x2 contingency table is calculated

---

Reality (reference image)

Simulated by threshold 1 0

1	A(number of cells)	B(number of cells)
0	C	D

For the given reference image: A+C=19 B+D=800147

No.	Exp. Thrhlds(%)	Act. Thrhlds(%)	Act. raw cuts	A	True posi.(%)	B	False posi.(%)
1	0	0	0	0	0	0	0
2	4	4	3	0	0	32008	4.0003
3	8	8	3	13	68.4211	64001	7.9987
4	12	12	3	17	89.4737	96004	11.9983
5	16	16	2	17	89.4737	128011	15.9984
6	20	20	2	17	89.4737	160017	19.9985
7	24	24	2	17	89.4737	192024	23.9986
8	28	28	2	17	89.4737	224030	27.9986
9	32	32	2	17	89.4737	256037	31.9987
10	36	36	2	17	89.4737	288044	35.9989
11	40	40	2	17	89.4737	320050	39.9989
12	44	44	2	17	89.4737	352057	43.999
13	48	48	2	17	89.4737	384064	47.9992
14	52	52	2	19	100	416068	51.9989
15	56	56	2	19	100	448075	55.9991
16	60	60	2	19	100	480082	59.9992
17	64	64	2	19	100	512088	63.9992
18	68	68	2	19	100	544095	67.9994
19	72	72	2	19	100	576102	71.9995
20	76	76	2	19	100	608108	75.9995
21	80	80	2	19	100	640115	79.9997
22	84	84	2	19	100	672121	83.9997
23	88	88	2	19	100	704128	87.9998
24	92	92	1	19	100	736135	92
25	96	96	1	19	100	768141	96
26	100	100	0	19	100	800147	100

** For the given reference image, the following seven statisticsare the same for all thresholds. The unit of each statistic is theproportion correct attributable to a combination of information of location and quantity.

No info of location and no info of quantity: N(n) = 0.5000
Perfect info of location and perfect info of quantity: P(p) = 1.0000
Perfect info of location and no info of quantity: P(n) = 0.5000
No info of location and perfect info of quantity: N(p) = 1.0000

No info of location and no info of quantity: PerfectChance = 0.5000
No info of location and perfect info of quantity: PerfectQuantity = 0.5000
Perfect info of location given no info of quantity:PerfectLocation = 0.0000

No.	M(m)	N(m)	P(m)	M(p)	M(n)
1	1	1	1	1	0.5
2	0.96	0.96	0.96	1	0.5
3	0.92	0.92	0.92	1	0.5
4	0.88	0.88	0.88	1	0.5
5	0.84	0.84	0.84	1	0.5
6	0.8	0.8	0.8	1	0.5
7	0.76	0.76	0.76	1	0.5
8	0.72	0.72	0.72	1	0.5
9	0.68	0.68	0.68	1	0.5
10	0.64	0.64	0.64	1	0.5
11	0.6	0.6	0.6	1	0.5
12	0.56	0.56	0.56	1	0.5
13	0.52	0.52	0.52	1	0.5
14	0.48	0.48	0.48	1	0.5
15	0.44	0.44	0.44	1	0.5
16	0.4	0.4	0.4	1	0.5
17	0.36	0.36	0.36	1	0.5
18	0.32	0.32	0.32	1	0.5
19	0.28	0.28	0.28	1	0.5
20	0.24	0.24	0.24	1	0.5
21	0.2	0.2	0.2	1	0.5
22	0.16	0.16	0.16	1	0.5
23	0.12	0.12	0.12	1	0.5
24	0.08	0.08	0.08	1	0.5
25	0.04	0.04	0.04	1	0.5
26	0	0	0	1	0.5

No.	Kno	Klocation	Kquantity	Kstandard
1	1	0	1	0
2	0.92	-0.043	0.92	0
3	0.84	0.656	0.84	0
4	0.76	0.881	0.76	0
5	0.68	0.876	0.68	0
6	0.6	0.87	0.6	0
7	0.52	0.861	0.52	0
8	0.44	0.853	0.44	0
9	0.36	0.847	0.36	0
10	0.28	0.837	0.28	0
11	0.2	0.826	0.2	0
12	0.12	0.812	0.12	0
13	0.04	0.797	0.04	0

No.	Kno	Klocation	Kquantity	Kstandard
14	-0.04	1	-0.04	0
15	-0.12	1	-0.12	0
16	-0.2	1	-0.2	0
17	-0.28	0.998	-0.28	0
18	-0.36	1	-0.36	0
19	-0.44	1	-0.44	0
20	-0.52	0.999	-0.52	0
21	-0.6	0	-0.6	0
22	-0.68	0	-0.68	0
23	-0.76	0	-0.76	0
24	-0.84	0	-0.84	0
25	-0.92	0	-0.92	0
26	-1	0	-1	0

No.	Correct Chance	Correct Quantity	Correct Location	Error Location	Error Quantity
1	0.5	0.5	0	0	0
2	0.5	0.46	0	0	0.04
3	0.5	0.42	0	0	0.08
4	0.5	0.38	0	0	0.12
5	0.5	0.34	0	0	0.16
6	0.5	0.3	0	0	0.2
7	0.5	0.26	0	0	0.24
8	0.5	0.22	0	0	0.28
9	0.5	0.18	0	0	0.32
10	0.5	0.14	0	0	0.36
11	0.5	0.1	0	0	0.4
12	0.5	0.06	0	0	0.44
13	0.5	0.02	0	0	0.48
14	0.48	0	0	0	0.52
15	0.44	0	0	0	0.56
16	0.4	0	0	0	0.6
17	0.36	0	0	0	0.64
18	0.32	0	0	0	0.68
19	0.28	0	0	0	0.72
20	0.24	0	0	0	0.76
21	0.2	0	0	0	0.8
22	0.16	0	0	0	0.84
23	0.12	0	0	0	0.88
24	0.08	0	0	0	0.92
25	0.04	0	0	0	0.96
26	0	0	0	0	1

4. Result of ROC for Logistic Regression (LR)

AUC = 0.767
The following section list detailed statistics for each threshold.
With each threshold, the following 2x2 contingency table is calculated

---

Reality (reference image)

Simulated by threshold	1	0
1	A(number of cells)	B(number of cells)
0	C	D

For the given reference image: A+C=19 B+D=800147

No.	Exp. Thrhlds(%)	Act. Thrhlds(%)	Act. raw cuts	A	True posi.(%)	B	False posi.(%)
1	0	0	0	0	0	0	0
2	4	4.0002	0.0001	8	42.1053	32000	3.9993
3	8	8.0001	0	11	57.8947	64003	7.9989
4	12	12.0001	0	11	57.8947	96010	11.999
5	16	16.0002	0	11	57.8947	128017	15.9992
6	20	20.0001	0	11	57.8947	160023	19.9992
7	24	24.0001	0	11	57.8947	192030	23.9993
8	28	28.0001	0	11	57.8947	224036	27.9994
9	32	32.0001	0	11	57.8947	256043	31.9995
10	36	36.0002	0	11	57.8947	288050	35.9996
11	40	40.0001	0	11	57.8947	320056	39.9996
12	44	44.0001	0	12	63.1579	352062	43.9997
13	48	48.0002	0	16	84.2105	384065	47.9993
14	52	52.0001	0	16	84.2105	416071	51.9993
15	56	56.0001	0	16	84.2105	448078	55.9995
16	60	60.0002	0	17	89.4737	480084	59.9995
17	64	64.0001	0	19	100	512088	63.9992
18	68	68.0001	0	19	100	544095	67.9994
19	72	72.0002	0	19	100	576102	71.9995
20	76	76.0001	0	19	100	608108	75.9995
21	80	80.0001	0	19	100	640115	79.9997
22	84	84.0001	0	19	100	672121	83.9997
23	88	88.0001	0	19	100	704128	87.9998
24	92	92.0002	0	19	100	736135	92
25	96	96.0001	0	19	100	768141	96
26	100	100	0	19	100	800147	100

** For the given reference image, the following seven statistics are the same for all thresholds. The unit of each statistic is the proportion correct attributable to a combination of information of location and quantity.
No info of location and no info of quantity: N(n) = 0.5000
Perfect info of location and perfect info of quantity: P(p) = 1.0000
Perfect info of location and no info of quantity: P(n) = 0.5000
No info of location and perfect info of quantity: N(p) = 1.0000

No info of location and no info of quantity: PerfectChance= 0.5000
No info of location and perfect info of quantity: PerfectQuantity= 0.5000
Perfect info of location given no info of quantity:PerfectLocation= 0.0000

No.	M(m)	N(m)	P(m)	M(p)	M(n)
1	1	1	1	1	0.5
2	0.96	0.96	0.96	1	0.5
3	0.92	0.92	0.92	1	0.5
4	0.88	0.88	0.88	1	0.5
5	0.84	0.84	0.84	1	0.5
6	0.8	0.8	0.8	1	0.5
7	0.76	0.76	0.76	1	0.5
8	0.72	0.72	0.72	1	0.5
9	0.68	0.68	0.68	1	0.5
10	0.64	0.64	0.64	1	0.5
11	0.6	0.6	0.6	1	0.5
12	0.56	0.56	0.56	1	0.5
13	0.52	0.52	0.52	1	0.5
14	0.48	0.48	0.48	1	0.5
15	0.44	0.44	0.44	1	0.5
16	0.4	0.4	0.4	1	0.5
17	0.36	0.36	0.36	1	0.5
18	0.32	0.32	0.32	1	0.5
19	0.28	0.28	0.28	1	0.5
20	0.24	0.24	0.24	1	0.5
21	0.2	0.2	0.2	1	0.5
22	0.16	0.16	0.16	1	0.5
23	0.12	0.12	0.12	1	0.5
24	0.08	0.08	0.08	1	0.5
25	0.04	0.04	0.04	1	0.5
26	0	0	0	1	0.5

No.	Kno	Klocation	Kquantity	Kstandard
1	1	0	1	0
2	0.92	0.397	0.92	0
3	0.84	0.542	0.84	0
4	0.76	0.521	0.76	0
5	0.68	0.499	0.68	0
6	0.6	0.474	0.6	0
7	0.52	0.446	0.52	0
8	0.44	0.415	0.44	0
9	0.36	0.381	0.36	0
10	0.28	0.342	0.28	0
11	0.2	0.298	0.2	0
12	0.12	0.343	0.12	0
13	0.4	0.696	0.4	0
14	-0.04	0.671	-0.04	0
15	-0.12	0.642	-0.12	0
16	-0.2	0.736	-0.2	0
17	-0.28	0.998	-0.28	0
18	-0.36	1	-0.36	0
19	-0.44	1	-0.44	0
20	-0.52	0.99	-0.52	0
21	-0.6	0	-0.6	0
22	-0.68	0	-0.68	0
23	-0.76	0	-0.76	0
24	-0.84	0	-0.84	0
25	-0.92	0	-0.92	0
26	-1	0	-1	0

No	Correct Chance	Correct Quantity	Correct Location	Error Location	Error Quantity
1	0.5	0.5	0	0	0
2	0.5	0.46	0	0	0.04
3	0.5	0.42	0	0	0.08
4	0.5	0.38	0	0	0.12
5	0.5	0.34	0	0	0.16
6	0.5	0.3	0	0	0.2
7	0.5	0.26	0	0	0.24
8	0.5	0.22	0	0	0.28
9	0.5	0.18	0	0	0.32
10	0.5	0.14	0	0	0.36
11	0.5	0.1	0	0	0.4
12	0.5	0.06	0	0	0.44

No	Correct Chance	Correct Quantity	Correct Location	Error Location	Error Quantity
13	0.5	0.02	0	0	0.48
14	0.48	0	0	0	0.52
15	0.44	0	0	0	0.56
16	0.4	0	0	0	0.6
17	0.36	0	0	0	0.64
18	0.32	0	0	0	0.68
19	0.28	0	0	0	0.72
20	0.24	0	0	0	0.76
21	0.2	0	0	0	0.8
22	0.16	0	0	0	0.84
23	0.12	0	0	0	0.88
24	0.08	0	0	0	0.92
25	0.04	0	0	0	0.96
26	0	0	0	0	1

5. Result of ROC for Multiple Regressions (MR)

AUC = 0.967
The following section list detailed statistics for each threshold.
With each threshold, the following 2x2 contingency table is calculated

---

Reality (reference image)

Simulated by threshold 1 0

1	A(number of cells)	B(number of cells)
0	C	D

For the given reference image: A+C=19 B+D=800147

No.	Exp. Thrhlds(%)	Act. Thrhlds(%)	Act. Raw cuts	A	True posi(%)	B	False posi.(%)
1	0	0	0	0	0	0	0
2	4	4	0.0002	13	68.4211	31995	3.9986
3	8	8	0.0001	19	100	63995	7.9979
4	12	12	0.0001	19	100	96002	11.998
5	16	16	0.0001	19	100	128009	15.9982
6	20	20	0.0001	19	100	160015	19.9982
7	24	24	0.0001	19	100	192022	23.9983
8	28	28	0	19	100	224028	27.9984
9	32	32	0	19	100	256035	31.9985
10	36	36	0	19	100	288042	35.9986
11	40	40	0	19	100	320048	39.9986
12	44	44	0	19	100	352055	43.9988

No.	Exp. Thrhlds(%)	Act. Thrhlds(%)	Act. Raw cuts	A	True posi(%)	B	False posi.(%)
13	48	48	0	19	100	384062	47.9989
14	52	52	0	19	100	416068	51.9989
15	56	56	0	19	100	448075	55.9991
16	60	60	0	19	100	480082	59.9992
17	64	64	0	19	100	512088	63.9992
18	68	68	0	19	100	544095	67.9994
19	72	72	0	19	100	576102	71.9995
20	76	76	0	19	100	608108	75.9995
21	80	80	0	19	100	640115	79.9997
22	84	84	0	19	100	672121	83.9997
23	88	88	0	19	100	704128	87.9998
24	92	92	-0.0001	19	100	736135	92
25	96	96	-0.0001	19	100	768141	96
26	100	100	-0.0002	19	100	800147	100

** For the given reference image, the following seven statistics are the same for all thresholds. The unit of each statistic is the proportion correct attributable to a combination of information of location and quantity.
No info of location and no info of quantity: N(n) = 0.5000
Perfect info of location and perfect info of quantity: P(p) = 1.0000
Perfect info of location and no info of quantity: P(n) = 0.5000
No info of location and perfect info of quantity: N(p) = 1.0000

No info of location and no info of quantity: PerfectChance= 0.5000
No info of location and perfect info of quantity: PerfectQuantity= 0.5000
Perfect info of location given no info of quantity:PerfectLocation= 0.0000

No.	M(m)	N(m)	P(m)	M(p)	M(n)
1	1	1	1	1	0.5
2	0.96	0.96	0.96	1	0.5
3	0.92	0.92	0.92	1	0.5
4	0.88	0.88	0.88	1	0.5
5	0.84	0.84	0.84	1	0.5
6	0.8	0.8	0.8	1	0.5
7	0.76	0.76	0.76	1	0.5
8	0.72	0.72	0.72	1	0.5
9	0.68	0.68	0.68	1	0.5
10	0.64	0.64	0.64	1	0.5
11	0.6	0.6	0.6	1	0.5
12	0.56	0.56	0.56	1	0.5
13	0.52	0.52	0.52	1	0.5
14	0.48	0.48	0.48	1	0.5

No.	M(m)	N(m)	P(m)	M(p)	M(n)
15	0.44	0.44	0.44	1	0.5
16	0.4	0.4	0.4	1	0.5
17	0.36	0.36	0.36	1	0.5
18	0.32	0.32	0.32	1	0.5
19	0.28	0.28	0.28	1	0.5
20	0.24	0.24	0.24	1	0.5
21	0.2	0.2	0.2	1	0.5
22	0.16	0.16	0.16	1	0.5
23	0.12	0.12	0.12	1	0.5
24	0.08	0.08	0.08	1	0.5
25	0.04	0.04	0.04	1	0.5
26	0	0	0	1	0.5

No.	Kno	Klocation	Kquantity	Kstandard
1	1	0	1	0
2	0.92	0.397	0.92	0
3	0.84	0.542	0.84	0
4	0.76	0.521	0.76	0
5	0.68	0.499	0.68	0
6	0.6	0.474	0.6	0
7	0.52	0.446	0.52	0
8	0.44	0.415	0.44	0
9	0.36	0.381	0.36	0
10	0.28	0.342	0.28	0
11	0.2	0.298	0.2	0
12	0.12	0.343	0.12	0
13	0.4	0.696	0.4	0
14	-0.04	0.671	-0.04	0
15	-0.12	0.642	-0.12	0
16	-0.2	0.736	-0.2	0
17	-0.28	0.998	-0.28	0
18	-0.36	1	-0.36	0
19	-0.44	1	-0.44	0
20	-0.52	0.99	-0.52	0
21	-0.6	0	-0.6	0
22	-0.68	0	-0.68	0
23	-0.76	0	-0.76	0
24	-0.84	0	-0.84	0
25	-0.92	0	-0.92	0
26	-1	0	-1	0

No	Correct Chance	Correct Quantity	Correct Location	Error Location	Error Quantity
1	0.5	0.5	0	0	0
2	0.5	0.46	0	0	0.04
3	0.5	0.42	0	0	0.08
4	0.5	0.38	0	0	0.12
5	0.5	0.34	0	0	0.16
6	0.5	0.3	0	0	0.2
7	0.5	0.26	0	0	0.24
8	0.5	0.22	0	0	0.28
9	0.5	0.18	0	0	0.32
10	0.5	0.14	0	0	0.36
11	0.5	0.1	0	0	0.4
12	0.5	0.06	0	0	0.44
13	0.5	0.02	0	0	0.48
14	0.48	0	0	0	0.52
15	0.44	0	0	0	0.56
16	0.4	0	0	0	0.6
17	0.36	0	0	0	0.64
18	0.32	0	0	0	0.68
19	0.28	0	0	0	0.72
20	0.24	0	0	0	0.76
21	0.2	0	0	0	0.8
22	0.16	0	0	0	0.84
23	0.12	0	0	0	0.88
24	0.08	0	0	0	0.92
25	0.04	0	0	0	0.96
26	0	0	0	0	1

APPENDIX F

Project Team

The project team comprises of **8** personnel. They are as follows:

- **Advisor and Geotechnical Specialist:** Professor Dr. Tahmeed M. Al-Hussaini, PhD
- **Foreign Advisor and Landslide Specialist:** Professor IkuoTowhata, PhD (Japan)
- **Foreign Advisor and Social Vulnerability Specialist**: Professor David E. Alexander, PhD (United Kingdom)
- **Disaster Management Specialist:** Md. Shahinoor Rahman
- **GIS Specialist and Web-GIS Programmer:** Bayes Ahmed
- **RS Specialist:** Sharmin Ara
- **Research Assistant:** Sonia Rahman
- **Research Assistant:** Ferdous Farhana Huq