Journal of Geoscience and Environment Protection, 2016, 4, 110-127
http://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Evaluation of Flooding Risk in Greater Dhaka District Using Satellite Data and Geomorphological Land Classification Map

Marju Ben Sayed, Shigeko Haruyama

Graduate School of Bioresources, Mie University, Tsu City, Japan
Email: 514d203@m.mie-u.ac.jp

How to cite this paper: Sayed, M.B. and Haruyama, S. (2016) Evaluation of Flooding Risk in Greater Dhaka District Using Satellite Data and Geomorphological Land Classification Map. *Journal of Geoscience and Environment Protection*, **4**, 110-127.
http://dx.doi.org/10.4236/gep.2016.49009

Received: July 1, 2016
Accepted: August 21, 2016
Published: September 28, 2016

Abstract

Flood is a common feature in rapidly urbanizing Dhaka city and its surrounding areas. In this research, evaluation of flood risk of Greater Dhaka in Bangladesh has been developed by using an integrated approach of GIS and remote sensing. The objective of the study is to measure the flooding risk based on the satellite data and geomorphological land classification map under the land use/land cover change from 1995 to 2015 related with the urbanization of Dhaka city. Comparing with each landform, land cover unit and historical rainfall data the flooding return period has been calculated. Terrace, natural levee and back swamp has been divided into three sub categories. Especially the built-up zone which is closer to the river channel, former river course and the back swamps are mostly vulnerable to flood inundation. This study revealed that, 70% of Greater Dhaka district within moderate to very high hazard zone, especially surrounding city like Manikganj Sadar Upazila areas. It is expected that, this study could contribute to effective flood forecasting, relief and emergency management for future flood event.

Keywords

Land Use/Land Cover Change, Manikganj Sadar Upazila, Greater Dhaka, GIS, Flood

1. Introduction

Because of unique geographic location, Bangladesh is one of the most disaster prone country in the world [1]. Among all natural disasters in Bangladesh, flood is the preeminent one. Every year a large portion of the country becomes flooded due to heavy rainfall and spilling water from the major rivers. The country lies on the downstream part of three major river basins: Brahmaputra, Ganges and Meghna and thus is frequently flooded. Floods of unusually large magnitude and long duration happen in the country affecting the majority of the population of Dhaka city and severely disrupting the socio-economic activities. Almost every year destructive floods reoccur in Bangladesh, including very severe floods of 1987, 1988 and 1998 (data were missing for 1957, 1958, 1959, 1979 and 1981) (**Figure 1**) [2]. The 1988 flood set a new record for flooded area, while 1998 flood was unprecedented with its long duration. The flood damage potential in Bangladesh is increasing due to the possible causes of climate change, urban concentration in the three river basins, encroaching of settlements into flood prone areas [3].

Dhaka is the largest and densely populated area in Bangladesh. Dhaka has become one of the fastest-growing cities in the world, primarily driven by explosive population growth. The city's population was 0.41 million in 1951 and 0.71 million in 1961. By 1974, it had risen to 2.06 million, averaging an annual growth rate of 11.15% between 1961 and 1974 [4] [5]. In 1981, the population rose to 3.44 million. The population reached around 6.48 million in 1991 and 9.6 million in 2001 [6] [7]. Recently, Dhaka city population is more than 14 million [8], with an average annual growth rate of 4.08% during 1991-2001 [9] [10], which outpaced the country's annual growth rate of 1.3% [11] [12]. In addition, growing population rate of Dhaka city put extra pressure on the low lying agricultural land the surrounding suburban areas [13].

Due to specific geographical location of Dhaka city, flood is the common natural hazard [14]; moreover urbanization has accelerated the degree of vulnerability to flood, particularly in the recent years [15]. Dhaka has experienced many disastrous floods in the past of which the 1988, 1998, 2004 and 2007 flood is said to be the worst in memorable records [16]. Disastrous floods in 1988 and 1998 inundated areas of 164 and 200 km^2, respectively [17]. The unprecedented flood of 1998 also severely affected Dhaka and its neighboring areas [18], which resulted in unusual damage and countless sufferings to

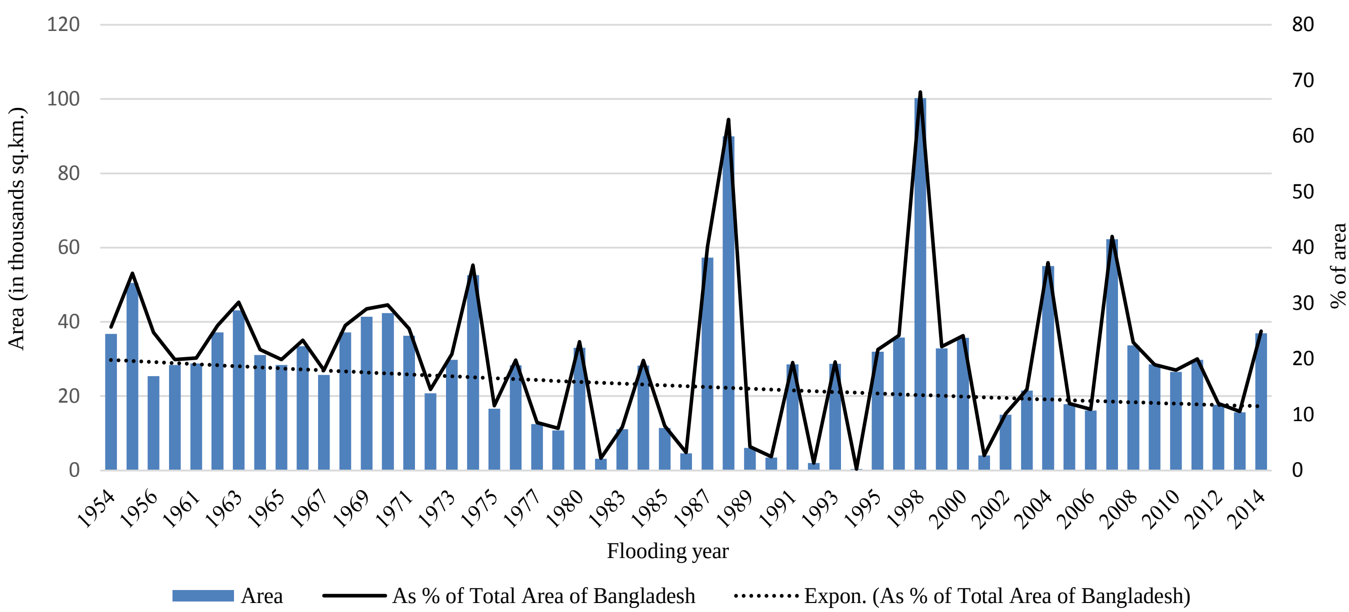

Figure 1. Historical flood affected data of Bangladesh from 1954 to 2014.

the people. In total, the 1988 flood affected 4.55 million people [19], and most of Dhaka was under water to various depths for more than 8 weeks [20]. The hardest-hit sector was housing; nearly 262,000 houses of various types were damaged during the 1998 flood, worth USD $46.6 million (Taka 2.3 billion) [21]. In 1998 flood, 1000 km of concrete roads were damaged [22]. The total loss incurred by the 1998 flood was estimated to about US$3000 million [19]. According to statically data book, on the 1988 and 1998 flood revealed that the death toll was at least 150, and more than 2.2 million people were affected [23]. The number of institutions and houses affected by the 1988 flood was estimated at 14,000 and 400,000, respectively [24]. Although fluvial flooding did not immerse most of the embanked areas of Dhaka, losses due to fluvial flooding were alarming in 2004 [25] [26].

There are several researches and maps on flood in Bangladesh has been done before at the local and government level. Ashraf M. Dewan (2007) described about estimating flood hazard in Greater Dhaka district zone by using remote sensing and GIS techniques, which essential traces the flood hazard management strategies in greater Dhaka city [27]. M. Oya (1976) prepared the geomorphological map of the Brahmaputra Jamuna River and Ganges River plain (1:1,000,000), and the geomorphological map has been prepared by utilizing the mozaic of the photographs of ERTS-I taken in 1972 as a base map. Utilizing the infrared photographs of the ERTS, and field observation by helicopter, he classified each geomorphological units of the R. Brahmaputra-Jamuna and R. Ganges flood Plain. It was found that, the Maduhupur Forest Terrace, Barind Terrace, and Tippera Surface were formed by upheaval, and Sylhet Basin, Brahmaputra-Jamuna valley and Ganges plain were formed by ground subsidence. The alluvial plain consists of an alluvial fan formed by the Brahmaputra-Jamuna and old Brahmaputra River, and the natural levee, back-swamp, and delta mainly formed by the Ganges River and also he mentioned the flood features of land form units [28].

M. Masood (2012) explained about the vulnerability and risk of mid-eastern Dhaka by using DEM and 1D hydrodynamic model, presented the flood risk and vulnerability from DEM data of mid-eastern part of Dhaka [29]. R. Rahman (2013) wrote about the flood risk and reduction approaches in Bangladesh and evaluated partial flood control model during monsoon season [30]. These reports and maps are not concerned with the Flood inundation mapping by using satellite data and geomorphological land classification map of the study area. Realizing the situation this research has been conducted on greater Dhaka district, where the major focus to generate the flood inundation mapping based on the satellite data and geomorphological land classification map compare with the land use change.

From the above discussion it is very clear to understand that, no research has been done before in Greater Dhaka district zone regarding to the evaluation of flooding risk on the basis of geomorphological land classification map. Considering this situation, the objective of the study is to evaluation of flooding riskbased on the satellite data and geomorphological land classification map under the land use/land cover change from 1995 to 2015. Specifically, the purpose of the study is to evaluation of flooding risk using satellite data and geomorphological land classification map concerning with the big flooding event (1988, 1998 and 2004) and with urbanization of greater Dhaka district zone.

2. Geographical Settings of the Study Area

The study area chosen for this research is the greater Dhaka district of Bangladesh (Figure 2), where the total amount of population is 18,305,671 [31]. The study area lies between 23˚40'N to 23˚551'N latitude and 90˚20'E to 90˚30'E longitude. It is occupied by the Buriganga River to the south, the Turag River to the west, the Tongi River to the north, the Balu River to the east and the Kaliganga River at the Manikganj district zone. The greater Dhaka city is located mainly on an alluvial terrace, popularly known as the Modhupur terrace in Pleistocene period. Topographically, Dhaka city is relatively a flat land, the surface elevation of the city ranges between 1 and 14 meters [32]. It belongs to sub-tropical monsoon zone and experience humid climatic conditions. Dhaka city experiences about 2000 mm annual rainfall of where more than 80 percent rainfall take place during monsoon. Historically, Dhaka city has been built up in a flood plain with numerous water bodies and canals that used to drain water from its upper reaches during monsoon season. As population increased, these areas were encroached. Moreover, unplanned urbanization, or urban sprawl has been taking place since 1971 in Greater Dhaka area which will be resulted more people to live in highly flood vulnerable place [33] [34].

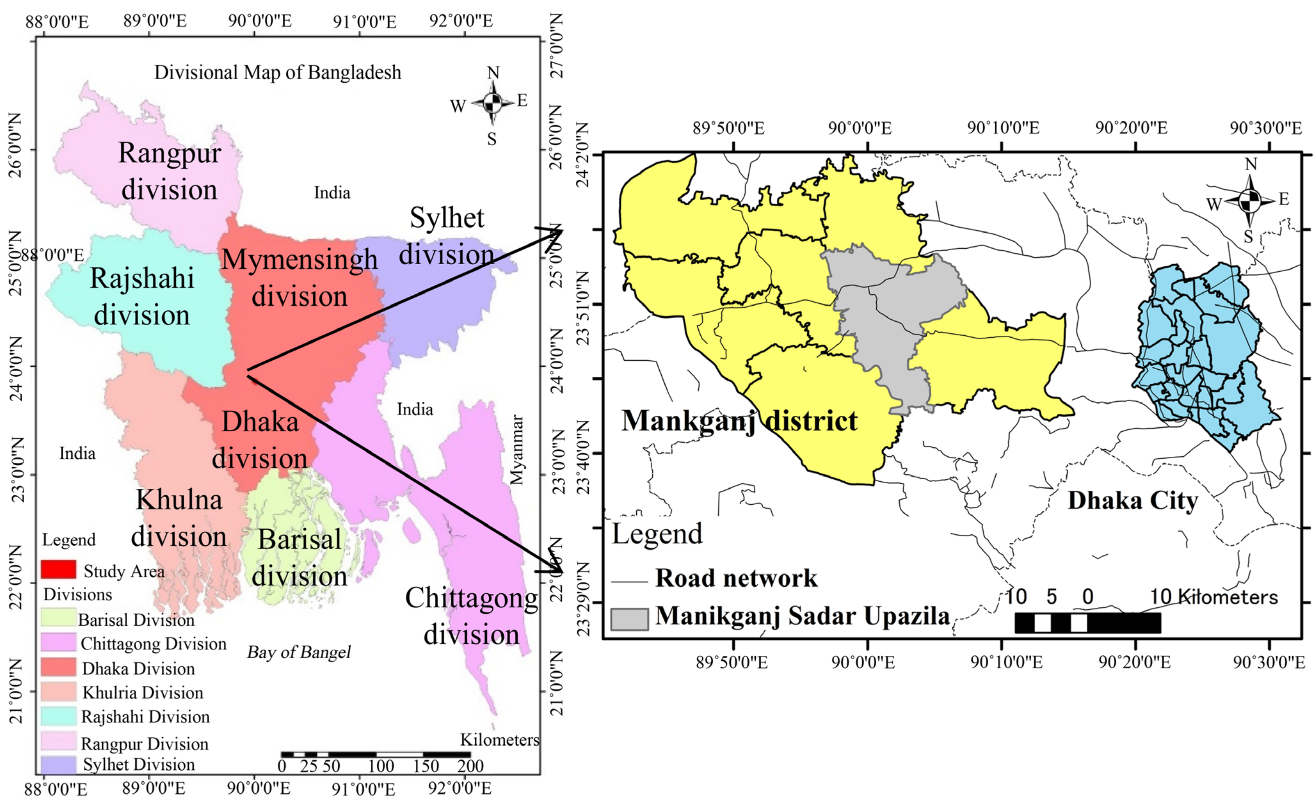

Figure 2. Geographical location of the study area.

3. Data Source and Methodology

The data for generating flood risk map of the study area has been collected from. The U.S. Army Topographic sheet (Scale 1:250,000) of 1955 [35] and geomorphological map of the Brahmaputra-Jamuna River and Ganges River plain (1:1,000,000) by M. Oya (1976) was used for preparation of our base map, Dhaka district land elevation map and ASTER data of 30 m resolution for preparation of Digital Elevation Model (DEM) [36] was downloaded from the website (http://www.gdem.aster.erdac.or.jp/search.jsp). Field observation data has been collected to measure ground control points with the ground verification data by the Geological Survey of Bangladesh (GSB).

Photographic elements and field knowledge was utilized to delineate various land use/land cover categories such as agriculture land use, built up area, water surface, bare land and vegetation cover. Satellite data was interpreted using photographic and geo-technical elements besides field knowledge about the study area. For GIS and remote sensing data analysis, a time-series of Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) images were used to derive land use/cover maps of the study area were used (**Table 1**). Satellite images were geometrically corrected with the Global Positioning System (GPS) points. The images included the visible (bands 1, 2 and 3), the near infrared (NIR), the shortwave infrared (SWIR), and the middle infra-red (MIR) bands with 30 m spatial resolution for TM and ETM+ images. The dataset was mainly downloaded from the archive of Landsat (http://earthexplorer.usgs.gov). After preprocessing the imageries, we performed supervised classification of both imageries with maximum likelihood classification algorithm in ERDAS IMAGINE 9.1 using the field data to produce five cover classes.

Area under each category of land use/land cover was calculated and computed in the area (km^2) as well as in percentage. A comparative analysis of the land use/land cover maps was attempted to find out the changes during 1995-2015 period, by superimposing the two maps. The maps were then overlaid on DEM to know the correlation between elevation and land use/land cover (**Figure 3**).

Table 1. Materials and methods.

Satellite Name	Path and Row	Bands	Date of Acquisition	Special Resolution
Landsat-ETM+	137 and 44	4, 3, 2	24th Nov, 1995	30 meters
Landsat-TM	137 and 44	4, 3, 2	12th Oct, 2015	30 meters
No.	**Categories of Data**	**Period**	**Publish Place**	
1	Digital elevation model (30 m resolution)	October 26, 2011	USGS	
2	Flood historical data	2005	Bangladesh Meteorological Department, 2005	
3	Topographic map	1955	U.S. Army Map Service	

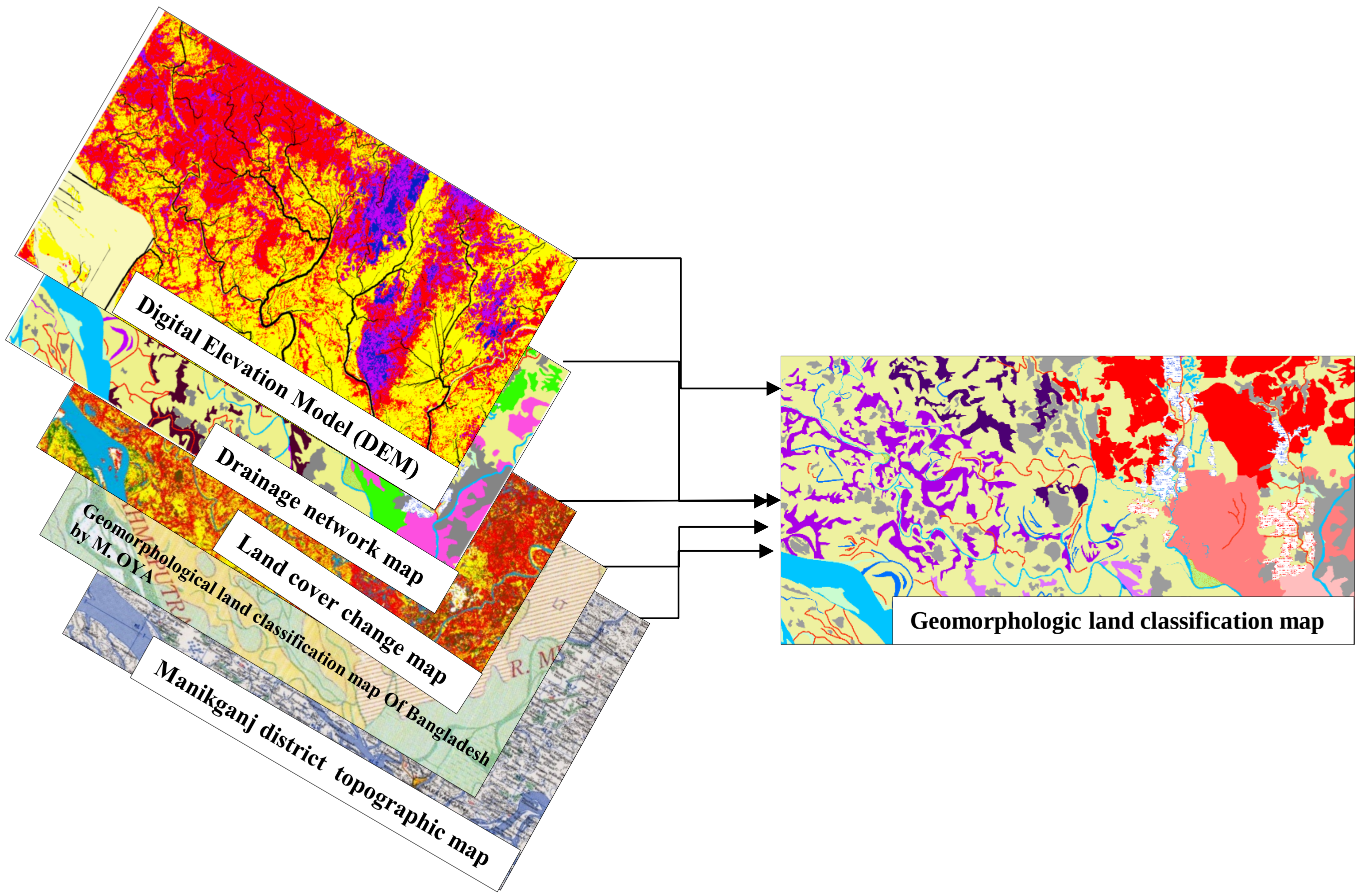

Figure 3. Methodology flowchart of the study.

4. Result

4.1. Digital Elevation Model (DEM)

Figure 4 shows a cross session of flood plain with different landform units. The elevation range between 0 and 6 m were used to separate various landform unites. From the above cross section profile, it can be seen that the areas from 0 - 4 m is under the high vulnerability of submerging when flood occur. It is observed that the land-cover also have closed relation on flood hazard. The areas of agricultural lands are also belong to submerged areas during flood time, and also corresponding to 2 m elevation boundary line. Agricultural land is characterized with the low-lying and well irrigated areas. Figure 5 could also explain the geomorphological landform unit clearly.

Cross section profile (Figure 5) provides a side view of the relief of the terrain along a line drawn between two locations (C0 to C1) on DEM map (Figure 4). This map included 2 m interval contour lines. From this detection, it is easy to determine the flood basin base on elevation and land cover classification. A cross section profile was built based on elevation information from Digital Elevation Model (DEM). The data used for DEM generation is elevation data extracted from topographic map given by The US Army Topographic sheet (Scale 1:250,000) of 1955 and Bangladesh land level data.

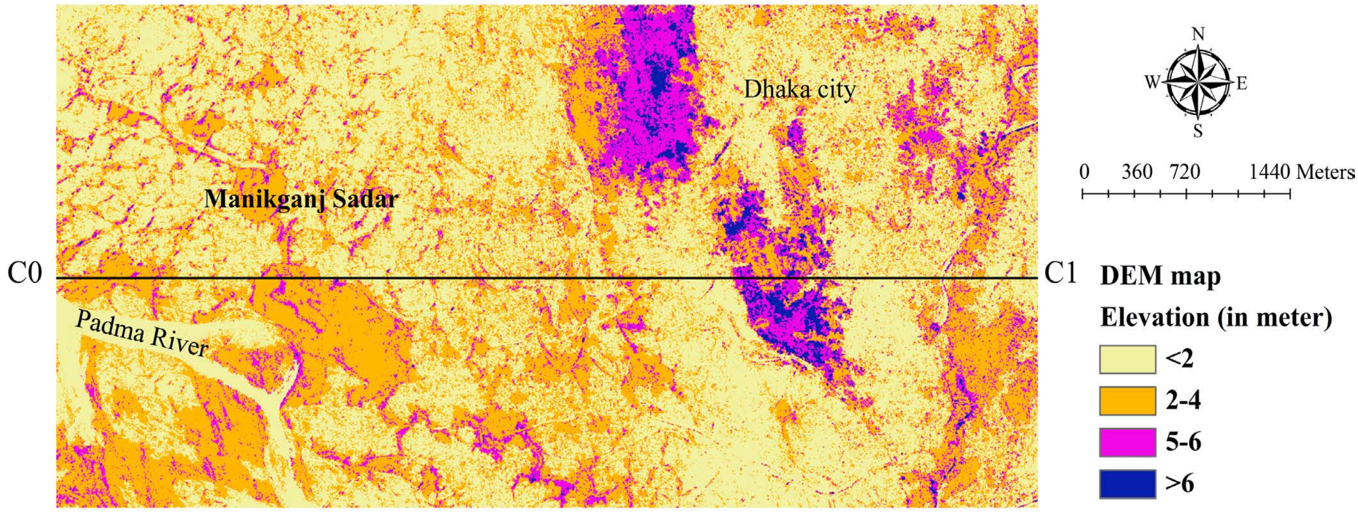

Figure 4. Digital elevation model (DEM) and cross section points (C0 and C1) of the study area.

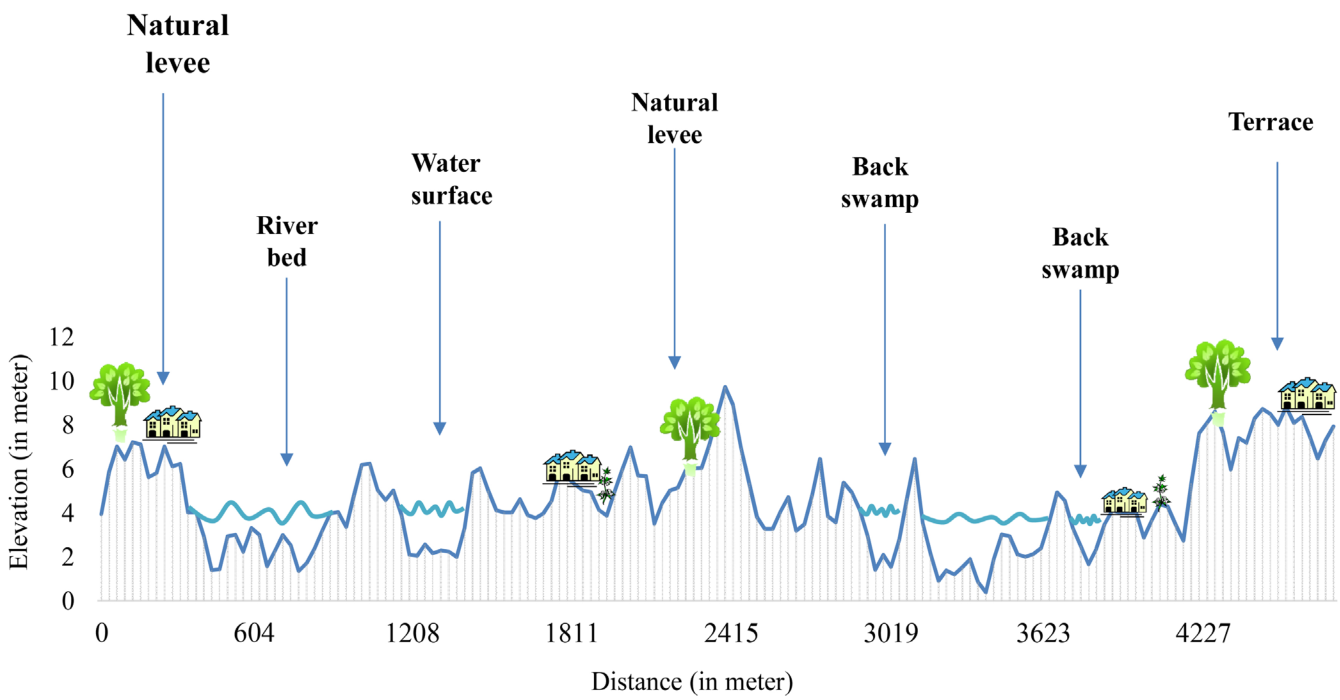

Figure 5. Cross section profile of Digital Elevation Model (DEM).

4.2. Superimposed Image of Digital Elevation Model and Land Cover Map

Unplanned urban expansion is one of the most important factors intensifying flood hazards in Greater Dhaka district zone. From the period of 1995 to 2015 (Figure 6 and Table 2), the major land-use change is caused by the increasing demand for non-agricultural land because of urban and infrastructure development. The decrease of agriculture land use was caused by development of infrastructure and factory (in Manikganj Sadar and Dhaka district zone). From 1995 to 2015, a significant decrease of agriculture

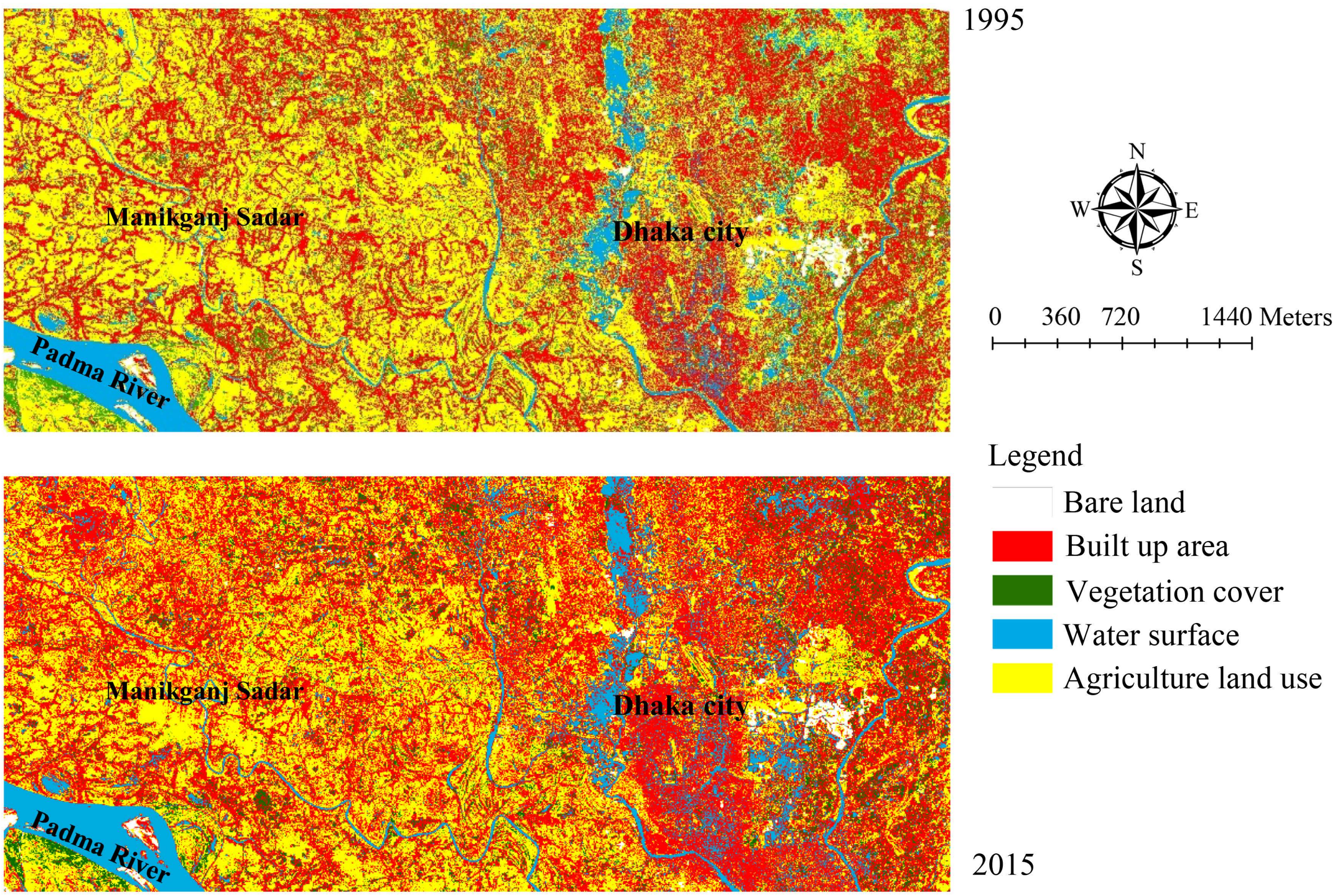

Figure 6. Land cover maps of Greater Dhaka district from 1995 to 2015.

Table 2. Land cover change from 1995 to 2015 of the study area with elevation range.

Land use/land cover categories	Land use/land cover (1995)		Land use/land cover (2015)		Difference (1995-2015)		Elevation range (in meters)
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	
Agriculture land use	1121	43	895	34	−226	−9	<3
Vegetation cover	308	12	198	8	−110	−4	3-5
Water body	352	14	239	9	−113	−5	<1.5
Built up area	716	27	1213	47	497	20	1 - 6
Bare land	108	4	59	2	−49	−2	1 - 4
Total land	2605	100	2605	100			

land use (−9%) is found in the study area because most of the built up zone has been developed around the capital city Dhaka and at the same time the transportation network has been developed too.

The built up zone is composed of residential land use, commercial land use and industrial land use. In 1995, the built up zone was 27% and expanded to 47% in 2015, the significant change had occurred because of convert agricultural infrastructure into urban infrastructure in the urban fringe zone. Commercial and industrial land use changes have been observed also with the growth of the area. The accelerated industrialization and urbanization following economic reforms and population increases have greatly affected land cover change through the increase of built up areas. The net bare land area had decreased 2% because with the increase of population, the demand of food had increased too. As a result, the bare has been converted to both agriculture land use and urban land use. The vegetation cover was 12% in 1995 and dropped to 8% in 2015 .The decrease of vegetation cover was a result of the construction of residential, commercial and industrial zone to promote urban development.

The remarkable change has been occurred in the urban areas (increased 20%), where residences are developed because of expansion of the urban area around the Dhaka city, are extremely vulnerable to flooding. A superimposed image of Digital Elevation Model (DEM) and land cover map was prepared (Figure 7) to identify the residential zone which is located in the low lying area. From Figure 7 it is also very clear to understand the relationship between land use/land cover units and various elevation range (Table 2).

By comparing land use/land cover change maps, geomorphological land classification map with DEM data following results are obtained.

1) From 1995 to 2015 major land use/land cover changes in agricultural land occurred in low lying areas where is elevation ranging below 3 m. Increase in built up areas is due to shrinkage of agriculture land use and mostly transformation into residential and commercial activity. Moreover this area is located into the low lying floodplain zone.

2) Changes in built up area (20%) have occurred in almost all elevation range between 1 m and 6 m. Agricultural land use associated with high elevation range converted into bare land, and at the same time low elevated agricultural land is converted to build up zone to meet the demand for housing to accommodate growth in population.

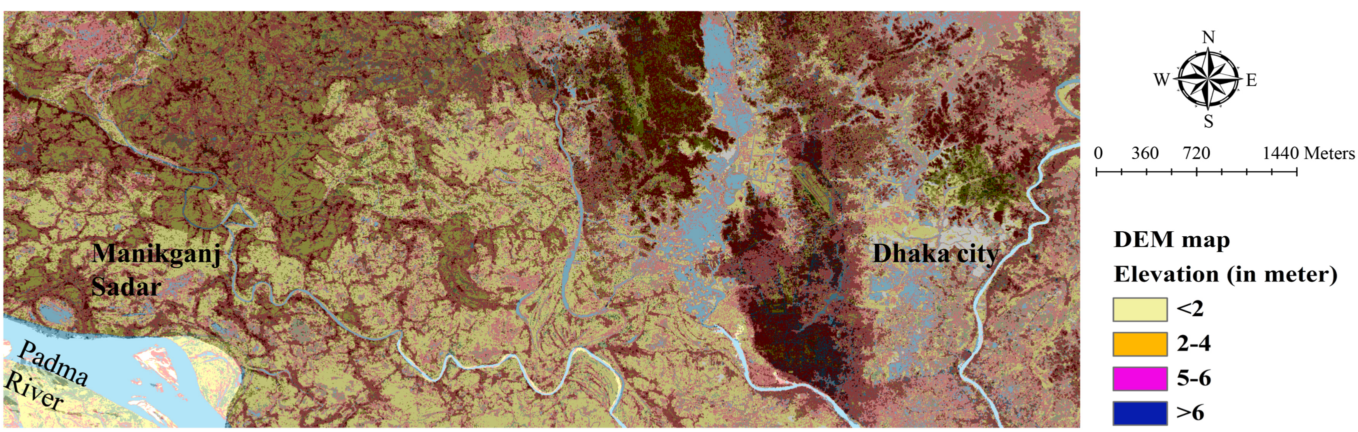

Figure 7. Land cover map and DEM superimposed of Greater Dhaka district.

3) Vegetation cover has been increased substantially in low elevation range between 2 and 4 m, at the periphery of dried up water body and almost all low lying floodplain areas.

5. Return Period of Floods and Yearly Average Rainfall

Flooding due to rainfall is also a severe problem for certain city areas that may be inundated for several days, mainly due to drainage congestion. The main reason for the 1998 flood was excessive rainfall over the catchments area of the Ganges-Brahmaputra Meghna (GBM) river basin [37]. Excessive rainfall is reported in Dhaka and Manikganj Sadarfrom 1953 to 2015 (**Figure 8**) [38]. Monthly annual rainfall records show that the

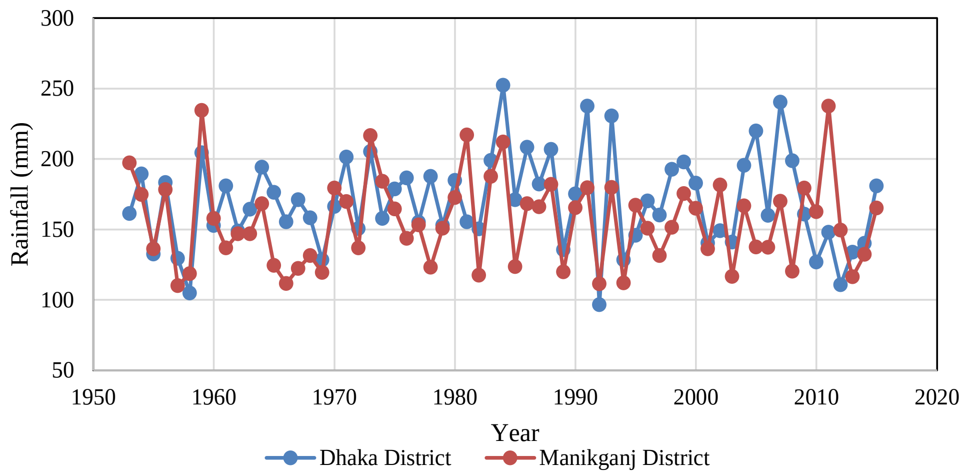

Figure 8. Yearly average rainfall of Dhaka and Manikganj district from 1953 to 2015.

amount of precipitation during flooding year (1988, 1998 and 2004) were considerably higher than average rainfall. For example, the rainfall was 250 mm percent higher in 1988 compare to its normal condition. Thus, the runoff generated by rainfall could not flow out to the surrounding rivers since the water level of the river stage was also at peak. The accumulated runoff in low lying areas pushed long inundation and remained stagnant until the water level of the river stage receded. During 1988, 1998 and 2004 flood events, rainfall statistics shows that in June, rainfall was tremendously longer, for other three monsoon months it was terribly larger in 1998 event. For example, 552 mm rainfall was recorded for the month of August in 1998 which was 176 mm bigger than normal rainfall, meanwhile in 1988 it was only 169 mm which was even less than the normal.

Flood Return Period Calculation from Yearly Precipitation Data

In this study, to calculate the return period of floods from yearly precipitation data the *Hazen* method has been applied [39], the probability, and the annual precipitations of concern, for the historical statistical data in recent 62 years. This method consisted in assembling the annual precipitations shown in **Table 3** below.

This procedure was done using the above equation, for the sample size of 62 years, by assigning ranges in ascending order, the precipitations, and the probabilities of occurrences and return periods for each year. These calculations are shown in Table 3 below.

$$\text{Probability}(\text{Fa}) = \frac{100(2n-1)}{2y} = 100/\text{Return period}$$

where:

Fa = Probability of occurrence (%)

n = Rank of each event

y = Total number of events

100/Fa = Return period

Table 3. Table showing ranges, annual precipitations, probabilities of occurrence and return periods for Dhaka and Manikganj Sadar in the period of 1953-2015.

Year	Annual Precipitation (mm)	Rank	Probability (Fa)	Return Period	Year	Annual Precipitation (mm)	Rank	Probability (Fa)	Return Period
1984	252.3	1	0.8	126	**1963**	164.3	33	51.6	2
2007	240.4	2	2.4	42	**1953**	161.2	34	53.2	2
1991	237.5	3	4.0	25	**2009**	160.9	35	54.8	2
1993	230.6	4	5.6	18	**1997**	160.1	36	56.3	2
2005	219.8	5	7.1	14	**2006**	159.9	37	57.9	2
1986	208.3	6	8.7	11	**1968**	158.3	38	59.5	2
1988	206.8	7	10.3	10	**1974**	157.9	39	61.1	2
1973	205.3	8	11.9	8	**1966**	155.4	40	62.7	2
1959	204.4	9	13.5	7	**1981**	155.4	41	64.3	2
1971	201.3	10	15.1	7	**1977**	155.1	42	65.9	2
1983	199	11	16.7	6	**1979**	153.1	43	67.5	1
2008	198.8	12	18.3	5	**1960**	152.8	44	69.0	1
1999	197.8	13	19.8	5	**1972**	150.7	45	70.6	1
2004	195.6	14	21.4	5	**1982**	150.4	46	72.2	1
1964	194.3	15	23.0	4	**2002**	149.1	47	73.8	1
1998	192.7	16	24.6	4	**1962**	148.8	48	75.4	1
1954	189.5	17	26.2	4	**2011**	148.0	49	77.0	1
1978	187.6	18	27.8	4	**1995**	145.9	50	78.6	1
1976	186.5	19	29.4	3	**2003**	141.1	51	80.2	1
1980	184.8	20	31.0	3	**2001**	140.4	52	81.7	1
1956	183.4	21	32.5	3	**2014**	140.2	53	83.3	1
2000	182.8	22	34.1	3	**1989**	135.6	54	84.9	1
1987	182.3	23	35.7	3	**2013**	133.8	55	86.5	1
2015	181.0	24	37.3	3	**1955**	132.5	56	88.1	1

Continued

1961	180.8	25	38.9	3	**1957**	129.5	57	89.7	1
1975	178.8	26	40.5	2	**1969**	128.3	58	91.3	1
1965	176.4	27	42.1	2	**1994**	128.3	59	92.9	1
1990	175.3	28	43.7	2	**2010**	126.9	60	94.4	1
1967	171.1	29	45.2	2	**2012**	110.7	61	96.0	1
1985	171.1	30	46.8	2	**1958**	104.8	62	97.6	1
1996	170.3	31	48.4	2	**1992**	96.6	63	99.2	1
1970	166.3	32	50.0	2					

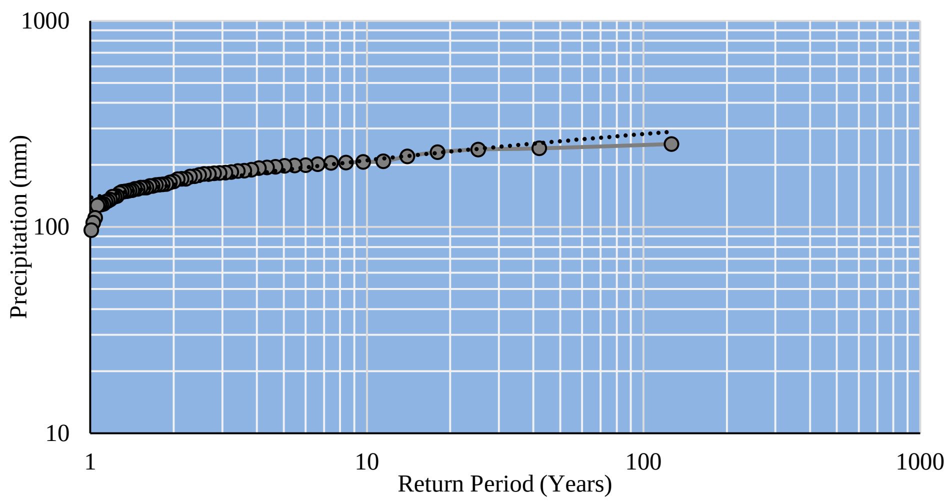

Figure 9. Yearly average precipitation of Dhaka and Manikganj district from 1953 to 2015.

By using *Hazen* plotting position, the above graph (**Figure 9**) consisted in the plotting of the 62 year data values of precipitations (in cm) and return periods of occurrences on log-probability graph paper, where precipitation as a dependent variable (log annual precipitations in centimeters) and return period as a independent variables. Finally, using the least squares method, a regression line that fitted the data was drawn, for the purpose of interpolating or extrapolating any desired calculation. **Figure 9** shows the graphical relationship of these two variables according to **Table 3** data.

After the liberation war in 1971, the urban area has been expanding rapidly in the study area. In recent decades, the development is more rapid then the previous. In recent years, rapid urbanization is mainly taken place in low lying areas around and within the city which serve as back swamp and flood plain zone and submerged during flooding season. Every year because of monsoon rainfall, Greater Dhaka district zone has been facing a serious drainage congestion which is one of the important factor to flood problems in Dhaka city. Due to the unplanned development of Dhaka city and filling of natural channels, it becomes very difficult for the artificial system to carry out vast amount of flood waters to the surrounding river.

6. Land Form and Flood Features in the Geomorphological Land Classification Map of Greater Dhaka District

In Figure 10, the geomorphic land form units are classified as follows, 1) Former river

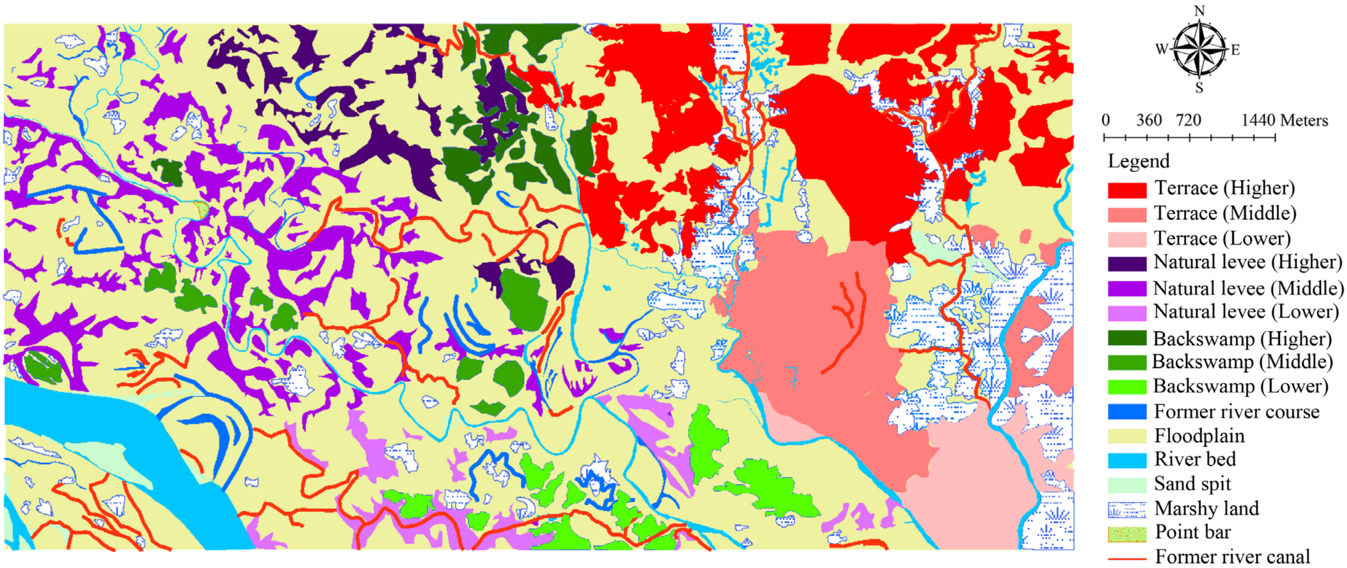

Figure 10. Geomorphological land classification map of Greater Dhaka district.

course, 2) River bed, 3) Sand spit, 4) Back swamp (High, Medium and lower), 5) Terrace (High, Medium and lower), 6) Natural levee (High, Medium and lower), 7) Flood plain, 8) Marshy land and 9) Point bar. The criterion of the landform classification has been done according to the difference of altitude from the river.

Terrace has been developed in the upper eastern part of the study area. According to the geological evolution of Bangladesh, terraces were formed in the Quaternary Period (Pleistocene Epoch). The northern part of Dhaka city is located in the terrace zone. Based on the elevation range, terrace has been divided into three types such as higher, middle and lower. The higher terrace has an elevation higher than 5.5 m, are mostly located at the upper part of the study area and covered with commercial activity purpose. The middle one has an elevation between 4 m and 5.5 m. Lower terrace has an elevation between 2.5 m and 4.0 m located in the lower part of Dhaka city are never influenced by the normal flooding condition. These zones are also not influenced by the river flood condition. Within the Dhaka city due to poor drainage condition rainfall flood had occurred in the big rainfall event.

The natural levee has been developed around river courses due to the deposition process during monsoon period and especially in the tremendous flooding year (e.g. 1988, 1998 and 2004). In the study area, according to the elevation the natural levee has been divided into three type's such as higher, middle and lower. The higher natural levee has an elevation between 5 m and 6 m, are mostly located at the upper part of the study area and covered with human settlements and commercial activity purpose. The middle one has an elevation between 4 m and 5 m works as a natural embankment during normal flood but submerged during extraordinary flood condition. Lower natural levee has an elevation between 2.5 and 4 m located in the lower part of the study area are submerged at the normal flooding condition.

Back swamps are also divided into three types as following; higher, middle and lower back swamps. Back swamps are located between the natural levees in the Manikganj Sadar zone. In the tremendous flooding year (e.g. 1988, 1998 and 2004), the back swamp has been long inundated. At the higher natural levee zone, the depth of inundation is higher compare with the lower natural levee zone. Severe flooding damages have occurred in this zone. The period of inundation is more than three months. The higher back swamp has an elevation between 1.5 m and 2 m, are mostly located at the upper part of the study area around the higher natural levee zone and which is covered with human settlements and commercial activity purpose. The middle one has an elevation between 0.5 m and 1.5 m and lower back swamp has an elevation of below 0.5 m located in the southern part of the study area are submerged at the normal flooding condition. At the higher back swamp zone, flood return period is much longer comparatively to the other moderate back swamp and lower back swamp zone.

The former river channel is usually channel without water bed. The former river course are located in the flood plain zone and especially in Buriganga River and Kaliganga river area and flooded in normal flood condition, which is flooded almost every year in the normal flood and rainfall condition.

7. Conclusions

In this paper to evaluate the risk of flood during 1995 to 2015 in Greater Dhaka district of Bangladesh, land-cover, elevation data, topographic map and geomorphic unit were overlaid on each other. The study demonstrates an effective way to modify the collected DEM so that it represents the current topography, which is very helpful to identify the various land cover and land form units. The objective of geomorphological land classification map is to provide information related to flood inundation risk on the basis of various landform units.

To find out the relationship between land cover and land form unit we have compared each other and the results of this paper are as follows:

Urban development of the Dhaka city and its surroundings was quite rapid during 1995 to 2015. The Urban areas have spread into lowland area such as flood plains and back swamps from 1995 to 2015. This is clearly reflected in the relationship between the urbanization area and the landforms. The results of this research revealed the relationship between land use/land cover change and the geomorphological changes indicate that the built-up areas have expanded on vulnerable landforms with respect to floods. Moreover annual rainfall is another important factor which is closely related to the flood return period regarding to different geomorphologic land form units.

From the topographic map and the land cover map, there are a higher amount of settlement and built-up zones are located in the low lying high hazard zones. Moreover the number of settlements and commercial activities are increasing in the recent decades (20%) over the low lying agriculture land, which putting an extra pressure not only on Dhaka city [13] [40] but also on the surrounding suburban city area. From the Digital Elevation Model (DEM), changes in built up area (20%) have occurred in almost all elevation range (1 m - 6 m). Agricultural land use associated with high elevation range has been converted mostly into built up area and bare land, and at the same time low elevated agricultural land is converted to build up zone to meet the demand for housing to accommodate growth in population.

From the geomorphologic land classification map, the northern part of Dhaka city is located in the terrace zone. Based on the elevation range, terrace has been divided into three types such as higher, middle and lower. The higher terrace has an elevation higher than 5.5 m, mostly located at the upper part of the study area and covered with commercial activity purpose. The natural levee lies between 2 m and 5 m. It has been divided into 3 types too. Sometimes it works as a natural embankment during normal flood but submerges during extraordinary flood condition. Lower natural levee has an elevation between 2.5 and 4.0 m located in the lower part of the study area submerged at the normal flooding condition. Back swamp has been divided into 3 types: the higher back swamp has an elevation between 1.5 m and 2 m, are mostly located in the upper part of the study area around the higher natural levee zone and covered with human settlements and commercial activity purpose. The middle one has an elevation between 0.5 m and 1.5 m and lower back swamp has an elevation of below 0.5 m located in the southern part of the study area submerged at the normal flooding condition. In the back swamp zone, the period of inundation is more than three months. At the higher back swamp zone, flood return period is much longer comparatively to the other moderate back swamp and lower back swamp zone.

Geomorphological land form unit represents the current scenario of the study area. The map provides helpful information about flood risk zone and should be useful in assigning priority for the development of higher flood risk areas. Furthermore, this type of study will provide the updated information about geomorphic land form which is related to flood protection measure such as construction and development of infrastructure and preparedness for future flood event.

Acknowledgements

We are grateful to acknowledge the support of Bangladesh Bureau of Statistics (BBS), Dhaka University Library, Local Government Engineering Department (LGED), Survey of Bangladesh (SoB), Bangladesh Water Development Board (BWDB) and Bangladesh Meteorological Department (BMD) for providing us valuable materials and necessary assistance. We are also very much thankful to the city corporation authorities of both Manikgonj and Dhaka city for their cooperation in this research. We sincerely remember their assistance and valuable suggestions in conducting this research.

References

[1] Cutter, S.L. (1996) Societal Reponses to Environmental Hazards. *International Social Science Journal*, **150**, 526-536.

[2] Bangladesh Water Development Board (BWDB) (2014) Annual Flood Report. Flood Forecasting and Warning Centre, Dhaka.

[3] Bangladesh Disaster Knowledge Network (2013). http://www.saarcsadkn.org/countries/bangladesh/hazard_profile.aspx

[4] Bangladesh Bureau of Statistics (BBS) (1991) Population Census—1991. Community Series. Bangladesh Bureau of Statistics, Ministry of Planning, Dhaka.

[5] Bangladesh Bureau of Statistics (BBS) (2001) Population Census—2001. Zila Series. Bangladesh Bureau of Statistics, Ministry of Planning, Dhaka.

[6] Bangladesh Bureau of Statistics (BBS) (2003) Population Census—2001. Community Series. Bangladesh Bureau of Statistics, Ministry of Planning, Dhaka.

[7] Bangladesh Bureau of Statistics (BBS) (2005) Statistical Yearbook of Bangladesh. Bangladesh Bureau of Statistics, Ministry of Planning, Dhaka.

[8] Bangladesh Bureau of Statistics (BBS) (2008) Population Census—2001. National Series, Vol. 3, Urban Area Report. Bangladesh Bureau of Statistics, Ministry of Planning, Dhaka.

[9] Bangladesh Bureau of Statistics (BBS) (2010) Compendium of Environment Statistics of Bangladesh 2009. Bangladesh Bureau of Statistics, Ministry of Planning, Dhaka.

[10] Bangladesh Bureau of Statistics (BBS) (2011) Population Census—2011. Preliminary Report. Bangladesh Bureau of Statistics, Ministry of Planning, Dhaka.

[11] Bangladesh Bureau of Statistics (BBS) (2012) Population and Housing Census—2011. Community Report, Dhaka, Narayanganj and Gazipur Zila. Bangladesh Bureau of Statistics, Ministry of Planning, Dhaka.

[12] World Bank (2007) Dhaka: Improving Living Conditions for the Urban Poor. Sustainable Development Unit, South Asia Region, Report No. 35824-BD.

[13] Sayed, M.B. and Haruyama, S. (2015) Dynamics of Land Use/Cover Change in Manikganj District, Bangladesh: A Case Study of Manikganj Sadar Upazila. *Journal of Geographic Information System*, **7**, 579-587. http://dx.doi.org/10.4236/jgis.2015.76046

[14] Faisal, I.M., Kabir, M.R. and Nishat, A. (1999) Non-Structural Flood Mitigation Measures for Dhaka City. *Urban Water*, **1**, 145-153. http://dx.doi.org/10.1016/S1462-0758(00)00004-2

[15] Dewan, A.M. and Yamaguchi, Y. (2008) Effects of Land Cover Changes on Flooding: Example from Greater Dhaka of Bangladesh. *International Journal of Geo-Information*, **4**, 11-20.

[16] Bromley, R., Hall, P., Dutt, A., Mookherjee, D. and Benhart, J.E. (1989) Regional Development and Planning. In: Gaile, G.L. and Willmott, C.J., Eds., *Geography in America*, Merrill Publishing Company, Columbus.

[17] Flood Action Plan (FAP) 8A (1991) Master Plan Study for Greater Dhaka Protection Project. Japan International Cooperation Agency, Dhaka.

[18] Disaster Management Bureau (DMB) (1998) Report on Bangladesh Flood 1998: Chronology, Damages and Responses. DMB, Dhaka.

[19] Hye, A. (2000) Effects on Livelihood. In: Nishat, A., Reazuddin, R., Amin, R. and Khan, A.R., Eds., *The* 1998 *Flood*: *Impact on Environment of Dhaka City*, Department of Environment, Dhaka, 201-216.

[20] Jahan, S. (2000) Coping with Flood: The Experience of the People of Dhaka during the 1998 Flood Disaster. *The Australian Journal of Emergency Management*, **15**, 16-20.

[21] Islam, N. (1998) Flood'98 and the Future of Urban Settlements in Bangladesh. *National Seminar on Flood*'98 *and Management of Floods in Future*, jointly organized by National

Committee for Relief and Rehabilitation and Dhaka University, Dhaka, 8 December 1998.

[22] Siddique, Q.I. and Chowdhury, M.H. (1998) Flood-98: Losses and Damages. *National seminar on Flood'*98 *and Management of Floods in Future*, jointly organized by National Committee for Relief and Rehabilitation and Dhaka University, Dhaka, 8 December 1998.

[23] Huq, S. and Alam, M. (2003) Flood Vulnerability of Dhaka City and Its Management. In: Kreimer, A., Arnold, M. and Carlin, A., Eds., *Building Safer Cities*: *The Futures of Disaster Risk*, The World Bank, Washington DC, 121-145.

[24] Alam, M. and Rabbani, M.G. (2007) Vulnerabilities and Responses to Climate Change for Dhaka. *Environment and Urbanization*, **19**, 81-97. http://dx.doi.org/10.1177/0956247807076911

[25] Ahmed, S.U., Gotoh, K. and Hossain, S. (2006) Integration of Remote Sensing and Economic Valuation Techniques to Find the Causes of Water Logging Problem in Dhaka City, Bangladesh. *Proceedings of the* 13 *ARSPC Conference*, Australia, CD-ROM.

[26] Dewan, A.M. (2013) Floods in a Megacity: Geospatial Techniques in Assessing Hazards, Risk and Vulnerability. Springer Publication, Netherlands. http://dx.doi.org/10.1007/978-94-007-5875-9

[27] Dewan, A.M., Islam, M.M., Kumamoto, T. and Nishigaki, M. (2007) Evaluating Flood Hazard for Land-Use Planning in Greater Dhaka of Bangladesh Using Remote Sensing and GIS Techniques. *Water Resources Management*, **21**, 1601-1612. http://dx.doi.org/10.1007/s11269-006-9116-1

[28] Oya, M. (1976) Geomorphological Map of the Brahmaputra-Jamuna River and Ganges River Plain. JICA.

[29] Masood, M. and Takeuchi, K. (2012) Assessment of Flood Hazard, Vulnerability and Risk of Mid-Eastern Dhaka Using DEM and 1D Hydrodynamic Model. *Natural Hazards*, **61**, 757-770. http://dx.doi.org/10.1007/s11069-011-0060-x

[30] Shaw, R., Mallick, F. and Islam, A. (2013) Disaster Risk Reduction Approaches in Bangladesh. Springer, Berlin, 65-90. http://dx.doi.org/10.1007/978-4-431-54252-0

[31] Bangladesh Bureau of Statistics (2000) Population Census: Preliminary Report, BBS. Ministry of Planning, Dhaka, 36.

[32] Flood Action Plan 8A (1991) Master Plan Study for Greater Dhaka Protection Project. Japan International Cooperation Agency, Dhaka, Bangladesh, Supporting Report I, A1-A7.

[33] Dewan, A.M., Nishigaki, M. and Komatsu, M. (2004) Use of Multi-Temporal RADARSAT-1 ScanSAR Data to Differentiate between Flooded and Non-Flooded Areas. *Annual Meeting of the Chugoku Branch of the Japan Society of Civil Engineers*, Tottori, Japan.

[34] Dewan, A.M., Yeboah, K.K. and Nishigaki, M. (2005) Flood Mapping and Damage Evaluation in Greater Dhaka Bangladesh with Remote Sensing. *Asian Profile*, **33**, 495-512.

[35] U.S. Army Map Service (1955) India Pakistan Topographic Map 1:250,000; Series U502, http://www.lib.utexas.edu/maps/ams/india/nf-46-01.jpg

[36] USGS (2011) Digital Elevation Model. http://earthexplorer.usgs.gov/

[37] Ahmed, F. (1999) Impact on Water Supply Sanitation and Waste Management. In: Nishat, A. and Reazuddin, M., *et al*., Eds., *The* 1998 *Flood*: *Impact on Environment of Dhaka City*, Department of Environment in conjunction with IUCN Bangladesh.

[38] (BMD, 2011) Annual Precipitation Data, Bangladesh Meteorological Department. http://www.bmd.gov.bd/?/home/

[39] Urías, H.Q., Garcia, H. and Plata Mendoza, J.S. (2007) Determination of the Relationship between Precipitation and Return Periods to Assess Flood Risks in the City of Juarez, Mex-

ico. Paper 47.

[40] Sayed, M.B. and Haruyama, S. (2016) Urbanization Impact on Agricultural Land of Manikganj Pourashova, Bangladesh. *International Journal of Sciences*: *Basic and Applied Research* (*IJSBAR*), **28**, 243-253.