GIS and RS Combined Analysis for Flood Prediction Mapping – A Case Study of Dhaka City Corporation, Bangladesh

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Abstract- **Flood is a type of hydro-meteorological phenomenon and it is very hazardous as it can cause devastating losses in property and human lives. Fast and unplanned development aggravates the consequences of flooding by increasing the monetary costs of losses. These kinds of losses are especially high in urban areas which would be possible to ease with proper planning and management of the urban structures. Geographical Information Systems (GIS) based modeling and Remote Sensing (RS) techniques can help by supplying maps and techniques as assistance to make early warning for risk areas. In this case study, different criteria have been analyzed that have potential impact on the amount of devastation, such as the elevation of the areas, flooding depth, building density, terrain slope, soil type, land use types etc. Based on different factors analysis, results are visualized with the help of GIS and RS presentation and dissemination techniques. In addition, the impacts of different factors on flooding itself are also discussed. Finally, a flood prediction map for Dhaka City Corporation (DCC) in Bangladesh was prepared using the Multi-Criteria Evaluation (MCE) method with particular focus on the different criteria that influence the flooding in Dhaka city.**

Keywords- Dhaka City Corporation (DCC), Flood prediction mapping, Remote Sensing (RS), Geographical Information Systems (GIS), and Digital Elevation Model (DEM).

I. INTRODUCTION

Water logging is a very common problem in Dhaka city during the monsoon period as well as all the year round. Even a little rain causes serious problems in some parts of the city on every occasion and can create water logging situation for several days which in turn causes huge infrastructural damages by reducing the amount of accessible assets and supplies in the city. This situation normally occurs due to unplanned infrastructure development, insufficient or limited drainage systems, blockage of the drainages, lack of consciousness of these problems by the inhabitants, unplanned build-up of areas within the city, filling up the canals, lakes and water bodies in areas which are mainly acquired by housing companies and brick burning industries within the city. The Dhaka city is usually flooded as a result of rainfalls and the high water level of surrounding river systems. For instance, 1998 flooding was the most catastrophic in the flooding history of Bangladesh, where Dhaka city was affected by heavy rainfall and the high water levels of the river system.

Unplanned urbanization is increasing the number of floods in the urban areas (Fig. 1). Also, the annual losses are increasing in urban areas (ESCAP, 1999) because of the increasing population and higher building density. Moreover, the unplanned development and inappropriate drainage also contributes to damages in urban areas during flooding period. The resources and land areas are limited in the urban zones, so it is important that proper decisions are made by the authorities so that the urbanization process is sustainable. Further polluted and stagnant water as a result of floods and heavy rainfall can contribute to severe health hazards that have to be prevented. Part of this effort is to build up and maintain a proper mechanism that can help to reduce flood risks. For a long time, Remote Sensing (RS) techniques and Geographic Information Systems (GIS) have grown in popularity both in public and private organizations for their increasing ability in organizing, manipulating, analyzing, handling and presenting information of geographic data. GIS along with RS has proven to be an efficient tool for analysis, particularly suitable for identifying flood risk zones and flood impacts on inundated areas.

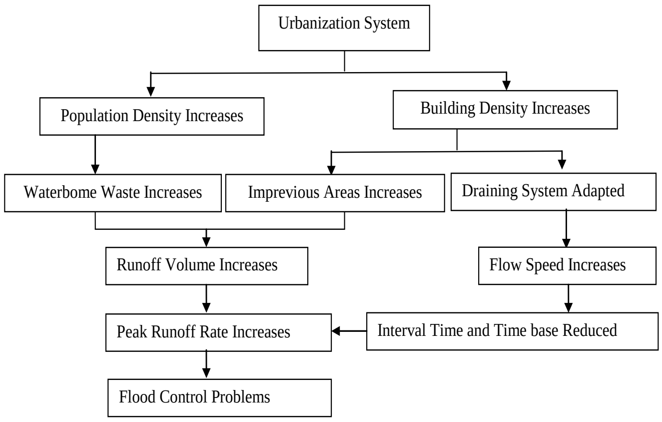

Fig. 1 The impact of urbanization process on flooding. Adapted from Hall (1984).

A. Purpose of Study and Background

The purpose of this study is to demonstrate how GIS and RS techniques can be used for flood prediction mapping in an urban zone. This study will analyze different factors that have a potential impact on recurring floods; and finally, create a flood prediction map for Dhaka City Corporation (DCC). The analysis and results of the different factors for flood events are intended to be presented to the related authorities with all information that can help them to systematize the infrastructure management, disaster management, rescue operations, evacuation planning as well as improving fire control. In this way, the population living in these areas will benefit from this study.

Dhaka, the capital city of Bangladesh with 10 million people (BBS, 2000) that lies between 23º40´ to 23º55´ N and 90º20´ to 90º30´ E has been chosen as the study area. It is surrounded by four rivers named as Buriganga, Balu, Tongi and Turag which run to the south, east, north and west respectively. Topographically, Dhaka city is relatively flat and the elevation ranges between 1 to 14 meters, and mostly all built-up areas are located on the areas with elevation of 6-8 m (FAP 8A, 1991). The city is located mainly on an alluvial terrace that is popularly known as Modhupur terrace of the Pleistocene period (Miah & Bazlee, 1968). The city is generally a part of sub-tropical monsoon zone with humid climatic conditions. The rivers that surround Dhaka city are mainly filled by rainfalls and also get delivery of water from the three biggest rivers of the country named Ganges, Meghna and Brahmaputra through their distributaries during the monsoon period. About 2000 mm rainfall is experienced annually in Dhaka city of which 80 percent takes place during the monsoon period from June to September. The annual population growth rate for Bangladesh is about 2.1 percent while in Dhaka city it is around 5 percent (BBS, 2000). This huge population growth is increasing the challenges in the urbanization process of Dhaka city. The drainage systems and two other major channels known as Dholai channel and Begunbari channel had played a vital role in passing away of excessive water. These two channels are now narrowing down due to illegal construction activities and hence, are not capable of discharging excessive water like before. In addition to that, unplanned urbanization has been increasing rapidly in Dhaka city since 1971, and about 366 square kilometer (km^2) will be urbanized by the year 2010 (Islam, 1998). Mostly for the above reasons, flood vulnerability has increased within the city area.

TABLE 1 Population Growth in Dhaka City

Year	Population (million)	Growth rate (%)	Remarks
1951	0.36	1.28	Census of Pakistan, 1954
1961	0.56	5.28	Census of Pakistan, 1961
1974	1.77	9.32	Census of Bangladesh, 1974
1981	3.45	9.94	Census of Bangladesh, 1981
1991	7.35	7.10	Census of Bangladesh, 1991
2000	9.92	6.00	Census of Bangladesh, 2000

Source: BBS, 2000

B. Reasons of Flooding in Dhaka City

Flooding is a common phenomenon in Dhaka city. Mainly two types of flooding takes place in Dhaka city such as external flood that is caused by the increased water level of the rivers; and the internal flood that results from local rainfall and drainage blockages (FAP 8A, 1991). The main causes of flooding in Dhaka city area are: unplanned urban development, encroachment of low lands, river floods, drainage clogging, precipitation, water logging around DND (Dhaka-Narayangonj-Demra) project, natural process of soil erosion and man-made causes.

II. GIS AND RS TECHNIQUES APPLIED TO FLOODING

A computer based geographical information system (GIS) is used for storing and manipulating and analyzing geographically referenced data. GIS is offering facilities that help the users to make decisions in, for example, city area planning. In addition, GIS used in flood mapping register geographic features of an area, to allocate rainfall intensity, to analyze and show runoff coefficient and discharge quantities of the area. In studies as Castle (1993), Sivertun & Prange (2003) and Sdao et al. (2010) and many others, GIS has been shown to be a valuable tool to predict as well quantitative as qualitative impact from runoff and floods. Hence, mapping and modelling in GIS can be treated as a mechanism by which any developer or user can inquire related information to find out different flooding features such as damage to property, loss of life and so on.

Sustainable urban development through successful implementation of GIS mostly relies on four factors where the first one is the GIS database automation. In this case, it requires working with only necessary data for specific task to be cost effective and not too time consuming. Second one, GIS methods need to be combined for gathering data either from existing records and maps, aerial photography or field surveys. Third one, the ability to achieve spatial modelling for generating the substitute choices; and last one is the application of related criteria for evaluating the efficiency of achievable planning strategies before reaching to the final solution (Yaakup & Johar, 1996). GIS has three basic data structures (point, line, and polygon) and three derived data structures (grid, TIN-triangulated irregular network, and network). Besides these GIS data in form of rasters (or GRIDS) can be stored and analysed preferable together with Remote sensing data and for complex analysis.

From long since, the progresses in the field of GIS and RS are facilitating the flood risk estimation (Coppock, 1995). GIS has the advantages of visualizing the flood mapping and can create potential for further analysis by estimating potential damages during flooding period (Hausmann et al., 1998; Clark, 1998). Remote sensing can easily detect river inundation, stages and discharges focusing on flooding edge delineation (Smith, 1997). Sattelite scenes like the SPOT multispectral imageries in the near infrared portion of the spectrum are used in flood delineation; for example, SPOT imageries along with DEM were used in flood delineation in Bangladesh (Brouder, 1994; Sanyal & Lu, 2004).

The cloud cover during bad weather conditions is an obstacle to monitor the improvement of floods (Rango & Solomonson, 1977; Melack et al., 1994) but microwave remote sensing such as radar imageries can solve this problem as radar pulse can go through the cloud cover. Synthetic Aperture Radar (SAR) imagery and RS imagery are simultaneously used as common approach for flood management (Honda et al., 1997; Chen et al., 1999). SAR imageries have the capabilities to differentiate land and water. The combination of optical and microwave remote sensing technologies provide the better results for flood mapping. The imageries of Landsat Thematic Mapper (TM) and radar images with SAR can solve the obstacles to identify the flooding areas when there is heavy cloud coverage (Yang et al., 1999). An imagery that is captured in dry season lead to an underestimation of the natural drainage which in turn can lead to an overestimation of the inundated area (Islam & Sadu, 2002).

A good quality flood mapping is needed for respective authorities or the end users in order to get the clear outline of the affected flooding area. Now a day, the experts in GIS and RS techniques are necessary because the flood risk mappings are normally so technical. The experts need to make a good overview of the flood mapping so that the end users can easily understand the devastating effects of flooding as well. The below figure (Fig. 2) represents the application of GIS and RS techniques related to each other; and also shows how the data visualizes in different manners for experts or users.

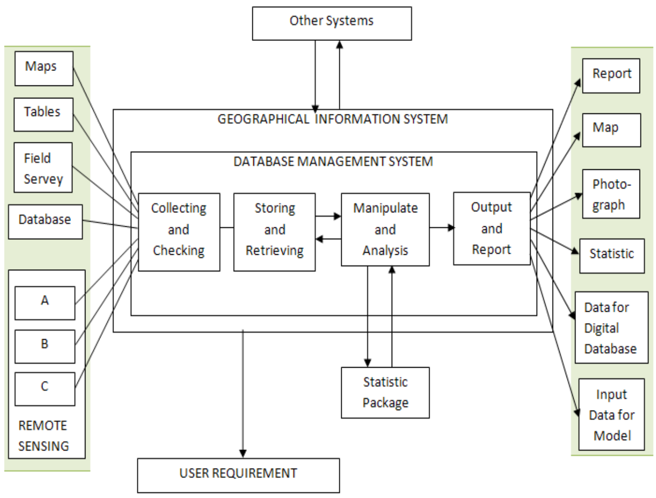

Fig. 2: GIS and RS techniques with their functions. Adapted from Yaakup et al. (1997)

Flooding depth is usually calculated through subtracting the elevation of each cell in a raster from its flooded level (Townsend & Walsh, 1998; Islam & Sadu, 2002) which means that the precision of the flooding depth depends on the accuracy of the DEM. The resolutions of the ground data normally control the accuracy of the flooding depth

(Brakenridge et al., 1998). As a result, High resolution satellite digital image data are commonly needed for DEM in order to get the actual level of flooding depth. Light Detecting and Ranging (LIDAR) is the recent improvement of the RS application for flood related problems. It is growing very popular in the developed countries and is used for generating DEMs within flooding risk areas. LIDAR sensors can recognize the vertical differences of the land uses and easily form DEMs with outstanding accuracy to identify the flooding depth (Hodgson et al., 2003). The flood reaches a high peak that usually lasts for a few hours. It is very difficult to get the spatial extent of that peak point with the present Radarsat ScanSAR used in Bangladesh. In this case, it is possible to use comparatively inexpensive high resolution optical remote sensing in the humid tropics for separating vulnerable areas during river flooding, for example, SPOT imageries.

III. METERIALS AND METHODS

A. *Data Used*

Flooding is a result of complex interaction between several factors. Successful mapping of flood depends largely on the proper consideration of those factors and methods used to integrate them to get the final map. Factors used in the current study to prepare a flooding map for DCC are discussed in the following paragraphs:

1) Administrative Map of DCC

A paper map of DCC was collected from Nogor Bhaban, the administrative center for DCC control and management. The map was prepared by city development consultant and it was published by urban planning department of Dhaka city corporation in April, 2004.The city corporation map is divided into 90 different parts from 1 to 90 with administrative boundaries and every part within administrative boundaries is known as a 'ward' which means that DCC has 90 wards. The map was digitized and resampled after scanning to prepare a vector map using CartaLinx and ArcGIS 9.3. On an average, the areas of the wards are bigger in the northern part of the city compared to the south. Moreover, areas of some of the wards are so small compared to the bigger ones that considering them as an analysis unit could generate erroneous results. So, a grid system with a grid value of 2.5 km^2 was considered for the entire study area (Fig. 3) in order to get a reasonable total grid which is 38 to work on easily. For instance, if the grid system is considered with a grid value of 1 km^2 or less km^2 for the entire study area then the total number of grids will be more and in that case, it will be time consuming to deal with. On the other hand, if the grid system is considered with a grid value of 5-6 km^2 for the entire study area then the total number of grids will be very less and in that case, it will be time consuming as well to find information from a bigger area for a specific purpose.

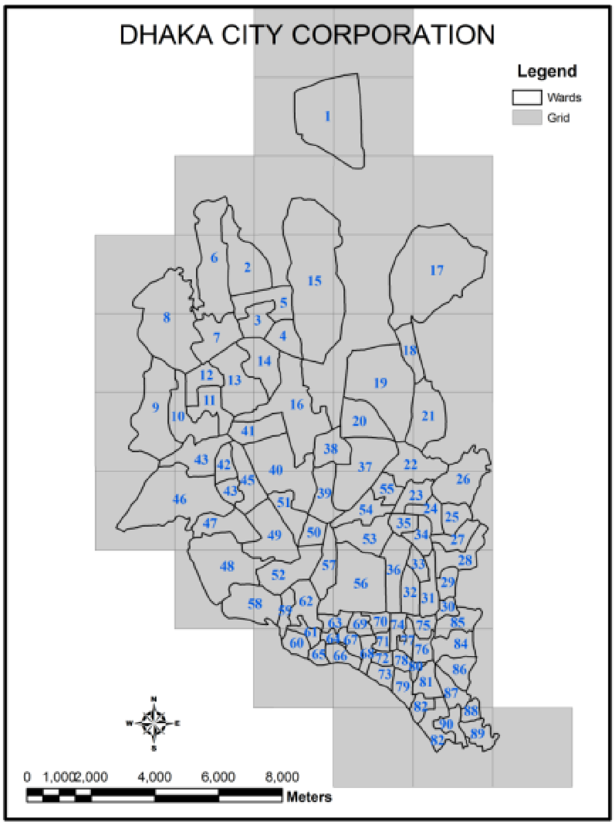

Fig. 3: Digitized map for Dhaka City Corporation area with grids. Source: DUP, 2004.

2) Building Information

Information about the built environment is necessary for any hazard mapping because risks increase with the increasing building density (Hall, 1984). From the urbanization system (Figure 1), it could be summarized that if the building density increases then it increases flood control problems by increasing the peak runoff rates. Building information was also obtained from RAJUK (Rajdhani Unnayan Kartripakkah), the capital development authority of Dhaka in Bangladesh as paper map. After that, it was digitized and resampled to prepare a vector map using CartaLinx and ArcGIS 9.3.

3) Elevation Data

A digital elevation represents the ground plane topography digitally based on RS techniques and it helps to identify the flooding depth from discharge data by comparing the real flooding areas of satellite imageries (Sanyal & LU, 2004). So, the more flooding depth in a zone represents the more elevation difference in that area. Elevation data was obtained from satellite images and it was then transformed into point form using ArcGIS 9.3.

4) Flooding Depth

Flooding depth is normally calculated through subtracting the elevation value of each flooded cell from its height level. It demonstrates the water flow passes over the area, and the more flooding depth means more water logged situation in that area (Islam & Sadu, 2002). Flooding depth data was obtained from Bangladesh Water Development Board (BWDB) as images and then, prepared a vector map using ArcGIS 9.3.

5) Land Use

Land use like buildings, roads, slum areas etc. decreases penetration capacity of the soil and increases the water runoff. In other words, land use types work as resistant covers and decrease the water hold up time; and typically, it increases the peak discharge of water that enhances a fastidious flooding (Murck et al., 1996). So, land use change is a crucial factor in flood happenings. The land use data was extracted through the interpretation of landsat satellite images using RS technique.

6) Slope

Low gradient slopes are highly vulnerable to flood occurrences compared to high gradient slopes. Rain or excessive water from the river always gathers in an area where the slope gradient is usually low. Areas with high slope gradients do not permit the water to stay (USDA, 1986). So, slope has a vital impact on flooding. This data was derived from digital elevation model data using IDRISI15.0-the Andes Edition.

7) Soil Texture

Soil textures have a great impact on flooding because sandy soil absorbs water soon and few runoffs occurs. On the other hand, the clay soils are less porous and hold water longer than sandy soils. So, the areas characterized by clay soils are more affected by flooding. This data was obtained from Bangladesh geological survey.

8) Soil Moisture

Soil moisture is normally estimated by the feel and appearance of the soil. It acts as an interface between the land surface and atmosphere, and plays an important role in partitioning of precipitation into runoff and ground water storage (Satalino et al., 2002).The increase of soil moisture increases more water runoff volume (Noguchi et al., 1997) which means water logging or flooding situation increases with the increase of soil moisture. The levels of soil moisture rise when there is sufficient rainfall to exceed losses to streams and groundwater, and it is important for soil erosion, slope stability as well as the growth for plants and crops. This data was also obtained from Bangladesh geological survey.

B. Methodology

To prepare flood prediction maps, a built-in multi-criteria evaluation (MCE) module in IDRISI environment was used. All the factors mentioned in the previous paragraphs were used as inputs to the MCE analysis. MCE combines the provided inputs into a single index using different methods. Among the methods that are used to combine the inputs, Boolean criteria and weighted linear combination are most commonly used (Nihar et al., 2002). In the current study, to integrate the inputs, the weighted linear combination has been used and the weights of different inputs have been decided using a pair-wise weighting method (Malczewski, 1999). Based on it, a total score was obtained for each alternative by multiplying the importance weights assigned for each attribute by the scaled value given to the alternative. Pair-wise weighting method is very useful to reduce the uncertainty of the decision making to reach a final goal (Nihar et al., 2002). Pairwise comparison method can exchange subjective measurements of comparative importance into a linear set of weights that is developed by Saaty (1980) known as Analytical Hierarchical Process (AHP).

AHP is a systematic method that breaks down the complex problem into a number of small constituent elements to structure it in a hierarchical form (Cheng et.al, 1999). Pairwise comparison of all factors mentioned in the previous paragraphs were taken as input in the pairwise comparison matrix using IDRISI environment to obtain the relative weight values as output for each input data where AHP makes availability of the mathematical techniques to convert this matrix into a vector relative weights of the criterion. As a built-in MCE module in IDRISI environment was used for the current study, and as that module supports data only in the raster form so all the factors (criteria) were converted into raster form before starting the analysis. After converting all the factors into raster, they were classified into different zones. Then different standard vulnerability values were assigned to these zones and finally, all these classified variables were fed into the MCE to obtain the flooding risk map. At the end, the area was calculated for different flood prediction mappings using IDRISI environment. The methodological work performed for this study is illustrated in Fig. 4:

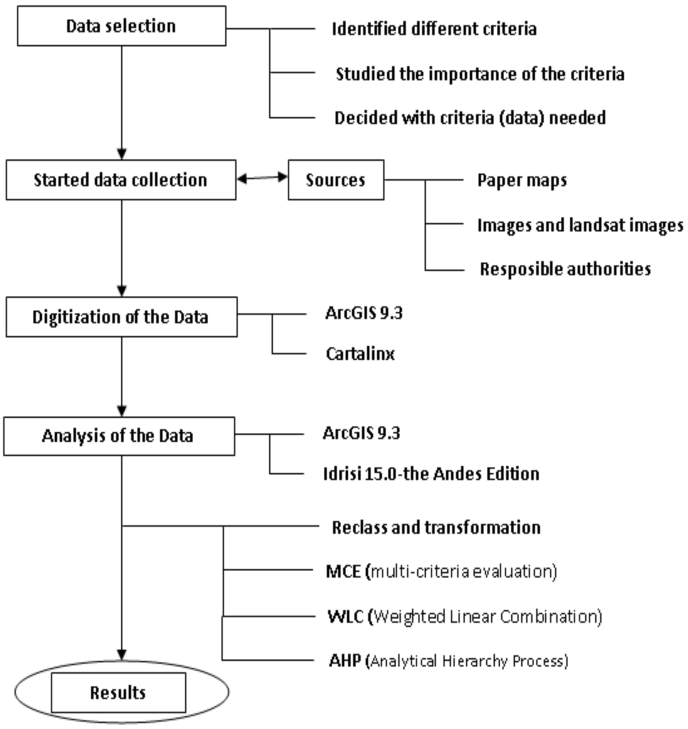

Fig. 4 Methodological flow-chart of the case study.

C. Limitations

There are very few previous studies linked to building density, water logging and drainage systems of Dhaka city. So, the current study faced difficulties to enrich the analysis of the findings.

The base map used in the current study was not recent. Moreover, the rate of infrastructural change in the study area is very high. So, it is hard to say that the used building and road information will exactly match with the current situation.

IV. ANALYSIS & RESULTS

Results obtained during different stages of analysis and through MCE operation are presented in this chapter.

A. Digital Elevation Model (DEM)

DEM was generated from point elevation data to extract topography of the study area. In the case of flood prediction mapping, topography is particularly important because it has direct influence on level of flooding. Before generating DEM, both the base-map of the study area and the point elevation data were referenced into the same coordinate system so that they match with each other (fig. 5a and 5b).

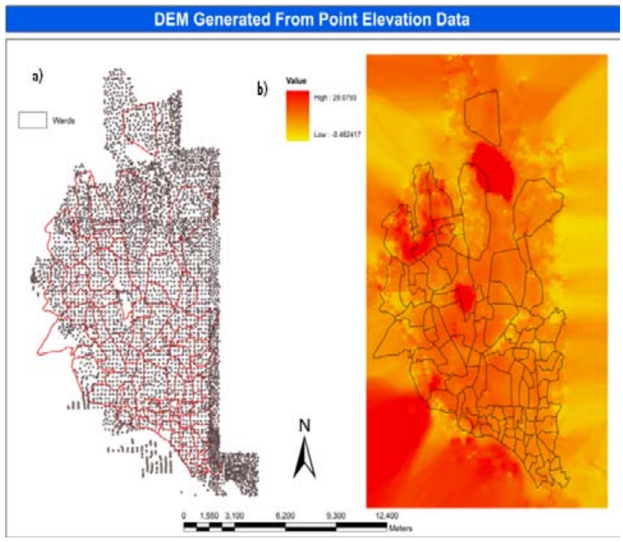

Fig. 5 Elevation data for Dhaka City Corporation generated from point elevation data. 5a Elevation data in point form; 5b Interpolated elevation data.

Then the DEM was classified into different zones based on the pixel values (heights) where areas with lower elevation have been considered to be more vulnerable to flooding compared to the areas with higher elevation (Fig. 6).

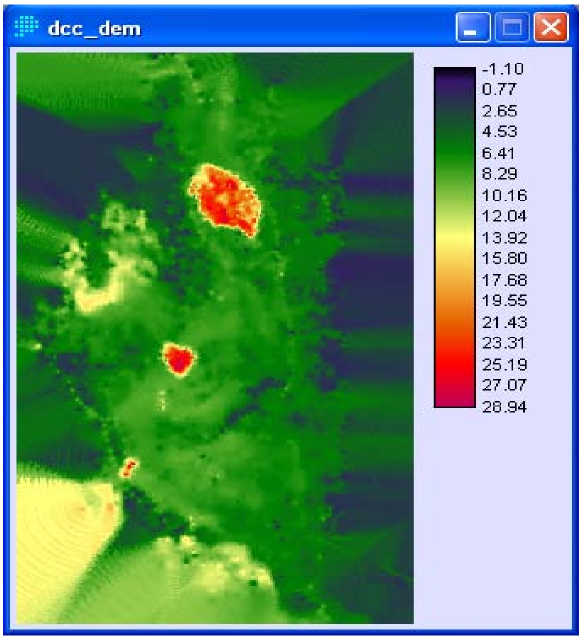

Fig. 6 Elevation ranges (ft) for DCC.

This classification was done in IDRISI environment and the details of the reclassification procedure are given in Table 2. Class 5 here represents the areas of highest elevation, so these areas are least vulnerable to flooding. Like this, class 2 represents areas with low elevation, so these areas are more vulnerable to flooding compared to class 5 (Table 2).

TABLE 2: Reclassification Ranges with Correspondent Risk Areas for Elevation Differs

Ground elevation range (ft)	Indicator	Risk area
Less than -1.10	0	Background
25.50 to 30.00	1	Very low risk
22.00 to 25.50	2	Low risk
12.50-22.00	3	Moderate risk
2.50 to 12.50	4	High risk
-1.10 to 2.50	5	Very High risk

Finally, using the elevation ranges with fig. 6, a new image was created (Fig. 7) that was used as input into the MCE process.

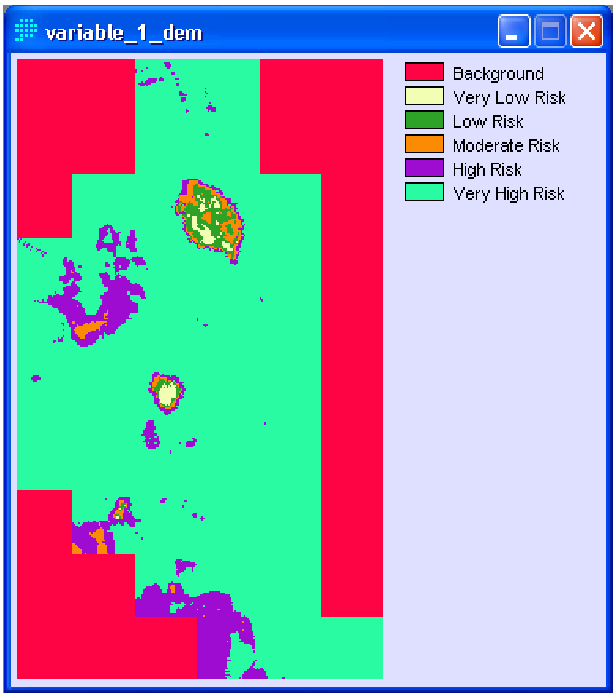

Fig. 7 Flood affected areas for DEM variations.

The result indicates that almost all the areas of DCC are highly vulnerable to flooding (Fig. 7).

B. Vulnerability maps for Other Factors

Following the above steps in A under analysis and results, raster maps were generated where the pixels are now indicating the level of vulnerability to flooding for each factor and all of these raster maps have used as input into the MCE process.

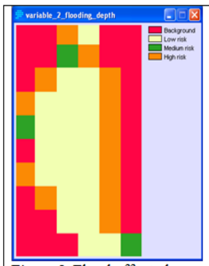

Figure 8: Flood affected areas for flooding depth variations.

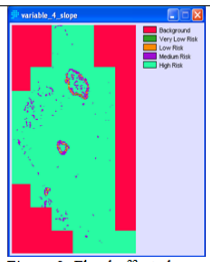

Figure 9: Flood affected areas for slope variations.

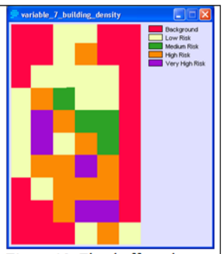

Figure 10: Flood affected areas for building density variations.

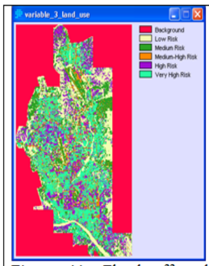

Figure 11: Flood affected areas for land use variations.

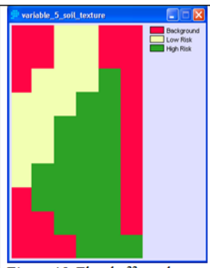

Figure 12: Flood affected areas for texture variations.

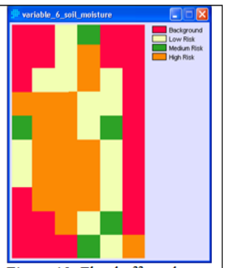

Figure 13: Flood affected areas for moisture variations.

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The results indicate that mostly all the areas of DCC are high vulnerable to flooding due to all the factors variations.

C. Flood Prediction Mapping

Flood prediction mapping is very important for a densely populated city like Dhaka because it can help the authorities to take proper decision during flooding and plan for the future. For instance, if the housing companies have access to the flood maps before they build residential areas then they can take earlier initiatives to save the residential areas from flooding either through avoiding those high risk flooding zones or by taking protective measures.

For preparing the flood prediction mapping, pairwise comparison matrix and factor weights were calculated for the above analyzed data. Pairwise comparison is developed by AHP with the concern of the relative importance of the two criteria involved in determining of the suitability of the stated objective (Estman et al., 1995).

Seven types of data are used in this study but digital elevation data and the flooding depth are correlated to each other as flooding depth depends on digital elevation. Also, soil moisture data and soil texture data are correlated to each other as soil moisture has significant impacts on soil textures. For preventing the correlated issues, digital elevation data and soil moisture data are ignored for further consequences of this study.

In this study, ratings were provided on a five-point continuous scale that has ranged from 5 to 1/5 as there are 5 factors considered for this area mapping. Since the matrix is symmetrical then only the lower triangular half of the table needs to be filled in because the other triangular half is the reciprocal of that one.

TABLE 3: Pairwise Comparison Judgment Table for Different Factors

	Flooding Depth	Land Use	Slope	Soil Texture	Building Density
Flooding Depth	1	---	---	---	---
Land Use	4	1	---	---	---
Slope	3	1/3	1	---	---
Soil Texture	3	2	1	1	---
Building Density	3	1/2	2	1/3	1

The choices of this pairwise judgment are subjective. The reasons of choosing different values for different factors in the pairwise judgment table (Table 3), for instance, the chosen values for building density, flooding depth and slope correspondingly have described in below (Table 4) respected to flooding impacts.

TABLE 4: Alternatives Compared with respect to Flooding

Building Density	3	Flooding depth	1	Building density has more impact on flooding than the flooding depth because more building density increases the flooding depth for that area.
Building Density	2	Slope	1	Building density impacts moderately on flooding than slope because more building density decreases the slope areas during new establishment of residential areas.
Flooding Depth	1	Slope	3	Slope has more impact on flooding than flooding depth because more slope height decreases flood occurrences for that area.

In the weights (Table 5) calculation step, the pairwise comparison matrix and the factor maps were used with the WEIGHT module in the IDRISI environment. After that, the principal eigenvector of the pairwise comparison matrix was figured out to produce a best fit to the weight set. Using a weighted linear combination in a MCE, it is obvious that the weights sum to 1. The consistency ratio of the pairwise matrix (Table 3) was calculated as well where the values indicate the probability that the ratings were randomly assigned. A consistency ratio of 0.10 or less is considered as acceptable (Saaty, 1980).

TABLE 5: Factors weights for Analyzed Data

Factors	Weights
Flooding Depth	0.1252
Building Density	0.1398
Slope	0.1844
Soil Texture	0.2798
Land Use	0.2708
Total	1.0000

Consistency ratio for the above weights is 0.09 and this consistency is acceptable as the consistency ratio is less than 0.10 which means the subjective judgments need not to be revised and output is good enough for further testing.

Weight is referred to importance, or preference, or likelihood, or whatever factor is being considered by the decision makers. Weights values represent the priorities which are absolute numbers between zero and one. A higher weight value of the factors represents more priority or more impact than others within the study. From the factor weights found for this study area, it is clear that building density, slope, soil moistures and land use have higher weights value. So, they have more impact on flooding relative to the other factors.

Once the weights for the factors were selected then the MCE module in IDRISI environment was performed by utilizing the specific weights for each factor, the factors themselves, and the constraint maps for each factor to produce the flood prediction mapping. As MCE forms a single map from the combination of all analyzed map then the final output (Fig. 14) will represent the desired result for flood prediction mapping.

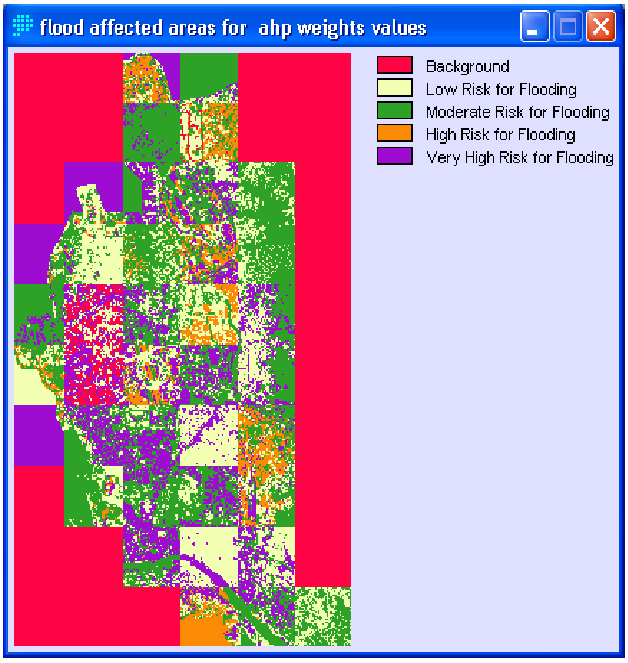

Fig. 14 Flood prediction mapping for analyzed data.

To demonstrate the importance of different factors on flooding, two other flood prediction mappings were illustrated using two different calculation methods in MCE of IDRISI environment where different weighting methods are available. One flood mapping was created by equal weighting method in MCE; and in this case, weights for each variable were generated 0.1429 as there are seven factors available in this study. Flood prediction map obtained using equal weights have shown in below (Fig. 15).

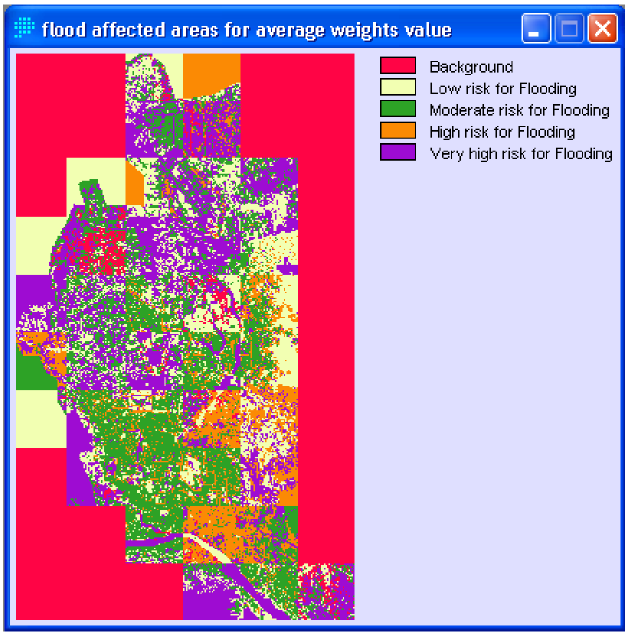

Fig. 15 Flood prediction mapping for equal weights values.

For another mapping, the approximated value option was chosen where the factor weights are entered by the individuals according to their own priority importance of the factors with total sum of 1.00. The approximate weighting method in MCE was selected in IDRISI environment and the weights values were entered for each factor as below (Table 6).

TABLE 6: Approximated weights Chosen by Author of the Study

Factors	Weights
Flooding Depth	0.0930
Building Density	0.1360
Slope	0.2005
Soil Texture	0.2900
Land Use	0.2805
Total	1.0000

The flood prediction mapping (Fig. 16) found in this case of approximated weighting method using MCE application has shown in below.

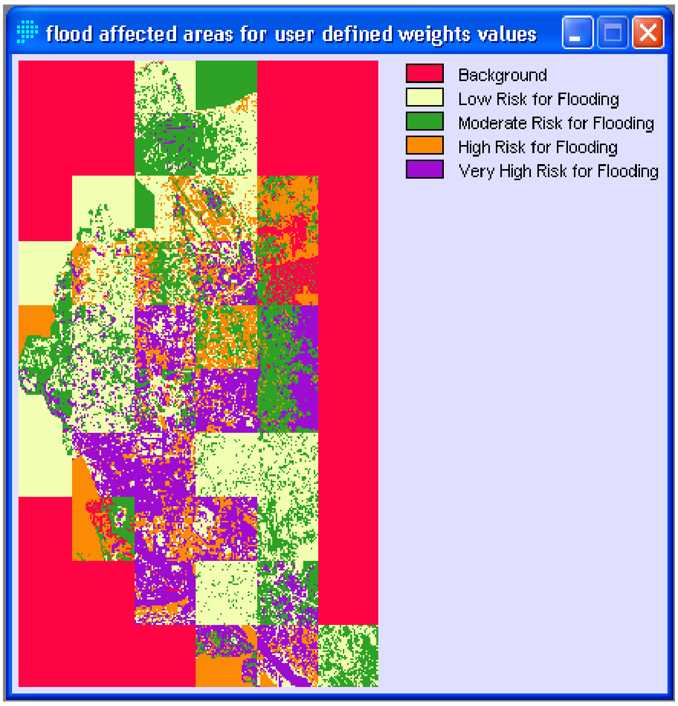

Fig. 16 Flood prediction mapping for approximated (Fuzzy) weights values

Finally, the areas were calculated for each of three flood prediction maps which have illustrated above (Fig. 14, Fig. 15 and Fig. 16) using Area module in IDRISI environment to show the total affected areas for different risk zones, and the resulted areas for corresponding risk zones were tabulated in below table (Table 7) correspondently.

TABLE 7:Calculated Risk Areas (km^2) for Three Different Flood Maps

Cate-gory	Legend	Risk areas for AHP data (km^2)	Risk areas for equally weighted data (km^2)	Risk areas for fuzzy weighted data (km^2)
1	Low risk for flooding	61.0783627	58.4823026	83.3698840
2	Moderate risk for flooding	72.2106375	63.2284573	55.8470515
3	High risk for flooding	38.6062240	32.5554863	37.6530078
4	Very high risk for flooding	52.4201377	70.1787631	48.9994530

To see the relationship among different flood prediction mappings obtained from different weighting methods, similar very high flooding zones are selected for different weights in below (Fig. 17).

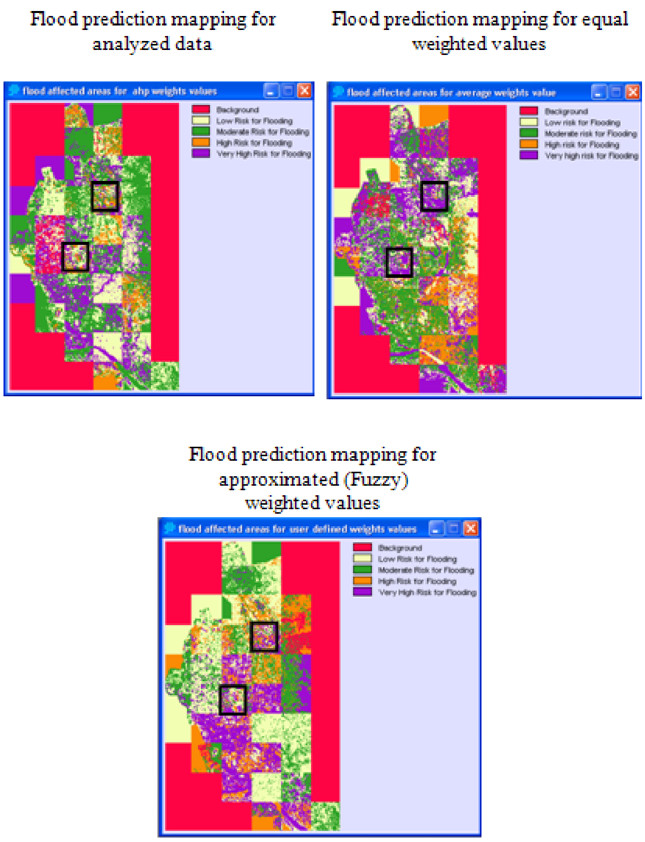

Fig. 17 Similar very high flooding zones for different weights

In the above results, it can be seen that some areas have consistently been classed as very high risk flooding zones although different weighting methods have been used in combining the contributing factors. These high-risk flooding zones have been marked with black box (Fig. 17)

V. DISCUSSIONS ON RESULTS

Different weights using the MCE module in the IDRISI environment were tested in this study to see how the different factors would influence the flooding risk assessment of different areas. For instance, the study has used different weights which are subjective for preparing the flood maps but areas marked with black squares (Fig. 17) were consistently classed as high-flooding-risk zones. The results therefore indicate that these areas need to be avoided for construction purposes or need to be taken proper support to save the areas from flooding during construction purposes. City authorities can also take special measures in those areas to reduce the intensity of flooding.

The grid system has been chosen for this study because the original map for DCC was not well referenced and also, the areas or boundaries are not fixed as the city area is expanding rapidly with the rapid growing population. So, grid system is a better technique to work with such kind of situations either the areas are fixed or not because anyone can choose the grids anytime without thinking of specific changes for any specific areas.

Factors weights allocated in different weighting methods for MCE module have an impact on risk assessment of flooding. For example, the factor weights of ‘slope’ changes in different weighting method have impacted the total risk areas. The changes of slope weights for different flood prediction mapping (Fig. 14, Fig. 15 and Fig. 16) have changed the flooding risk areas (Table 7). For instance, it is found that low flooding areas have decreased as slope weights value decreases to 0.1429 for average weighting method, and the low flooding areas have increased as the approximate slope weights value increases to 0.2005 respected to the risk areas for analyzed data where the slope weights were 0.1844 and vice versa. One more example of factor weights of ‘building density’, it is found that very high risk flooding areas have increased as building density weights value increases to 0.1429 for average weighting method but the high risk flooding areas have decreased as the approximate slope weights value decreases to 0.1360 respected to the risk areas for analyzed data where the slope weights were 0.1398 and vice versa. The above investigations for different factors are also applied with the factor weights changes regarding to the corresponding flood prediction mapping.

This flood prediction mapping can be a good model of vulnerability testing. It can help to find out the terrible situation for a specific area. For example, someone want to get how many people are affected by flooding for a desired area then he can do it easily with the population data incorporate with flooding depth data, building density data or others data or combination of all of them.

This flood prediction mapping model can help the decision makers such as city planners or the related authorities for analyzing different factors and weights values effect in DCC or in a desired area. Based on it, the authority can change the weighs values for factors to get the maximum flooding affected areas for their safety and thus, they can save the areas by supporting needs. Moreover, with the help of this model, authorities can upgrade or build up new drainage systems, take initiatives to save the low lands areas for water runoff easily, follow the building codes strictly and so on as they can easily get the risk data for specific area at any time. In addition, this model will also help the authorities to take right initiatives in an urgent or long term basis to make the city less affected by flooding or water logging situation all the year round. In this way, people can be benefitted from this mapping model in an urgent basis or in the long run.

VI. CONCLUSION

This study confirms the method used here was enough to integrate the flood mapping mapping in a GIS context with the help of RS techniques. The integration of MCE and GIS techniques provide a powerful tool for decision-making procedures in area mapping because it always allows a coherent and efficient use of spatial data. The use of MCE for different factors such as DEM, building data, slope, flooding depth and soil moistures demonstrated to be useful to define the risk areas for the flood prediction mapping. So, the accuracy of the factor weights needs to be estimated carefully in order to figure out the important roles of the factors and the uncertainties of the factor’s weights. Flood vulnerability mapping helps to access flooding risks areas which are very much important to the planners, emergency services or to the decision makers because it can help to systematize well planning for future possibilities with land use planning, management and other services as well.

The MCE approach has presented the results in an understandable form to authorities/end users but it also allows them to model and simulate different land use allocation strategies as to prevent from further catastrophic flooding events. So, GIS and RS techniques can help the authorities or decision makers to estimate the factors more accurately in order to protect areas from flooding or water logging situation. The results not only identified the areas with flooding risks areas but also clarified which factors are more important in the case of flood prediction mapping. This findings help to make appropriate decisions and take suitable measures to reduce the losses created by flood. Furthermore, the results of this study can be a useful source for other researchers for diverse studies in future.

In this study, MCE approach was applied to identify the risk areas within a GIS context with the help of RS technique. This approach has been used in many countries for different sectors and studies. However, this approach is a new and innovative application in risk measurement in Dhaka city because it has not been used to categorize flood risk areas in Bangladesh before. The combination was constructive for evaluating multiple factors in a consistent way in order to acquire flood prediction mapping, and to calculate the affected risk areas. Therefore, GIS-RS combination technique has the potential to make available a rational, objective and non-biased flood prediction mapping for DCC in Bangladesh.

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