

## DEM based Flood Extent Delineation in Dhaka City, Bangladesh

A.M. DEWAN\*, Makoto NISHIGAKI\*\*, Mitsuru KOMATSU\*

(Received December 3, 2003)

Dhaka city, the capital of Bangladesh and home for more than 10 million people, has been affected by seasonal flooding almost in every year, however, the situation aggravates depending on rainfall and surrounding river waters. The aim of this paper is to delineate the flood extent in Dhaka city using digital elevation model (DEM), an integral part of geographic information system. Catastrophic floods of the 1988 and 1998 events are taken into consideration. Hydro-meteorological assessment of these events revealed that the 1988 flood was severe due to the lack of flood protection in the city together with transboundary flow of the major rivers while the 1998 flood was become deluge due to incessant monsoonal downpour along with early peaked of the river water levels. The 1998 event has done colossal damage in the city compare to the 1988 event. Flood extent estimation showed that DEM data is very precious to model inundation in the city, however, in order to be spatially explicit flood model, high resolution DEM is necessary. Finally, flood management issues are reviewed and found that combination of structural and nonstructural measures are necessary to help reducing flood induced losses and damage in the city.

**Key Words:** Dhaka City, Floods, Digital Elevation Model, 1998 and 1988 Floods

### 1 INTRODUCTION

Accurate information on the extent of water bodies is a prerequisite for flood disaster management (Smith, 1997; Baumann, 1999). Mapping of accurate flood prone areas not only helpful to prevent flood induced losses and damages but also important for evaluating the extent of damages and emergency management. Ground observation techniques were used to analyze flood prone areas in the past, however, with the advent of new technology, this techniques is neither useful nor produce precise information on flooding since flood is a highly dynamic event. To facilitate accurate flood information with the new technology, Geographic Information System (hereinafter, GIS) has proven its capability. GIS derived flood map are invaluable to national agencies for disaster management, land use planning and to reduce catastrophic effects for many years (Brivio et. al., 2002; Islam and Sado, 2002). There has been growing use of GIS techniques all over the world to model flood hazard using Digital Elevation Model (hereinafter, DEM). DEM data has become an integral part of Geographic Information System (GIS) and extensively use for hydrological assessment. Many researchers used to analyze DEM to model flooding (Correia et. al., 1998; Townsend, 1998), verification of insurance claims (Barnes, 1996) after a flood event and flood extent delineation (Wang et. al., 2002; Leenaers and Okx, 1989). These researches showed a prolific potentiality of using

DEM for hydrologic assessment. Floods are the most destructive and pervasive natural disasters in Bangladesh. Recent catastrophic examples are the 1988 and 1998 floods that inundated 61 percent (Paul, 1997) and 68 percent (O'Donnell et. al., 2002) of the total areas of Bangladesh. Huge damage occurred on those events which hinder the national economic development. Dhaka city, the capital of Bangladesh has been severely affected in those events and paralyzed the life and livelihoods of the city dwellers. Although, structural measures have been taken into consideration right after the 1988 floods, however, they could not help ameliorate flood induced damage during the 1998 events. In addition, the flood risk has increased considerably due to technological fixes in and around the city (Rasid, 1993). Until now, flood prone areas delineation in the city has been conducted using ground observation techniques. Studies showed that ground observation technique is not helpful to delineate flood boundaries accurately and efficiently that inhibit developing proper flood management system (Brivio et. al., 2002). Owing to third world cities, it is also difficult for the government to update the database very frequently. Moreover, rapid and unplanned urbanization have been taking place which force people to live in more hazardous place. In order to manage flood disaster very efficiently, it is a pressing need to map flood prone areas using the modern technology which can help emergency management during the catastrophe. Therefore, modern technology such as GIS is deemed to facilitate accurate mapping of flood prone areas in Dhaka city during the 1988 and 1998 events along with hydro-metrological assessment.

\* The Graduate School of Natural Science and Technology, Okayama University \*\* Department of Environmental and Civil Design, Faculty of Environmental Science and Technology, Okayama University.

The objectives of this paper are: (i) to study the general background of 1998 of 1988 flooding in Dhaka city in the light of flood history; (ii) to estimate the extent of flooding using digital elevation model during the devastating flood of 1998 and 1988 events and finally (iii) examine the present flood management system.

In this paper, first we described the study area followed by historical flooding in Dhaka city. Types and causes of floods in the city have been analyzed and presented. In the second part, hydro-meteorological and damageable aspects of two catastrophic floods viz. 1988 and 1998 events are analyzed. Flood extent delineation using DEM data for those two events have been put in the following section. Finally, aspects of flood management in the city are analyzed and some recommendations are put forward.

## 2 ENVIRONMENTAL SETTINGS OF THE STUDY AREA

The study area chosen for this research is the capital of Bangladesh and home of about 10 million people (BBS, 2001). The study area extends to 23°40' to 23°55' N latitude and 90°20' to 90°30' E longitude. It is surrounded by the Buriganga river to the south, Turag River to the west, Tongi Khal to the north and the Balu river to the east. The greater Dhaka city is located mainly on an alluvial terrace, popularly known as the Modhupur terrace of Pleistocene period. Topographically, Dhaka city is relatively a flat land, the surface elevation of the city ranges between 1 and 14 meters (FAP 8A, 1991). It belongs to sub-tropical monsoon zone and experience humid climatic conditions. Dhaka city experiences about 2000 mm annual rainfall of which more than 80 percent rainfall take place during monsoon. Historically, Dhaka city is built up in a flood plain with numerous *khals* (ephemeral water bodies) and canals that used to drain water from its upper reaches during monsoon season. As population increased, these areas were encroached. As a consequent, those khals and depressions were detached and lost their ability to drain and store flood water. For instance, in earlier centuries the city's massive runoff was drained by the two major khals, viz. Dholai khal and Begunbari Khal. Moreover, unplanned urbanization has been taking place since 1971 (Islam, 1996) and by 2010 around 366 sq. km. suppose to be urbanized in Greater Dhaka area (GOB, 2000) which will be resulted more people to live in highly vulnerable place (Rasid and Mallick 1993).

## 3 HISTORICAL ASPECTS OF FLOODING IN DHAKA CITY

Flood is not a new phenomenon for the inhabitants of Dhaka city. Historical accounts on flooding in the city demonstrated that Dhaka city was heavily inundated during 1787 and 1788 following heavy monsoon downpour and the depth of flooding was sufficient enough to admit boats sailing across the streets in Dhaka city (Hunter, 1877). Again in 1833-34, 1870 a number of floods devastated Dhaka and its adjacent areas (Hunter,

1877). Floods those occurred in 1950s and 1960s also severely affected Dhaka city (Rizvi, 1969). The recent flood history revealed that some parts of Dhaka city has been regularly inundating during the monsoon season since 1954 (Fig. 1), however, the situation exacerbate depending on rainfall and inflow from upstream. Among the catastrophes, the 1987 and 1988 floods were worst before the 1990s that inundated an area of 164 and 200 km<sup>2</sup> respectively with a maximum duration of 22 and 28 days (FAP 8A, 1991). Another unprecedented flooding has occurred in 1998 which is said to be catastrophic in memorable record due to its prolonged duration (Islam, 1998; DMB, 1998). It is postulated that rainfall amounts, river water level records, flood duration, inundated area, economic losses during 1998 floods excelled all its past records (Faisal et. al., 2003). According to Flood Action Plan 8A (1991), two types of flood occur in Dhaka city, one is external flood mainly caused by the spilling of river water levels and the other one is internal flood which is the result of rainfall and drainage congestion.

## 4 CAUSES OF FLOODS IN DHAKA CITY

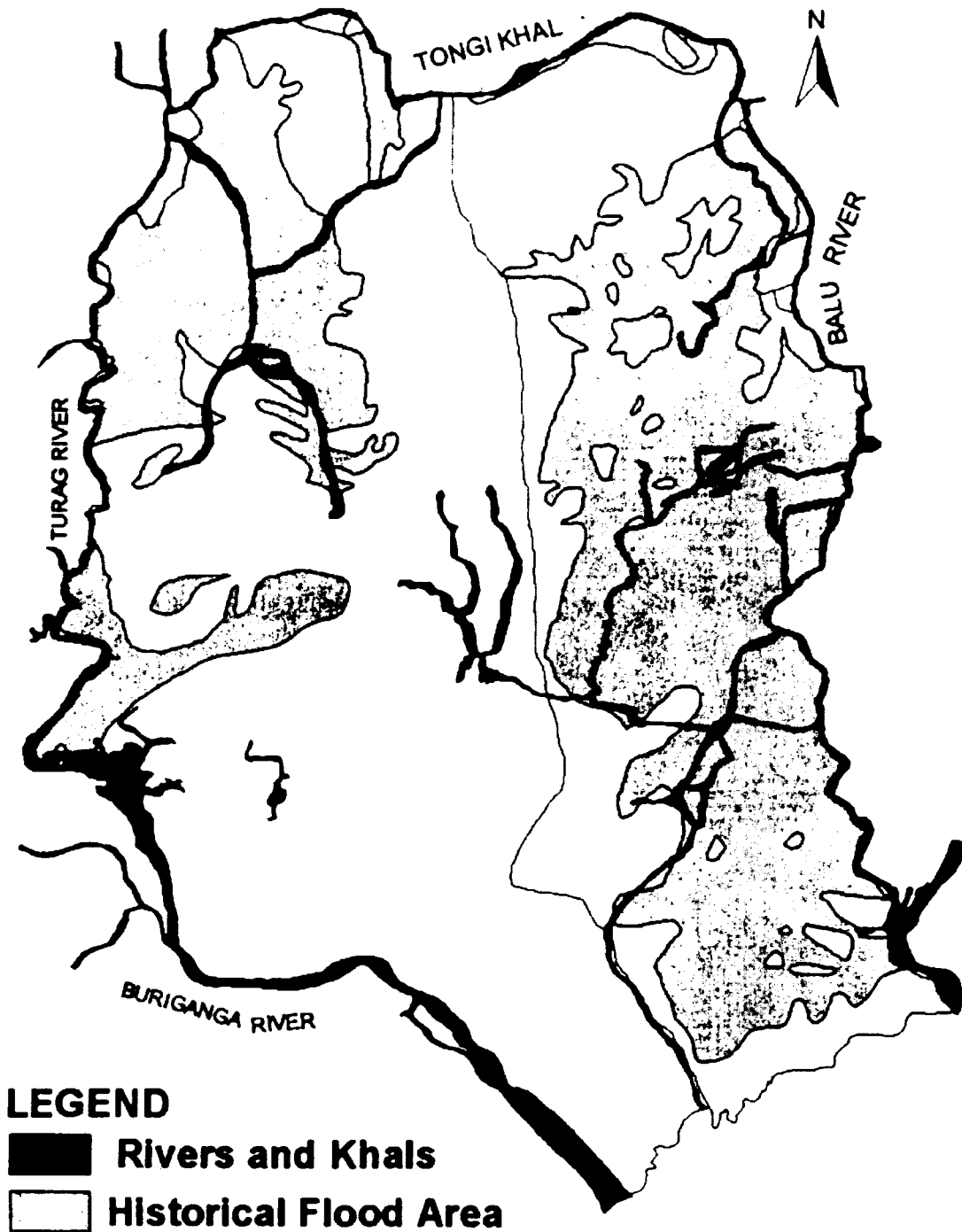
A vast literature search revealed that there are many causes affecting the occurrence of floods in Dhaka city of which three identified are very imperative. They are:

### A. Urban Development and Population Growth

In order to understand the issues of flood disaster management in Dhaka city, it is necessary to know the process of urbanization in Dhaka city. Dhaka city has been expanding rapidly since the independence of 1971. The growth of Dhaka city in 1950s could well be treated as slow and gradual, in the 1960s the pace picked up and onward 1971, the process of urban growth is phenomenal (Chowdhury and Faruqui, 1991). The rate of urban expansion in Dhaka city is the higher in Bangladesh due to massive rural-urban migration (Islam, 1996). Population of Dhaka city has increased about 10 times (Table 1) and area has been expanded about 4 times since all economic activities are being centered at the capital city.

### B. Encroachment of Lowlands

In recent times, rapid urbanization is mainly taken place in lowlands in the city which serve as retention pond during flooding season. A recent study (Kamal and Midorikawa, 2003) shows that out of 194 km<sup>2</sup> low-lying areas in Dhaka city 79 km<sup>2</sup> experienced urbanization with different fill thickness. The study shows that the low-lying geomorphic units within the higher landmass such as Pleistocene terrace and gently sloping erosional terrace edge have been subjected to significant amount of fill based urbanization. It implies that the filling process advancing towards the lowest elevated geomorphic units stretched from the fringes of higher landmass, for instance, deep alluvial valley and deep marshy land (Kamal and Midorikawa, 2003).



**Fig. 1** Historical Flooding in Dhaka City before 1988.

**Table 1** Population Growth in Dhaka City

Year	Population (m)	Growth rate (%)	Remarks
1951	0.36	1.28	Census of Pakistan, 1954
1961	0.56	5.18	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	7.1	Census of Bangladesh, 1991
2001	9.92	6.0	Census of Bangladesh, 2000

Source: BBS, 2000

### C. Drainage Congestion

In the monsoon season, Dhaka city has been facing a serious drainage congestion which is a contributing factor to flood problems in Dhaka city. Due to the filling of natural channels it becomes very difficult for the artificial system to carry out vast amount of flood waters in the monsoon. Literature suggests that only 185 km storm sewerage is available for flood flows in the city which is inadequate to bear flood waters from more than 300 km<sup>2</sup> area of the city (Shams, 1999).

## 5 FLOODS OF 1988 AND 1998: AN ASSESSMENT

### i. Water Level

As mentioned earlier, Dhaka city is bordered by the four major rivers along with numerous *khals* (ephemeral water bodies) and canals. The rise of water levels of these rivers has significant impact on flooding to be worsening in Dhaka city. Here, a comparison of individual river water levels for the 1998 and 1988 event have been made to understand river flood hydrology in the city.

#### a. The Buriganga at Millbarak (St. ID 42)

The Buriganga is a distributory of the Dhaleshawri river. The rise of water level in the Buriganga has a significant impact on flooding in the western part of the city. The 1998 and 1988 flood hydrograph of this river demonstrated that the former one has peaked very early than the latter one. In 1998, the flood level crossed its danger level on 25th of July and remained until 19th of September while the 1988 record shows that flood level peaked on 28th August and remained until 19th September (Fig. 2). The water level remained over danger level for 56 days in 1998 whereas in 1988 it was only 22 days.

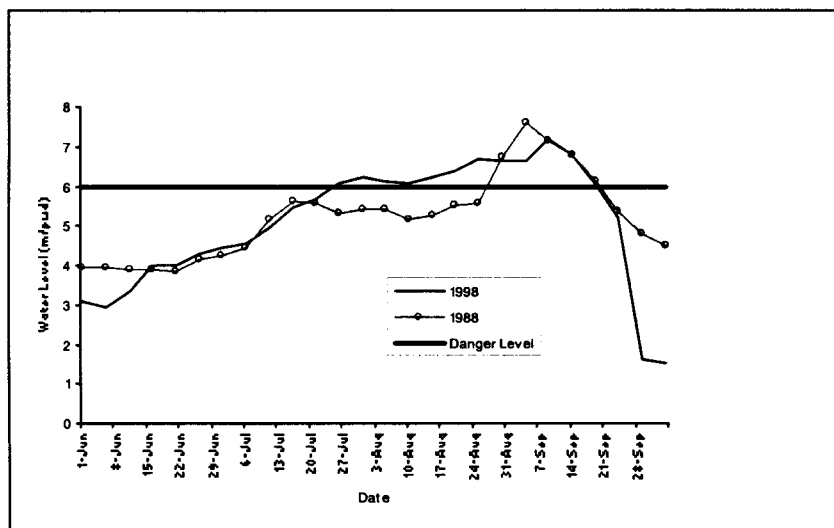


Fig 2 Hydrographs of the Buriganga River at Millabark gauge station.

#### b. The Balu River at Demra (St. ID 7.5).

The water of this river played a vital role for the flood situation to be worsening in those two deluges in Dhaka city. Statistics on water level of this river for those two events revealed that the 1998 flood level peaked on 8th July and went down on 2nd October while in 1988 it crossed its danger point on 8th July and remained until 1st October (Fig. 3). Interestingly, peak flooding of this river was at the same day for both cases. It is necessary to note here that flooding in this river has had a significant impact on flooding in Dhaka city since eastern part of the city is yet to be brought under flood protection measure.

#### c. The Turag at Mirpur (St. ID 302)

Comparison of those events hydrograph for Turag river suggests that the flood water in 1998 started to rise from the second week of July and reached its peak level on 27th August (7.39 m/pwd) and stayed over danger point until 24th September (Fig. 4). In 1988, water level crossed the corresponding danger point on 27th August and started to fall in the 3rd week of September. Duration of flood level over danger point indicates that in 1998 it was for 68 days whereas in 1988 duration was only for 26 days.

#### d. The Tongi Khal at Tongi (St. ID 229)

The water level of this river has a little impact on flood situation of Dhaka city as a whole however, for local level flooding in the northern part of the city it has major role to play. In 1998 event, the flood level started to rise in the second week of July and flood water started to recede on the third week of September (Fig. 5).

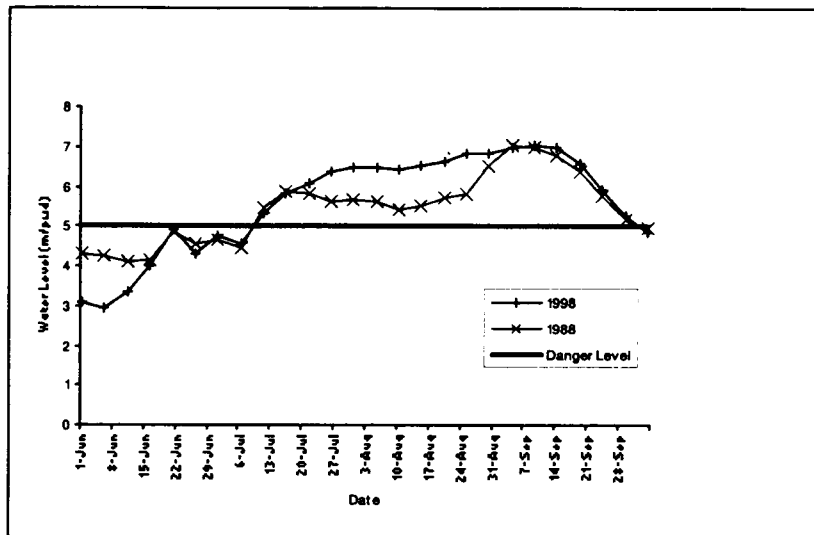


Fig. 3 Hydrographs of the Balu River at Demra gauge station.

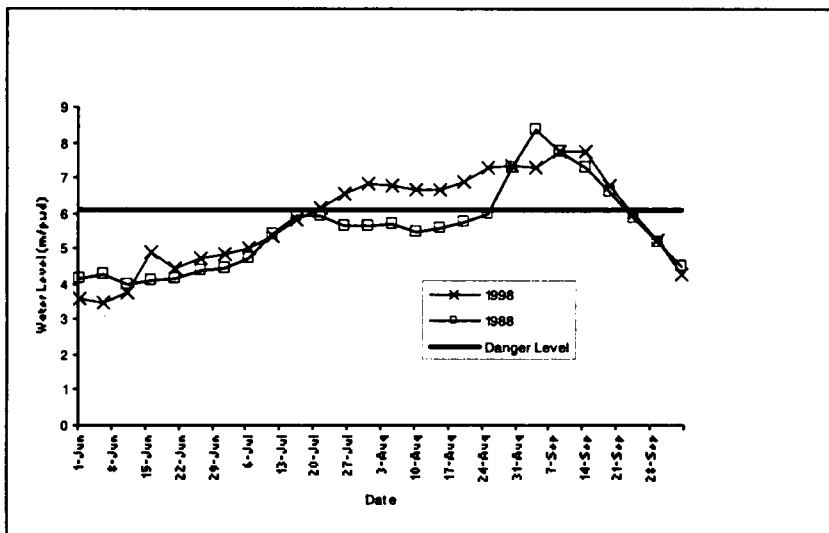


Fig. 4 Hydrographs of the Turag at Mirpur gauge station.

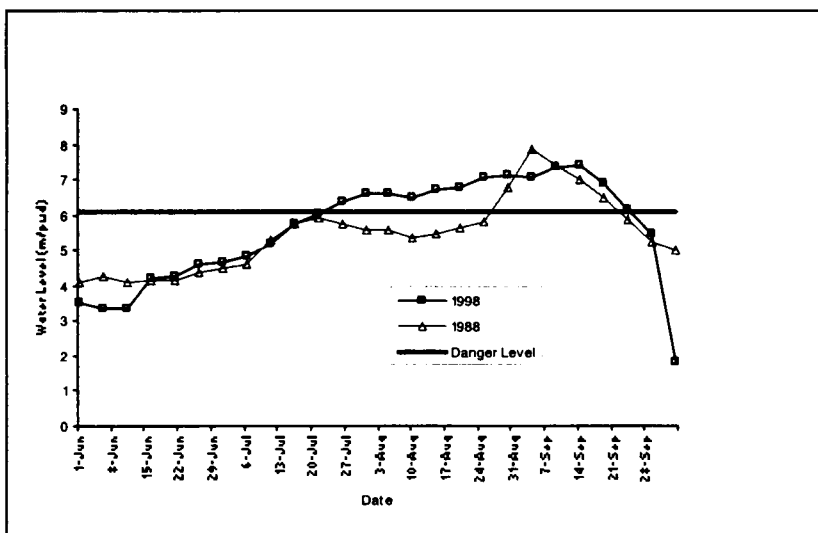


Fig. 5 Hydrographs of the Tongi Khal at Tongi gauge station.

Duration above danger level was for 64 days in 1998 while in 1988 it was only for 25 days.

Analysis of river hydrographs indicate that the 1998 event peaked very early than that of the 1988 event. On the other hand, duration of days above danger level of the water level was also higher than the 1988 event. It is found that, water level of all the rivers around the city started to rise in the third week of July in 1998 and remained until the last week of September. Thus, the 1998 event was prolonged for more than two months making it the longest flood in memorable time. It is believed that the 1988 flood was become severe due to excessive transboundary inflow and lack of flood protection in the city (Faisal et. al., 2003) while the 1998 event became severe due to hydraulic leakage as well as huge monsoonal rainfall. In addition to that, drainage congestion, inadequate pumping, lack of institutional coordination are auxiliary factors that made the flood situation critical (IFCDR, 1998). Since big lakes of northern parts of the city are hydraulically connected to the lowlands therefore, leakage of waters in this area causing floods. Recession of flood waters during 1998 was also delayed due to the back water effect of downstream rivers (IFCDR, 1998).

#### *ii. Rainfall*

Excessive rainfall is reported in Dhaka city during 1998 flood. Monthly rainfall records show that the amount of precipitation during July, August, and September were considerably higher than average rainfall. For example, the rainfall was 43 percent higher in July compare to its normal and in August it was 67 percent higher. Thus, the runoff generated by rainfall could not flow to the surrounding rivers since the river stage was also at peak. The accumulated runoff in low lying areas remained stagnant until river stage receded. During 1988 event, rainfall statistics shows that in June, rainfall was tremendously higher than that of 1998 June, conversely, for other three monsoon months it was terribly higher in 1998 event. For example, 552 mm rainfall was recorded for the month of August in 1998 which was 176 mm higher than normal rainfall, meanwhile in 1988 it was only 169 mm which was even less than the normal (Fig. 6).

#### *iii. Damage*

Although the 1998 flood was the worst in flood history in Dhaka city, however, handful damage reports are not available. It may be a cause that different organizations estimate damage from different points of view, therefore, estimation varies. Nonetheless, this paper is trying to provide a brief damage statistics of the 1998 and 1988 floods upon screening relevant literature. In general, most of the flood damage occurs in agricultural sector in Bangladesh, but in the case of Dhaka city, damage can be for infrastructures, human sufferings, and public facilities.

The hard hitting sector was housing in the 1998 event. According to a study, nearly 262000 houses of various types were damaged in Dhaka city during 1998 flood worth Taka 2.3 billion (Islam, 1998). It has been found that about 1000 km of various types of roads were damaged (Siddique and Chowdhury, 1998). Estimated loss of water supply and sanitation sector was \$10 million while massive damage on power sector has been reported (Faisal et. al., 1999). A total of 223 km of box culvert, open drain and storm sewer were reported to have silted up or damaged (Siddique and Chowdhury, 1998). In Dhaka City Corporation area (DCC), out of 90 wards, 71 were affected and the number of affected people was about 3.7 million in DCC area alone (Ali et. al., 2000). Conversely, available statistics of the 1988 event suggests that the death toll was recorded for 150 persons. At least 2.2 million people were affected. It is estimated that the number of institutions and houses affected in the 1988 flood was 14000 and 400000 respectively. Total damage was about 4 billion Taka for residential buildings while more than Tk. 400 million for institutional damage is reported (Nishat et. al., 2000).

## **6 FLOOD EXTENT DELINEATION USING DIGITAL ELEVATION MODEL (DEM)**

Digital elevation data are a set of elevation measurements for locations distributed over the surface (Arnoff, 1991). Several terms are interchangeably used for digital elevation data and its derivatives. For example, the term digital terrain model (DTM) is also commonly used and can incorporate landcover data with other landscape attributes (Burrouhg, 1986). In recent times, digital elevation data become very important data sources for geoscientists and has been intensively using in a wide range of topographic analysis, flood modeling and other natural hazard studies. However, in this study we have adopted Brouder (1994) method to delineate flood extent using DEM for the 1998 and 1988 flood events.

#### *a. Creation of Digital Elevation Model (DEM)*

A precise flood map for Dhaka city was not possible in the past due to the lack of proper digital elevation model (DEM). Since the study area is very flat in nature, therefore, a higher resolution DEM is necessary to facilitate inundation modeling in any area. In order to develop a digital elevation model for the study area, this paper uses existing Spot Elevation map (scale 1:20000) produced by the Survey of Bangladesh (SOB). In the beginning, individual spot height has been digitized into a geographic information system in vector format. Then using Triangular Irregular Network (TIN) module of Integrated Land and Water System 3.1 (ILWIS, 2002) software, data has been interpolated into 50 meter and a digital elevation model is constructed. The interpolation method that used is very simple and well known, moving average.

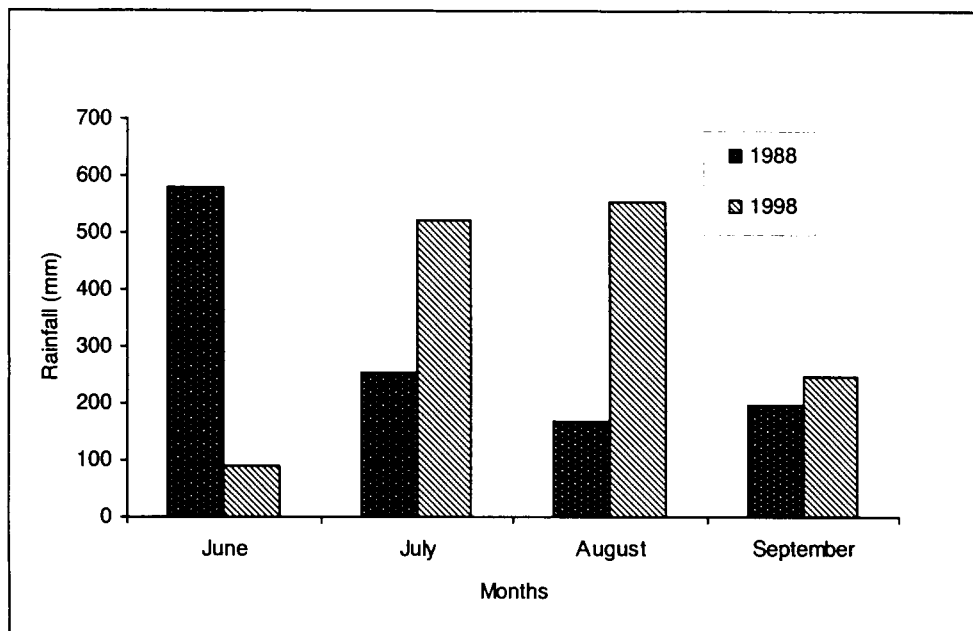


Fig. 6 Monthly total Rainfall in Dhaka city during 1998 and 1988 floods.

#### b. Creation of Flood Map using DEM

Using DEM, maps can be created showing the extent of the area that is inundated, provided that the DEM is accurate enough. In this case, we tried to map the extent of command areas of each river in the study area first. Secondly, we used peak and average flood height data of surrounding rivers of the study area in the 1998 and 1988 event. To get flood map for the study area, flood elevation is subtracted from the ground elevation data. Land level data for the area concerned has been extracted from DEM data. In order to develop flood inundation map/flood depth map for Dhaka city, first a starting cell was created corresponding to the location of rivers commanding area. Afterwards, an algorithm has been established in ILWIS software (ILWIS, 2002) to find all neighboring cells of the marked cell that have an elevation lower or equal to the specified flood level. This procedure was optimized using iteration propagation in combination with the neighborhood aggregation function. This process of iteration with propagation continues until no more cells were marked as flooded. It is necessary to note that during preparation of the flood depths maps/inundation maps, rainfall induced flooding and/or water logging inside the study area has not been considered. In addition, backwater effect from downstream rivers was also ignored. Flowchart of the creating of flood map is shown in Fig. 7.

#### c. Results of Flood Mapping using DEM

As this paper intends to develop flood maps for the study area for peak and average flood heights, therefore, four final flood depths/inundated maps has been produced for each land category and subsequently flooded areas were obtained in the city. Peak level flood inundated maps for the study area are developed and shown in Fig. 8 and Fig. 9 for the 1988 and 1998 floods

respectively. It can be mentioned here, during 1988 flood time, there was no flood protection in the study area, therefore, almost all part of the city was inundated, a small portion was remained flood free. Conversely, during the 1998 event, western part of the city was embanked and large portion was flood free compare to the unprotected part of eastern zone of the city. It may be mentioned here that although western portion was embanked and remained flood free from river waters, but the rainfall induced flooding was very severe. Moreover, existence of the embankment made storm water to recede at faster rate. Area analysis of the four inundated maps revealed that during the peak season for 1988 about 200 km<sup>2</sup> were inundated at different depths while in 1998 event, total inundated area was 145 km<sup>2</sup> during peak flooding condition. Average flood level of the surrounding rivers of the study area also shows the similar pattern of inundation. Literature search on this issue revealed that hydraulic leakage, lack of coordination among different flood management authority, shortage of pumping stations made the flood situation worst during 1998 flood in Dhaka city (Faisal et al., 1999). In this study, we realized that a higher resolution DEM would be good enough to facilitate flood mapping in a precise spatial extent. The DEM used in this study is not that higher resolution and it is not up-to-date data. In addition, internal drainage system of Dhaka city is not considered here while flood model has been developed. Moreover, the study area is a flat land which is a barrier to develop spatially precise estimation of flooding in Dhaka city.

## 7 FLOOD MANAGEMENT IN DHAKA CITY

Flood management system in Dhaka city has been developed rigorously right after the 1988 flood. However, historical flood management in and around the city shows that flood management approach has started in

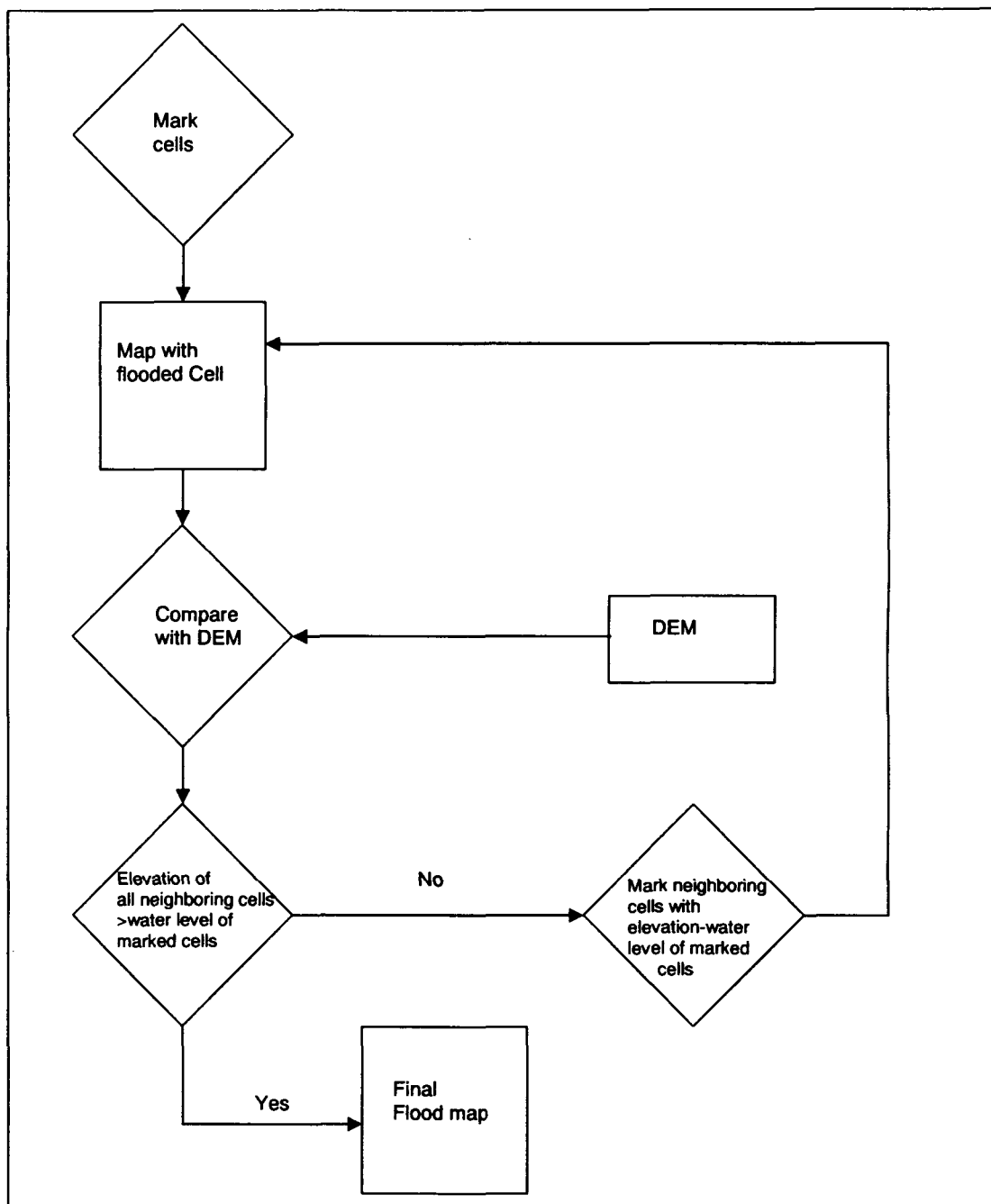


Fig 7 Flowchart showing developing Flood Map from DEM

1864, by constructing an embankment along the Buriganga River to protect the city from river induced flooding which is popularly known as Buckland Bund. The embankment was completed in 1880s (Mohit and Akhter, 2000). Afterwards, a number of studies were carried out to solve the perennial flood problem in Dhaka city under the auspices of different authorities and agencies. These studies are as follows:

1. Master Plan and Feasibility Report for Storm Drainage and Flood Control for Dhaka, 1968.
2. Bangladesh Water Development Board (BWDB) study on Dhaka City Drainage and Flood Control Project, 1975.
3. Dhaka Metropolitan Area Integrated Urban Development Project, 1981.

4. JICA Study on Storm Water Drainage System Improvement Project in Dhaka city, 1987.
5. Study on Dutch Expert T.G.H. Jensen, 1989.
6. Report on Flood Control and Drainage of Greater Dhaka, 1989.

The unprecedented flood of 1988 flood in the country in general and Dhaka city in particular, led to the adoption of several structural measures to mitigate flood problems. Subsequently, the Government of Bangladesh prepared an urgent flood protection and drainage plan, which included enclosing the greater Dhaka area with flood embankments, reinforced concrete walls, and drainage structures such as sluices and pumping stations. Table 2 shows the current status of flood management practices in Dhaka city. After the 1988 flood, Dhaka



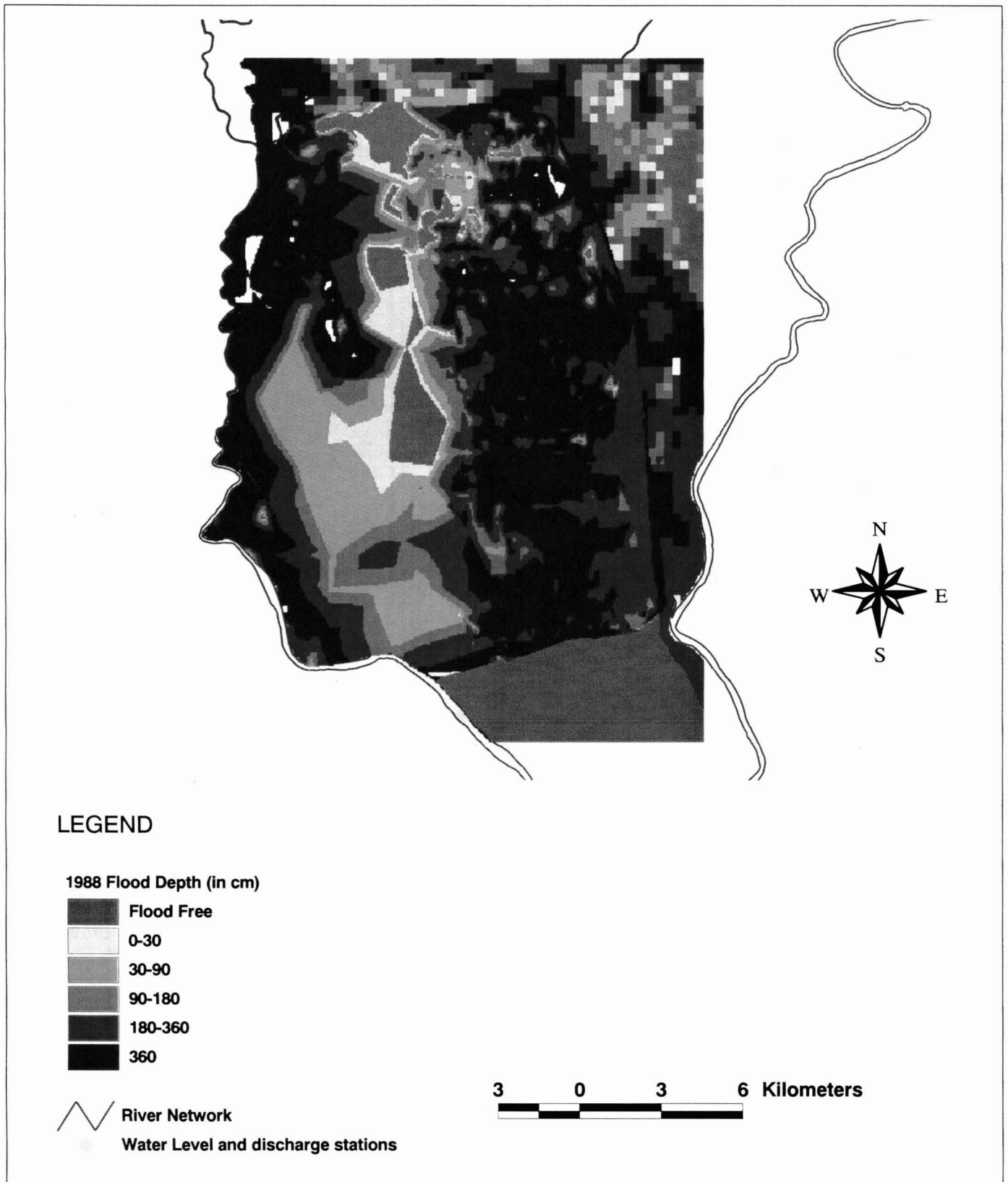


Fig. 8 DEM based Flood Extent Mapping in Dhaka City during 1988 Peak Flood Period (without embankment)

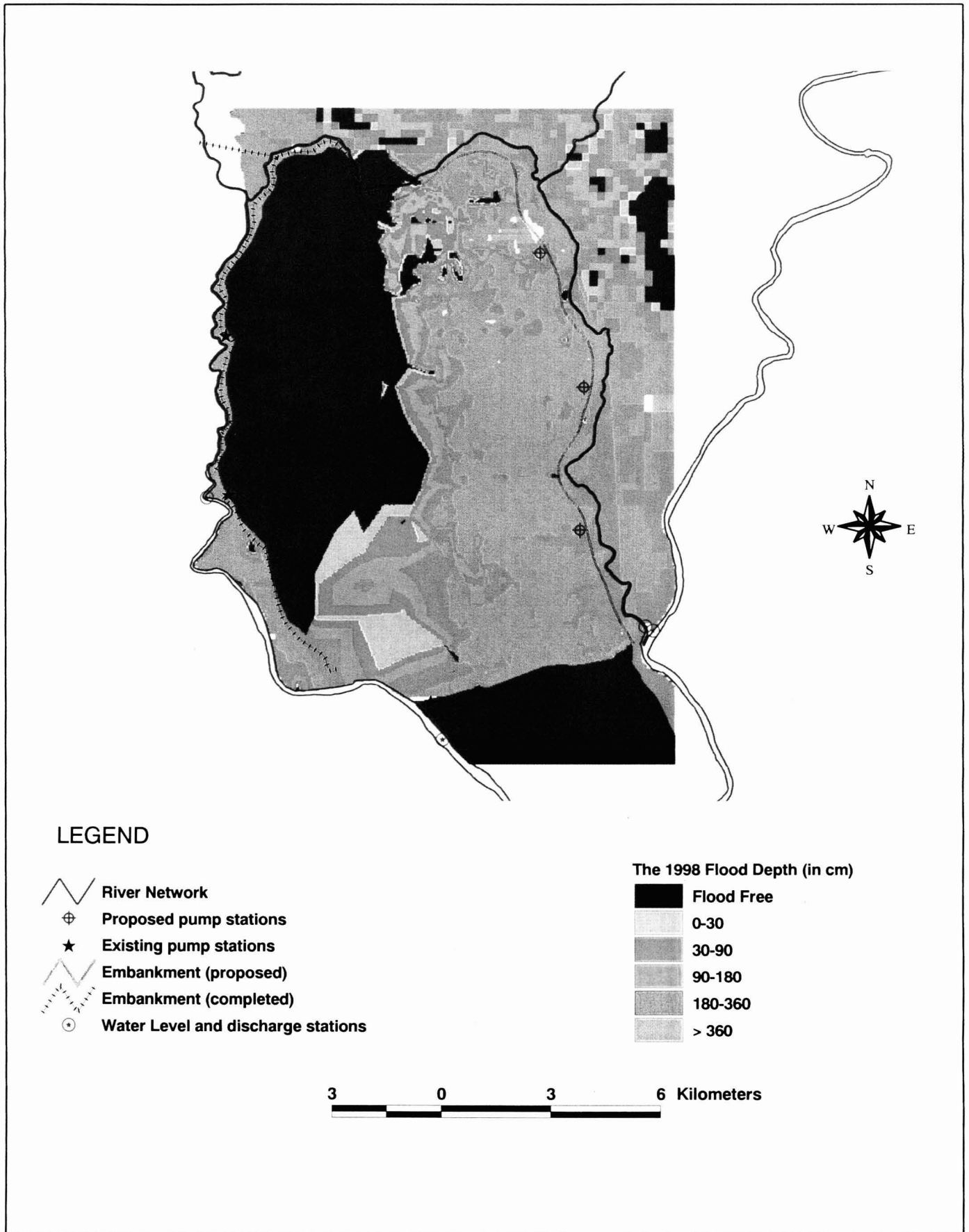


Fig. 9 DEM based Flood Extent Mapping in Dhaka City during 1998 Peak Flood Period (with embankment)

Integrated Flood Protection Project (DIFPP) has been started to work under the national program on Flood Action Plan (FAP). In this respect, western part of the city has been embanked with 31.67 km together with 6 sluice gates. The eastern part of city is yet to protect though a massive plan was taken under DIFPP. The phase-II is not implemented yet which resulted flood

problem worst in 1998 (Faisal et. al., 2003). At present, the government planning to use the eastern part flood protection project as multi-purpose road-railway embankment. Along with these structural measures for Dhaka city, non-structural measures were suggested in different study. Those can be found in Faisal et. al., (1999; 2003).

**Table 2** Current Status of Greater Dhaka Flood Control and Drainage Projects (Phase I and II)

Projects	Agency	Cost (m US \$)	Present Status
<b>Phase I</b>			
1. 17.62 embankment from Tongi railway bridge to Shirnir tek with 5 sluices gates	BWDB and BA	19.6	Completed
2. 2.27 km embankment & flood protection wall from shirnir tek to Mirpur bridge	DCC	2.4	Completed
3. 0.77 km road construction from Shirnir Tek to Mirpur Mazar	RAJUK	1.2	Completed
4. 25 km embankment from Mirpur Bridge to Satmasjid road	DCC	4.4	Completed
5. 5.76 km embankment from Satmasjid road to Keller morh	DCC	8.5	Partially
6. 7.20 km flood protection wall from Keller morh to Friendship bridge	DCC		ditto
7. 29.40 km flood protection wall around Dhaka-Narayangonj-Demra project	RHD	3.0	Completed
8. 1.40 km new road construction from Kamalapur to Saidabad bus terminal	RAJUK	2.7	Completed
9. 2.50 km road raising of Rampura road	DCC	0.6	Completed
10. 6.0 km road raising of Progoti Sarani road with temporary gates	RAJUK	1.1	Completed
11. 10.53 km of flood protection bund around Zia Int'l airport	CAAB	1.9	Completed
12. Cleaning of 13 canals of the city	DWASA	6.3	Completed
13. Repair and restoration of sewerage gates	DWASA	0.4	Completed
<b>Phase II</b>	-	37.0	Partially Completed
1. 30.0 km embankment-cum-road from DND to Tongi bridge			
2. 17.62 km road from Tongi Bridge to Shirnir tek	-	2.5	Not implemented
3. Installation of 5 pumping stations	-	141.6	2 completed, 3 ongoing
<b>Total Cost</b>		<b>141.6</b>	

Note: BA: Bangladesh Army; BWDB: Bangladesh Water Development Board; CAAB: Civil Aviation Authority; DCC: Dhaka City Corporation; DWASA: Dhaka Water and Sewerage Authority; RAJUK: Capital Development Authority; RHD: Road and Highway Department.

## 8 CONCLUSION

Floods of 1998 and 1988 were caused enormous damage to life, property and livelihoods in the city. It is evident from this study that the 1998 flood was prolonged than the 1988 event. And also the damage caused by the 1998 event was colossal. Although western part of the city has been brought under flood protection right after 1988 flood, the effectiveness of these measures became questionable during the 1998 flood. Therefore, a

combination of structural and non-structural measures can help ameliorate flood induced losses in Dhaka city. In addition, it is anticipated that the city's flood vulnerability will be aggravated due to climatic change. Therefore, flood magnitudes would be higher than 1998 and 1988 floods and frequency could have increased. Thus, it is imperative that a long-term flood mitigation and climate change adaptation strategy should be developed for the future management of floods in and around greater Dhaka city.

## REFERENCES

- Ali, M.A., Seraj, S.M. and Ahmed, S., (eds.), 2000. Engineering Concerns of Flood, Bangladesh University of Engineering and Technology, Dhaka, pp. 380.
- Aronoff, S., 1991. Geographic Information System: a management perspective, WDL publication, Ottawa, Canada.
- Bangladesh Bureau of Statistics, 2000. Population Census 2001: Preliminary Report, BBS, Ministry of Planning, Dhaka, pp. 36.
- Barnes, S.B., 1996. Northwest Flood '96: GIS in the face of disaster, *Geographic Information Systems*, 22-25.
- Baumann, P., 1999. Flood Analysis, <http://www.research.umbc.edu/~tbenjal/baumann/mod2.html>, 10 February, 1999.
- Brivio, P.A., Colombo, R., Maggi, M., and Tomasoni, R., 2002. Integration of Remote Sensing data and GIS for accurate mapping of flooded areas, *International Journal of Remote Sensing*, 33(3): 429-441.
- Brouder, J.A.M., 1994. Flood Study in the Meghna-Dhonagoda Polder, Bangladesh, <http://www.gisdevelopment.net/aars/acrs/994/ts3/ts3007pf.htm>
- Burrough, P.A., 1986. Principles of Geographical Information Systems for Land Resources Assessment, Monographs of Soils and resources survey no.12, Clarendon Press, Oxford, pp. 193.
- Chowdhury, A.M. and Faruqui, S., 1991. Physical Growth of Dhaka City, IN S. Ahmed (eds). Dhaka: Past Present and Future, The Asiatic Society of Bangladesh, Dhaka.
- Correia, F.N., Rego, F.C. Saraiva, M.D.S., and Ramos, I., 1998. Coupling GIS with hydrologic and hydraulic modeling, *Water Resources Management*, 12: 229-249.
- Disaster Management Bureau (DMB), 1998. Report on Bangladesh Flood, 1998: Chronology, Damages and Responses, DMB, Dhaka.
- Faisal, I.M., Kabir, M.R. and Nishat, A., 1999. Non-structural flood mitigation measures for Dhaka city, *Urban Water*, 1, 145-153.
- Faisal, I.M., Kabir, M.R. and Nishat, A., 2003. The disastrous flood of 1998 and long term mitigation strategies for Dhaka City, *Natural Hazards*, 28: 85-99.
- Flood Action Plan 8A, 1991. Master Plan Study for Greater Dhaka Protection Project, Japan International Cooperation Agency, Dhaka, Bangladesh, Supporting Report I, pp. A1-A7.
- Government of Bangladesh (GOB), 2000. Baseline Information Study of the Dhaka Combined Flood Control Cum Eastern Bypass Road Project, Final Report, pp. 106.
- Hunter, W.W., 1877. A statistical account of Bengal, Vol. V, Trubner and Co. London, p. 103.
- Institute of Flood Control and Drainage Research (IFCDR), (1998): Impact of 1998 Flood on Dhaka City and Performance of Flood Control Works, Dhaka, pp. 76.
- Institute of Flood Control and Drainage Research (IFCDR), 1998. Impact of 1998 Flood on Dhaka City and Performance of Flood Control Works, Dhaka, pp. 76.
- Integrated Land and Water Information System (ILWIS), 2002. Version 3.1, ITC, The Netherlands.
- Islam, Md. Monirul and Sado, K., 2000. Development of Flood Hazard Maps of Bangladesh using NOAA-AVHRR images with GIS, *Hydrological Sciences*, 45(3): 337-355.
- Islam, N., 1996. The State of the Urban Environment in Bangladesh IN Islam, N. and R.M. Ahsan (eds.) Urban Bangladesh: Geographical Studies, Department of Geography, University of Dhaka. pp. 21-31.
- Islam, N., 1998. Flood '98 and the future of urban settlements in Bangladesh, *CUS Bulletin 35*, July-December, p. 3.
- Kamal, A.S.M. Maksud and S. Midorikawa, 2003. GIS-based landfill aping of Dhaka city area, Bangladesh, using Remote Sensing Data, Proceedings of the second International Symposium on New Technologies for Urban Safety of Mega For Cities in Asia, pp. 457-466.
- Leenaers, H. and J.P. Okx, 1989. The use of digital elevation models for flood hazard mapping, *Earth Surface Processes and Landforms*, 14: 631-40.
- Mohit, M.A. and Akther, S., 2000. Delineation of Flood Dmaaged Zones of Dhaka City based on the 1998 Flood by using GIS, IN M.A. Ali, S.M. Seraj and S. Ahmed (eds.) Engineering Concerns of Flood, Bangladesh University of Engineering and Technology, Dhaka, pp. 303-318.
- Nishat, A., Reazuddin, R., Amin, R. and Khan, A.R., 2000. The 1998 Flood: Impact of Environment of Dhaka City, Department of Environment, Dhaka, pp. 253.
- O'Donenell, M.R., Bacos, D and M. Bennish, 2002. Nutritional response to the 1998 Bangladesh Flood Disaster: Sphere Minimum Standards in Disaster response, *Disasters*, 26: 229-241.
- Paul, B.K., 1997. Flood Research in Bangladesh in retrospect and prospect: a review, *Geoforum*, 28: 121-31.
- Rasid, H. and Azim U. Mallik, 1993. Poldering vs Compartmentalization: The choice of Flood Control Techniques in Bangladesh, *Environmental Management*, 17, (1): 59-71.
- Rasid, H., 1993. Preventing Flooding or Regulating Flood Levels?: Case Studies on perception of flood alleviation in Bangladesh, *Natural Hazards*, 8: 39-57.
- Rizvi, S.N.H., 1969. East Pakistan District Gazetteers-Dacca, East Pakistan Government Press, Dacca, pp. 33-34.
- Shams, Nur A., 1999. Urban Geology of Dhaka City for Geohazard Mitiation and Development Planning, unpublished Masters Thesis, Department of Geology, University of Dhaka, pp. 90.
- Siddique, Q. I. and Chowdhury, M. H.: 1998. Flood-98: Losses and Damages, National Seminar on Flood '98 and Management of Floods in Future (December 8, 1998), Jointly organized by National Committee for Relief and Rehabilitation and Dhaka University, Dhaka.
- Smith, L., 1997. Satellite Remote Sensing of River Inundation Area, Stage, and Discharge: A Review, *Hydrological Processes*, 11: 127-1439.
- Townsend, P. A., 2001. Mapping Seasonal Flooding in Forested Wetlands using Multi-Temporal RADARSAT SAR, *Photogrammetric Engineering & Remote Sensing*, 67(7): 857-864.
- Wang, Y., Colby, J.D. and Mulcahy, K.A., 2002. An efficient method for mapping flood extent in a coastal floodplain using Landsat TM and DEM data, *International Journal of Remote Sensing*, 23(18): 1681-3696.