Water Resour Manage (2007) 21:1601–1612
DOI 10.1007/s11269-006-9116-1

Evaluating Flood Hazard for Land-Use Planning in Greater Dhaka of Bangladesh Using Remote Sensing and GIS Techniques

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Received: 3 February 2006 / Accepted: 13 October 2006 / Published online: 8 November 2006

Abstract Floods are a common feature in rapidly urbanizing Dhaka and its adjoining areas. Though Greater Dhaka experiences flood almost in every year, flood management policies are mostly based on structural options including flood walls, dykes, embankments etc. Many shortcomings of the existing flood management systems are reported in numerous literatures. The objective of this paper is to assess flood hazard in Greater Dhaka for the historical flood event of 1998 using Synthetic Aperture Radar (SAR) data with GIS data. Flood-affected frequency and flood depth calculated from the multi-date SAR imageries were used as hydrologic parameters. Elevation heights, land cover classification, geomorphic division and drainage network data generated from optical remote sensing and analogue maps were used through GIS approach. Using a ranking matrix in three dimensional multiplication mode, flood hazard was assessed. All possible combination of flood hazard maps was prepared using land-cover, geomorphology and elevation heights for flood-affected frequency and floodwater depth. Using two hazard maps which produced the highest congruence for flood frequency and flood depth, a new flood hazard map was developed by considering the interactive effect of flood-affected frequency and floodwater depth, simultaneously. This new hazard map can provide more safety for flood counter-measures because pixels belonging to higher hazard degrees were increased due to the

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consideration of higher degrees of ranks. The estimation of flood hazard areas revealed that a major portion of Greater Dhaka comprised moderate to very high hazard zone. Only a little portion (8.04%) was found to be the least vulnerable to potential flood hazard. Conversely, 28.70% of Greater Dhaka was found within very high hazard zone. Based on this study, comprehensive flood hazard management strategies for land use planning decision were proposed for the efficient management of future flood disasters.

Key words greater Dhaka · GIS · flood hazard · SAR · flood frequency · floodwater depth

1 Introduction

During the last two decades, Remote Sensing (RS) has been played an important role in the fields of hydrology and water resources management (Bastiaansen 1998). Geographic Information System (GIS) on the other hand has also been used extensively to model surface water, particularly flood and associated damage (Boyle et al. 1998; Green and Cruise 1995; Werner 2001). Recently, the integration capabilities of satellite data with GIS have opened up opportunities for quantitative analysis of hydrological events, such as flood, at all geographic and spatial scales. Remote sensing application is however, considered imperative for third world countries because it is difficult for government to update their database frequently with the ground observation techniques because of time and cost associated with traditional methods (Dong et al. 1997). The potential of this facility for improving hazard evaluation and risk reduction is continually being explored (Carrara and Guzzetti 1993).

Floods are a regular feature in Greater Dhaka, the capital of Bangladesh during the monsoon season. Dhaka has experienced many disastrous floods in the past of which the 1998 flood is said to be the worst in memorable records (Faisal et al. 1999; Dewan et al. 2004). The 1998 flood resulted in severe damage and untold sufferings to the inhabitants of Dhaka and adjoining areas. For example, damage on water supply and sanitation sector alone caused massive monetary loss worth US $ 10 million (Institute of Flood Control and Drainage Research (IFCDR) 1998). Furthermore, 262,000 houses were fully or partially collapsed (Islam 1998) and 3.7 million people were directly affected by the 1998 flood (Jahan 2000). Though various measures including flood walls, embankments have been constructed, the loss of properties and causalities are on the rise (Mohit and Akhter 2000). Available data suggests that the Bangladesh government, in association with international agencies, have spent 141.6 million US $ on flood control measures to solve the perennial flood problem in Dhaka, but the annual flood damage and flood affected areas increased considerably (Mohit and Akhter 2000). For example, a total of 4.55 million people were affected by the 1998 flood (Hye 2000) and most of the part of Greater Dhaka was under water of various depths for more than 8 weeks (Jahan 2000). It is necessary to mention here that the construction of embankments fosters to the encroachment of floodplains in Dhaka (Chowdhury et al. 1998). In addition, Rasid and Mallik (1996) identified several environmental problems linked with the embankment in Dhaka.

Even though the occurrences of floods cannot be prevented, the negative consequences can be lessened by an integrated approach to disaster management. Disaster management includes four elements such as mitigation, preparedness, response and recovery (Quarantelli 1991). Literature suggests that flood control works and post disaster recovery are the primary approaches for flood management in Greater Dhaka. It has become apparent in

1998 that such an approach is inadequate to combat recurrent flood problems. It is also clear that the growing flood hazards of Dhaka have not been analyzed for purposes of disaster mitigation (Mitchell 1999). As Dhaka contributes 16.7% of GDP to the national development (Bangladesh Bureau of Statistics (BBS) 1998), the potential loss of GDP due to flood is very high. Experts fear that the flood vulnerability of Dhaka is likely to exacerbate in the effect of the probable climatic change. Thus, following the 1998 devastation flood monitoring, hazard assessment and disaster relief have been identified to be the major issues by the water experts, urban planners and key policy makers of the country. They have called for the accurate mapping of flood prone areas (Islam 1998), assessment of flood hazard (Nishat 1998) and the development flood risk maps for land-use planning (Hossain 1998).

Considering the above fact, the objective of this article is to assess flood hazard in Greater Dhaka of Bangladesh for the historical flood event of 1998 using Synthetic Aperture Radar (SAR) data with GIS. A land-use planning decision for the mitigation of potential flood disaster is also put forward on the basis of this study.

2 The Study Area

The study area was the Greater Dhaka of Bangladesh (Figure 1). The latitudes and longitudes of the study area are 23°68′ N 90°33′ E and 23°90′ N, 90°50′ E, respectively. The study area is located mainly on an alluvial terrace, known as the Modhupur terrace of the Pleistocene period. Topographically, Dhaka is a flat land. The surface elevation of the area ranges between 1 and 14 m (Flood Action Plan (FAP) 8A 1991). It lies in the sub-tropical monsoon zone and experiences humid climatic conditions. The City experiences about 2000 mm annual rainfall, of which more than 80% occurs during the monsoon season. Historically, the city is endowed with rivers, numerous *khals* (ephemeral water bodies) and canals that drain water from the upper reaches during the monsoon season. As population increased, these areas have been encroached on, thus compounding flood problems. In the Figure 1, it is depicted that the urban areas in Greater Dhaka have increased in 1996 and 2000 over the year 1990.

3 Data Preparation

Six RADARSAT SAR (Synthetic Aperture Radar) (Narrow and Wide Beam mode) imageries were acquired that covered the entire flood season of 1998 (July–Sept). The selected SAR data were justified by analyzing the water level records of five monitoring stations in and around Greater Dhaka (Dewan et al. 2005). The SAR data were despeckled using the GAMA-MAP filter with 5×5 window sizes. After suppressing the speckle inherent to SAR images, geometric correction was carried out using a referenced Landsat TM image of 1999 covered the same area until the root mean square errors resulted in less than one pixel. A second order polynomial fit was applied and the pixel values were resampled. A pixel of SAR data covers 50 m for narrow and 100 m for wide beam mode in beneath. This is the ground resolution of the SAR data.

The major impediment to study flood hazard in the study area was the unavailability of GIS data in digital format. Therefore, in this study, a number of GIS layers were generated. A Digital elevation model (DEM) of Greater Dhaka area was obtained from the Institute of

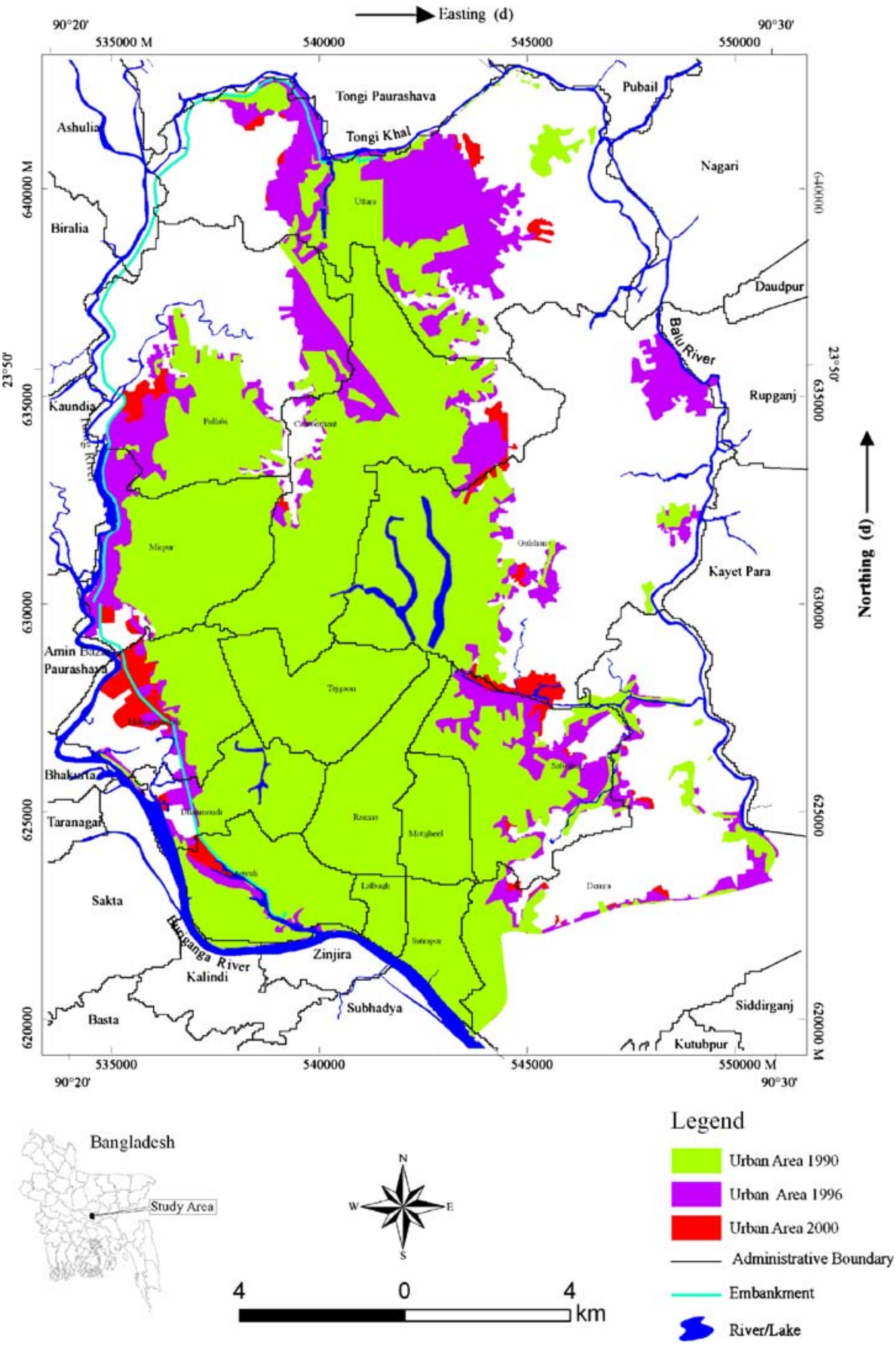

Figure 1 Extent of the study area.

Water Modeling, Bangladesh (IWM). Using the DEM, an elevation map was constructed. The elevation data were grouped into 14 categories, at 1 m intervals. The land-cover map was generated in a GIS platform, using one IRS-1D PAN data which was acquired during the dry season of 29 February 2000 (path 110 and row 055). Field data and the recent topographic map (scale 1:10,000) were aided to develop land-cover data. A geomorphic map was also developed by using a Landsat TM of 1999. Training areas were selected by on the TM Image by using the available analogue maps and field investigation. An administrative division map for Greater Dhaka was also digitized using the recent topographic map (scale 1:10,000). A total of 34 administrative boundaries were obtained in the study area. In addition, the drainage network of Greater Dhaka was generated from IRS-1D PAN data. Finally, all GIS data were integrated with geometrically corrected SAR data within a GIS approach. The Bangladesh Transverse Mercator System (BTM) was used as the coordinate system. Each of the GIS and SAR images produced 166,560 pixels in a common coordinate system and each pixel covered 50 m on the ground.

4 Analysis of Flood-Affected Frequency

The concept of flood-affected frequency (Islam and Sado 2000) was used to develop flood hazard maps. A flood frequency map based on flood duration was developed using the multi-date SAR imagery. The classified imageries obtained by the threshold algorithm (Dewan and Nishigaki 2004) were used to generate a flood frequency map. Total six available SAR images during the flood, which were acquired on July 7 and 31 1998; August 10 and 25 1998; and September 10 and 17 1998, were classified into water and non-water areas. Initially, the classified images of July 7 and 31 were combined to construct a single classified image of July; similarly two images of August and two images of September were combined to construct the single image for August and September, respectively. These combinations provided an opportunity to get a common boundary needed to develop a flood-affected frequency map. Finally, these three images were superimposed to characterize the inundated areas. The inundated area that appeared in all the images was considered the highly damaged area. The common inundated areas that appeared in two and one of the three images were deemed as medium damaged and low damaged areas, respectively. Non-inundated area in all the images was considered as non-damaged areas. Thus, four flood frequency categories were obtained, corresponding to damage rankings of class 4, class 3, class 2 and class 1 as high, medium, low and non-damaged areas, respectively.

5 Analysis of Floodwater Depth

Multi-temporal SAR imageries were also used to estimate the floodwater depth. It is very difficult to obtain flood-depth information from SAR data. However, in this study we used the technique suggested by Islam and Sado (2000), to estimate floodwater depth from SAR images. First, a land level map of Greater Dhaka was extracted from the DEM that consist four height classes. This land level map was used to collect representative ground truth data for each unit. Using a Global Positioning System (GPS), a total of 100 signatures (25 for each category) were collected and plotted on the land level map. Thus, a ground truth map was created and subsequently brought into GIS. These signatures were then used to extract training pixels. To do so, 7 July, 25 August and 10 September 1998 images were considered that comprised early to peak flooding of 1998. Signatures were collected by superimposing the ground truth map and a digital elevation model on each SAR image. In addition, visual interpretation and grey level differences of digital number (DN) values were also helpful to determine the selection of training pixels. A minimum distances algorithm of supervised classification was then applied to classify SAR data into four flood depth categories, i.e., deep, medium, shallow and no-flooding. If deep floodwater depth observed in a single image then it was regarded as deep depth, and if medium depth appeared in any single image for the area but that was represented as shallow depth area by other two images, then it was considered as medium depth. After the classification of deep and medium, the remaining inundated pixels were considered as shallow depth. Non-inundated areas were considered as no-flooding areas. Thus, four flood depth categories were obtained, corresponding to depth rankings of class 1, class 2, class 3 and class 4 as no-flooding, shallow, medium and deep depth, respectively. It is necessary to mention here that the DEM was not considered for the estimation of flood depth because of its coarse spatial resolution (300 m). However, to derive flood depth, we checked and used benchmark points to get training areas from the DEM and field data, which was eventually used to develop flood depth categories from SAR data.

In order to evaluate the classified results of floodwater depth, derived depth map was further authenticated by a flood depth map which was developed in Institute of Water Modeling (IWM) (2000) using a hydrodynamic model. A comparison was made to understand the agreement between two floodwater depth maps. It is found that deep flooded category, for instance, covered 20.95% area in the depth map produced by IWM, whilst the same category covered 21.21% area in the floodwater depth map developed in this study.

6 Flood Hazard Assessment

Even though satellite remote sensing has shown great potentiality for hazard assessment (McKean et al. 1991), the big challenge is the lack of generally accepted methods for producing hazard maps or even on the scope of producing such maps (Rhoads 1986). Moreover, many well developed methods usually applied in developed nations may not be accessible to developing country particularly in Bangladesh, due to the lack of digital data or restriction to access to data sources. For example, DEM based detail flood mapping is not possible for the entire Bangladesh since high resolution digital elevation data of the whole country or part of it, is not available. Therefore, a simple procedure is adopted in this paper for flood hazard assessment.

To assess flood hazard, a model was constructed in Model Maker utility of ERDAS IMAGINE (v. 8.6) software. In order to assess the flood hazard for each category of land cover, geomorphology and elevation units, a weighted score was estimated and hazard ranks were decided using the technique suggested by Rahman et al. (1991). Following steps were involved in the development of flood hazard maps. *Step 1:* Flood-affected frequency and floodwater depth maps were superimposed on thematic layers to estimate the percentage of area occupied by each category of flood-affected frequency and floodwater depth. We used land cover data with elevation height and geomorphic data to signify the different types of land covers. Because of the importance of the land use, value and the significance uses of different types of land cover are not same. Hydrological parameters like flood frequency and flood depth maps obtained from remote sensing data were superimposed onto the land cover, elevation height and geomorphologic maps to view the interactive effect between hydrological parameters and thematic information.

Step 2: A weighted score for the acquired area percentage for each category of land cover, elevation, and geomorphic unit was estimated using the following equation:

$$\text{Weighted Score} = \text{Class 1} \times 1.0 + \text{Class 2} \times 3.0 + \text{Class 3} \times 5.0 + \text{Class 4} \times 7.0 \quad (1)$$

Where, class 1 to class 4 represents the area percentage occupied by the categories of each hydraulic component i.e., flood-affected frequency and floodwater depth, for each ID category of the respective GIS component. The coefficients 1.0, 3.0, 5.0 and 7.0 in Eq. 1 were used to describe the weight for the flood loss. Calculated weighted score and their corresponding hazard ranks for each geomorphic category for flood-affected frequency is presented in Table I. *Step 3:* After calculating the weighted score, points for each category of land cover, elevation and geomorphology was estimated on the basis of a linear interpolation between 0 and 10, where 0 represents the lowest score and 10 represents the highest score. This represents the degree of flood hazard. *Step 4:* On the basis of the estimated points, hazard ranks were determined. In order to quantify flood hazard, three hazard ranks were established. For example, hazard ranks were fixed by assigning 1–3.5 for hazard rank 1, 3.5–6.5 for hazard rank 2 and 6.5–10.0 as hazard rank 3. The higher the ranking value, the more susceptible that particular class is considered to be to the occurrence of flood. *Step 5:* Using three dimensional multiplication mode suggested by Islam and Sado (2000), assessment of flood hazard was performed for flood-affected frequency and floodwater depth. The resulting flood hazard maps were further reclassified according to the intensity of hazards. Thus, five distinct hazard zones corresponded to least, less, moderate, high and very high were obtained. To illustrate flood hazard on the basis of mapping unit, three dimensional multiplication mode applied for three thematic maps.

Two hazard maps were developed for flood-affected frequency and floodwater depth by considering three dimensional multiplication mode. Although the two flood hazard maps showed only 34% congruence, these maps provide hazard information for flood frequency and floodwater depth, independently. They cannot represent higher hazard ranks for two hydraulic parameters at the same time. Moreover, these maps may not be perceptible to many people since they represent two hydrologic parameters. Therefore, a new hazard map was constructed using the interactive effect of flood-affected frequency and floodwater depth simultaneously, which can provide more safety for flood countermeasures because

Table I Flood hazard ranks for geomorphological division by flood-affected frequency (ID: geomorphic identification number; HR: hazard rank)

ID	Class 1	Class 2	Class 3	Class 4	Score	Point	HR 1–3
1	38.94	23.86	13.18	24.02	344.58	5.01	2
2	83.08	10.01	3.26	3.66	154.99	2.25	1
3	28.63	17.86	15.01	38.50	426.76	6.20	2
4	0.44	0.80	2.93	95.82	688.27	10.00	3
5	56.58	13.67	8.74	21.01	288.37	4.19	2
6	63.35	17.26	9.52	9.88	231.85	3.37	1
7	47.83	15.69	11.03	25.46	328.24	4.77	2
8	0.55	0.95	3.18	95.32	686.55	9.98	3
9	23.18	16.45	12.73	47.63	469.64	6.82	3
10	42.79	23.41	12.53	21.27	324.55	4.72	2
11	5.91	5.40	6.20	82.49	630.55	9.16	3
12	9.66	7.43	7.59	75.32	597.13	8.68	3
13	55.36	7.14	5.36	32.14	328.57	4.77	2

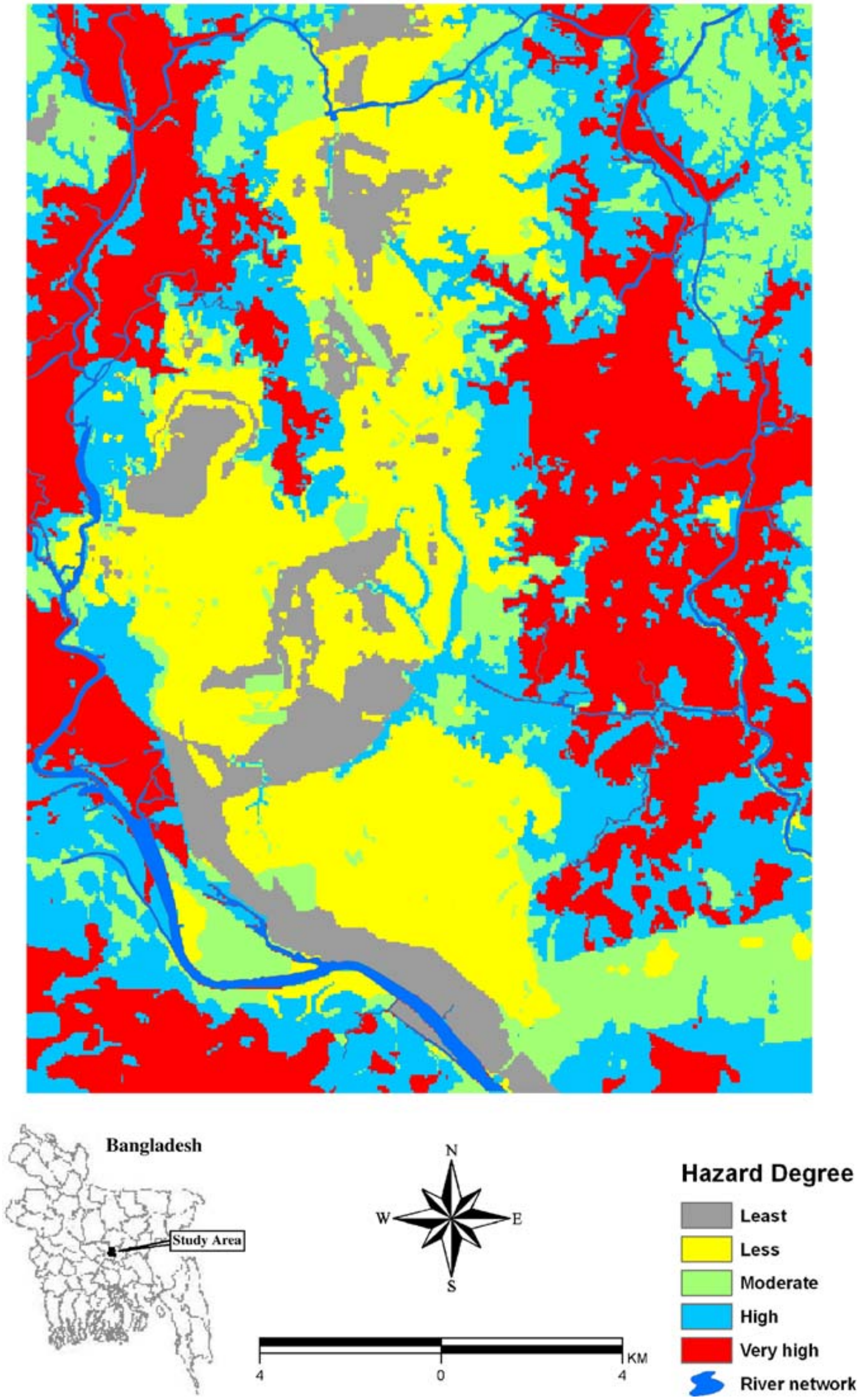

Figure 2 Flood hazard map developed using land-cover, elevation and geomorphic categories for flood-affected frequency and floodwater depth simultaneously.

the pixels belonging to higher ranks were increased due to the consideration of higher hazard degrees. If one hazard map shows the higher rank than the other for a pixel, then the higher rank was assigned for that pixel. The final hazard map is shown in Figure 2.

The hazard area estimation using the final flood hazard map developed by the interactive effect of flood frequency and floodwater depth concurrently revealed that only 8.04% areas were within the least hazard zone (Table II) that corresponded to the non-flooded areas in Greater Dhaka. Highly elevated lands (>13 m) of the study area represented the least hazard zone. Moderately high lands were within the group of less hazard zone and constituted 21.65%. These are the most extensively developed area in Greater Dhaka. Urban peripheral zones of Greater Dhaka were characterized by moderate hazard zone (15.05%). High hazard (26.56%) and very high hazards (28.70%) were assigned to cells where higher degrees of ranks observed. Extreme lowlands and areas adjacent to river banks are designated as very high hazard zone.

7 Disaster Management Policy for Land-Use Planning

The developed flood hazard map further can be incorporated to land-use planning decisions. This may help to reduce potential flood damage in Greater Dhaka. Micro scale flood management plan can be of little help in the effort of flood damage abatement. A comprehensive plan addressing flood hazard management is therefore, necessary. This plan should combine land use strategies for each zone with the careful consideration of certain structural controls. This can be achieved by the minimal disruption of natural environments. Table III presents an example of general management strategies based on this study and rigorous field investigation. These strategies could serve as basic components in a comprehensive flood management plan for Greater Dhaka.

Infilling of natural channels and lowlands is the primary cause for increasing flood hazard in Greater Dhaka. Therefore, preservation of natural channels and infiltration processes should be the top priority when formulating policy. It is postulated that during urban developments small channels are often viewed as being insignificant and are destroyed, but in reality they have very vital role in easing flood peaks (Dunne and Leopold 1978 cited in Rhoads 1986). Greater Dhaka is endowed with natural channels and canals that used to drain floodwater. Due to the increasing population pressure, those canals have lost their ability to drain floodwater during the monsoon. Therefore, further infilling of those channels must be prohibited and every effort should be made to prevent the destruction of any channel regardless of size. Human settlements should not be allowed in those areas comprised of high and very hazard zones. If necessary, structures must be flood

Table II Areas in Greater Dhaka with various degree of flood hazard

Hazard zone (s)	Area (ha)	Percentage (%)
Least	3348.50	8.04
Less	9013.75	21.65
Moderate	6266.75	15.05
High	11061.00	26.56
Very high	11950.00	28.70
Total	41640.00	100.00

Table III General flood hazard management strategies – Greater Dhaka of Bangladesh

General management strategies
Least hazard zone
(i) High development densities allowable provided that stormwater retention basins are adequately constructed. It also requires of their proper maintenance.
Less hazard zone
(i) Moderate development densities can be maintained.
(ii) Require structures should be put on higher places.
(iii) Should have separate drainages facilities wherever possible.
(iv) Existing natural channels should be kept for flood flow.
(v) Require proper maintenance and cleaning of storm water facilities on timely basis.
Moderate and high hazard zone
(i) Detail hydrologic analysis of flood characteristics must be performed prior to allocate for the new development.
(ii) Low development densities may be allowed on condition.
(iii) Structures must be flood-proofed.
(iv) Adequate drainage facilities of floodwaters must be secured.
(v) Require maintenance of drainage facilities, natural channels, canals and *khals*.
(vi) Detail flood zoning should be conducted and require to introduce proper land development rules.
(vii) Should have emergency evacuation facilities and adequate flood shelters.
(viii) Community based flood management program should be introduced.
Very high hazard zone
(i) Must be kept open for flood conveyance as permanent natural open space.
(ii) Any kind of developments must be prohibited.
(iii) Structures must not be allowed.
(iv) Require preservation of natural drainage systems, existing floodplains.

proofed and must be put in elevated places. Proper maintenance of the existing storm water facilities in the least and less hazard zones should be another priority.

8 Conclusions

In this paper, flood hazard assessment for the historical flood event of 1998 in Greater Dhaka of Bangladesh was examined using an integrated approach of GIS and remote sensing. The study demonstrated a simple and cost effective way to use geographical information system for creating flood hazard maps from the available dataset. Although it was very time consuming to derive the GIS database because of the size of the study area, GIS was invaluable in reducing the complexity associated with hazard assessment.

Flood hazard maps by considering the interactive effect of land cover, elevation, and geomorphic units for flood affected frequency and floodwater depth were constructed. The hazard maps showed that a major portion of Dhaka were within moderate to very high hazard zone, especially fringe areas. It is projected that these areas will be fully urbanized by the year 2010, therefore higher priorities must be paid for the development of apposite flood countermeasures for areas having higher hazard potential. Comprehensive land-use policies for flood disaster management have been proposed on the basis of this study. It is anticipated that proposed land-use policies can contribute to effective flood forecasting, relief and emergency management for future flood event.

As observed in Dhaka, increasing population pressure is forcing many people to enter the vacant land of the City by filling up of natural channels and floodplains. Consequently, flood risk is increasing. In order to ameliorate flood induced damage, the developed flood hazard map would be invaluable. Government can use hazard maps for ensuring the proper development planning of the very high and high hazard zones which is suppose to be urbanized by the year 2010. Urban planners can use this information to make environmentally sound land-use decisions. One more advantage is that the hazard maps can be quickly updated if modification, such as changes in land use, occurs subsequent to the original study. Furthermore, this type of study will provide information about flood protection measure such as construction and development of infrastructure and preparedness of aid and relief operation for high hazard areas for future flood event.

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