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Evaluating Flood Damage using GIS and RADARSAT data- A case of the 1998 Catastrophe in Greater Dhaka, Bangladesh

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The objective of this paper is to delineate flood prone areas and estimate damage in Greater Dhaka during the 1998 catastrophic flood using an integrated approach of GIS and remote sensing. Time series RADARSAT SAR data is acquired and used to demarcate flood boundaries for the 1998 flood event. This was accomplished by thresholding linear SAR imageries. Flood estimation demonstrated that flood areas steadily increased from early July 1998 and peaked on 25 August 1998 inundating 53 % lands due to heavy monsoonal downpour and discharge from upstream points. Different thematic layers were combined with a derived flood map in order to assess flood damage for the same event. Flood damage analysis revealed that substantial damage has occurred in Greater Dhaka during the 1998 flood.

Key words: *Synthetic Aperture Radar (SAR), flood delineation, 1998 flood, flood damage, Greater Dhaka*

1 INTRODUCTION

Delineation of precise flood prone areas is the first step to devise an efficient flood management system (Baumann, 1999). Flood damage assessment on the other hand provides ways to develop future alternative flood control policies (Boyle et al. 1998). At a flood prevention and impact assessment level, it is very important to know the damage areas within different land-cover types. A flood map is of little help unless it is combined with land use/cover information for flood damage assessment which in turn helps assess flood risk adequately (Consuegra et al. 1992). Historically, flood delineation and damage estimation is made using ground measurement technique which has many shortcomings (Smith, 1997). To surmount the problems associated with ground observations, data from earth observation satellites may provide an alternative method. This technique is especially useful for developing countries in development planning where aerial photograph is not readily available (Imhoff et al. 1987). However, operational problems are associated with each method. For instance, data from optical sensors may not be suitable for studying floods due to the presence of clouds or shadows. Microwave remote sensing provides a solution to these problems as it can image the earth at almost all weather conditions with their own source of illumination. The capability of remote sensing during rainy season has been greatly enhanced by the Canadian RADARSAT equipped with SAR (Synthetic Aperture Radar). SAR data is believed to be particularly useful in detecting flood boundaries in lowland environment where subtle topographic variation hinders flood delineation by digital elevation model (Townsend, 2001). Moreover, to develop comprehensive relief efforts during a catastrophe (Corbley, 1993), accurate information on flooding areas is indispensable which can merely be facilitated by SAR (Liu et al. 2002). Many successful applications of SAR revealed that it is a very promising technology for hydrologic assessment (Hess et al. 1990).

In the summer of 1998, there was a cataclysm over Dhaka, the capital of Bangladesh which caused severe damage and untold sufferings for the people. The long duration and extensive area of the flood are rare in its history (Faisal et al. 1999). Though flooding is an increasing problem in Dhaka, it is a neglected priority for urban planning. Available literature suggests that flood delineation and associated damage estimation in Dhaka is conducted using ground measurement techniques (Ali et al. 2000; Nishat et al. 2000). Besides, constructing embankment along riverbanks is the principal means to combat flood disaster. However, it has now been accepted by the hydrologic community that structural options are often counterproductive and that, it engenders a false sense of security (Green et al. 1991). Thus, following the 1998 catastrophic event, hydrologists and urban planners in the country have emphasized on developing a non-structural flood management systems. This can be accomplished by identifying exact flood prone areas (Islam, 1998) and consequent damage assessment (Boyle et al. 1998; Miranda et al. 1998).

In this paper, an attempt has been made to delineate flood boundaries in Greater Dhaka using microwave remote sensing data for the 1998 greatest flood which can portray the utmost inundation areas in a disastrous scenario. Flood damage is also evaluated according to different thematic layer using an integrated approach of GIS and remote sensing after estimating the flood areas.

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2 ENVIRONMENTAL SETTING OF THE STUDY AREA

The study area extend to $23^0 40'$ to $23^0 55'$ N latitude and $90^0 20'$ to $90^0 30'$ E longitude. There are four major rivers flowing over the study area, namely 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 is located mainly on an alluvial terrace, popularly known as the Modhupur terrace of Pleistocene period. Topographically, Dhaka is a relatively flat land, the surface elevation ranges between 1 and 14 meters (FAP 8A, 1991). It belongs to sub-tropical monsoon zone and experiences humid climate. About 2000 mm annual rainfall occurred here of which more than 80 percent takes place during monsoon.

3 DATA PREPARATION

In order to study spatially precise inundation mapping, the present paper employed eight RADARSAT ScanSAR (Narrow and Wide mode) images that comprise of entire flood season and a dry season image of 1998. Data preparation was facilitated by the data collected from the field. Site observations along with GPS reading were the principal means for field data collection. Land-cover, elevation units, geomorphic division, administrative division and drainage network data also prepared and brought within a GIS platform to facilitate integrated GIS and remote sensing approach for flood damage analysis.

Speckle is the result of the interaction between the radar pulse and the different scatterers of a distributed target. It has a great significance in SAR image interpretation, since it limits the radiometric resolution and therefore, the subsequent ability to discriminate between different intensity levels. In this study, Gamma-MAP filter with 5x5 windows was used to oppress speckle inherent to SAR image. The geocoding of the images was then performed using a Landsat TM geometrically corrected image as the reference image. A total of 75 ground control points (GCPs) (about 10-11 GCPs for each image) uniformly distributed over the area of interest were used for the image registration process. A second-order polynomial fit was applied and pixel values were resampled to 50m. The resulting root mean square error (RMSE) was less than one pixel. Remote sensing data was subsequently transformed to Bangladesh Transverse Mercator System (FAP 19, 1995) in order to integrate them with GIS database.

4 ANALYTICAL METHODS

a. Extraction of flood information

Generally, there is a clear distinction between water and non-water objects on SAR image. Water appears very dark tone in the radar image due to volume scattering while land areas appear as bright tone due to corner reflection. However, sometimes it becomes very difficult to get the clear boundary between flooded and non-flooded lands. To obtain flooded areas from multi-temporal SAR image, a simple threshold technique was adopted. The desire threshold value was obtained by determining corresponding pixel value to land and water. This was done by drawing few perpendicular lines from land to water and vice versa using the spatial profile tool of image analysis software. Hence, highest pixel values for water and non-water were acquired. In addition, image histogram and visual interpretation methods were used to decide empirical threshold values for each image. On the basis of above steps, a rule based approach (Wang et al. 2002) was utilized to extract flood coverage from linear SAR images which is as follows:

{DN<X then pixels represented "flood"}{DN>=X then pixels represented "non-flood/land"} where X represents provided threshold value.

In order to differentiate flooded and non-flooded areas in SAR data, different cut-off values were provided and tested. If a pixel's DN (digital number) value was satisfied then it was assigned to water category otherwise it would be assigned as a non-water category.

b. Determination of flooded areas

After extraction of water and non-water areas from individual image, every image was superimposed separately on a dry season classified SAR image to estimate net inundated areas in each date of the 1998 flood in Greater Dhaka. It is necessary to note here that the dry seasonal water bodies were discarded for flood area estimation, thus revealing only the inundated area. Flooded area percentage (%) for each flood time image was then obtained using the following equation:

$$\text{Inundation area percentage} = \frac{a}{a+b} \text{ x } 100 \quad \text{..............(1)}$$

Where, a= inundated area, b= land area during the flood.

c. Flood damage evaluation

In order to estimate the extent of flood damage in each thematic data, a model was constructed and considered in this study (**Fig. 1**). The model has two parts. In the first part, flood maps obtained by threshold method were combined to form monthly flood image, for example, two July images (7 & 31) were combined to get July image of 1998. Four flood season images (July, August, September and October) were obtained and further recoded into 1 for water and 2 for non-water. To estimate maximum water area, two categories of the four images, water and non-water, were combined first. Then, the combined flood time image was superimposed onto the two categories of dry season image. This was accomplished by using a conditional statement that comprises three conditions in order to identify land, flooded area and normal water flow. Water areas appearing in both images are deemed as normal water (lake, river, pond etc), non-water areas are considered being non-flooded areas and the areas representing water in the combined image but non-water areas in the dry season image are considered to be flooded areas. Thus, three classes raster file such as land, flooded and normal water is derived as output file. In the second part of the model, an overlaying function was used to estimate flood damage for land-cover, digital elevation, and administrative units for combined four images of flood season. Consequently, the extent of flood damage for each thematic layer was derived and presented here.

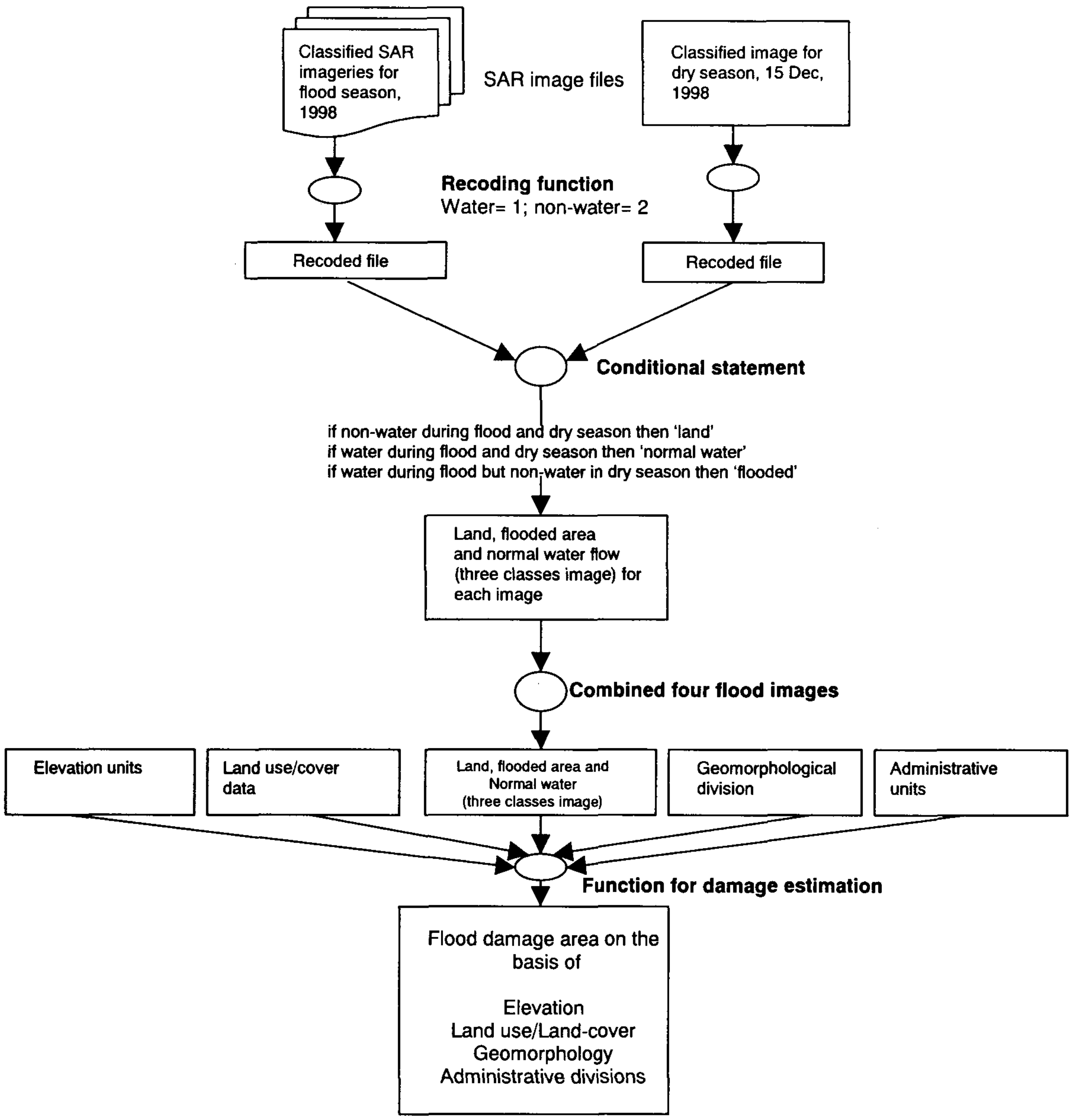

Fig. 1 Schematic concept for the model to evaluate flood damage.

5 RESULTS

Spatial distribution (**Fig. 2**) of flooding revealed that most of the eastern part of Dhaka was severely flooded for more than six weeks whereas the western part of the city, the magnitude of flooding was not as horrible as in the eastern flank. This is due to the existence of embankment that was constructed after the 1988 deluge and also this area is relatively higher than other parts.

The temporal dynamics of flooding in greater Dhaka is obtained by using the equation 1 and presented in **Table 1**. It is found that inundated areas of study site steadily increased from early July 1998 e.g. inundating 34.55% in 7 July 1998. With the increase of monsoonal downpour, flooding areas also increased to 53.00% in August 25 1998. Recession of floodwaters started in the last week of September followed by the lowering of rainfall and surrounding rivers water level. Three hypotheses can be made concerning the presence of water, either it rained again or more waters came down from the upstream and spread over already flooded zones, consequently enhanced the affected area or both phenomena occurred simultaneously. In order to ascertain our hypotheses, rainfall and water level data were analyzed. Rainfall records confirmed one of the hypotheses, which revealed that remarkable changes of rainfall in the month of August (367.8 mm higher than the normal) caused more areas to be inundated. Examination of surrounding rivers water level of study area confirmed that all of the rivers peaked very early and remained above the Danger Level (DL) for more than two months, which multifaceted flood problems in the 1998 deluge (Dewan et al. 2004; Faisal et al. 1999).

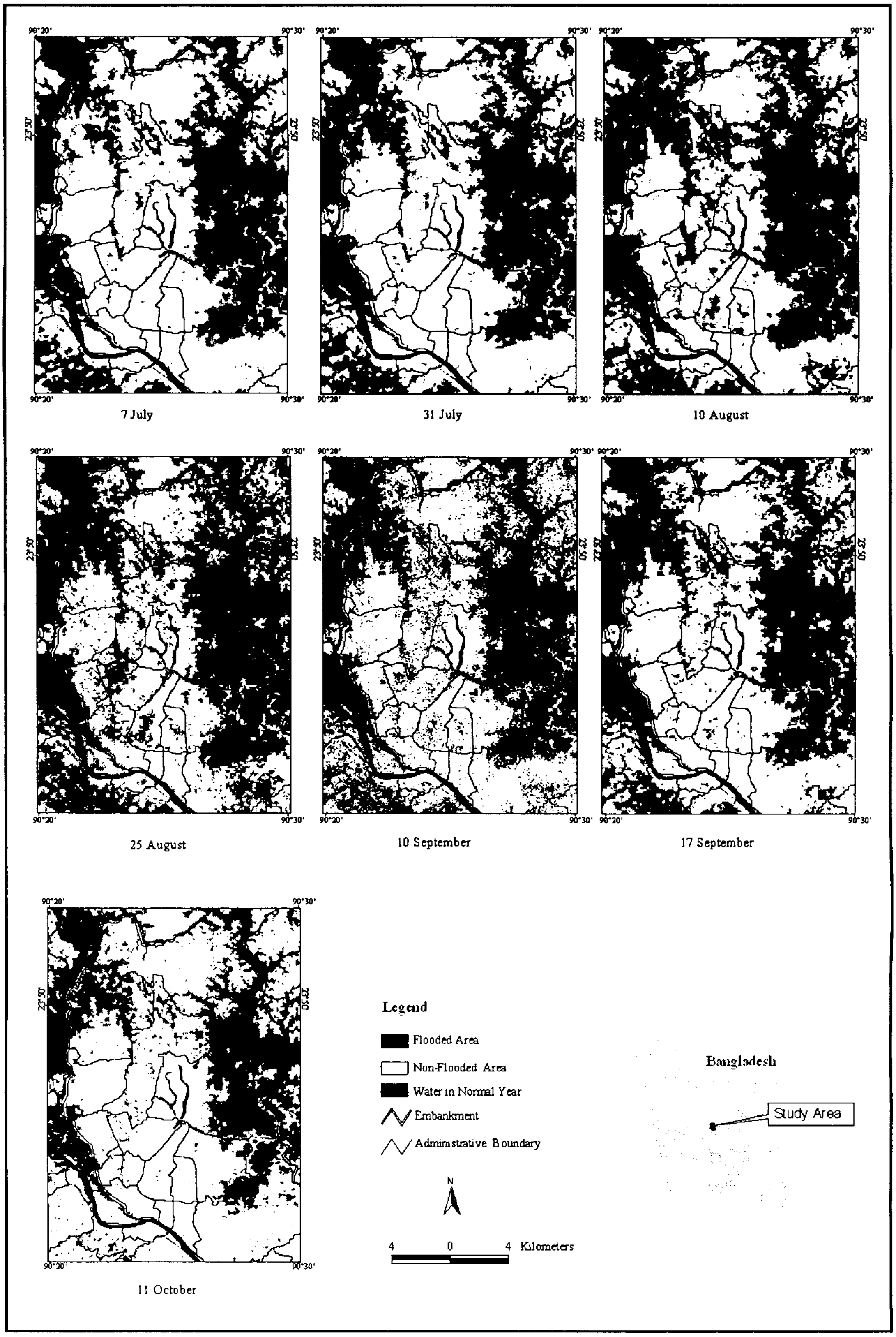

Fig. 2 Spatial distribution of floodwaters in 1998 flood in Greater Dhaka, Bangladesh.

Table 1 Flooded area percentage (%) derived from SAR.

Image date	Flooded area percentage (%)
07 July, 1998	34.55
31 July, 1998	34.01
10 August, 1998	43.83
25 August, 1998	53.00
10 September, 1998	43.54
17 September, 1998	43.16
11 October, 1998	28.17

Flood damage estimation on the basis of land-cover categories shows that floodplain of Greater Dhaka suffered rigorous flood damage followed by the intensely developed area (**Table 2**). As intensely developed areas are synthetic and very expensive, huge infrastructural damage occurred. In contrast, less intensely developed areas also suffered considerable damage which was mainly housing mostly made from straw/bamboo or adobe. Therefore, flood damage in this category badly impacted life of the poor people (Islam and Ali, 2000). A land-use/cover flooding map is prepared and shown in **Fig. 3** which illustrating inundation in each land cover categories during the 1998 event.

Table 2 Occupied area and flooded area (%) for each land-cover category.

Land-cover types	Occupied area (%)	Flooded area (%)
Intensely developed area	31.79	54.00
Industrial	1.37	1.16
Floodplain	29.91	122.65
Less intensely developed area	10.88	26.45
Cultivated land with scattered settlements	15.98	67.12
Dense vegetation	5.33	26.45
Recreational water bodies	1.08	2.91
Educational	0.77	1.84
Total	**100.00**	

Elevation data is overlaid onto the final flood map in order to figure out the damage in each elevation category. The result obtained here revealed that certain low-lying areas have had less damage compare to many elevated areas. The result demonstrated that except the extreme higher places, (e.g. above 1301 cm elevation category) all other elevation categories suffered variable flood damage (**Fig. 4**). Highest flood damage occurred in the elevation category of 301-400 (cm) followed by 201-300 (cm) elevation units. It is imperative to note that in 31 July 1998 flooded areas were slightly reduced from its earlier date (7 July 1998). This reduction was attributed to the drastic drop of rainfall in the study area. Thus many areas submerged in 7 July were regained from the ingress of flood water. Nevertheless, with the increase of rainfall and surrounding river waters more areas were submerged

Table 3 Occupied area and flooded area (%) for each administrative units (by Thana*).

ID #	Administrative Name	Occupied area (%)	Flooded area (%)
1	Pubail	0.97	1.36
2	Nagari	4.16	5.81
3	Tongi Pourshava	3.01	2.91
4	Ashulia	2.31	2.69
5	Uttra	11.86	12.62
6	Daudpur	0.19	0.31
7	Biralia	1.41	2.20
8	Pallabi	7.48	7.95
9	Cantonment	6.92	6.59
10	Rupgonj	1.37	2.28
11	Gulshan	12.83	14.53
12	Kaundia	1.31	1.89
13	Mirpur	3.71	1.46
14	Kayet	2.72	3.61
15	Aminbazar	0.84	0.91
16	Bhakurta	0.42	0.63
17	Demra	11.16	11.96
18	Mohammadpur	2.77	2.43
19	Tejgaon	2.31	1.45
20	Ramna	1.99	1.23
21	Taranagar	0.38	0.50
22	Sabujbagh	3.90	3.30
23	Dhanmondi	1.94	1.20
24	Motijheel	1.17	0.30
25	Sakta	2.98	3.66
26	Kotwali	2.30	1.36
27	Lalbagh	0.47	0.04
28	Sutrapur	1.03	0.05
29	Kalindi	1.74	1.69
30	Zinzira	0.86	0.22
31	Siddirgonj	0.47	0.24
32	Subadhya	1.58	1.18
33	Basta	1.14	1.23
34	Kutubpur	0.29	0.25
	Total	**100.00**	

* Thana is the third largest administrative unit in Bangladesh. Here, old Thana boundary is used.

from early August caused more damage. More than 72 percent damage has been occurred for the elevation category of 201-500 (cm). Revealing that flood in these units has serious impact on agricultural lands in the outskirts of urban Dhaka.

Flooded areas in each category of geomorphic units revealed that young floodplain is the most vulnerable to floods in terms of the occurrence of floods of the 1998 event. In contrast, highly populace areas such as higher Pleistocene Terraces (59.08%) were found to be highly affected by the 1998 flood. In other word, this category occupies only 25.29 percent of total land but the flood affected area percentage is obtained as 59.08%

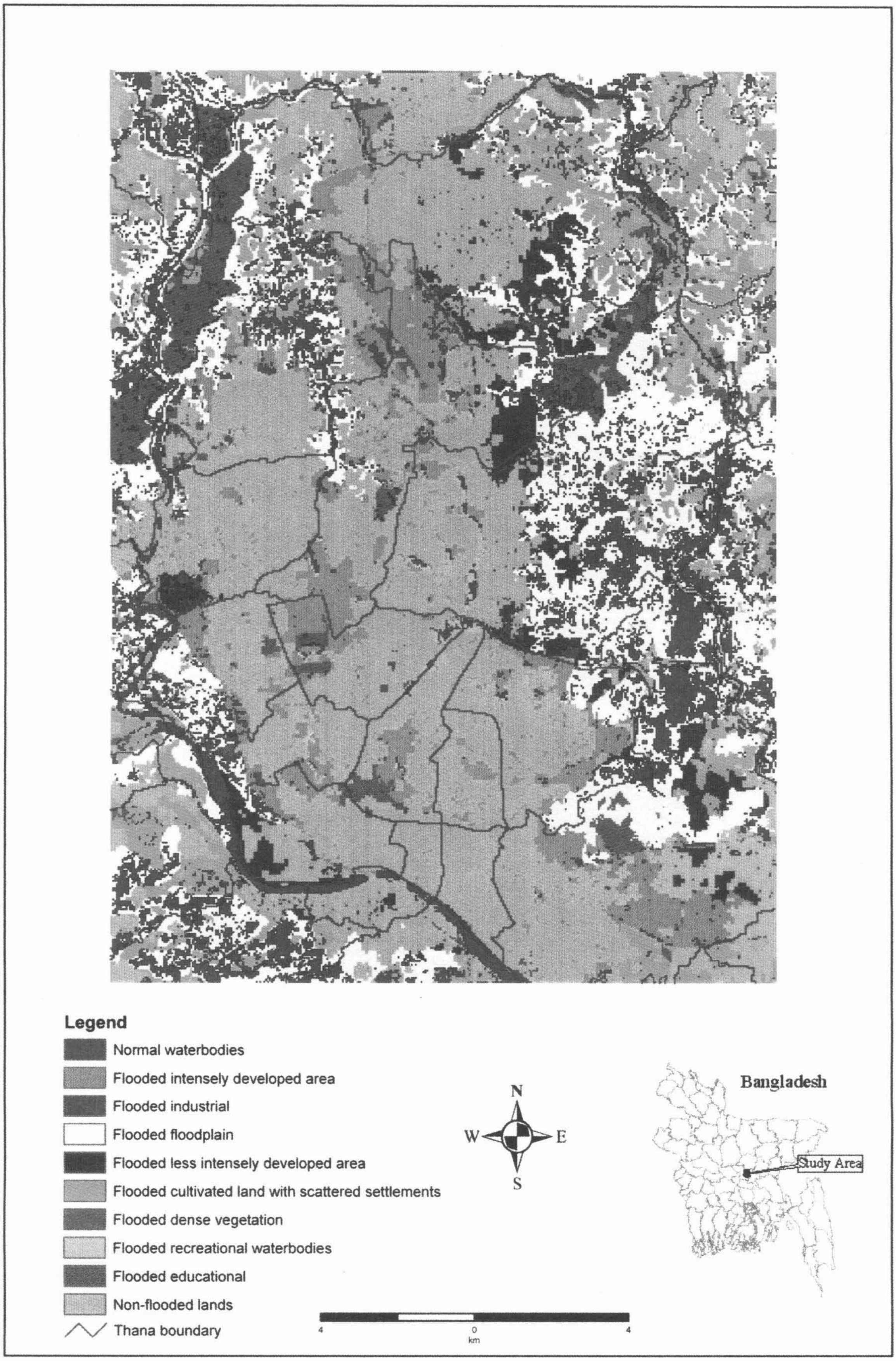

Fig. 3 Landuse/cover flooding map of Greater Dhaka.

which depicting that this category suffered spectacular flood damage. Among other categories, higher to low Pleistocene terraces also (52.20%) suffered widespread flood damage followed by old inactive floodplain (35.81%) and shallow marshy land (12.80%).

The literature claimed that protected portion of Dhaka remained flood free due to the embankment and also suggested more structural options to protect the whole metropolitan Dhaka (Faisal et al. 1999). However, this study confirmed that every county (in terms of old *Thana* boundary) of Greater Dhaka was affected during the 1998 flood in varying magnitude (**Table 3**).

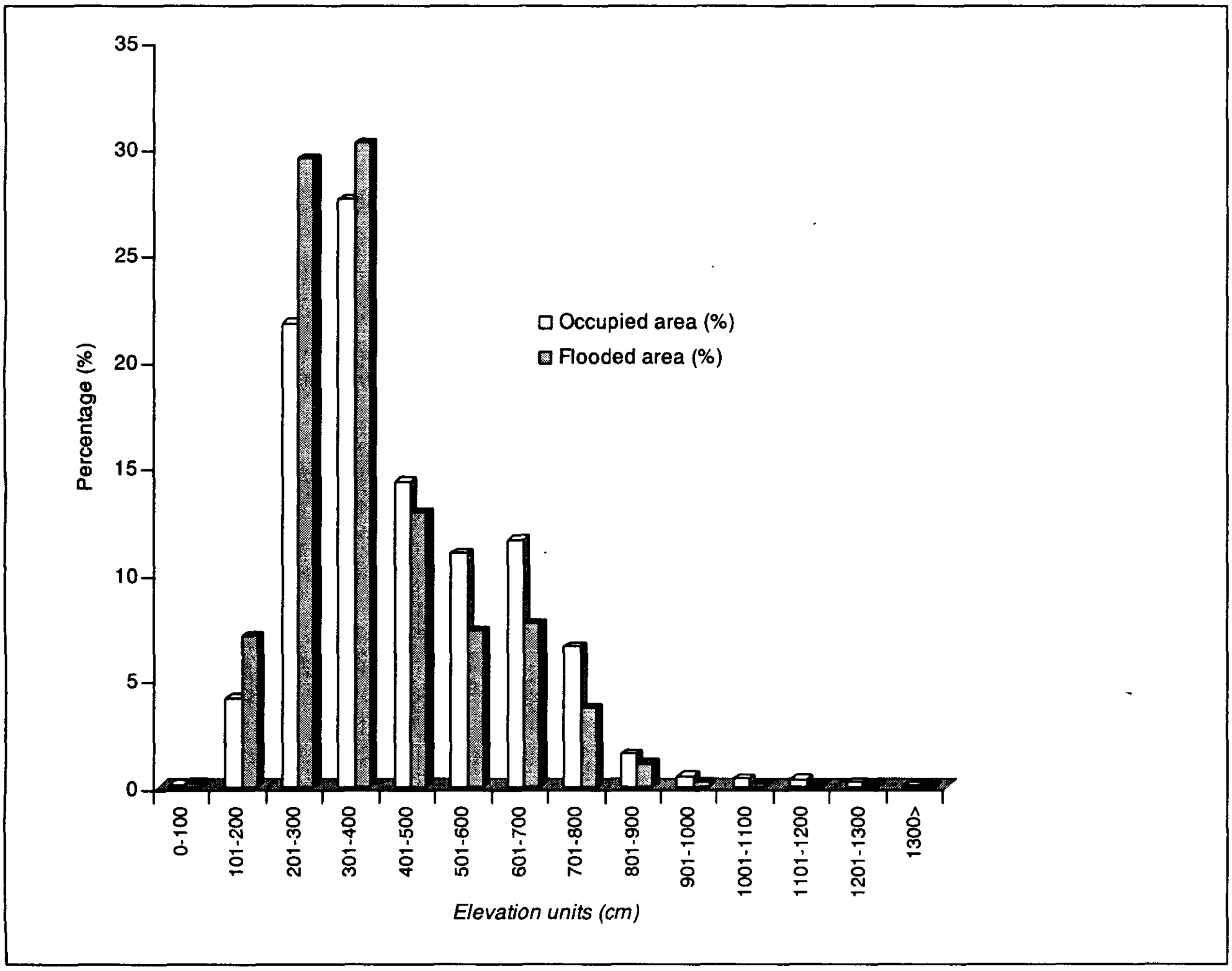

Fig. 4 Occupied area and flooded area (%) for each elevation units.

Flood damage estimation revealed that on the protected site of the study area, highest damage transpired in Pallabi (flooded area percentage is 7.95 while occupied area is 7.48%), Uttara, Cantonment, Mohammadpur *thanas* whereas in the non-protected zone, Gulshan suffered remarkable flood damage. As this portion of Dhaka is the diplomatic enclave, huge infrastructural damage was reported (Haque et al. 2000). Since people in this area are economically well off, they had their shelter in nearby rest houses or hotels in flood free regions. The flood damage was comparatively lower in the old part of the protected areas (**Table 3**). Compare to Gulshan, other *thanas* in the non-protected part were also badly affected of which Demra and Sabujbagh are noteworthy. Outside of metropolitan area, the flood damage concern mainly agricultural crops.

6 CONCLUSIONS

In this study, multi-temporal SAR data is used to delineate flood boundary of the greatest flood of 1998 in Greater Dhaka. The result demonstrated that SAR data is of value to operationally map and monitor flooding in third world cities where flood is a regular occurrence. Derived flood map is combined with different thematic layers to estimate flood damage.

(1) The study explored the widest flood prone areas in Greater Dhaka using time series SAR data which suppose to be very essential for urban planning and flood disaster management.

(2) The delineation and estimation of flood extent during the catastrophic flood of 1998 revealed that flood water started rising from early July 1998 inundating

34.55 percent of the total area and reached its maximum flooding areas on 25 August (53 percent) which was largely attributed to heavy monsoonal downpour together with discharge from upstream points.

(3) In order to estimate the extent of flood damage during the 1998 flood, land-cover, elevation data, geomorphic unit and administrative division were overlaid with the flood map and found that during the aforementioned flood, widespread damage has been occurred in Greater Dhaka. Intensely developed area suffered substantial damage which was mainly housing and infrastructure. In addition, higher elevated lands also registered considerable damage in the 1998 flood though certain low-lying lands had less damage. Non-protected parts accounted rigorous damage in contrast to protected sites however, all counties (thana) were badly affected during the 1998 catastrophic flood. This information can be further used to develop future flood countermeasures.

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