

Remote Sensing of 1998 and 2000 Floods in Greater Dhaka, Bangladesh: Experiences from Catastrophic and Normal events

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This paper is an attempt to develop a series of maps that precisely depict flood prone areas in Greater Dhaka, Bangladesh using remote sensing techniques. Multi-temporal RADARSAT SAR data were acquired and employed to delineate open water flood boundary during the floods of 1998 and 2000. Using a threshold algorithm, SAR data is segregated into water and non-water areas. The empirical threshold value was obtained by using visual interpretation technique, local knowledge of the study site and by deriving corresponding pixel values to land/water from each image. The result demonstrated that 53 percent of the study area was heavily inundated in 1998 flood which is the largest submerged area during a catastrophic scenario. In contrast, 35.32 percent area was flooded during the year 2000 which represents the area under water for a normal event. Using the reference data acquired from field visit, derived flood maps were further validated. Moderate accuracy is obtained for all flood maps, however, July 1998 image attained the highest overall accuracy (86%) in the dataset. The derived flood maps are expected to be useful to mitigate losses of lives and property from river water flooding in Greater Dhaka. Furthermore, this information would be worthwhile to develop an efficient flood disaster management system.

Key words: SAR, open water flood, 1998 and 2000 floods, Greater Dhaka, RADARSAT

1 INTRODUCTION

Among natural disasters, flood perhaps is the most pervasive and destructive natural hazard in Bangladesh. There have been many disastrous floods in Bangladesh. Recent examples include the 1988 flood, which claimed 2379 lives (Paul, 1997) and the 1998 floods with its prolonged duration longer than any known event, resulted in 918 deaths and was responsible for total losses of US\$ 3.5 billion (Shehabuddin, 2000). In Bangladesh, constructing embankment along the riverbanks is the most popular means for flood management. It is believed that the construction of embankment could be of little help to save life and alleviate flood loss (Chowdhury et al. 2000). Moreover, a number of environmental threats have already been emerged due to immense structural measures across the country (Paul, 1997). Consequently, the 1998 floods with its incredible effects drew the attention of water experts in the country to contemplate the existing flood control measures. Considering the complexities associated with technological fixes, flood monitoring, damage assessment and disaster relief have been addressed by the water experts and key policy makers for the management of future floods that can be achieved through precise mapping of flood prone areas (Islam, 1998), assessment of flood hazard (Nishat, 1998) and flood risk mapping/zoning (Hossain, 1998).

Accurate information on the extent of flood is very important for flood prediction and monitoring that could be useful to prevent future floods (Baumann, 1999; Smith, 1997). This information can further be enhanced to calculate the dimensions of embankment constructions, to identify retention areas and to delineate flood endangered areas (Oberstadler et al. 1997). Often this information is difficult to generate using traditional survey techniques because flood is a highly dynamic event. In contrast, images from earth observing satellites can provide a means for inundation mapping over large areas at near real time and are therefore widely used in mapping and monitoring floods.

Synthetic Aperture Radar (SAR) offers many advantages over traditional optical sensors (Foody, 1988). Due to its imaging capability near all weather, SAR data becomes a valuable method for inundation mapping for decades (Hess et al. 1995). SAR data is particularly invaluable for flood studying in the monsoon regions of the world where persistent cloud coverage precludes imaging by the optical sensors during flood season (Imhoff et al. 1987). In addition to that, it is especially effective in detecting lowland floods where subtle topographic variation inhibits demarcation of precise flood map using digital elevation model (Townsend, 2001). Many successful applications showed that SAR is a very promising technology for accurately mapping the extent of inundation during floods and under vegetation (Hess et al. 1990). For example, Townsend (2001) used multi-temporal C band HH polarized RADARSAT data to delineate flooding under vegetation condition in North Carolina. Toyora et al. (2002) used RADARSAT SAR and SPOT data to map freshwater wetland flooding in Canada. Zhou et al. (2000) used NOAA-AVHRR and

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RADARSAT SAR in combination to map flooding caused by monsoon rain in China.

In Bangladesh, flood prone areas demarcation is mostly done by using traditional survey techniques which is regarded as one of the most important pitfalls for efficient flood management. Very few studies have so far been done using optical remotely sensed data (Islam and Sado, 2000; Blasco et al. 1992; Rahman et al. 1991; Rasid and Pramanik, 1990; Ali et al. 1989). However, available literature suggests that satellite borne radar application of flood in Bangladesh is very rare. Using remote sensing data for studying flood is imperative for third world countries since it is difficult for governments to update their databases by traditional surveying and mapping methods which are both costly and time consuming (Dong et al. 1997). Thus, we recognized the need for a series of maps depicting the maximum and minimum extent of floods to aid future flood disaster prevention and mitigation. The objective of this study is to delineate open water flooding in an urban area by using microwave remote sensing. Specifically, the objective is to evaluate the utility and validity of C band HH polarized radar remote sensing (RADARSAT) for flood boundary delineation during 1998 and 2000 floods in Greater Dhaka that can be used to represent spatial inundation pattern during a catastrophic and normal scenario.

2 THE STUDY AREA

In this study, we consider Greater Dhaka area for flood analysis. Dhaka, the capital of Bangladesh is located in the central region of the flat deltaic plain of the three mighty rivers, the Ganges, the Brahmaputra and the Meghna. The Dhaka Statistical Metropolitan Area (DSMA) covers about 1464 km² and the area under present study constitutes 420 km² that includes the whole of Dhaka City Corporation (DCC) area plus the surrounding fringe zones. Latitude and longitude of lower left and upper right corners of the study area are 23°68' N 90°33' E and 23°90' N, 90°50' E, respectively (Fig. 1).

There are four major rivers flowing across the study area namely, Buriganga to the south, Turag to the west, Tongi Khal to the north and Balu river to the east. The city and adjoining areas are composed of alluvial terraces of the southern part of the Modhupur tract and low lying areas at the doab of the river Meghna and Lakkha. In course of time, this tract had been merged and dissected by recent floodplains in its fringe to form the present landform of Dhaka City and its periphery. The major geomorphic units of the city are the high land or the Dhaka Terrace, the lowlands or floodplains, depressions and abandoned channels (Miah and Bazlee, 1968). However, low lying swamps and marshes located in and around the city, are other major topographic features. The elevation of the study site ranges between 1 and 14 meters above mean sea level (FAP 8A, 1991). The climate of Dhaka can be classified as tropical monsoon type, characterized by three distinct seasons, monsoon, warm and cool. The average annual rainfall is about 2000

mm. The temperature during warm month's ranges between 28°C and 34°C. In winter, the temperature ranges between 10 °C and 21°C. The monsoon season stretches from May to October during which 90% of annual rainfall occurs (FAP 8A, 1991).

Dhaka is one of the fastest growing cities in the world. The growth of Dhaka can be categorized into five distinct periods, the Pre-Mughal period, the Mughal period, the British colonial period, the Pakistan period and the Bangladesh period. The growth of Dhaka was under ups and downs during the first four periods (Islam, 1996). Onward 1971, the growth of Dhaka has become phenomenal (Chowdhury and Faruqui, 1991). Population in Dhaka is growing very rapidly as it is the major social, economic, administrative center in Bangladesh. The annual growth during 1961-1974, 1974-1981 and 1981-1991 periods have been 9.3%, 9.4% and 7.8% (BBS, 1991), which is attributed to high natural rate of increase, massive rural to urban migration and the redefinition of settlements as urban centers (Eusuf, 1996). At present, population of Dhaka Statistical Metropolitan Area is more than 10 million. The current growth rate is 4.2% and population density is 6545 persons/km² (BBS, 2001).

Historically, Dhaka City is built up on a floodplain 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 have been encroached. As a result, many *khals* and depressions have been detached and lost their ability to drain and store flood water. Furthermore, unplanned urbanization is one of the foremost factors for increasing flood problems in greater Dhaka (Islam, 1996). For example, it is projected that by the year 2010 around 366 km² will be urbanized in Greater Dhaka (GOB, 2000) that could compel more people to live in the most flood vulnerable areas (Rasid and Mallick, 1993).

3 SAR DATA ACQUISITION AND PRE-PROCESSING

In order to figure out flooding during a catastrophic and normal events, four RADARSAT SAR images were acquired of which two (July, August) comprise of the 1998 floods corresponding to catastrophic year and two (July, August) are for the year 2000 representing normal flooding. These images were collected from Center for Environment and Geographic Information Systems (CEGIS) and Space Research and Remote Sensing Organization (SPARRSO) at Dhaka. RADARSAT images were transformed from slant to ground range at ground receiving station of satellite.

Radar data need to be despeckled prior to analysis. Speckle is a multiplicative random noise that can significantly reduce competent interpretation. Various filters were applied. However, the Gamma MAP filter with 5x5 windows was found to be suitable in oppressing speckle for the data used in this paper. The geocoding of the images was then performed using a Landsat TM geometrically corrected image as the reference image. A total of 43 ground control points (GCPs) (about 10-11

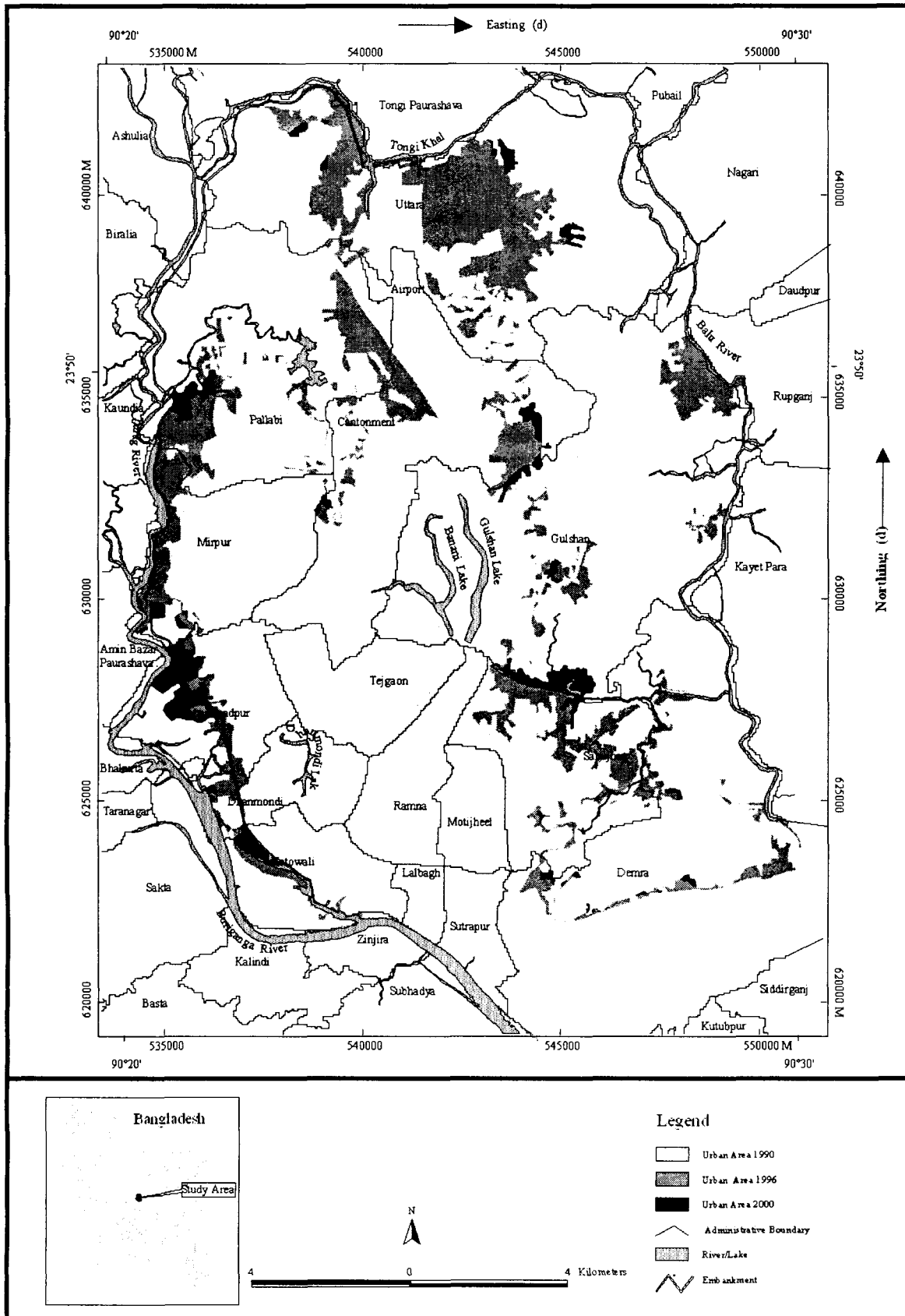


Fig. 1 The Study Area.

GCPs for each image) uniformly distributed over the area of interest were used for the image registration process in ERDAS IMAGINE software. A second-order polynomial fit was applied and pixel values were resampled to the same pixel size (50 m) using nearest neighbor algorithm. The resulting root mean square error (RMSE) was 0.45 to 0.48 pixels (22 m to 24 m) for all images. Finally, all images were projected to Bangladesh Transverse Mercator (BTM) system (FAP 19, 1995) that produces a total of 166560 pixels (480*347) in a computer monitor.

4 IMAGE ANALYSIS

RADARSAT SAR images were classified into water and non-water using a threshold algorithm developed here. Generally, threshold value can be obtained from radar backscatter on a ratio image which is known as decibel (dB) and a binary algorithm is applied to determine whether a raster cell is flooded or not. However, when the image is in linear scale then it may not be possible to get decibel value to segregate continuous data. In that case, threshold value can be obtained from linear SAR image using overall spectral signature of the imagery as well as using local knowledge of the area to be studied (Liu et al. 2002). To obtain flooded areas from multi-temporal SAR image, a simple threshold technique was adopted and the desired threshold value was accomplished by using the following steps. First, land-water profile from the images was determined by drawing few perpendicular lines from land to water and vice versa using the spatial profile tool of an image analysis system, hence highest pixel values for water and non-water were acquired and recorded (Fig. 2). Secondly, a ground truth map was studied and evaluated along with each flood time image in order to ascertain desired threshold values. Finally, Image histogram and visual interpretation helped to determine empirical threshold values for each image. On the basis of above steps, a rule based approach was adopted (similar to the approach used by Wang et al. 2002) to extract flood extent from 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. If a pixel's DN value was satisfied then it was assigned to water category otherwise it would be assigned as a non-water category. Although, the selection of threshold values may seem to be somewhat arbitrary, we used selection of optimal threshold method suggested by Fung and LeDrew (1988) to validate the results. With a view to obtain optimal cut-off value for each image, overall accuracy and kappa coefficient (Congalton, 1991) of agreement was computed with the help of reference data. The threshold value producing the highest kappa coefficient was selected for the optimal value. Threshold

images resulted in a binary image that contained two categories, flooded and non-flooded areas.

5 MAP VALIDATIONS

In order to assess the validity of flood maps extracted from SAR data, a total of 100 equalized random pixels (50 for each class) were first generated for each classified image. Then using the ground truth map, sample pixels were verified separately and the results derived in error matrix. For each map, we calculated the overall accuracy as the number of correctly classified sites divided by the total number of testing sites (Story and Congalton, 1986). A non-parametric Kappa test is also used to measure the classification accuracy as it accounts for all elements in the confusion matrix rather than just the diagonal elements (Rosenfield and Fitzpatrick-Lins, 1986).

6 DETERMINATION OF FLOODED AND NON-FLOODED AREAS

After extraction of flooded and non-flooded areas from individual image, every image was then superimposed with a dry season classified SAR image in order to estimate net inundated areas at each date of the 1998 and 2000 floods in Greater Dhaka. It is necessary to note here that the dry seasonal water bodies were discarded for flood area estimation, thus showing only the flooded area. Inundation area percentage (%) for each flood time image was then obtained using the following equation:

$$\text{Inundation area percentage} = \frac{a}{a+b} \times 100 \text{ -----(1)}$$

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



Fig. 2 Process of determining threshold value.

7 RESULTS AND DISCUSSION

(a) Spatio-temporal pattern of inundation during the 1998 and 2000 floods

Spatial distribution of inundation during the 1998 catastrophic flood revealed that floodwaters were mainly distributed on the extreme lowlands of the study area in the beginning of flood season. As rainfall and discharge increased considerably many highly elevated lands started submerging and reached its peak on 25 August 1998 (Fig. 3). Surprisingly, many areas of the western part of Dhaka City were not flooded while almost all areas of eastern part were heavily flooded. This is due to the higher elevation of western part as well as the existence of embankment that was constructed after the 1988 deluge. In contrast, during the year 2000, floodwaters were largely distributed over the lowlands (Fig. 4) which is usual for any normal flood season. Though the submerged area increased a bit in the month of August however it was not as severe as the 1998 flood. Since the 2000 year flood was a normal event therefore, it caused negligible flood damage of study site.

The temporal dynamics of the flood extent at different dates (in terms of percentage of inundation area) during the 1998 and 2000 floods were computed and shown in Table 1. Using equation 1, one can calculate the flood progress. For example, the December 15, 1998 image represents the dry season while the July 7, 1998 image represents the flood season. Therefore, water areas in both dry and flood seasons (11.85%) are normal water bodies such as river, lake, ponds, etc. Water areas in flood season but non-water areas in dry season (30.02%) represent the inundated areas in flood season. Non-water areas in both dry and flood season (56.88%) represent the non-inundated area (only land area) of Greater Dhaka. Water areas in dry season but non-water areas in flood season (1.25%) represent the error in pixels. Therefore, the total flooded areas in percentage is $30.02/(30.02+56.88)*100=34.55$, excluding the normal water bodies from the total land areas. Time series of newly flooded and flood recovered areas can therefore be understood. It is found that the highest percentage of flooded area (53.00%) was on August 25, 1998 that complies with the earlier results obtained by the supervised maximum likelihood classification technique (Nishigaki et al. 2004). 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 enhancing flood 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, which was 367.8 mm higher than the normal, caused more areas to be inundated. Examination of surrounding rivers water level of the 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 (Dewan et al. 2004; Faisal et al. 1999). In addition, the back water effect from downstream rivers

causes water to recede at a faster rate (IFCDR, 1998). Temporal dynamics of flooding during the year 2000 indicated that in July 20, 32.97 percent of the study area was flooded and in August 13, the flooded area percentage was 35.32. This is the exact flooded area that can be submerged during a normal event when rainfall and water level of surrounding rivers are at standard level. Thus, it is clear that the excessive rainfall and soaring water levels of the surrounding rivers played a significant role in 1998 floods and made it the most severe flood of the century.

Table 1 Inundation area percentage (%) during the 1998 and 2000 floods.

July 07 1998	Dry season (December 15 1998)		
	Water	Non-water	Total
Water	11.85	30.02	41.87
Non-water	1.25	56.88	58.13
Total	13.1	86.9	100

Total inundated area (%) = 34.55

Aug. 25 1998	Dry season (December 15 1998)		
	Water	Non-water	Total
Water	12.29	45.92	58.21
Non-water	1.08	40.71	41.79
Total	13.37	86.63	100

Total inundated area (%) = 53.00

July 20 2000	Dry season (December 15 1998)		
	Water	Non-water	Total
Water	12.93	28.01	40.94
Non-water	2.11	56.95	59.06
Total	15.04	84.96	100

Total inundated area (%) = 32.97

Aug. 13 2000	Dry season (December 15 1998)		
	Water	Non-water	Total
Water	13.12	29.87	42.99
Non-water	2.31	54.7	57.01
Total	15.43	84.57	100

Total inundated area (%) = 35.32

(b) Accuracy of derived flood maps

Accuracy of maps obtained from remote sensing data can be done with the reference data collected from the field. In this study, accuracy of flood maps were conducted by comparing derived maps from SAR images with ground truth flood map. Since detail flood maps on the 1998 and 2000 events are not available for the whole study site, we produced a flood map by looking at daily newspapers as well as interviewing local people. Thus, accuracy of the flood maps obtained from remotely sensed data is evaluated. The accuracy of flood maps derived by image segmentation is shown in Table 2. On radar image, water and land areas can be easily separated due to their distinct tonal variation. Generally, water pixels consist of very low radar return due to volume scattering resulting in dark grey tone while land areas are often characterized by high radar returns resulting in

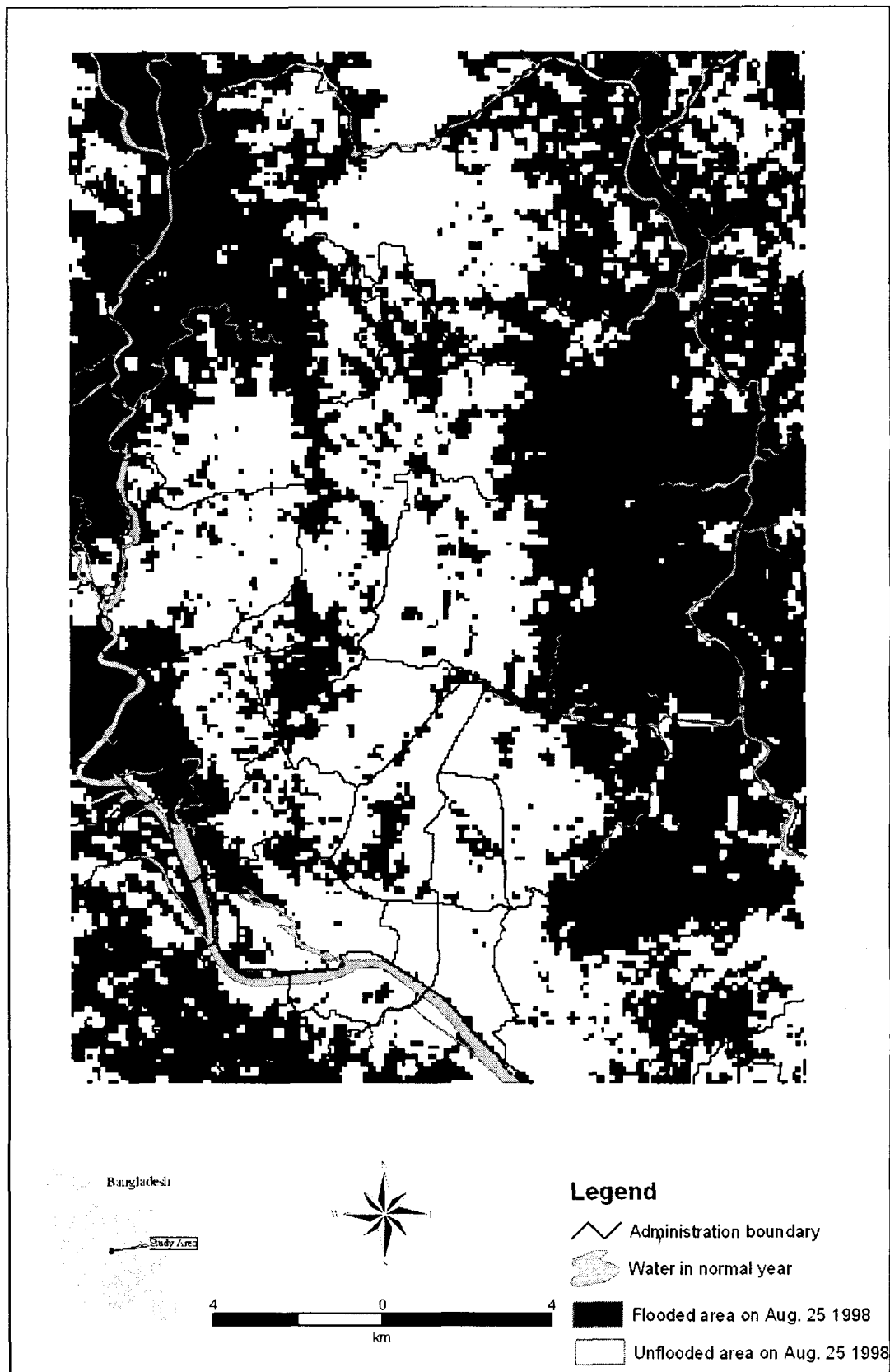


Fig. 3 Spatial Extent of the widest inundation areas in a catastrophic event (August 25 1998).

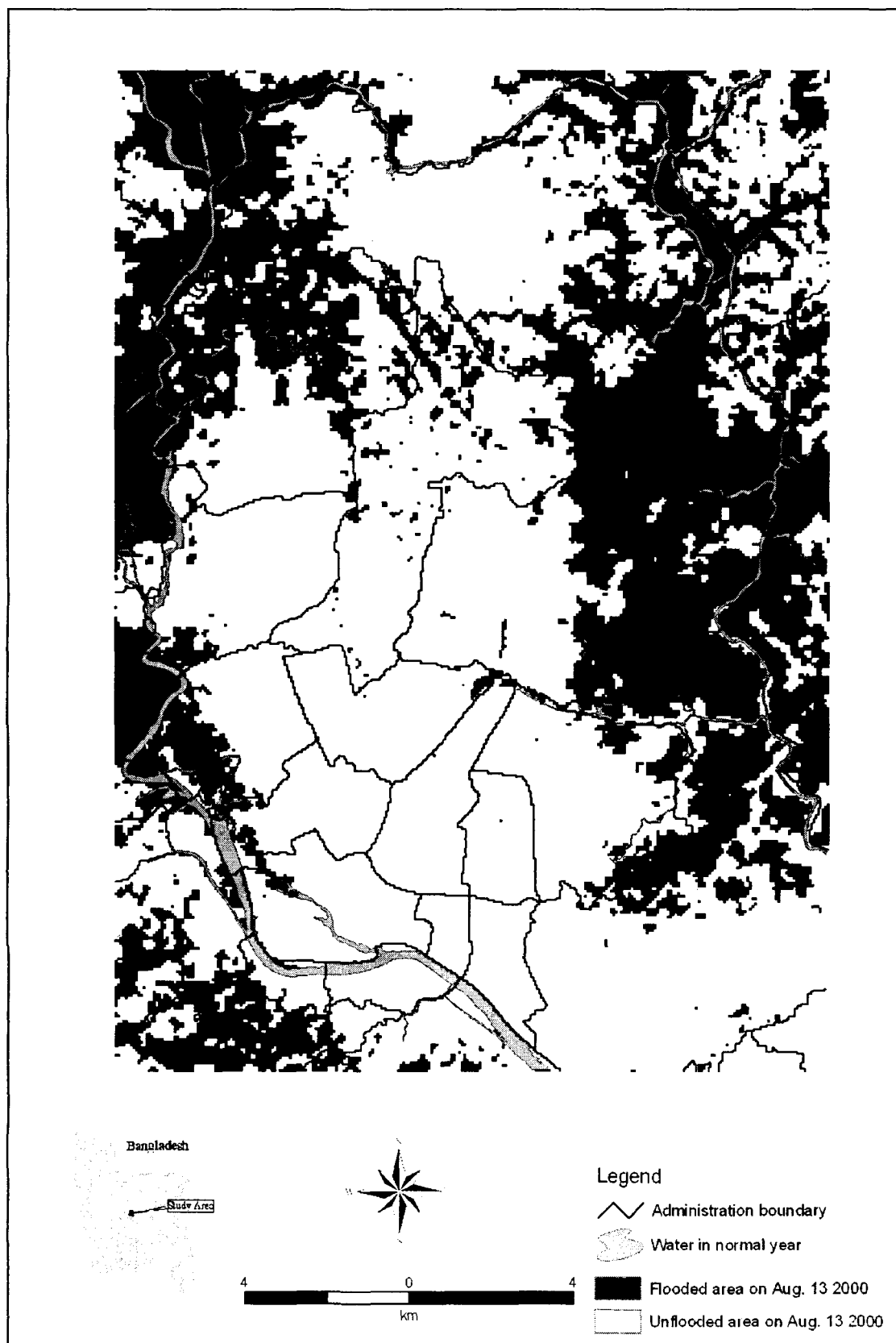


Fig. 4 Flood extent in a normal event (August 13 2000).

very bright tone due to corner reflection. Analysis of error matrix of SAR images implies that misclassification of water and non-water pixels observed for classification schemes. As a result, lower accuracy obtained for flood maps during the 1998 and the 2000 flood. The rate of misclassification varies according to image dates. This misclassification might be attributed to several errors associated with radar image. For instance, it was difficult to spectrally separate open spaces (parks, institution grounds, golf courses with grassy characteristics, linear features e.g. roads) because of their intermediate tonal characteristics. This group of features generally appeared as medium grey and their DN values were slightly higher than that of water pixels. Difficulty was also encountered with the occurrence of low returns from features adjacent to water bodies, such as airport runways bordered by lakes. These are common problems in studying urban surface using radar data (Dong et al. 1997). Some of the map errors are likely to stem from interactions between ground features (land/water boundaries) surface roughness, moisture content and radar parameter configurations (incidence angle, polarization, wave length). These are very complex phenomenon and subject to much research (Lee and Lunetta, 1995; Ramsey, 1999). RADARSAT's polarization may have been another source of error. Sensors with H-H polarization are known to be less sensitive to changes in vegetation moisture content than are cross-polarized sensors, HV, VH (Avery and Berlin, 1992). This may provide an additional explanation for confusion between classes. Larger incidence angle may increase specular reflectance for a given surface (Sokol et al. 2000). Thus, relatively large incidence angle may have been the source of error in the confusion of land covers. Another possible source of error could be miss-registration of images (Townsend et al. 1992).

Table 2 Accuracy of flood maps by Threshold algorithm.

Image date	Optimal threshold value	Overall accuracy (%)	Overall Kappa coefficient (%)
7 July, 1998	70	86.00	72.00
25 Aug, 1998	96	75.00	50.00
July 20, 2000	78	77.00	54.00
13 Aug, 2000	83	73.00	46.00

8 CONCLUSION

Floods are regular phenomena in Greater Dhaka during monsoon. Flood maps derived from ground measurement comprise of errors in delineating actual flood prone areas that precludes development of appropriate flood disaster management system. In order to overcome the problem associated with traditional flood mapping, microwave remote sensing can be operationally used to map and monitor open water flooding in third world cities e.g. Dhaka or elsewhere. In this study, Radarsat SAR data have been employed to map flooding during a catastrophic and normal flood event in greater Dhaka. It is found that during a normal flood event 35.32

percent of land was flooded which was the highest in the year 2000. Conversely, in 1998 flood which has been termed as the flood of the century inundated 53 percent of land in Greater Dhaka. Thus, the highest and lowest flooding areas during a normal and catastrophic flood event can be distinguished. This information is worthwhile to incorporate in developing an efficient flood disaster management system in greater Dhaka that can save life and property from recurrent flood disaster.

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