Locating Villages in the Floods: The Use of RADARSAT Imagery in Flood Hazard Management in Bangladesh

by

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ABSTRACT

Bangladesh lies almost entirely on the delta of three major rivers: the Padma (the Ganges), the Jamuna (the Brahmaputra), and the Meghna. A considerable portion of Bangladesh has been repeatedly devastated by floods associated with cyclonic storm surges along its coastal islands and riverine flooding along the rivers traversing the low-lying deltaic plain. Extensive flooding is a recurring event affecting a significant proportion of the population.

The International Council of Scientific Unions (ICSU), through the International Geographical Union (IGU) is providing scientific support to the Bangladesh Flood Action Plan as part of the United Nation's International Decade for Natural Disaster Reduction (IDNDR). The IGU study has focused on a long term survey of flood prone areas using remote sensing, geographic information systems (GIS), and the global positioning system (GPS). RADARSAT imagery serves to improve the imagery base for the area, as Synthetic Aperture Radar (SAR) imagery of terraces and levees in natural areas nearly covered by seasonal floods have better discrimination of elevated land surfaces than many other imagery sources. RADARSAT provides an "all-weather" remote sensing tool for monitoring flood events. In this study, the imagery is being used to determine areas affected by annual and catastrophic floods, specifically isolated villages in the flooded areas.

A protocol using the application of "low pass" smoothing filters to the RADARSAT data, followed by defined digital number thresholds to select regions of interest allows for the identification of villages in the imagery. After further testing of the chosen threshold ranges combined with ground truthing in Bangladesh, this protocol would be suitable for emergency management use during flooding. Isolated villages needing assistance during a flood event would be identified and prioritized accordingly.

The day/night and cloud-penetration characteristics of radar may be the only practical means of mapping the extent of monsoonal flooding of the deltaic plain, where a large rural population is forced to adapt to seasonal isolation in a flooded landscape. Maps of rural hamlets and isolated flood refuge sites will never keep pace with the growing population and constantly changing fluvial landscape without the use of high altitude remote sensing satellites such as RADARSAT.

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DEDICATION

This research paper is dedicated to my husband Greg and to my mom, Amy Bartels Massey. They have each taught me, in their own ways, to be confident in myself and to continually strive towards higher goals in life. I would not be the same person otherwise.

Locating Villages in the Floods: The Use of RADARSAT Imagery in Flood Hazard Management in Bangladesh

INTRODUCTION

In recent years, there has been an increased emphasis on improving flood survival strategies for nations such as Bangladesh who experience flood events on an annual basis. Between 1797 and 1991, Bangladesh was struck by 59 severe cyclones, most which were accompanied by storm surges. Coastal Bangladesh is typically the worst affected region and possesses the least preparedness for dealing with natural disasters such as catastrophic flooding (Khan 1995). This study builds upon ongoing research into the distribution, causes, and future flood mitigation strategies for Bangladesh.

The International Council of Scientific Unions (ICSU), through the International Geographic Union (IGU), is providing scientific support to the Bangladesh Flood Action Plan (FAP) as part of the United Nation's International Decade for Natural Disaster Reduction (IDNDR). The IGU study has focused on a long-term survey of flood prone areas using remote sensing, geographic information systems (GIS), and the global positioning system (GPS). RADARSAT imagery serves to improve the imagery base for the area, as Synthetic Aperture Radar (SAR) imagery of terraces and levees in natural areas nearly covered by seasonal floods has better discrimination of elevated land surfaces than many other imagery sources (CONAHA 1992). RADARSAT provides an "all-weather" remote sensing tool for monitoring flood events. In this study the imagery is being used to determine areas affected by annual and periodically catastrophic floods, specifically isolated villages in the flooded areas.

THE SITUATION

Bangladesh lies almost entirely on the delta of three major rivers: the Padma (the Ganges), the Jamuna (the Brahmaputra), and the Meghna (Figure 1). This delta is one of the largest deltas in the world (Umitsu 1997) and is composed of over 5000 miles of waterways. Its relative height above sea level is 9-33 feet in the north and 0-17 feet in the south, and it is actively subsiding (Begum and Fleming 1997). The delta is neither homogenous nor static. Bank erosion and alluvial deposition cause significant annual changes along the lower Ganges and Meghna rivers, and major shifts in river courses have occurred in recent centuries (Brammer 1993). The combined watershed is twelve times the size of Bangladesh (FAO/WFP 1998). Six percent of the total land area is permanently under water, while nearly two-thirds is inundated for a portion of the year.

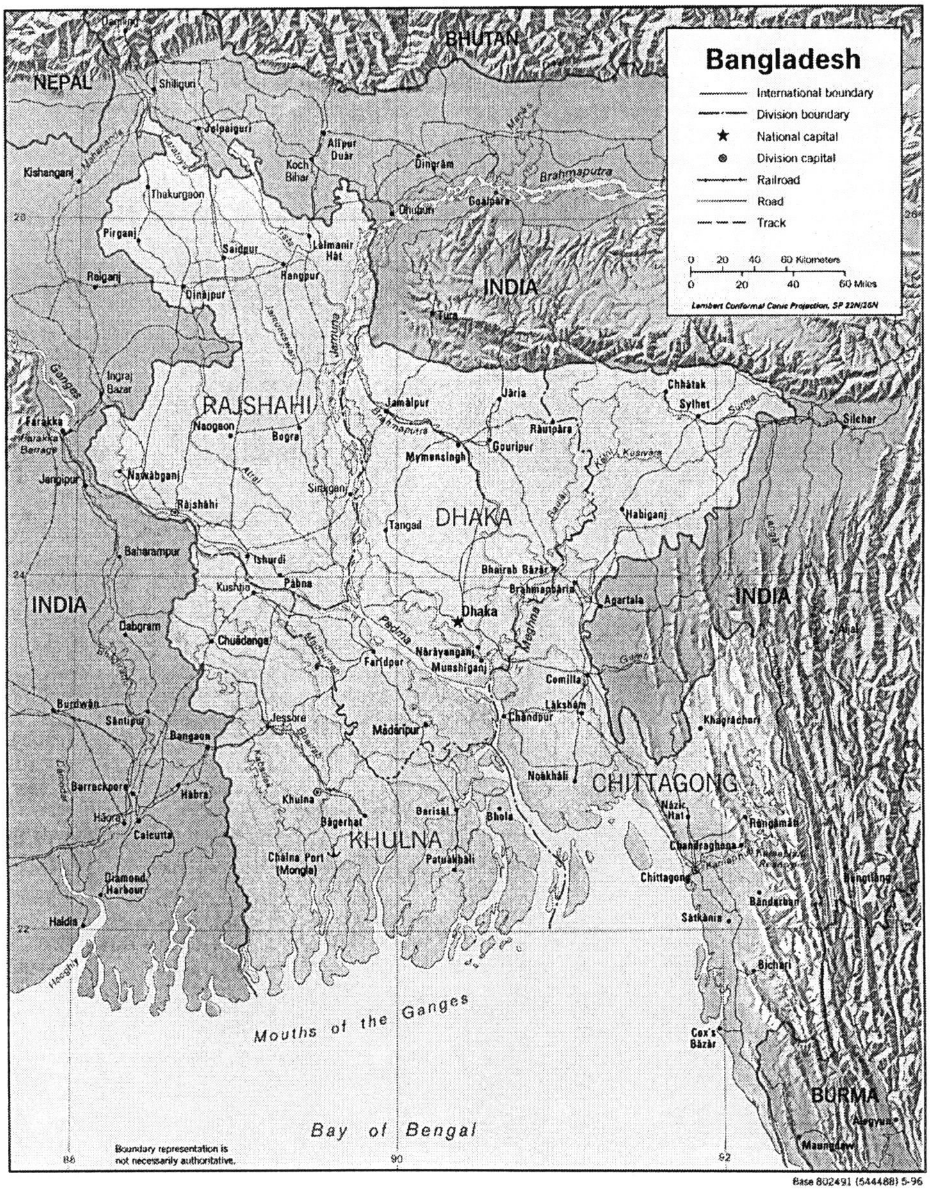


Figure 1. Map of Bangladesh

Flooding conditions and changes in the river courses are related to the characteristics of the alluvial landforms in the lowland delta (Umitsu 1997). Many of these landforms are highly unconsolidated and unstable, and are thus easily altered by flooding water and storm surges during the southwest monsoon season (June through October). Few of the landforms offer much natural protection from rising water, although they are related to the flooding conditions of individual regions of coastal Bangladesh. The southern region of the delta along the Bay of Bengal is classified as active, including the area in and around the mouth of the Meghna, and is composed of soft, unconsolidated silt and clay. Multiple islands have been both created and destroyed by floods and sediment movement.

A considerable portion of Bangladesh has been repeatedly devastated by floods associated with cyclonic storm surges along its coastal islands and riverine flooding along the rivers traversing the low-lying deltaic plain. The country's coastal areas experience two main types of floods on a yearly cycle. External floods, also called tidal floods, are the result of the high stages of the surrounding rivers during the monsoon season each year in late summer and early fall. Secondly, internal or riverine floods are caused by rainstorm and drainage congestion, particularly in the city of Dhaka, due to inadequate drainage facilities and improper operation of flood control structures. Flash floods also occur due to heavy rainfall, but these are usually confined in a certain area for a relatively short duration of time. The flood situation is further enhanced by the high tide in the Bay of Bengal (Begum and Fleming 1997). The tidal range along the coast of Bangladesh varies between 3 and 6 meters.

Bangladesh rainfall is dominated by the Asian monsoon, called *barsha* in Bangladesh, and is concentrated within six months of the year, from May to October. Monsoon means a seasonal wind, but "monsoon season" is typically used to mean a wet season. People in Southeast Asia use this term to simply mean rainfall (Yoshino and Aihara 1971). The direction of flow of these seasonal winds reverses twice per year as a manifestation of the effects of the reciprocal thermal and pressure conditions aloft. Monsoons coming into an area from a body of water such as the Bay of Bengal bring heavy, torrential rainfall with great interannual variability and striking regional differences (Yoshino 1971).

Severe flooding usually occurs from August through September (Islam 1993). Much of the delta flooding is caused by rainwater or the raised groundwater table, which is ponded on the land by high external river levels during the monsoon season (Brammer 1993). Flooding during this season covers nearly 20 percent of the country one year out of two and 37 percent of the country one year in ten. One of the world's worst disasters was the flooding of 1970, which claimed an estimated, 300,000 to 500,000 lives. Floods in 1987 covered approximately 40 percent of Bangladesh, and the following 1988 floods covered nearly 60 percent (Rosenfeld 1994). Since 17 million of the 125 million people of Bangladesh live less than one meter above sea level and 38 percent of the country's food production is related to the floodplains and the water, it is obvious that extensive flooding is a recurring disaster affecting a significant proportion of the population.

EXISTING RESEARCH

In the past, satellite observations of floods have been limited by the presence of clouds and other atmospheric disturbances. High-resolution satellite data have also not been available in near real-time. Tests in the United Kingdom have shown the ERS-1 SAR to be a suitable sensor for flood mapping, and fast delivery products can be obtained within hours of satellite acquisition (Blyth 1994).

Table 1. Satellites with radar sensors suitable for flood monitoring (from Blyth 1994:60).

Satellite	Origin	Launch Date	Operational Life
SEASAT	USA	June 1978	3.5 months
Almaz	Russia	March 1991	2.5 years
ERS-1	EC	July 1991	4 years
J-ERS-1	Japan	February 1992	3 years
ERS-2	EC	(early 1995)	3-5 years
RADARSAT	Canada	(early 1995)	5 years
Envisat	EC	(1998)	3-5 years

(Launch dates in parentheses indicate satellites that had not yet been launched at the time of Blyth's article's publication.)

This study by Blyth focused on a pilot project for flood hazard assessment and mapping using ERS-1 in the Philippines. He found that short term needs or requirements for remote sensing of flooding include overview information on floodwater extent to enable relief efforts to be directed to areas of greatest need, to prioritize the rescue and/or evacuation of residents, food and medical supply, strengthening and repair of flood defenses, communication repair, and the repair of utilities and infrastructure. Long term requirements include flood hazard assessment and mitigation as well as updated mapping of changes in river channels and of relocation of villages after a major flood event. Imagery collected with fine resolution (less than 30 meters) works well for both short and long term goals. The sensitivity of the radar to changes in surface roughness provide an adequate basis for the detection of erosion and deposition features due to flooding, as well as for the delineation of crop damage. The ERS-1 SAR was first tested to record floodwater extent in the United Kingdom of the River Thames. The remotely sensed images provide faster interpretation of the flooded areas than aerial photographs.

ERS-1 was also used to collect data for the Mississippi River floods of 1993 during a "persistent cloudy period (Blyth 1994:62)" when non-radar techniques could not capture images through the clouds. It was also found that combining the radar images with optical images (taken in the visible spectrum) obtained from Landsat and SPOT (Systeme Pour l'Observation de la Terre) satellites allowed for more detailed land use information than with the radar imagery alone, and the effects of flooding could be more easily extracted (RADARSAT International 1993).

Advanced Very High Resolution Radiometer (AVHRR) imagery was used in 1989 (Ali et al.) to monitor and study the river floods of 1984 and associated hydrological conditions in Bangladesh and adjoining regions. It was determined that since river floods in Bangladesh are primarily caused by conditions near the source regions of the major rivers, which lie in other countries, regional data coverage and observations are essential. AVHRR provides this large areal coverage daily from its NOAA (National Oceanic and Atmospheric Administration) satellites, so measurements and observations of the major rivers leading through Bangladesh can be obtained and studied prior to their reaching the Bangladesh border, through the country, and finally discharging into the Bay of Bengal. Information can therefore be obtained for nearly all parts of the hydrologic cycle.

Storm surge models for coastal Bangladesh were developed in a study using the Integrated Land and Water Information System (ILWIS) GIS combined with remote sensing technologies which include Landsat Multispectral Scanner (MSS), Landsat Thematic Mapper (TM), and SPOT (Khan 1995). These storm surge models aided in preparing a storm surge susceptibility map at regional scale (1:250,000) and hazard zonation maps, based on digital elevation models, at more detailed scale (1:50,000). Landsat MSS imagery was used to create thematic inventory maps at the national scale, whereas Landsat TM and SPOT data were more appropriate for regional or semi-detailed scale due to higher resolutions (30-meter and 20-meter resolution, respectively). Panchromatic SPOT imagery (10-meter resolution) was also used and found to be suitable for mapping of post-cyclone landcover types, as well as for input in the storm surge models. The combination of remote sensing and GIS proved very suitable for the analysis and monitoring of flood hazards (Khan 1995).

In February 1996, shortly after the November 1995 launch of RADARSAT, flooding along the Willamette and Columbia rivers in Oregon was imaged and studied to provide North American analogs for the ground truth previously conducted in Bangladesh. RADARSAT imagery as well as aerial videography integrated with a global positioning system (GPS) were used to interpret this major flood event in the Willamette Valley (Rosenfeld et al. 1996). Imagery having 25-meter resolution was effectively interpreted for the study since floodwaters affect the complex dielectric constant, which is dependent upon the electrical properties of a material and is a measure of a material's ability to conduct or reflect microwave energy (Avery and Berlin 1992). The dielectric of a terrain material increases in a nearly linear relationship to increasing moisture content, so ground targets produce significantly stronger returns when they are moist. In the case of open floodwater, however, almost all of the microwave energy is reflected away from the radar antenna, and the resulting signature is very smooth and dark (Rosenfeld et al. 1996). Image characteristics of the RADARSAT data were clearly favored over aircraft mounted systems such as Side-Looking Airborne Radar (SLAR) since the higher illumination angles of the satellite sensor provide a greater range of information on surface conditions related to flood events. The RADARSAT imagery was compared to SLAR images obtained during a dry period in the valley, thus enabling the accurate mapping of flooded areas. Obtaining the imagery from RADARSAT in near real-time allowed for rapid assessment of the extent of flooding, for the state of dikes, and for the locations of ships in navigation channels.

Asaduzzaman (1994) assessed riverine flood hazard (location, magnitude, and frequency) in the Dhaka region and in the area of the Ganges and the Meghna river confluence in Bangladesh. His study employed a geomorphic approach based on the interpretation of SPOT satellite imagery (from 1987 - 1990) and aerial photographs, the study of thematic maps and related reports, and fieldwork. SPOT imagery from different seasons provided important data, which was used to map and monitor the spatial distribution of flooding and the rapid changes in confluence location and channel morphology after the catastrophic floods of 1987 and 1988. It was determined that the temporal variation is one of the primary indicators of landforms and relative elevation (Asaduzzaman 1994).

ERS-1 SAR imagery was used in by Syed (1996) to map geomorphological features at reconnaissance and detailed scales in central Bangladesh. The radar's sensitivity to surface roughness and moisture content was optimized using single date and multitemporal images. An extensive field survey was also conducted to provide ground truth information for the study's results.

Work using Landsat, SPOT, and AVHRR imagery has consistently been hindered by the lack of large area cloud-free imagery, especially at peak flood periods. The current RADARSAT study revisits the same sites in Bangladesh and uses the atmospheric penetration capabilities of RADARSAT SAR modes to determine a protocol for rapidly locating villages isolated within the flooded areas. This research optimizes the imagery acquisition characteristics for flood susceptibility mapping and damage assessment in frequently flooded regions, previously examined with imagery and ground assessments.

DATA

Imagery data used in this study were obtained from Canada's RADARSAT, an operationally-oriented radar satellite system. RADARSAT was developed under the management of the Canadian Space Agency (CSA) in cooperation with the National Aeronautics and Space Administration / National Oceanic and Atmospheric Administration (NASA/NOAA), provincial governments, and the Canadian private sector. The satellite, with a five-year design life, was launched in 1995. RADARSAT-2 is scheduled to be launched in 2000 (RADARSAT International 1998).

The original objective of the RADARSAT mission was to "establish an all-weather proto-operational satellite system providing SAR image data for surveillance applications (Goodison et al. 1985:80)". Frequent coverage through shorter revisit periods was another main goal in order to provide timely data for operational applications.

RADARSAT differs from optical sensors in the kind of data it acquires and in how these data are collected. Typical multispectral sensors (e.g., SPOT and Landsat) collect the energy reflected from the Earth's surface at frequencies roughly equivalent to those that are detected by human eyes, in the visible spectrum. RADARSAT sensors capture the Earth's transmitted energy within a single microwave frequency, known as C-band (5.6-cm wavelength) which generates one channel of data. As the active sensor or antenna, RADARSAT's Synthetic Aperture Radar (SAR) transmits a microwave energy pulse to Earth. The SAR measures the amount of energy that returns to the satellite after it interacts with the Earth's surface. The steerable SAR antenna has seven beam modes and 25 beam positions, as well as multiple image modes (RADARSAT International 1998).

RADARSAT's SAR does not collect data continuously, as the satellite is programmed to use specific beam positions only when a data request has been made (RADARSAT International 1998). A RADARSAT image can only be acquired once the orbital path of the satellite aligns with the target area (Rosenfeld et al. 1996). RADARSAT was designed to be sensitive to a diverse range of application requirements and responds well to earth's surface features, such as surface roughness, topography, land/water boundaries, anthropogenic features, and moisture. RADARSAT can penetrate clouds, rain, fog, and other atmospheric disturbances due to the longer wavelength of its single band. This "all-weather" remote sensing tool can be effectively used to analyze annual innundation areas in conjunction with multi-spectral maps and ground truth studies (Rosenfeld and Bloomer 1995).

The RADARSAT imagery for this study, with 12.5-meter resolution, were collected for selected regions of Bangladesh at different times of the year. The flooded image was collected on 28 August 1996, during monsoon rains. It was collected in SAR standard 2-beam mode, which indicates an incidence angle of between 24.1° and 30.9°. The non-flooded image was collected less than a year later, during partial overcast by clouds on 3 July 1997, in SAR standard 6-beam mode, indicating an incidence angle of between 41.7° and 46.5°. The day/night and cloud-penetration characteristics of radar may be the only practical means of mapping the extent of monsoonal flooding of the deltaic plain, where a large rural population is forced to adapt to seasonal isolation in a flooded landscape. Maps of rural hamlets and isolated flood refuge sites will never keep pace with the growing population and constantly changing fluvial landscape without the use of high altitude remote sensing satellites such as RADARSAT.

The image processing software package utilized in this study is The Environment for Visualizing Images (ENVI), a robust and easy-to-use image processing system which provides analysis and visualization of single-band, multispectral, hyperspectral, and radar remote sensing data (ENVI 1998). ENVI was installed onto a Microsoft Windows NT platform. Byte RADARSAT data files are read into ENVI by selecting the RADARSAT option from the remote sensing formats menu. ENVI then automatically extracts the needed header information and enters the image band into the available bands list (ENVI 1997). The image is easily viewed, interpreted, and processed using the graphical user interface (GUI) and menu system.

STUDY AREA

The city of Dhaka and surrounding area just north of the Ganges-Meghna river junction was chosen for this particular study. The total area of the study site is 602 square miles. RADARSAT data were collected for this site on several different dates. The two dates chosen for comparison between flooded and non-flooded times of the year are 28 August 1996 and 3 July 1997, respectively (Figure 2). The imagery's single frequency band was viewed in gray scale, which allows for relatively straightforward delineation of floodwaters, as the water appears considerably darker than the surrounding drier land. The "brightest" or lightest image returns are produced by dense, angular objects that are either on dry land or protruding from the floodwaters (Rosenfeld et al. 1996), such as urban buildings, bridges, and other man-made features.

Figure 2. Study area, just north of the Ganges-Meghna river junction on (a.) 28 August 1996 and (b.) 3 July 1997.

(a.) Study area on 28 August 1996.

(b.) Study area on 3 July 1997.

In the case of Bangladesh, some of the brightest returns are produced by corrugated metal roof sheets, often a family's most prized possession, which allow for detection of isolated flood refuge sites and rural villages. Villagers use these strong roofs as high ground refuges as they stand in the village, or they temporarily relocate, often taking the metal sheets of the roofs along to wait out the floods. In some instances, villagers are forced to build platforms in clumps of trees, taking with them only minimal supplies and reserves (Rosenfeld 1994).

The images clearly define areas that have been flooded (the darkest areas) through the use of raw data alone. The spatial distribution of the flooded areas appears to be concentrated very near to rivers and streams and to much of the land immediately surrounding Dhaka. The area of the DND polder in southeastern Dhaka (Figure 3) is an exception to the flooded areas, as it is kept dry through the use of man-made levees. Using this imagery, detection of flood refuges along roads and dikes will assist in determining the flood response strategies that produce severe crowding and public health problems in urban complexes.

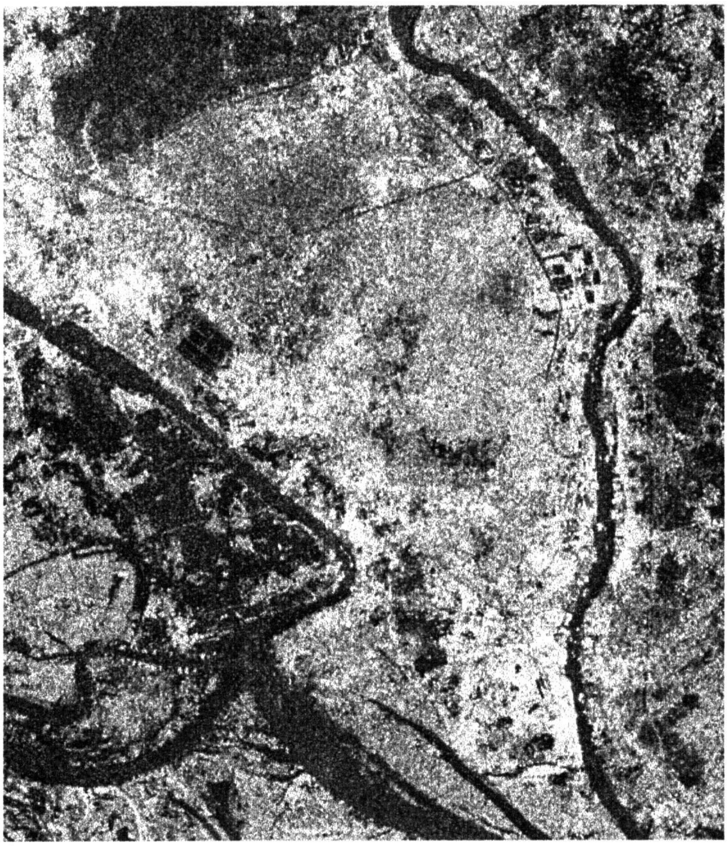


Figure 3. DND polder in southeastern Dhaka (28 August 1996).

METHODS

Spatial Filtering

Filtering a digital image alters the textural appearance of an image. This technique is used to enhance different scales of digital number, or tonal, roughness. It is also used to remove or reduce sensor errors obtained during data collection by normalizing individual pixels. The result of applying a filter depends on the value of the pixel being processed as well as that of the surrounding pixels, those in a single pixel's neighborhood (Avery & Berlin 1992). The process of evaluating the neighboring pixel values is called two-dimensional convolution (Jensen 1986).

Specific types of filters emphasize certain spatial frequencies and suppress others. "High-pass" filters emphasize detail in an image and maximize surface roughness throughout the data. Conversely, "low-pass" filters produce a smoother resulting image by suppressing the high spatial frequencies. The spatial filter is a subarray, window, or kernal, which may be square or rectangular in shape and a variety of sizes based on the anticipated result. For a low pass filter, the kernal moves in one-pixel increments across the image in both directions (left-to-right as well as top-to-bottom) until all pixel values in the original image have been replaced with kernal averages. A rectangular kernal would emphasize directional features in an image, whereas a square kernal would focus only on smoothing or sharpening the image. As kernal size increases, greater effects of smoothing or sharpening are produced (Avery & Berlin 1992).

As the raw data for this Bangladesh study appeared to be lacking any major data collection errors by sight, it was unclear as to whether a filter needed to be applied before further analysis. Statistics were calculated and histograms were created from the two images (flooded and non-flooded scenes) to evaluate any inaccuracies in the data. Statistics for each raw image are as follows:

	flooded image	non-flooded image
minimum value:	0	0
maximum value:	255	255
mean value:	104.9	120.7
standard deviation:	76.5	79.1

Both flooded and non-flooded images contained spikes in the digital number range at values 0 and 255, the lowest and highest values in the data (Figures 4 and 5).

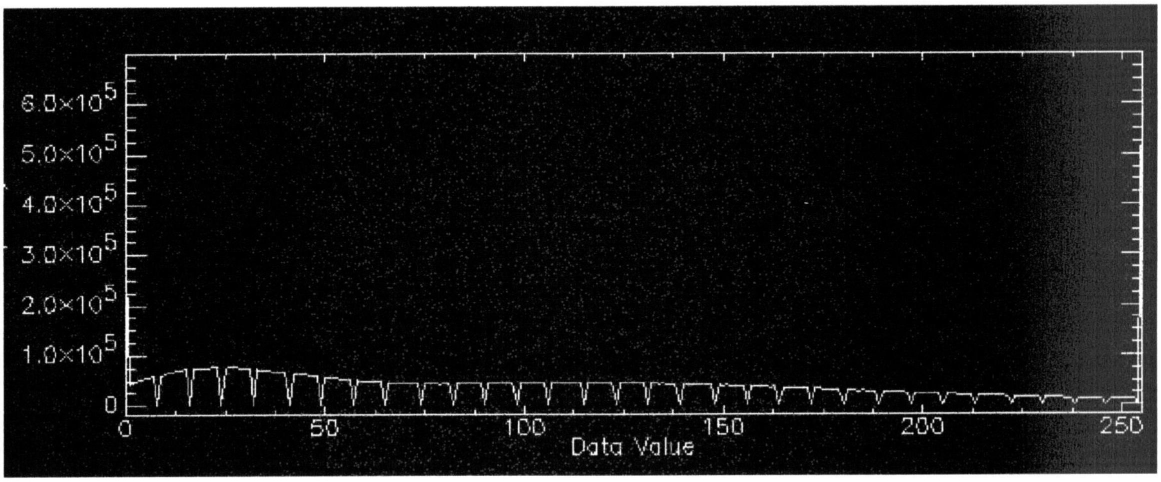


Figure 4. Histogram plot of raw data collected 28 August 1996.

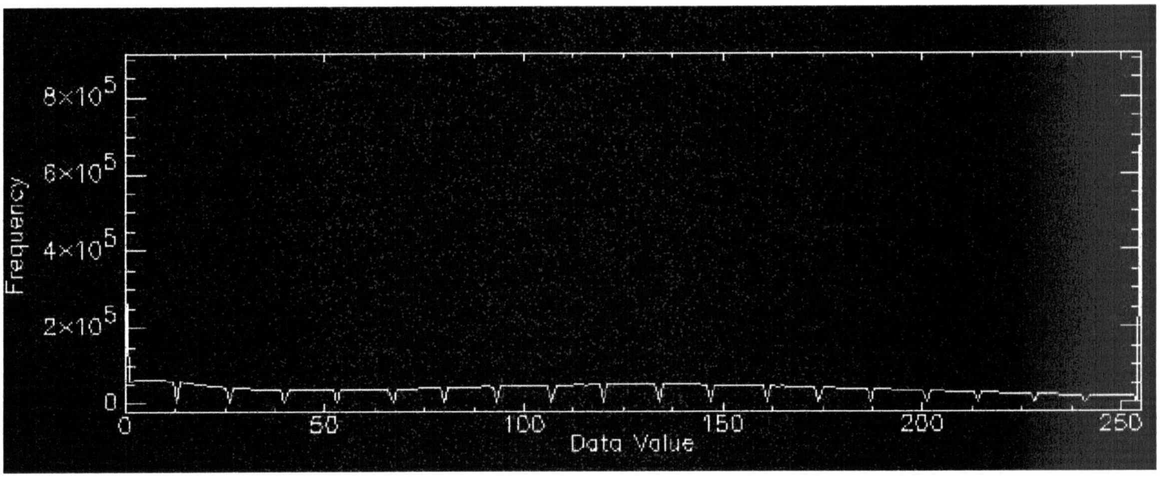


Figure 5. Histogram plot of raw data collected 3 July 1997.

In addition to those spikes, there were evenly spaced dropped out values in the digital number range, which no pixels carried. In the flooded scene, no pixels carried the values of 8, 16, 24, 32 and the remaining factors of eight (plus or minus one) throughout the range. In the non-flooded data, collected nearly one year later, pixels with values of 13, 26, 40, 53 and the remaining factors of thirteen (plus or minus one) up to 255 were missing. At this point, it was evident that some amount of error occurred in the original data, which needed to be filtered out.

The ENVI image processing package offers a variety of filter types. In order to smooth the digital number values without altering the Bangladesh images extensively, a low pass filter was chosen. Different kernal sizes were tried on the flooded image to visually determine the amount of smoothing resulting from each (Figures 6 and 7).

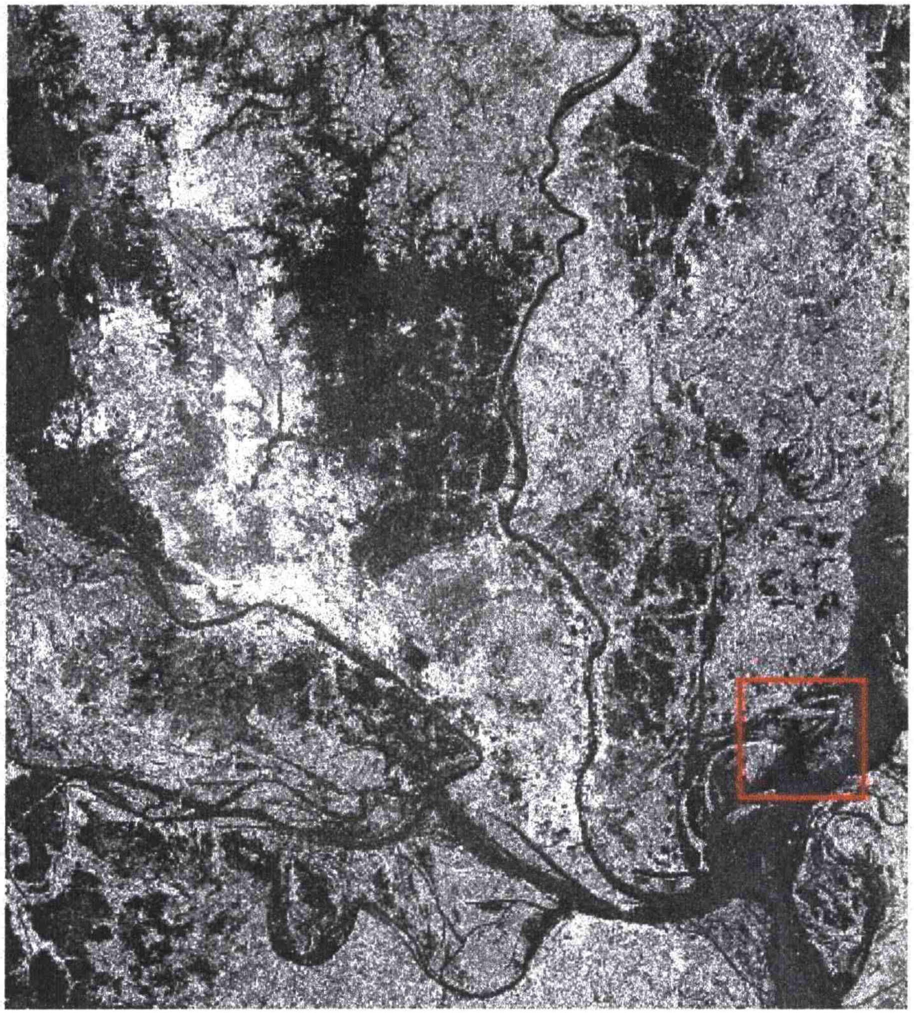
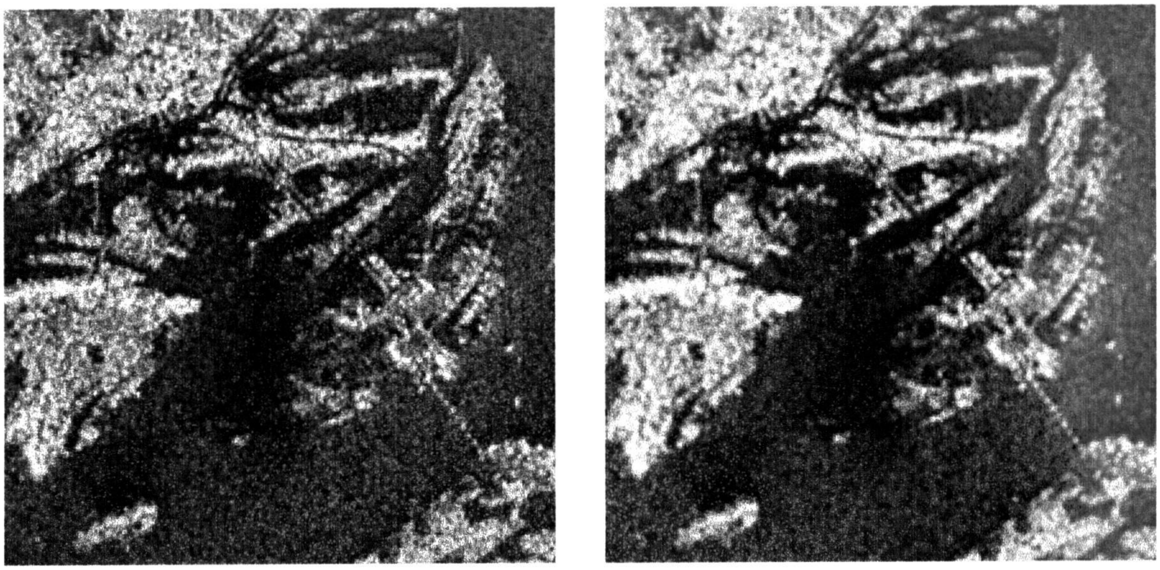
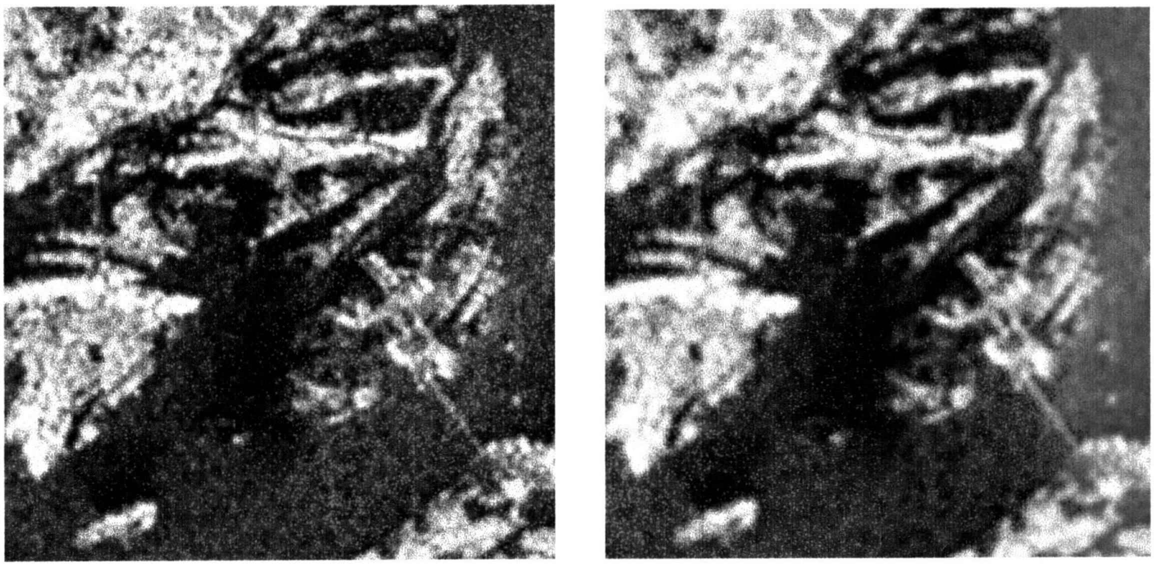


Figure 6. Location of site used to test filter kernals (28 August 1996).



No filter

3 x 3 filter



5 x 5 filter

7 x 7 filter

Figure 7. An image subset showing different filter sizes tested: raw data (no filter), 3 x 3, 5 x 5, and 7 x 7 (28 August 1996).

Statistics for the images after filtering with a 3 x 3 kernal are as follows:

	flooded image	non-flooded image
minimum value:	0	0
maximum value:	255	255
mean value:	104.5	120.2
standard deviation:	67.4	69.7

Histograms from the filtered images produced well-smoothed curves, lacking any severe peaks or absences of data (Figures 8 and 9). A spike remained in the digital number value of 255 in both the flooded and non-flooded images, yet these peaks were within the numeric range of the other filtered data, so they were determined to be appropriate and representative of the actual amount of bright returns in the images.

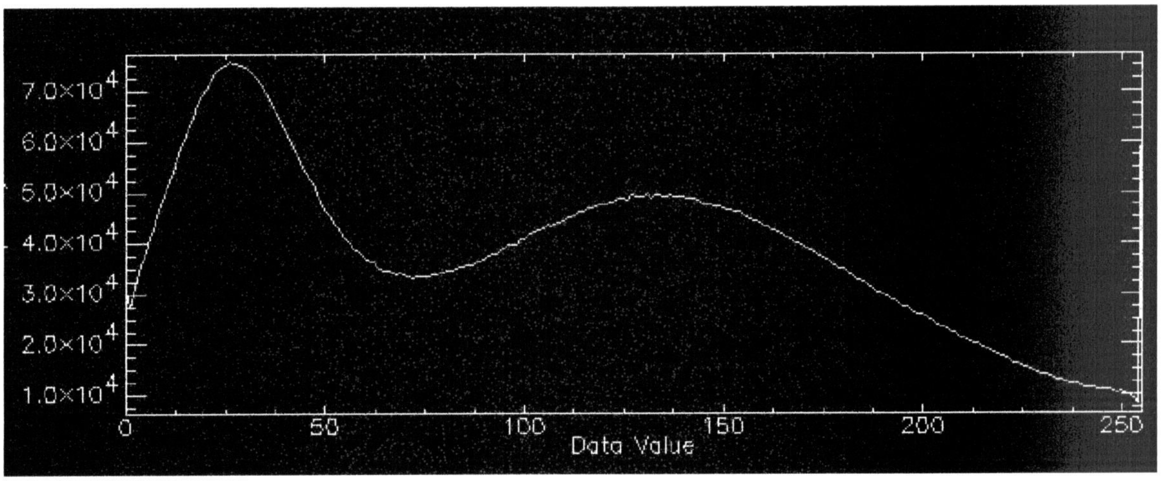


Figure 8. Histogram plot of filtered data, using a 3 x 3 kernal (28 August 1996).

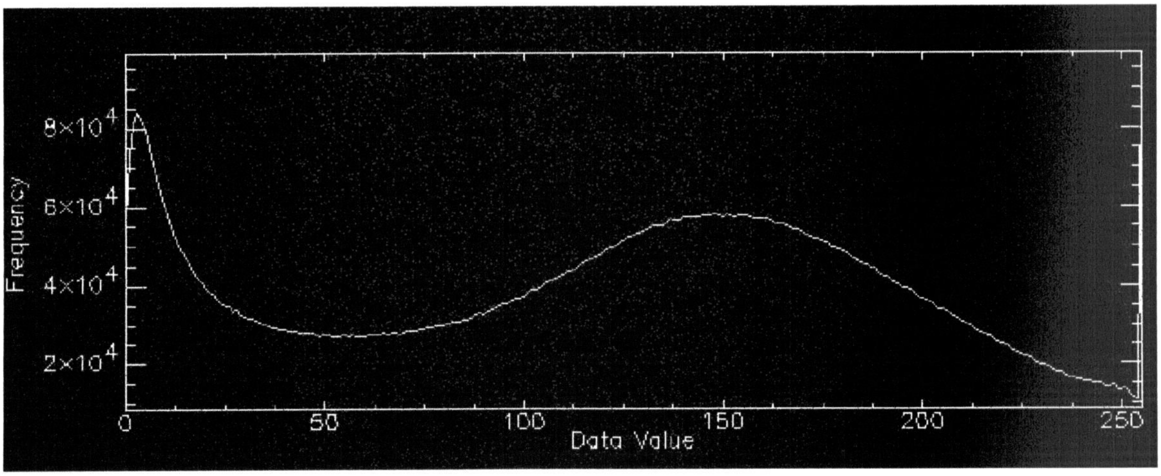


Figure 9. Histogram plot of filtered data, using a 3 x 3 kernal (3 July 1997).

As each of the histograms resulting from the different kernal sizes appeared similar in shape, it was determined that the 3 x 3 filter would be used for the analysis.

This decision was based on the importance of keeping the data as close to the original as possible. Too much filtering may result in losing resolution to the degree that some of the brightest pixels representing small villages may be "smoothed out". Since the focus of the study is to locate the isolated villages for providing emergency relief, only slight smoothing was desired. The necessary step was to smooth or average the digital number values, and the 3 x 3 filter produced the intended results.

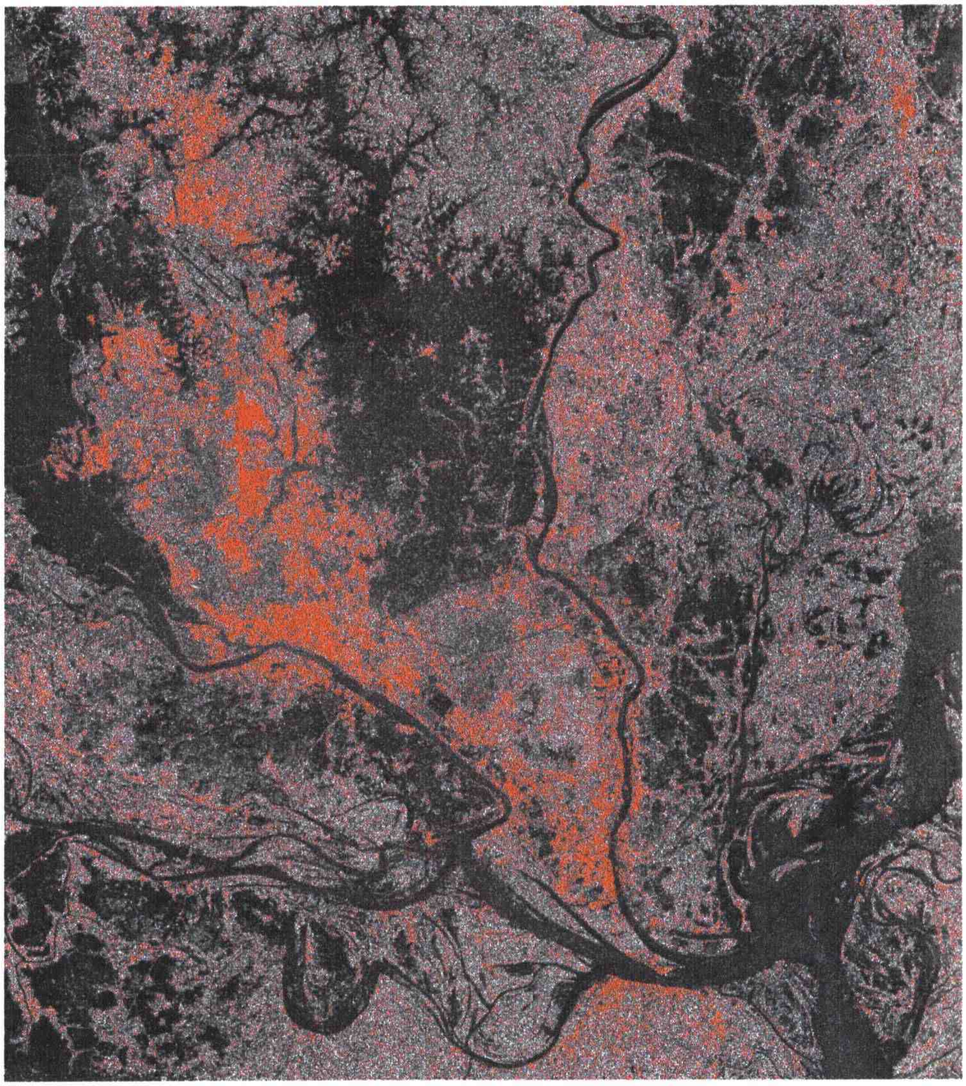
Regions of Interest

One of ENVI's interactive functions involves the delineation, processing and interpretation of Regions of Interest (ROIs). ROIs are graphically-selected image subsets, which are often drawn by the user (ENVI 1997). These regions are usually irregularly shaped and are typically used to extract statistics for classification, masking, and other operations. ENVI allows the selection of any combination of polygons, points, or vectors as a Region of Interest. For this study, ROIs were determined by an image threshold selection. Pixels with specific digital number values and ranges of values were selected for conversion to Regions of Interest.

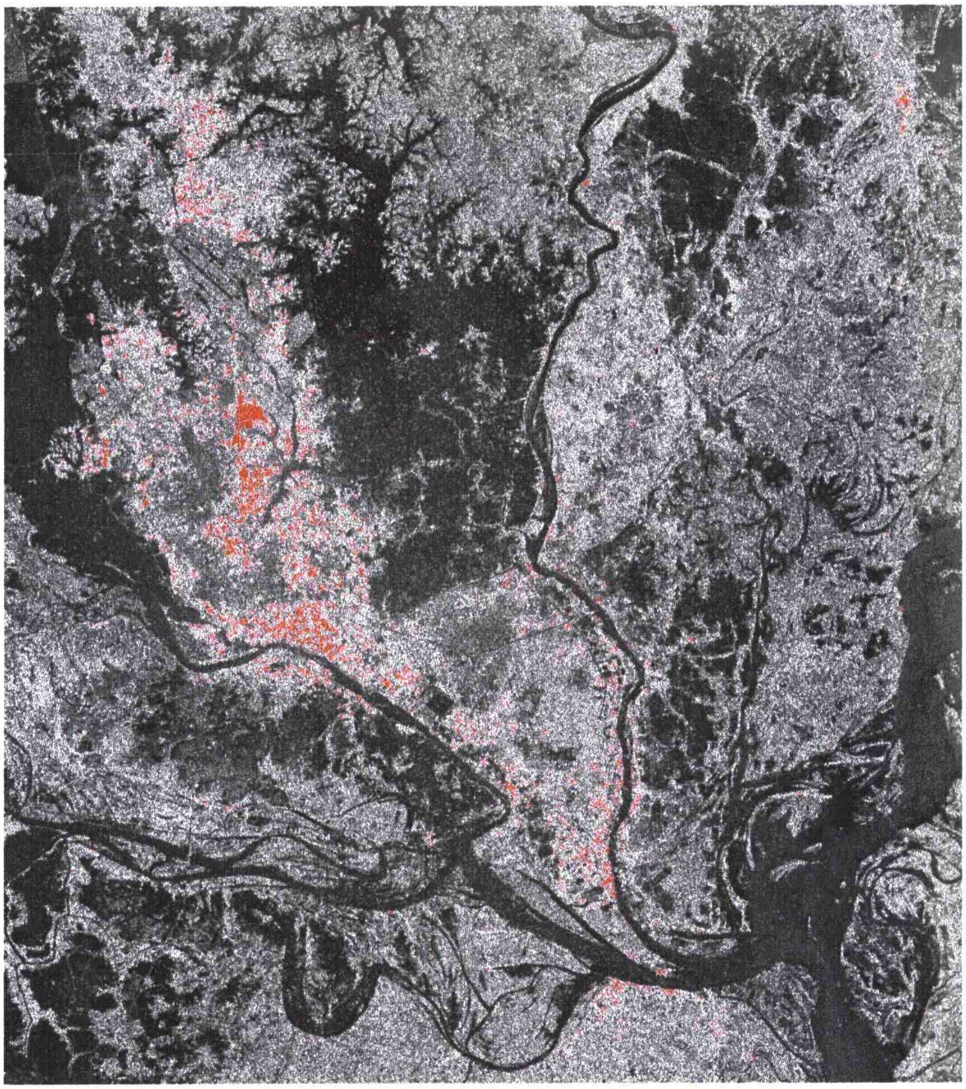
Once the appropriate filter was chosen and applied to each of the images, a threshold of digital number values representing those pixels identifying villages needed to be determined. It is known that the buildings and corrugated metal roofs would likely appear brighter than any other feature in the images, so thresholds were created to always consist of values up to and including 255.

Since the selected threshold range would always include 255, an initial range containing only this value was selected. The spatial distribution of the brightest pixels was observed in both the raw data and the 3 x 3 filtered data in the flooded image, for comparison (Figure 10).

Figure 10. The distribution of digital number 255 in both (a.) raw and (b.) filtered data, respectively (28 August 1996).



(a.) Raw data.



(b.) Filtered data.

It appears that this single value selects a high proportion of the urban areas in the raw data, as expected, but it also selects a large amount of what appears to be random noise throughout the rest of the image. In the filtered image, many parts of urban Dhaka are selected, while most of the noise, which was present in the original data have been removed. More specifically, digital number 255 covers an area of 41.28 square miles in the raw data, and only 4.57 square miles in the filtered image. The 3 x 3 filter averaged out nearly 89 percent of the large value-255 spike, which was present in the original flooded data. For the non-flooded image (not shown), the raw data contained 53.81 square miles represented by digital number 255, whereas the filtered data contained 5.83

square miles. The filter was responsible for an 89 percent reduction in the large value-255 peak in the non-flooded data as well. By observing the filtered data for the flooded image with this single value range selected, it is apparent that the value 255 contributes significantly to selecting urban areas and larger villages. A widening of this threshold range to include "less bright" values would aid in selecting smaller villages, with fewer metal roofs, throughout the image.

In attempts to efficiently select the smaller, isolated villages as well as larger urban areas throughout the image, threshold ranges applied to both flooded and non-flooded images include the following: range 235-255, range 225-255, and range 215-255. These thresholds were selected as ranges which contain an even number of pixel values, plus the value 255. In each threshold applied, an addition of ten values is included. The lowest value chosen in any threshold is 215, as noticeably scattered noise pixels were being selected with lower values in the range. Area measurements and statistics were calculated for each Region Of Interest, including the mean, standard deviation, and minimum and maximum spectra for each region (ENVI 1997).

RESULTS

Threshold Comparison

Three known rural villages of varying sizes were chosen for comparing the pixels selected by each threshold. The mapped locations of these villages are shown in Figure 11. The thresholds were characterized as to whether or not the village was selected without additional noise. In the case of Bangladesh, villages are often formed in a linear fashion, along a main road or along a stream. In this study, noise is defined as apparently random pixels that cannot be determined to be part of a village or other known feature. Frequently, these noise pixels are observed to be within an otherwise dark, flooded area in the image.

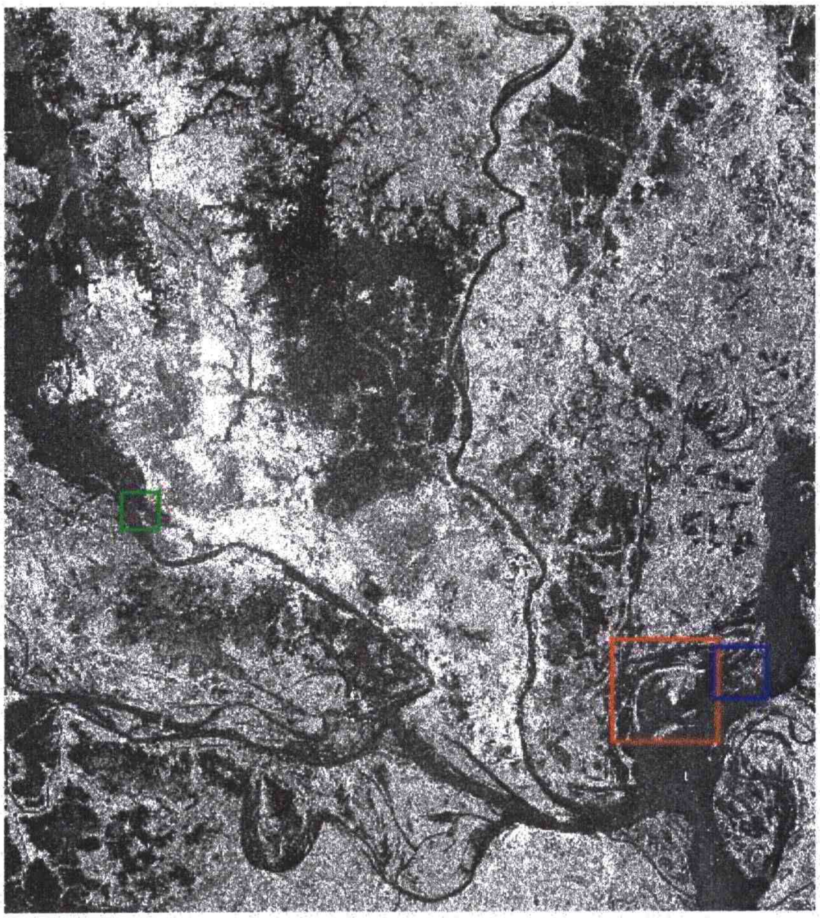
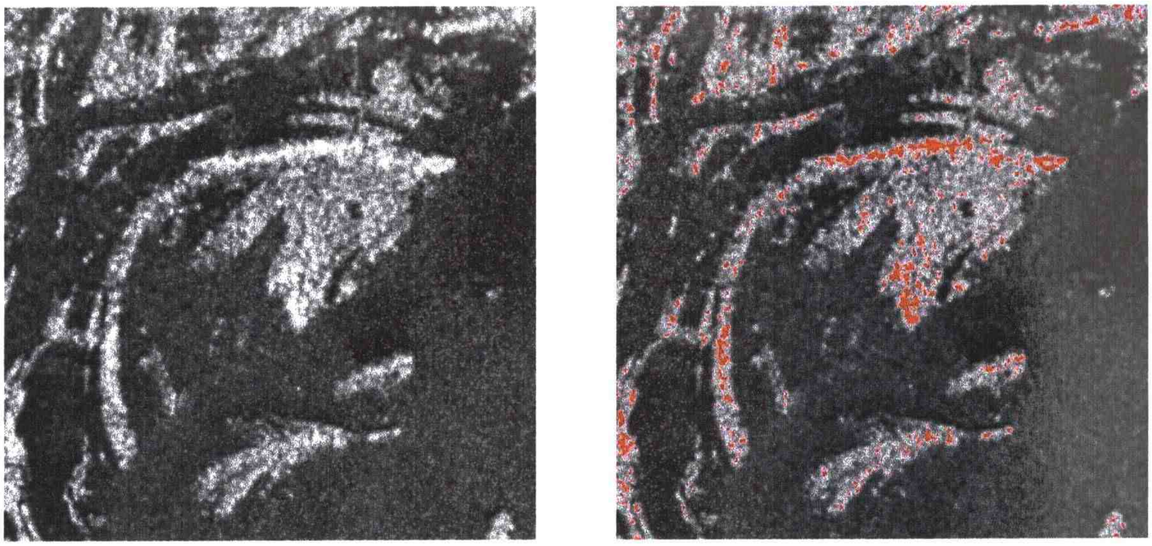


Figure 11. Location of three villages used in threshold comparison analysis: red indicates Village 1, blue indicates Village 2, and green indicates Village 3 (28 August 1996).

Village 1 (Baushia, Bangladesh) is located southeast of Dhaka near the Meghna River. This village is formed by at least five small hamlets along an embankment. Metal roofs can be seen on individual buildings in the photo below (Figure 12).

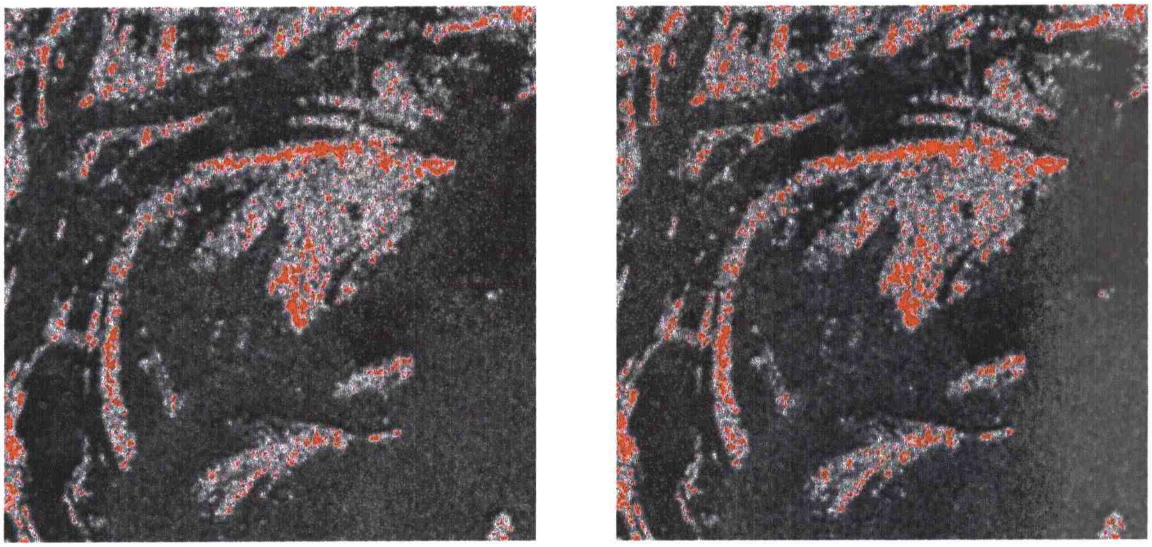
Figure 12. Village 1 (Baushia) is formed by five small hamlets along an embankment.

This village as selected in the radar image area is 9.65 square miles. The areas with the strongest return signal can be seen in white on the image labeled "No threshold" in Figure 13. With the thresholds applied, these white areas are mapped in red, indicating their inclusion in the selected set. The number of pixels expands in each additional threshold, illustrating the larger selections created by the wider threshold ranges (Figure 13). This elongate village appears to be partially selected in each of the threshold images. What appears to be some random noise is seen in the largest threshold range, 215-255.



No threshold

Threshold 235-255



Threshold 225-255

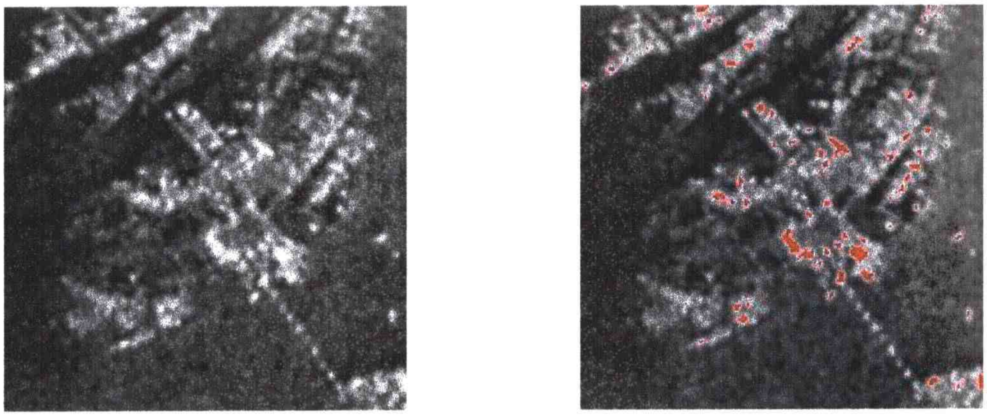
Threshold 215-255

Figure 13. No threshold, Threshold 235-255, Threshold 225-255, and Threshold 215-255 applied to Village 1 (28 August 1996).

Village 2 is located adjacent to the east side of Village 1, near a large bridge. Metal roofing on boats and houses can be seen near a bridge construction site (Figure 14).

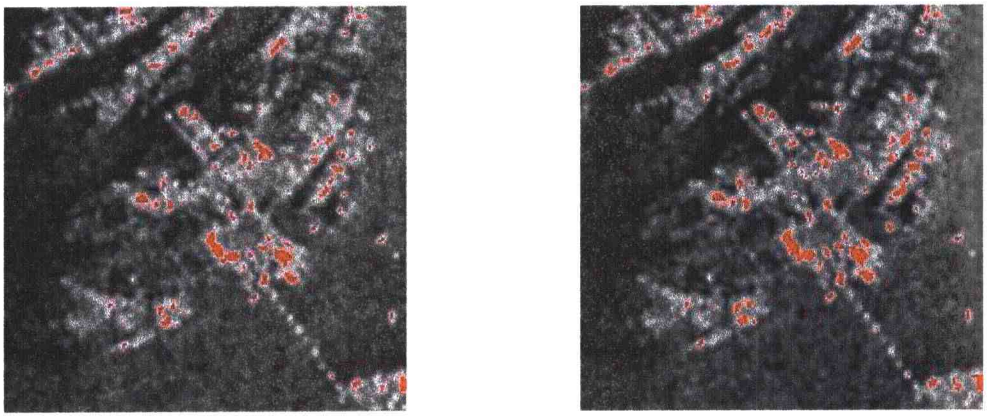
Figure 14. Boats and houses near bridge construction in Village 2.

This village is smaller than the first, covering an area of 2.44 square miles on the image. The individual pixels are easy to see in this smaller image subset. Again, the strongest backscatter area is visible without any applied threshold (Figure 15).



No threshold

Threshold 235-255



Threshold 225-255

Threshold 215-255

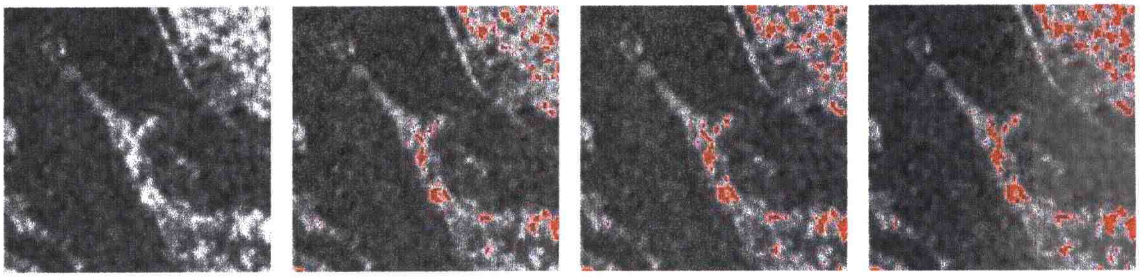
Figure 15. No threshold, Threshold 235-255, Threshold 225-255, and Threshold 215-255 applied to Village 2 (28 August 1996).

In this village scene, the number of additional pixels selected upon the application of each subsequent threshold is more apparent due to the ability to see individual pixels. Threshold 235-255 selects a part of each village area, while Threshold 215-255 selects a few areas outside the village (noise).

Village 3 is located west of Dhaka and is the most urban and smallest of the three villages chosen for comparison. The construction of temporary platforms in this village is seen in Figure 16.

Figure 16. Temporary platforms being erected along the edge of an elevated road bed in Village 3.

Its area on the image covers 1.07 square miles. This linearly formed village on a spit in the floodwaters appears to be well selected in each of the three thresholds, with little or no noise (Figure 17). A few extra pixels are seen in the Threshold 215-255 image, but they are less extensive than in the first two villages. Any of the three threshold ranges selects this village appropriately.



No threshold Threshold 235-255 Threshold 225-255 Threshold 215-255

Figure 17. No threshold, Threshold 235-255, Threshold 225-255, and Threshold 215-255 applied to Village 3 (28 August 1996).

After initial comparison between the three thresholds within each of the village areas by observation, it was determined that the middle range threshold of 225-255 selects the villages best overall. Each threshold has its benefits and drawbacks, however. Threshold 235-255 is not as likely to select any extraneous noise, but it might miss selecting some of the smaller villages, which might need the most emergency aid if isolated during a flood event. The largest threshold range, 215-255, should adequately select all or most small villages having some sheet metal roofing, yet it is probable that too much noise will be selected as well. The middle threshold range of 225-255, therefore, seems to be the overall best choice, as it is slightly conservative on either side of selecting, not enough or too much.

For stronger determination on which threshold range most effectively selects villages, ground truthing in Bangladesh needs to be performed. Areas which exhibit the signature of a village on the imagery need to be checked to confirm whether or not they are actual villages, as opposed to other unknown features which may produce a similar signature.

Flooded and Non-Flooded Image Comparison

To visually and statistically assess differences in the imagery due to flooding or drier periods, the same three villages were compared. A subset of each village area was taken from each of the filtered data sources, 28 August 1996 (flooded) and 3 July 1997 (non-flooded). Expectations in the data included an overall "brighter" spectral signature in the non-flooded image due to less floodwater, more contiguous land area in the non-flooded image, and slightly different village locations between the two images to account for temporary relocation during a flood event.

Village 1 (Baushia) appears to be nearly the same size and shape in either of the images, although its boundaries are sharper in the drier (non-flooded) image (Figure 18). Many of the islands between stream channels in the right side of the non-flooded image, as well as the brightest pixels in the lower right corner of the same image, do not appear in the flooded image. Villagers may or may not have lived on these islands prior to the event, which was in progress when the flooded image was collected in 1996.

Flooded (28 August 1996)

Non-Flooded (3 July 1997)

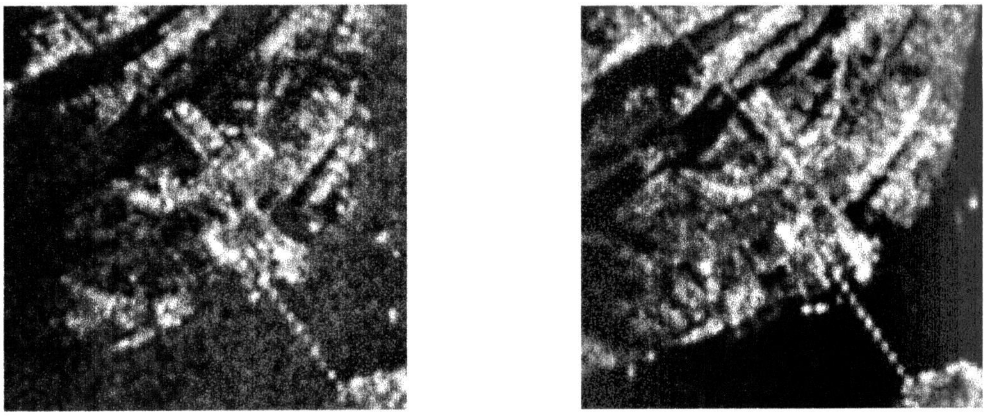
Figure 18. Flooded and non-flooded images of Village 1.

The contrast between the village area and the waterways is heightened in the drier image. Descriptive statistics for Village 1 are as follows:

	flooded image	non-flooded image
minimum value:	0	0
maximum value:	255	255
mean value:	70.1	73.4
standard deviation:	61.5	75.8

The higher values for the mean in the non-flooded image indicates an overall "brighter" signature than the flooded data. The standard deviation, however, is larger in the non-flooded image, which indicates greater variability within the data.

Village 2 shows similar overall features between the flooded and non-flooded images (Figure 19). Heightened contrast shows sharper edges between water and land areas. Some of the brightest pixels in the non-flooded image appear to be more spread out than in the flooded data, perhaps indicating a more densely populated central village area during the flood event.



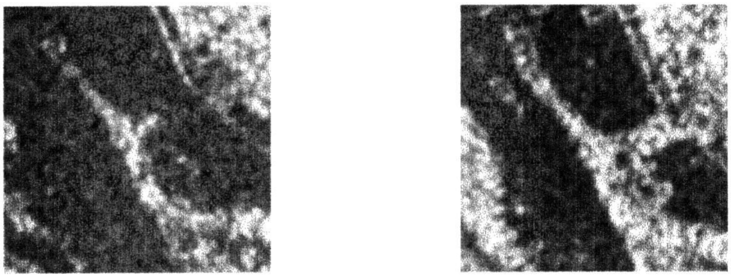
Flooded (28 August 1996) Non-Flooded (3 July 1997)

Figure 19. Flooded and non-flooded images of Village 2.

Descriptive statistics for Village 2, shown below, also illustrate a brighter non-flooded signature with increased variance throughout the data:

	flooded image	non-flooded image
minimum value:	0	0
maximum value:	255	255
mean value:	62.6	66.3
standard deviation:	54.3	67.6

In Village 3, the largest difference in overall signature between the flooded and non-flooded images can be observed (Figure 20).



Flooded (28 August 1996) Non-Flooded (3 July 1997)

Figure 20. Flooded and non-flooded images of Village 3.

Comparison of the descriptive statistics illustrates this difference best:

	flooded image	non-flooded image
minimum value:	0	0
maximum value:	255	255
mean value:	77.5	95.4
standard deviation:	53.8	67.5

A considerable amount more land is shown in the non-flooded image of this small village, and its boundaries with the waterways are more enhanced. Villagers are likely most concentrated centrally in the flooded scene since the amount of drier land is considerably less. Contrast between land and water is increased in the non-flooded images, but not to the heightened degree of Village 1 or Village 2 data subsets.

These selected village areas appear to have been partially isolated on pieces of dry land surrounded by crested rivers and floodwaters, yet it is difficult to fully assess the extent of flood damage to the Bangladesh people solely from a remotely sensed image. Not all households have these metal roofs which can be distinguished on a radar image, so some villages needing emergency flood relief may remain undetected.

CONCLUSIONS

In most flood times, there is a lack of knowledge about what type of relief is needed in which particular areas, especially since there is only sketchy information regarding the location of much of the rural Bangladesh population or its local flood survival strategy (Rosenfeld 1994). Responses to disaster remain at three distinct levels in society: individual or household level, community level, and beyond community level. The national government usually takes the leading role in providing relief to disaster victims, but many non-governmental organizations (NGOs) in Bangladesh have also played leading roles in aiding disaster victims and minimizing hardships through relief and rehabilitation efforts (Paul 1998). RADARSAT imagery may play an important role beyond the community level in providing emergency aid, if obtained in near real-time, during the flood event. The use of remotely sensed data from the RADARSAT satellite has been demonstrated to be integral to part of the rapid analysis of flooding in Bangladesh.

There is disagreement on the subject of flood protection versus mitigation. Some national groups favor structural enforcement (such as the DND polder) and containment of major rivers, while others would rather be prepared to deal with the event and see the floods run their natural course. In either case, the application of radar imagery serves to better assist flood managers and decision-makers in Bangladesh, whether in assessing the status of dikes and levees or getting relief supplies to isolated refuges until the waters subside.

Radar imagery should be a major factor in mapping and remote sensing support during future catastrophic flood events in Bangladesh and elsewhere. The cloud-penetration characteristics of RADARSAT may be one of the only practical means of mapping the areal extent and distribution of monsoonal flooding of the deltaic plain. A center for natural hazards research and training has been established in the Geography Program at the University of Dhaka. Education in the application of GIS and GPS technologies to flood hazard assessment and mapping is already operational. During future events, RADARSAT imagery acquired during a flood could be merged with existing map and image data, downloaded to a field-portable computer, linked to a GPS receiver, and used on site to assist in a variety of emergency service operations from rescue and recovery to damage assessment (Rosenfeld et al. 1996). RADARSAT imagery, in conjunction with previous SPOT, ERS, Landsat, AVHRR, and JRS studies, dramatically improves change detection capabilities and will assist the selection of future flood refuge and relief distribution sites (CONAHA 1992).

RECOMMENDATIONS FOR FUTURE RESEARCH

Standing water is accurately detected with SAR data, even when the open water is covered by vegetation. This characteristic enhances its usefulness in monitoring flood conditions and flood emergencies, particularly in the mangrove forests of Bangladesh. It is important to locate fresh water supplies during flood events, as disease is often one of the largest risks to life during these periods. Areas containing fresh water can be identified on the imagery and used for locating relief efforts if the area is not too remote or inaccessible.

The primary natural resources of Bangladesh include the fertile soils of the delta region, the long growing season, and the heavy precipitation that is distributed over the year in a fashion suited for growing rice and jute (The Far East and Australasia 1993). Agriculture accounts for 32 percent of the gross domestic product (GDP) and 63 percent of employment, so its performance, based on climate, has a direct bearing on the economy as a whole (FAO/WFP 1998). Radar imagery such as RADARSAT can provide information on flood damage to crops and other uses of the floodplain, even after the floodwaters subside.

In coastal storm surge areas, radar backscatter from flotsam and storm debris can improve the mapping capabilities of "run-up" and inundation areas, and would improve GIS predictions of hazard zones. It would also improve assessment of sea level rise in many countries. Exposure to sea level rise and its resultant increase in coastal flooding is a serious issue, which may be monitored using remote sensing on a long-term basis. Much land, particularly agricultural land, would be lost with only a small rise (less than one meter) in sea level over time. More than 90 percent of cultivable land in Bangladesh is already being cultivated, so it would be near impossible to find a replacement if that land is lost to the sea (Broadus 1993). Flood assessment in relation to sea level changes is yet another important issue that requires further study in Bangladesh.

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