BANGLADESH FLOOD ACTION PLAN

Ministry of Water Resources

Flood Plan Coordination Organization (FPCO)

GIS Technology for Disaster Management

A Pilot Study

May 1995

Prepared by

Geographic Information System (GIS)

FAP 19

ISPAN

IRRIGATION SUPPORT PROJECT FOR ASIA AND THE NEAR EAST

Sponsored by the U.S. Agency for International Development

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ACKNOWLEDGEMENTS

This study was a team effort of FAP 19. It was designed and managed by Michael Pooley, Chapal Choudhury, Timothy Martin (FAP 19 Team Leader) and Keith Pitman (ISPAN Chief of Party). Technical support was provided by Pia Afreena Haq and Scott Bartling. The report was written by Timothy Martin and Michael Pooley and edited by William B. Hurlbut.

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ACRONYMS

ADAB	Association of Development Agencies in Bangladesh
BBS	Bangladesh Bureau of Statistics
BCAS	Bangladesh Center for Advanced Studies
BIDS	Bangladesh Institute for Development Studies
BRAC	Bangladesh Rural Advancement Committee
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
DCMU	Disaster Coordination Monitoring Unit
DDC	Design Development Consultants
DEM	Digital Elevation Model
DMB	Disaster Management Bureau
FAP	Flood Action Plan
FPCO	Flood Plan Coordination Organization
GIS	Geographic Information System
GPS	Global Positioning System
ISPAN	Irrigation Support Project for Asia and the Near East
LGED	Local Government Engineering Department
MCSP	Multipurpose Cyclone Shelter Project
MoR	Ministry of Relief
NGO	Nongovernment Organization
RDRS	Rangpur Dinajpur Rural Service
SoB	Survey of Bangladesh
SPARRSO	Space Research and Remote Sensing Organization
SWMC	Surface Water Modelling Centre
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
WB	World Bank

CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 Bangladesh Disasters and FAP

Bangladesh, formed by the confluence of three great rivers and situated at the top of the Bay of Bengal, is among the most disaster-prone nations in the world. Its people annually face a double threat: those in the delta floodplains are subject to severe flooding when rivers overtop their banks or locally heavy rainfall cannot drain off, and those along the coast can be swept away in the storm surge flooding that accompanies periodic cyclones.

Disaster management that can effectively enhance people's ability to survive such calamities and sustain their livelihoods is a fundamental need in Bangladesh, both for the well-being of its people and for its economic development. While the destruction that accompanies a disaster does not discriminate between rich and poor, the latter are the most severely affected by such calamities. Disaster management, therefore has particular relevance for poor and marginal households and as such demands a high priority.

Disaster management consists not only of the aid response to cyclones and flooding but also to preparing for such events. Such a broad view of disaster management recently has been embraced by the government of Bangladesh and institutionalized with the creation of the Disaster Management Bureau (DMB) under the Ministry of Relief (UNDP/UNICEF 1993). It has far-reaching implications for the communications and stockpiling of supplies for a response as well as for institutional mechanisms that effectively warn people of imminent disaster.

As a result of a Flood Policy Study conducted in the aftermath of severe flooding in 1988, the government of Bangladesh established 11 guiding principles for flood protection. Four of these principles, which were subsequently adopted by the Flood Action Plan (FPCO, 1992), relate to disaster preparedness. They are:

- Strengthen flood preparedness and disaster management.
- Improve flood forecasting and early warning.
- Establish floodplain zoning where feasible and appropriate.
- Coordinate planning and construction of all rural roads, highways, and railway embankments and provide for unimpeded drainage.

The Flood Action Plan (FAP) is addressing these principles through various activities including regional plans utilizing advanced planning technology such as the Geographic Information System (GIS). FAP 19 is a supporting study of the Flood Action Plan (FAP) and is one of four activities funded by the U.S. Agency for International Development (USAID) and implemented by the Irrigation Support Project for Asia and the Near East (ISPAN).

1.2 The Magnitude of a Disaster: The 1991 Cyclone

Since 1905 seven severe cyclonic storms have hit the Chittagong coastline (MCSP 1992). The most recent of these was the cyclone of April 29, 1991 that killed an estimated 140,000 people. The impact of that storm has been summarized by the UN (UN Interagency Task Force, 1991), which reports that the storm surge of between 6 and 7.5 m in height extended 1 to 5 km inland in Chittagong District. Despite the fact that about 3 million people were moved to safety—some of them as long as three days before the storm—many people remained behind to face the storm and protect family assets and property. In addition to the loss of homes, assets, and lives, the infrastructure devastated by the storm was extensive; thousands of schools were destroyed, seven to eight thousand vessels were lost, Chittagong airport was disabled, almost every bridge and culvert in the area was damaged, roads were washed out and closed, and all communications with the capital were severed. The area economy was crippled by the loss of more than 278,000 acres of standing crops, 224,000 head of cattle, and many tons of commodities stored in government godowns.

Within two days government air drops of food and medicine started, but they were hampered by continuing bad weather associated with the storm. Nearly two weeks had passed before massive international aid was able to fully mobilize and react to the disaster and it was many months before the area returned to normal.

The government response to the cyclone included issuing warnings of the impending disaster through its Cyclone Preparedness Programme (a joint effort with Bangladesh Red Crescent). Following the disaster, in addition to the air drops of relief, military units were sent to the affected areas to provide security and assistance with relief distributions and burials. Many national and international NGOs also participated in the relief effort following the storm, among them, ADAB, BRAC, CARE, CARITAS, CCDB, Gonoshasthya Kendra, Nijera Kori, OXFAM, PRIP, and Rangpur Dinajpur Rural Service (RDRS). The government and NGO relief efforts were further enhanced by the participation of a Joint Task Force of U.S., British, and Japanese troops under the code name Operation Sea Angel (BCAS, 1991). In addition to transporting and distributing 300 metric tons of relief by the end of May, the task force provided much needed aerial reconnaissance of the coastal region where the cyclone struck and information gathering in the areas affected (Vigoda, 1991). The task force that responded to the 1991 cyclone was an *ad hoc* affair, however, and such aid may not be available the next time an event of this magnitude occurs.

Ultimately, the government of Bangladesh should undertake development of a National Disaster Information System as an integral part of its own disaster management and planning process. Such a system, properly institutionalized, would provide the data necessary to coordinate not only the immediate response of the government and NGOs but also assist planning for disaster preparation, such as the building of cyclone shelters, and long-term disaster recovery.

1.3 Case Study: CARE Bangladesh

CARE Bangladesh, an international NGO, worked very closely with the Joint Task Force following the 1991 cyclone. Since CARE played a large role in the response to that disaster, in connection with this pilot study, FAP 19 conducted a needs assessment with the CARE Disaster Management Unit and regional staff in Chittagong. According to the Chittagong staff, many of whom participated in the 1991 disaster, to meet their immediate needs following a cyclone NGOs like CARE could make use of accurate maps that can be quickly produced and readily revised during the rapidly changing circumstances following a cyclone strike. Detailed maps would allow relief workers to identify distribution points in advance of a disaster, and updated road information following a disaster would help determine the best route to reach the communities in need as well as to make additional assessments.

Moreover, they said, if the impact area of a cyclone could be modelled and vulnerable homesteads identified, then relief could be effectively targeted and quickly mobilized with less reliance on time-consuming reconnaissance and village-by-village information gathering. With accurate, up-to-date demographic data, the quantity of food and other supplies necessary could be acquired immediately or even prior to the actual disaster. (While government godowns are used at times of flood, during cyclone disasters relief agencies rely on private stocks bought in the market.)

The Chittagong CARE staff noted that coordination was haphazard both between NGOs and between NGOs and the government. On several occasions in 1991, for instance, trucks from a variety of agencies converged on the same location, ignoring or missing others that were equally needy.

1.4 GIS and Disaster Management

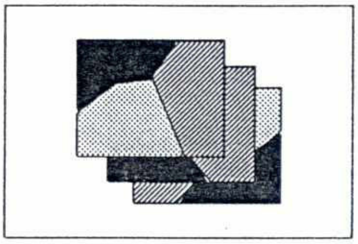
The needs expressed by the CARE staff in Chittagong as well as those of a National Disaster Information System can be met by developing a comprehensive geographic information system (GIS). A GIS, in simplest terms, integrates computer mapping technology with one or more databases to build a series of digital maps that are related to one another through common geographical references. The GIS can then be used to analyze the various features from different maps and derive new information from their relationships.

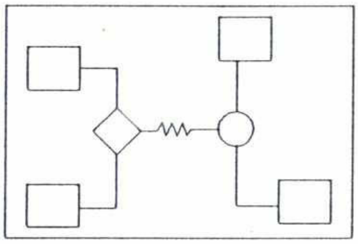
During its inception phase, FAP 19 surveyed potential GIS users and formulated GIS applications and pilot projects that would be of benefit to the FAP. At that time it was obvious that the data analysis and mapping capabilities of a GIS—which can relate such factors as population and housing structure; location of shelters, infrastructure, and flooding extent; economic assets and embankment alignments—could be valuable in formulating strategies to protect people, infrastructure, and the economy from damage by flooding. In a situation such as occurred with the 1991 cyclone, a GIS would be useful for planning the relocation of people and their livestock to safety and for protecting key communications links. After the cyclone, GIS could also be used in assessing the nature and extent of damage and in prioritizing and distributing humanitarian relief. This pilot study, then, represents a first step toward developing a useful disaster management GIS.

More recent discussions with NGOs and government projects confirmed that a comprehensive GIS could be of much benefit, particularly for the cyclone-prone coastal area. It appeared that GIS could be useful in each of the main aspects of disaster management: prevention/risk reduction, preparedness, disaster response, and long-term rehabilitation. **Preventative or mitigative measures**, if incorporated in development plans for areas subject to disaster, should be designed to reduce the disaster vulnerability and risks on a long-term basis. In Bangladesh, protection or hazard reduction includes structural measures such as embankments, drainage channels, and afforestation, as well as flood proofing or vulnerability reduction measures such as zoning and improvements in construction design or standards. **Disaster preparedness** planning and activities are used to warn people of approaching threats, through forecasting and warning dissemination, and to plan the response to potential disasters through contingency arrangements. **Emergency response** activities include not only the rescue and relief needs of disaster victims but also damage and needs assessment, which define the impact of a disaster and make recommendations based on both long-term and short-term needs. After the emergency has passed, post-disaster **rehabilitation** actions are taken to restore infrastructure and services and to enable victims to resume their livelihoods.

As illustrated in Figure 1.1, GIS can benefit all aspects of disaster management. Its most immediate application is for digital mapping—gathering maps from various sources and in different scales and integrating them as desired. The GIS can go beyond simple mapping, however. Once the map and attribute database is constructed, the GIS can then be used to manipulate and analyze the spatial and attribute data to create models and perform other analytical tasks.

GEOGRAPHIC INFORMATION SYSTEM





DATABASE AND DIGITAL MAPPING

ANALYSIS AND MODELLING

Preventive Measures

Database and digital mapping:

Maps at desired scale:
- Historic events and impacts
- Embankments and conditions
- Cyclone shelters, killas
- Forest and land cover

Regional/local management plans
Public awareness and education

Analysis and modelling:

Cyclone shelter design & siting
Land use planning (zoning)
Afforestation studies

Preparedness Plans

Database and digital mapping:

Early warning dissemination network
Location of all relief facilities
Common system for use by all gov't & NGOs

Analysis and modelling:

Interactive impact simulation of approaching cyclone
Storm surge modelling
Risk zone mapping at thana level
Training materials for disaster mgmt.
Early warning dessemination thru linkage of database & digital maps
Vulnerability mapping

Emergency Response

Database and digital mapping:

Base maps for reporting impact & damage
Field maps at desired scale

Analysis and modelling:

Impacts and damage, updated daily
Needs assessment
Briefings and press releases
Coordination & monitoring of relief distribution

Rehabilitation/ Reconstruction

Database and digital mapping:

Damage maps for planning rehab.
Update of base maps following disaster

Analysis and modelling:

Estimation of costs of various scenarios
Monitoring of reconstruction
Input for preventative measures

Figure 1.1 GIS Applications for Disaster Management

One scenario of a useful GIS application is for disaster preparedness in anticipation of an approaching cyclone and for an emergency response to the disaster. As cyclones approach Bangladesh, the Meteorological Department provides frequent updates of the cyclone center, wind velocity, and likely point of landfall. Initial warnings may be issued 48 hours in advance of landfall and are revised as more information becomes available. Frequently cyclones veer away from the predicted path in the period 12-24 hours before landfall and it thus becomes difficult to quantify the population at risk, which may range from as few as 10,000 to several million depending on cyclone severity and location of the affected area.

If a disaster management GIS including a database with population, risk zones, and storm surge scenarios was in place, then GIS modelling could be used to quickly produce an accurate estimate of the population at risk from a cyclone with any predicted point of landfall and intensity. Such frequent updates also could be provided to the emergency warning information network for dissemination or be used in formulating an overall, strategic response.

Once the cyclone hit land and the surge height was known, the GIS could be used to determine the extent of the disaster area, population affected, and supplies and facilities likely to have been damaged or destroyed. Within hours of receiving the information, the disaster management GIS could be printing strategic and logistical planning maps at appropriate scales for dissemination to planners and relief agencies. As more information became available, damage assessment maps and associated data listings could be produced for targeting relief areas and for avoiding constraints in the supply of relief materials.

1.5 Objectives

The objective of this FAP 19 pilot study is to assess the utility of GIS for flood disaster management in Bangladesh. Disaster management, as previously noted, includes all aspects of planning for and responding to disasters, managing therefore both the risks and the consequences of such events.

In this pilot study FAP 19 collaborated with and was assisted by a number of institutions. These included: the Flood Plan Coordination Organization (FPCO); the Disaster Coordination and Monitoring Unit (DCMU), a precursor to the Disaster Management Bureau of the Ministry of Relief (MoR); CARE Bangladesh; and Design Development Consultants (DDC).

1.6 Scope and Structure of the Report

The purpose of this report is to describe the study approach and present the findings of the pilot study, as well as to provide a list of recommended tasks for future implementation by those organization wishing to pursue further. In this pilot study much has been learned about the application of GIS technology for disasters in Bangladesh. The comments, suggestions, and actions stimulated by this pilot study will hopefully lead to action by organizations interested in helping in this important area.

This pilot study has focused on evaluating the use of GIS for anticipating the impact of storm surge flooding in Chittagong District. Anticipatory measures fall into two main categories:

- Preventive/mitigative measures, which reduce vulnerability and risks on a long-term basis.
- Preparedness, which provides warnings when possible and establishes contingency plans and the capacity for emergency response.

The preventive/mitigative GIS application described risk areas and characterized populations within "catchment areas" for existing and proposed cyclone shelters. The techniques used could also be employed to select sites and aid the design of new shelters. The preparedness application produced base maps and vulnerability information superimposed on maps that could be used in disaster contingency planning.

Recognizing that this document is intended for both disaster managers and GIS technologists, the report consists of a general overview of the study results and a more technical annex detailing the methods used to produce those results as well as technical recommendations arising from this pilot study.

CHAPTER 2

METHODOLOGY

2.1 Approach

This study evolved from a series of discussions between FAP 19 and disaster management experts from the MoR, DCMU, United Nations Development Program (UNDP), and CARE. During the course of study, FAP 19 also reviewed reports and literature on disasters and disaster management in Bangladesh, conducted interviews with government and nongovernment organizations in Dhaka and in Chittagong regional offices, interviewed inhabitants of the study area, verified existing data, and collected new information in the study area.

Background information for the study was derived from the Multipurpose Cyclone Shelter Project (MCSP). The MCSP investigated the adequacy of existing shelters and prepared a Master Plan for multipurpose cyclone shelter construction. The plan covered the entire area of Bangladesh that is at risk from cyclones and storm surge, and included a socioeconomic justification for the suggested shelters and their locations.

2.2 The Study Area

The area selected for study (Figure 2.1; figures are at the end of each chapter) is in Chittagong District and includes the coastal regions of Mirsharai, Pahartali, Anwara, Sandwip, Patia, Sitakunda, and Banshkali thanas.

A general database, based on MCSP data, was constructed for the entire study area. Detailed databases and analyses were done only for Sitakunda and Banshkali thanas.

2.3 Data Sources

FAP 19 assembled databases of disaster preparedness information for the study area in collaboration with DCMU, DDC, and CARE. Existing databases contained information on population, water supply, infrastructure, and other characteristics. FAP 19's intention was to utilize these existing data sets and move rapidly to the stage of testing applications, but in fact significant additional data were required to complete the task.

2.3.1 MCSP Data

The principal set of data used was developed by the MCSP for the entire coastal belt of Bangladesh. This digital data required conversion, the details of which are explained in the technical annex and Appendix A. Attempts to use this data highlighted several problems. First, as is the case with most computer-aided design databases in Bangladesh, the data used non-geographic coordinates. This required an extensive effort by FAP 19 to relate the database to universal geographic coordinates. Second, many of the map features in the digital files required extensive editing or redigitizing after conversion to ensure concordance with real physical features.

To check the results of the data conversion and correction, a complete map was then created for each thana and compared with both the MCSP source map and the Survey of Bangladesh (SoB) 1:50,000 scale topographic sheet (the source map for the FAP 19 GIS). For each map, five features (such as road intersections) were then selected and differences in location were calculated by comparing their MCSP coordinates with those of the same features on the SoB maps. The averages of these differences are shown in Table 2.1. The overall average, on the order of 400 meters in both east-west and north-south dimensions, was not considered critical for the regional-level (1:250,000 scale) database being compiled. For local-level mapping (1:50,000 and 1:100,000 scales) and analyses performed in this pilot study, however, such error is excessive and the data was used only for its valuable informational content.

Table 2.1 Feature Location Errors in MCSP Digital Mapping

Thana	Difference between MCSP Data and SoB Maps (m)	
	East-West Dimension	North-South Dimension
Anwara	450	500
Banshkali	750	450
Mirsharai	50	250
Pahartali	450	550
Patia	450	400
Sandwip	140	170
Sitakunda	300	150

2.3.2 Additional Data

Data provided by DCMU, DDC, and CARE was also converted or digitized as required and built into the FAP 19 database. The disaster contingency planning exercise described in Section 2.6 required additional information on location, especially where the limitations of the MCSP data made it insufficient for detailed analysis. In the exercise for Banshkali Thana, road status was added from the field survey using field observation and hand-held global positioning system (GPS) units (accurate to ±50 m). All topographic features for Banshkali Thana were digitized by FAP 19 from the most reliable source, and elevation data was taken from BWDB maps. The actively changing features, rivers and coastlines, were digitized from satellite imagery of October 1990 (the most recent available). Roads and settlement cluster boundaries were digitized from SoB 1:50,000 scale maps (last revised 1985; see Technical Annex).

2.3.3 Field Visit and Needs Assessment

Two field visits were made to the study area, one in May and the other in July 1993. The main purpose of the visits was to identify needs for disaster management from the perspective of NGO field offices and inhabitants of vulnerable areas. The visits were also used to verify base mapping and collect new information such as road type and travel times.

After completing an initial analysis of Sitakunda Thana FAP 19 made the first field visit to Chittagong District. Since the analysis found that Sitakunda had not been seriously affected by the April 1991 cyclone, efforts were redirected toward a second thana, Banshkali, where the cyclone had devastating effects. The field visit to Chittagong was designed to seek CARE's opinion on the Sitakunda analysis and to collect interview information from Banshkali that could be used in GIS surge inundation modelling. GIS results for Sitakunda Thana, including a computer demonstration, were presented to local field workers, regional office administration, and the Dhaka-based staff of CARE's Disaster Management Unit for evaluation in the organization's regional office.

A second field visit in July concentrated on obtaining more interview information on surge height and determining road condition. Most information came from spot checks and an interview with the Assistant Engineer in charge of the thana engineering office.

The findings of the field visits were used to direct subsequent analysis, which focused on identifying vulnerable homesteads and numbers of people likely to be affected by a cyclone disaster.

Table 2.2 Typical Storm Surge Inundation Characteristics for Cyclones of Varying Strength in Bangladesh

Wind Velocity (km/hr)	Storm Surge Height (m)	Limit to Inundation (km from coastline)
85	1.5	1.0
115	2.5	1.0
135	3.0	1.5
165	3.5	2.0
195	4.8	4.0
225	6.0	4.5
235	6.5	5.0
260	7.8	5.5

2.4 Storm Surge Modelling and Risk Zones

The disaster event examined for this pilot study was the flooding caused by the 1991 cyclone storm surge and its associated impacts. The demarcation of coastal areas prone to storm surge flooding is a complex task, but MCSP undertook delineation of a risk zone for the entire coastal region of Bangladesh using a standardized approach (MCSP 1992). The map MCSP produced (Figure 2.2) was the basis for the GIS risk zone analysis. Wind velocity was factored into the analysis based on the reported 235 km/hr winds of April 29, 1991. The surge reportedly travelled at about 2.5 meters per second, advancing 2.25 km in 15 minutes.

The MCSP risk zone map extends from the coast to the inland limit of surge water where property may be damaged by inundation. The most important parameters of this flooding are its depth and duration. Within the risk zone is a "high risk area" where lives may be lost as a result of flooding greater than one meter deep. This map was digitized and used in the study of cyclone shelters in Sitakunda Thana described in Section 3.3.

For more detailed mapping and GIS analysis of risk zones, the study used tables—published in the same MCSP report—estimating storm surge height and inundation limits for cyclones of varying strengths. Results of two such GIS modelling approaches, described in the following sections, were used in the vulnerability analysis.

2.4.1 GIS Modelling of Risk Zones

Various formulas can be used to predict the storm surges that accompany cyclones, but none is wholly reliable and the complex factors involved are the subject of ongoing research. One approach, based on data in the MCSP report, was a reference table showing likely surge height and the inundation limit for a given wind speed. The values in Table 2.2, which provided FAP 19 a basis for GIS modelling, are more refined than those of the regional map in Figure 2.2, but it should be noted that other estimates of surge height for a given wind speed differ widely, and the MCSP figures could be revised in the future.

The inundation estimates in Table 2.2 are only applicable as a guideline where the coastal plain is very flat and there is minimal friction from trees or other obstructions. For areas with large river outlets in the Bay of Bengal, these limits must be modified since those rivers allow deep inland penetration by the surge. Tidal phases, too, are not considered in the estimates.

The GIS used two hypotheses of tidal surge. The first hypothesis, based on the MCSP report, assumed that the surge height remained unchanged for the first kilometer inland. Thereafter it decreased in height by about 0.5 m per km inland. The second hypothesis assumed that after traveling one kilometer inland it suddenly tapered off in a breaking wave.

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2.4.1.1 Linear Method

The hypothesis that storm surge depth reduces linearly inland was supported by the MCSP work. For the GIS modelling, surge height at the coastline was kept constant for the first kilometer; thereafter a linear reduction in height was assumed to the limit of inundation, which was set at 5 km from the coastline. The 5 km limit was based on Table 2.2 estimates or reports of actual inundation limits of the 1991 cyclone.

Once the linear surge model was created, two models, both using the MCSP definitions of risk zone and high risk area, were used to delineate risk zones in the study area. The first model assumed that depth of inundation was equal to surge height and that land relief was smooth, a reasonable assumption for areas such as Banshkali with very flat terrain. In this manner, a GIS map of risk was created directly from surge inundation depth.

The second model for mapping risk zones took account of topographical variation by using a digital elevation model (DEM). It was created from spot elevations and other topographic information on 1:7920 scale BWDB maps. In this model the land surface was subtracted from the surge surface and grouped into one meter increments to produce a digital map of inundation levels with a water level for every 100 x 100 m area. These levels were then converted into a map of risk zone and high risk area as described above.

2.4.1.2 Non-linear Method

The second hypothesis of storm surge characteristics was modelled by simulating a minimal reduction in surge height inland up to the approximate limit of inundation, where the surge height reduced rapidly. Data from a FAP 19 field visit support this model for the flat terrain of Banshkali Thana. Information gathered during the field visit indicated that a wall of water crossed the coastline here and maintained its height until 4 to 5 km inland where inundation tailed off rapidly. As described above and represented in the schematic of Figure 2.3, the area between the coast and the 4 km limit, where inundation was greater than one meter, was determined to be the high risk area. The region between the 4 and 5 km limits, with inundation of less than one meter, was considered the risk zone.

2.5 Preventive/Mitigative Measures

Disaster anticipation measures require adequate risk analysis, which assesses the vulnerability of specific elements (structures, services, or whole communities) relative to a particular hazard. To assess vulnerability, the type of impact and the severity of the event must be described. For this pilot study, the assumed event was again the cyclone storm surge. GIS analysis for preventive/mitigative measures used storm surge risk zones combined with other information to analyze population vulnerability relative to cyclone shelter catchment areas.

2.5.1 Cyclone Shelter Catchments

GIS was used to define cyclone shelter catchment areas and to report the vulnerable population in relation to risk zones. Various GIS techniques were used in an effort to best represent the complex factors which influence the analysis.

Although the numeric values and weightings used in the modelling are thought to be representative of actual conditions, they can easily be changed and the analysis rerun with minimal effort. This is one of the advantages of using a GIS model; once set up, the parameters can be changed and the scenario run again.

2.5.1.1 Buffer Method

The first method used to determine the population service area of each shelter created zones with 3 km radii around proposed and existing shelters in Sitakunda Thana, as illustrated in Figure 2.4. This oversimplified actual conditions, and because overlapping areas could not be reliably and consistently resolved, the method was rejected.

2.5.1.2 Friction Surface Method

The second, more successful method allowed the effects of distance, type of road, wind direction, and land cover to be modelled with relative ease. With this method, a distance/proximity surface was generated where distance was measured as the least effort in moving over a friction surface. Movement incurred various costs depending on the type of surface or land cover. As shown in the example (Figure 2.5), moving along a feeder road required an effort with the equivalent nf one unit for each 100 m grid cell. Moving the same distance through agricultural land required an effort of 5. In other words, it was assumed that people would travel a maximum of 3 kilometers along a feeder road to get to a cyclone shelter but only 600 meters across agricultural land.

Each grid cell (pixel) in the study area was subjected to a friction surface analysis. Pixels with grid cell equivalents less than the specified maximum were assigned to a shelter. Pixels within the limit for more than one shelter were assigned to the shelter requiring the least effort. As illustrated in Figure 2.6, the maximum travel cost, or number of "grid cell equivalents," was assumed to be 30 (3 km).

2.5.1.3 Modifications for Wind and Surge Direction

An important factor in delimiting cyclone shelter catchment areas is whether people will seek shelter following a cyclone warning or wait until the cyclone hits before moving. For the latter scenario, it was apparent from field visits that wind and surge direction profoundly affected the distance people would travel. To illustrate how GIS could accommodate such factors, shelter catchments were divided into quadrants with different wind and surge characteristics. As shown in Figure 2.7, the quadrant closest to the sea was given a friction value of 1 signifying no additional constraint to travel. The leeward quadrant was given a value of 2, since people there would be moving against the wind and water and also because people are very reluctant to run toward the sea in a cyclone. The remaining two quadrants were given values of 1.5. The digital quadrant map was then overlaid with the shelter catchment map created earlier (Figure 2.6) which resulted in modified catchment areas for visual assessment.

2.6 Disaster Preparedness Measures

Disaster preparedness efforts ensure the readiness and ability of the government, other organizations, communities, and individuals to take precautionary measures in advance of an imminent threat and to organize timely response in the event of a disaster.

Disaster preparedness involves:

1) Forecasting and warning dissemination systems for cyclones and floods; and
2) Operational capability (plans, procedures, resources) to ensure timely action at all levels—by communities, government, major institutions, NGOs, and other organizations--when a warning is issued and following a disaster impact.

Several tasks were undertaken to analyze disaster preparedness including preparation of data from a detailed database and modelling and mapping of risk zones. Using these data, GIS modelling was used for vulnerability assessment of a cyclone event.

2.6.1 Database and Disaster Event

Accurate and detailed information is required for many disaster preparedness activities. Mapping at 1:50,000 or 1:100,000 scale is considered appropriate for local-level contingency plans and vulnerability assessment. For these purposes a detailed database, described in Section 2.3, was prepared for Banshkali Thana. In order to link population and other data to the map used in the analysis, FAP 19 digitized administration boundaries to the mouza level. The source for mouza boundaries were copies of original Police Station maps, dating from the early 1900s, which were reconciled with the BBS Small Area Atlas.

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Modelling of a disaster event is required for disaster preparedness; generalized hazard zones do not help those responding to a disaster to assess the number of people affected or the extent of damage to property and crops. For this reason the more detailed GIS risk zone mapping, described in Section 2.4.2, was used for the disaster preparedness exercise of contingency planning.

2.6.2 Vulnerability Analysis

Mouza-level 1991 census data was used as the basis for the vulnerability map themes used in the analysis. The themes selected were: population distribution, weak housing structure, landlessness, and unsafe drinking water.

Population distribution was selected as a vulnerability indicator because it provides the best estimate of affected numbers, gender, and age category. Weak housing structure was chosen because such houses are the most vulnerable to storm damage. Households occupying weak houses are also likely to require temporary accommodation such as tents or simple building materials to help rebuild their homes. For this study, houses reported in BBS statistics as straw/bamboo or tile/CI sheet were classified as weak.

Landless households were included in the analysis because they are likely to have fewer resources than the general population. These households are likely to need basic survival relief for a longer period. Households without access to a tubewell or piped water supply are vulnerable in the aftermath of a cyclone because they may have to drink unhygienic water. These households may resort to using polluted or saline water, which carries the attendant risk of water-borne infection and diarrhoeal disease.

Mouza-level 1991 BBS census data was linked to the maps using BBS geocodes. At first, a vulnerability index for each theme was calculated for each study area mouza. For example, the index for landless households was calculated on a mouza basis as follows:

Vulnerability index = Risk value x (landless households in mouza/area of mouza)

The vulnerability index approach was later rejected in favor of reporting numbers (i.e., quantity of landless, number of households with unsafe drinking water, etc.), wherever appropriate, in order to give planners unambiguous information.

The mouza-based vulnerability themes were modified by mapping actual settlements for Banshkali. Using GIS, the thematic information was then distributed to each settlement according to the area of the individual settlement in proportion to the total area of settlements in the mouza. The Technical Annex details the procedure followed. The level of risk for people in different zones across the thana was then assessed by overlaying each vulnerability theme with the risk zones prepared by the method described in Section 2.4.2.

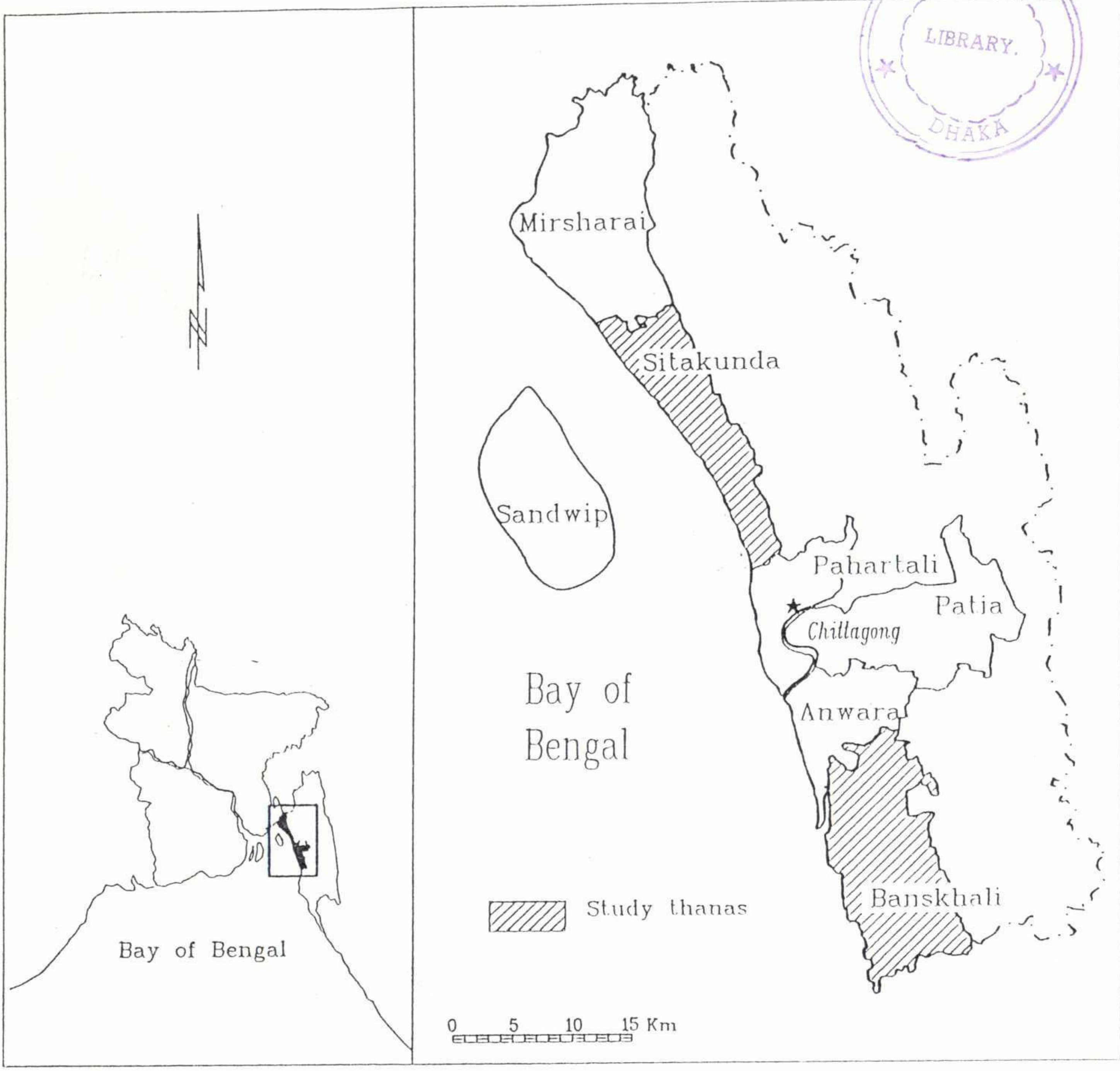

Figure 2.1 The Study Area

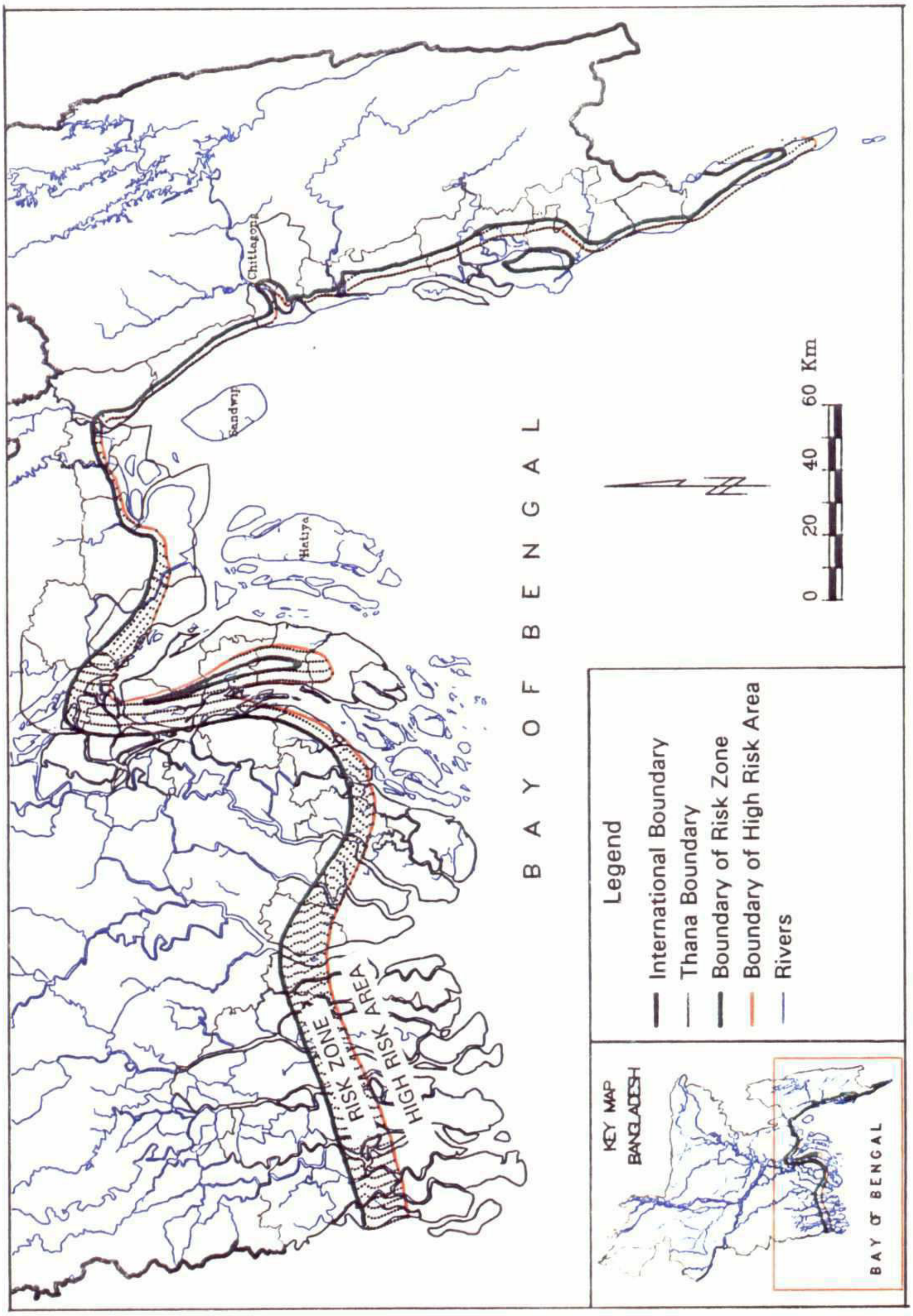

Figure 2.2 High Risk Area and Risk Zone (after MCSP 1992)

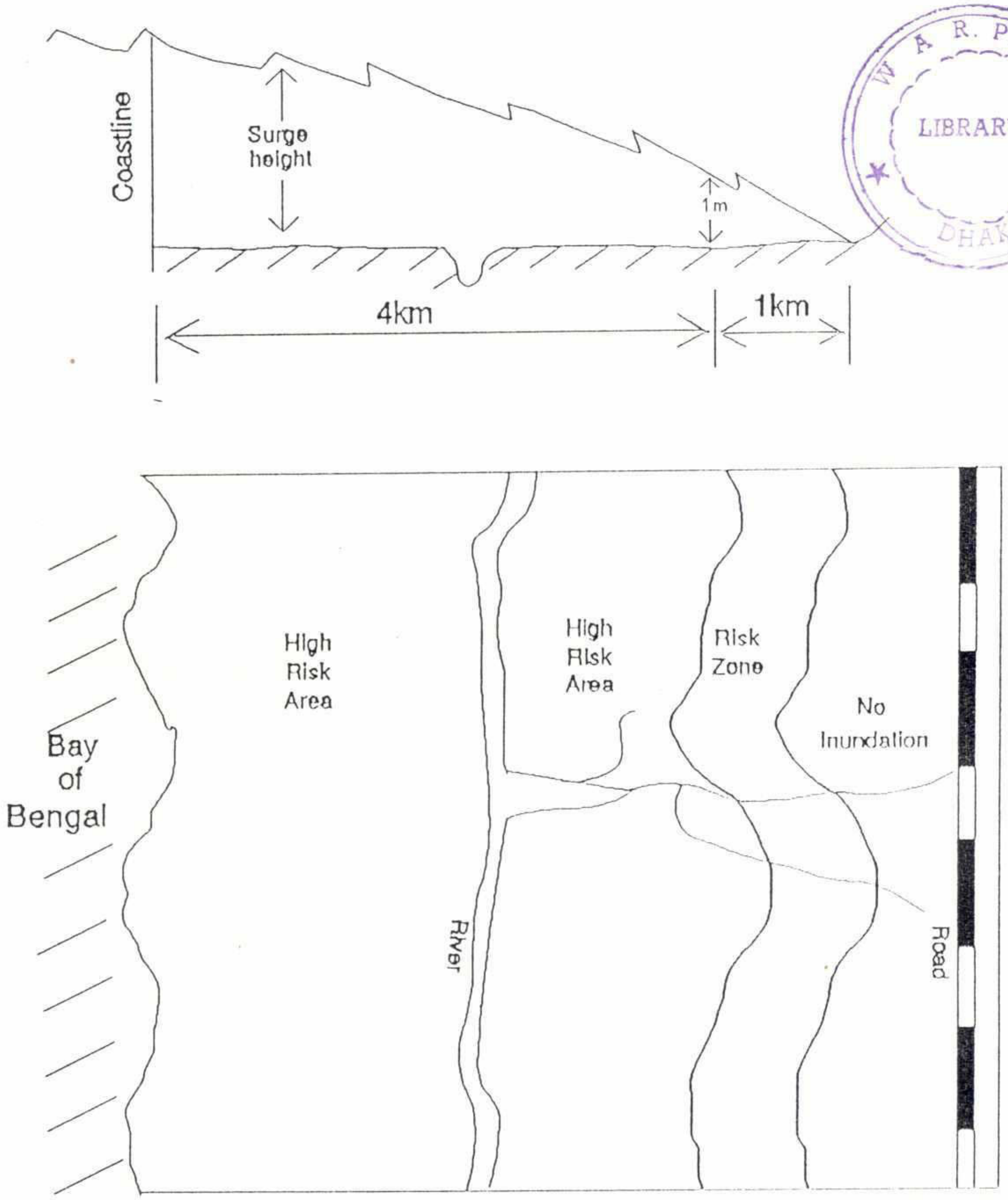

Figure 2.3 Schematic Representation of Risk Zones from a Simple Linear Model of Storm Surge

Figure 2.4 **Buffers of 3 km Around Cyclone Shelters of Sitakunda Thana**

Friction Value	Surface/Landcover
1	Feeder road A & B (highway)
2	Rural road (brick/earthen)
3	Embankment
4	Railway
5	Agriculture land
-1	River/khals

Infrastructure Vector File

0 1 Km

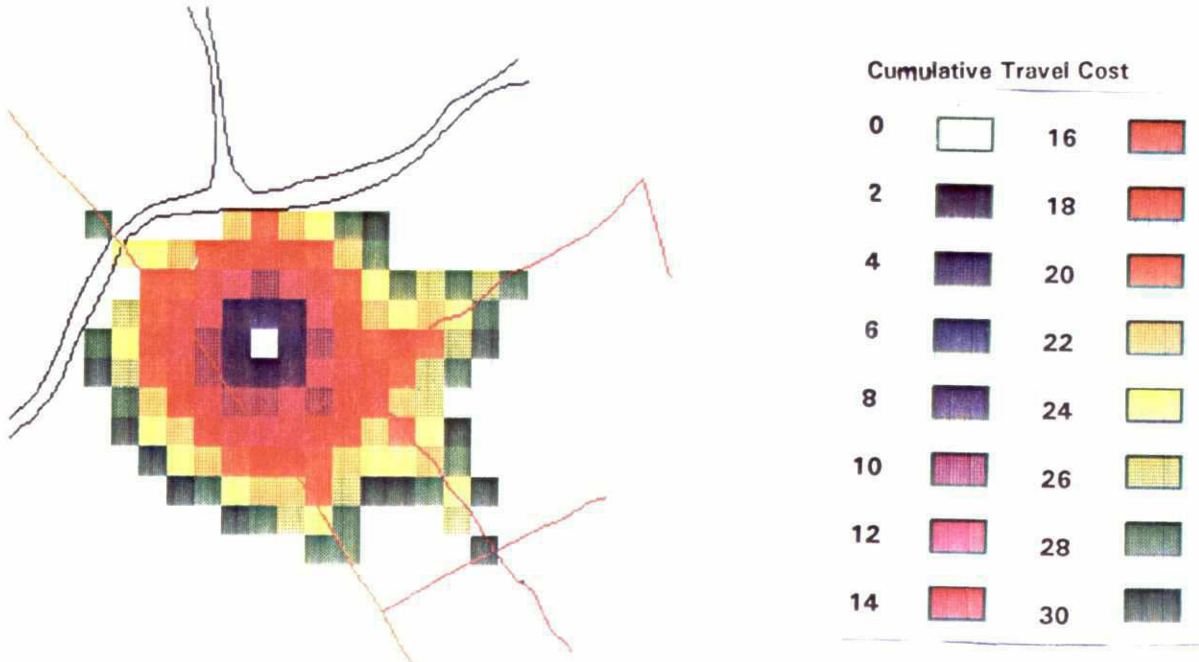

Image File with Cumulative Travel Effort or "Cost"

Figure 2.5 Cyclone Shelter Catchment Area with Distance as Least Effort in Moving Over a Friction Surface

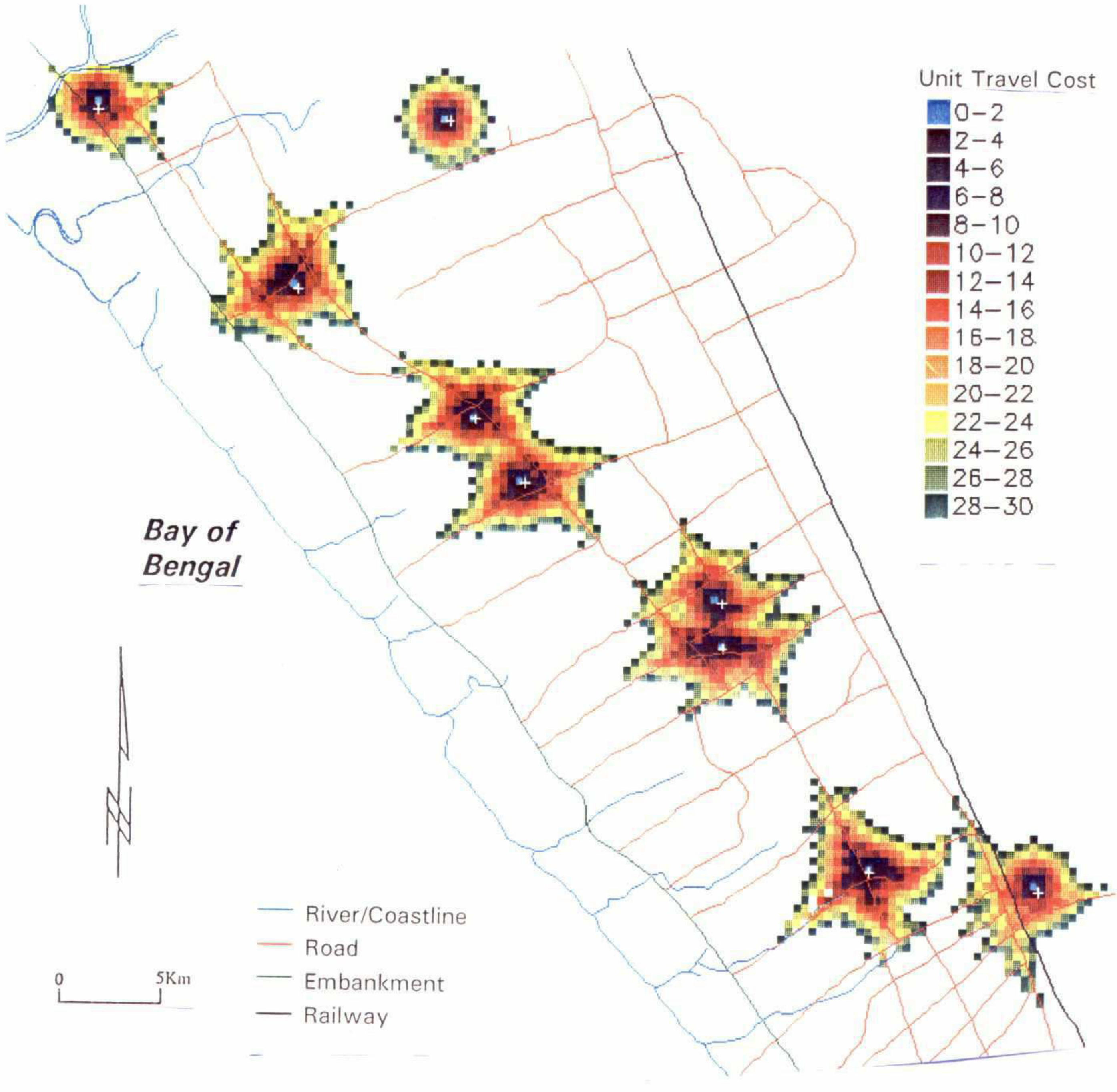

Figure 2.6 Cyclone Shelter Catchment Areas from GIS Friction Surface Analysis

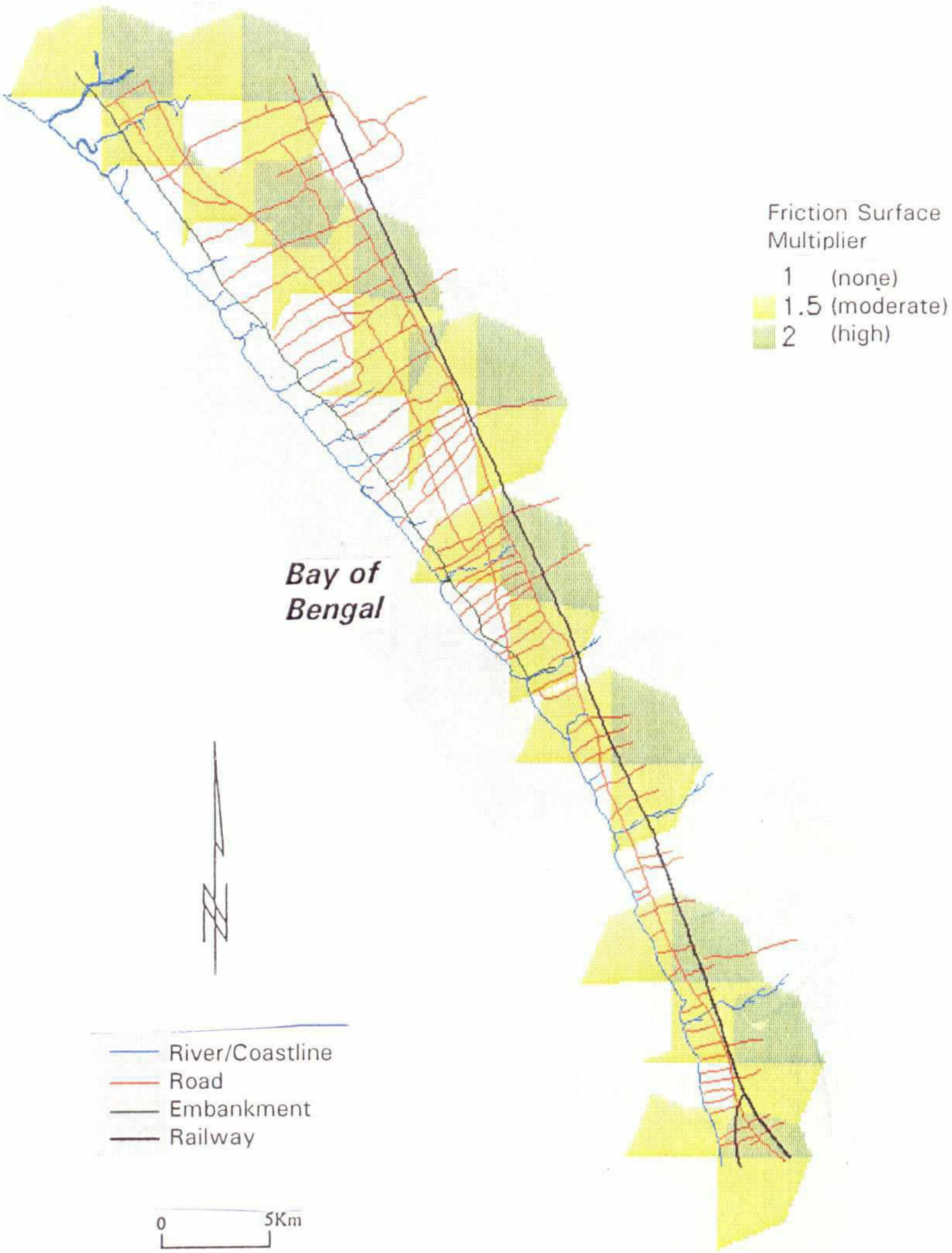

Figure 2.7 **Friction Values Due to Wind/Surge Characteristics Used to Modify Cyclone Shelter Catchment Areas**

Figure 2.8 Landsat TM Image 31 Oct. 1990 with Mauza Boundaries of Banshkali Thana

CHAPTER 3

GIS RESULTS AND DISCUSSION

3.1 Digital Mapping

The digital database built for the study area is a flexible and dynamic means of presenting information. It can be queried to produce maps at any scale and with any selected combinations of data. Among the spatial features of the pilot database are: administration boundaries, roads, railways, rivers, coastline, embankments, and cyclone shelter locations. In addition to feature information such as road type and condition and place names, the associated database includes other attributes, including mouza-level descriptors from 1991 BBS census data.

The utility of this database is further enhanced by the fact that the data it contains is unbiased. In the chaos that follows a disaster the size of the 1991 cyclone, information about vulnerable populations can be subject to manipulation by locally influential people. This can impair the effective distribution of relief supplies, and it is easy in such circumstances for people in need to be overlooked.

The GIS digital database was used to generate all the analyses and maps in this pilot study. As Figure 3.1 shows, important features derived from a variety of sources and in different scales can be combined in the GIS and output as a color map within minutes. This flexibility enables interactive display and mapping that can be used for disaster management planning, damage assessment, and relief activities. Figure 3.2 is a population density map of Sitakunda Thana using mouza-level BBS population data. This simple but effective technique for data display can be applied to most of the MCSP data for coastal Bangladesh. Used alone or in combination with the base maps (such as Figure 3.1) or other map themes it could assist in determining evacuation routes, strategic locations for relief supplies and emergency shelters, vulnerable infrastructure in heavily populated areas, or many other disaster management needs.

3.2 Storm Surge Modelling

Two hypothetical models of cyclonic storm surge were represented using GIS techniques, as described in Section 2.4. It was found that GIS could incorporate either simple or complex models and could represent results in a quantified and unbiased format. The ability to model storm surges can help to identify vulnerable populations and infrastructure.

Figure 3.3 shows storm surge inundation based on a 6 m surge height at the coastline with linear decay beyond the first kilometer inland (Section 2.4.1.1). In this approach, a digital elevation model was used to represent variations in land topography, a factor which will be of greater importance as more sophisticated surge models are developed.

The second storm surge modelling method maintained surge height for some distance inland before rapidly tailing off. In this non-linear model (Section 2.4.1.2), flood depth was generalized into two zones. The risk zones represented on the vulnerability maps (Figures 3.6 through 3.8) were created using two simple GIS distance buffers, one for high risk areas (flooding greater than 1 m depth) and another for the risk zone (flooding 1 m depth or less). Since such broad risk categories were

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Table 3.1 Capacity and Population Served for Shelter Catchment Areas

	Shelter Catchment Population by Risk Zone			Shelter Allocation			
Shelter No.	No Risk	Risk	High Risk	Capacity	From Risk Zone	From High Risk Zone	Surplus or Deficit
1	-	-	382	500	0	382	+118
2	549	-	-	500	0	0	+500
3	-	314	567	1,000	314	567	+119
4	-	603	7	300	297	3	-310
5	-	866	204	300	243	57	-770
6	98	1,798	-	1,500	1,500	0	-298
7	35	3,286	6	500	487	13	-2,872
8	-	2,064	960	1,500	1,024	476	-1,524
9	2,898	2,609	-	300	300	0	-2,309
10	-	-	3,028	300	0	300	-2,728
11	-	-	2,524	1,500	0	1,500	-1,024
12	-	-	1,830	500	0	500	-1,330
13	-	-	2,989	500	0	500	-2,489
14	-	-	195	300	0	195	+105
15	-	-	11,504	1,500	0	1,500	-10,004
16	-	-	318	1,000	0	318	+682
Total	3,580	11,540	24,594	12,000	4,165	5,811	

used, the slight topographic variations of Banshkali were considered to have an insignificant effect on the vulnerability results. The advantage of this approach is its simplicity. It would not, however, be appropriate for areas with more complex topography or when more precision was required.

3.3 Cyclone Shelter Catchments

A variety of GIS techniques were used to model the "catchment" areas of cyclone shelters. The most realistic result was created with the friction surface, as described in Section 2.5.1.2. Using the GIS, the catchment area was combined with a digital map of mouza-level population density and the MCSP risk zones. The result, shown in Figure 3.4, can be used by planners and decision-makers to estimate populations likely to be served by each shelter. Table 3.1 shows population surplus or deficit computations for each shelter catchment. For example, shelter No. 16, which has a capacity of 1,000 people, shows a catchment area population of only 318 people; this suggests that siting criteria for this shelter may have been inadequate. Shelter No. 15, on the other hand, has a capacity of 1,500 but a catchment population of more than 11,000 in the high risk area; this indicates the need for more shelters in the area to cover the large population at risk.

This shelter zoning exercise illustrates how GIS techniques can be used to calculate potential usage of existing shelters or to plan sites for new shelters. If criteria for defining catchment areas are changed, or databases are updated to account for new conditions, then the analysis can be rerun. For example, field results indicate that the maxi-

Table 3.2 Union Population in Banshkali Thana by Age and Gender for Risk Areas

Union Name	Children	Adult Male	Adult Female	Elderly	Total
High Risk Area					
Baharchara	11,531	5,410	6,139	1,355	24,435
Bailchhari	249	137	138	32	556
Chambal	9,967	4,449	4,563	1,068	20,047
Chhanua	9,766	4,695	4,120	733	19,313
Gandamara	10,936	4,727	4,795	866	21,324
Jaldi	936	526	518	117	2,097
Kalipur	3,321	1,635	1,769	476	7,201
Katharia	4,949	2,199	2,544	570	10,262
Khankhanabad	11,633	6,462	6,024	1,265	25,384
Puichhari	11,339	5,371	5,385	1,044	23,139
Pukuria	8,269	3,557	3,720	866	16,412
Sadhanpur	7,148	3,633	3,823	895	15,499
Saral	7,491	6,311	3,643	924	18,369
Sekherkhil	6,948	3,098	3,129	558	13,733
Silkup	5,325	2,617	2,683	544	11,169
Subtotal for High Risk Area	109,808	54,827	52,993	11,313	228,941
Risk Zone					
Bailchhari	549	302	304	70	1,225
Chambal	205	95	95	20	415
Jaldi	1,558	884	869	197	3,509
Kalipur	2,283	1,071	1,176	258	4,787
Katharia	1,216	538	603	129	2,485
Saral	1,713	859	853	171	3,595
Silkup	594	329	313	66	1,301
Subtotal for Risk Zone	8,118	4,078	4,213	911	17,317
Outside Risk Area					
Bailchhari	4,023	2,209	2,139	495	8,866
Jaldi	5,582	3,162	3,098	700	12,542
Kalipur	2,932	1,542	1,602	350	6,425
Katharia	211	100	102	16	428
Saral	341	193	194	31	759
Subtotal Outside Risk Area	13,089	7,206	7,135	1,592	29,020
TOTAL	131,015	66,111	64,341	13,816	275,283

Table 3.3 **Mauza-Based Estimates of Landless Households by Risk Zone (Example Showing 2 of 15 Unions in Banshkali Thana)**

Mauza Code and Name	Number of Households			
	High Risk Area	Risk Zone	No Risk Zone	Total
Baharchara Union				
041 Baharchhara	486	0	0	486
096 Banskhla	197	0	0	197
165 Chapachhari	305	0	0	305
262 Dhandhair	0	0	0	0
345 Ilsa	378	0	0	378
690 Maizpara	9	0	0	9
925 Ratanpur	309	0	0	309
Bailchhari Union				
055 Bailchhari	0	0	503	503
207 Chechuria	58	92	392	542

Table 3.4 Mauza-Based Estimates of Households Occupying Weak Housing Structures by Risk Zone (Example Showing 2 of 15 Mauzas in Banshkali Thana)

Mauza Code and Name	Number of Households			
	High Risk Area	Risk Zone	No Risk Zone	Total
Baharchara Union				
041 Baharchhara	982	0	0	982
096 Banskhla	661	0	0	661
165 Chapachhari	842	0	0	842
262 Dhandhair	0	0	0	0
345 Ilsa	1,520	0	0	1,520
690 Maizpara	100	0	0	100
925 Ratanpur	802	0	0	802
Bailchhari Union				
055 Bailchhari	0	0	1,019	1,019
207 Chechuria	137	218	931	1,286

Table 3.5 Union-Based Estimates of Households Using Unsafe Drinking Water by Risk Zone

	Number of Households		
Union Name	Inside Risk Area	Outside Risk Area	Total
Baharchara	981	0	981
Bailchhari	21	100	121
Chambal	173	496	669
Chhanua	194	0	194
Gandamara	508	0	508
Jaldi	80	249	329
Kalipur	105	292	397
Katharia	295	3	298
Khankhanabad	1,142	0	1,142
Puichhari	22	388	410
Pukuria	226	209	435
Sadhanpur	330	37	367
Saral	418	17	435
Sekherkhil	355	0	355
Silkup	14	9	23
TOTAL	4,708	1,800	6,509

mum distance people are willing to travel to a shelter may be on the order of 1 km. This maximum could be specified in the GIS analysis and rerun to quickly produce new tables and graphics.

3.4 Vulnerability Analysis

Using mouza data from the 1991 census, vulnerability maps were developed for the key variables of population at risk, landlessness, weak housing structure, and unsafe drinking water. These data were combined with zones approximating the risk from a storm surge similar to that of the 1991 cyclone. Results were depicted at different scales and in a variety of formats for demonstration and discussion. The versions presented in this report are subsets of the full maps at approximately 1:75,000 scale and are included for illustrative purposes only; original full-scale maps are available in the ISPAN project office.

The total at-risk population is shown in Figure 3.5, which depicts the total population of each settlement in the risk area in various colors. Settlements outside the risk zone are in yellow. Table 3.2 presents a union-based summary of population by age and gender for each risk area.

Figure 3.6 shows the distribution of landless households. The basis for the map is the total number of landless households in each settlement. These figures were calculated by GIS overlay of settlement boundaries with mouza boundaries. Because the source data is mouza-based, the associated attribute data on landlessness was distributed proportionately to the land area in each settlement; that is, landless household density was

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assumed to be constant throughout the mouza. In this presentation, both the location and numbers of vulnerable households are depicted. This graphic could be used directly for planning, or in the event of disaster, for distribution of relief goods. The map is supplemented with results in tabular form for each mouza, as illustrated in Table 3.3.

The map showing distribution of weak housing structures, Figure 3.7, also presents household data on a mouza basis. In this graphic, settlement areas are ignored and map shading is according to the density of weak houses for the entire mouza. This presentation is easy to construct, and interpretation is simple. If supplemented with tabular information, as in Table 3.4, the map could be used for strategic planning or decision support and the table could provide the details for implementing a plan or for distribution of relief.

The total number of households with unsafe drinking water is depicted in Figure 3.8 for each union. Although data are compiled on a mouza basis, presentation of aggregate figures could be more useful for certain planning activities or for implementation. By referring to Table 3.5, a disaster response coordinator could estimate total supply of potable water needed for the thana. For coordination of relief distribution, union-level information could be derived from the table or the map to determine water quantity and to select the distribution point or routing plan. For example, safe drinking water would be needed in 295 of the 298 households in Katharia union, but in only 21 of the 121 households in Bailchhari union. Reference to the map shows that settlements in Katharia are of moderate size and evenly distributed, except for the north where settlements are sparse. The five settlements requiring water in Bailchhari are in the southwest of the union and are served by earthen roads.

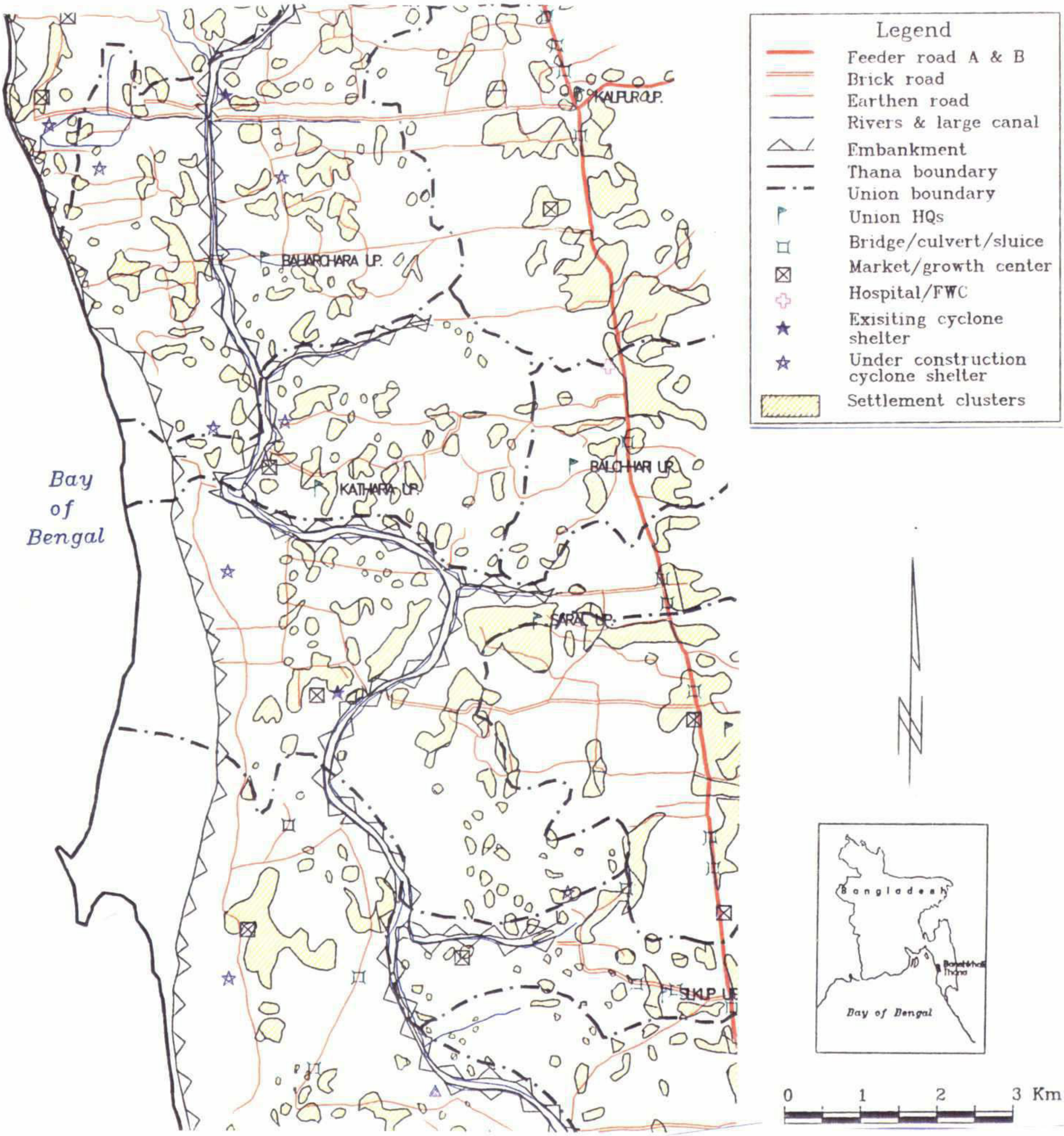

Figure 3.1 Base Map Example from Banshkali Thana

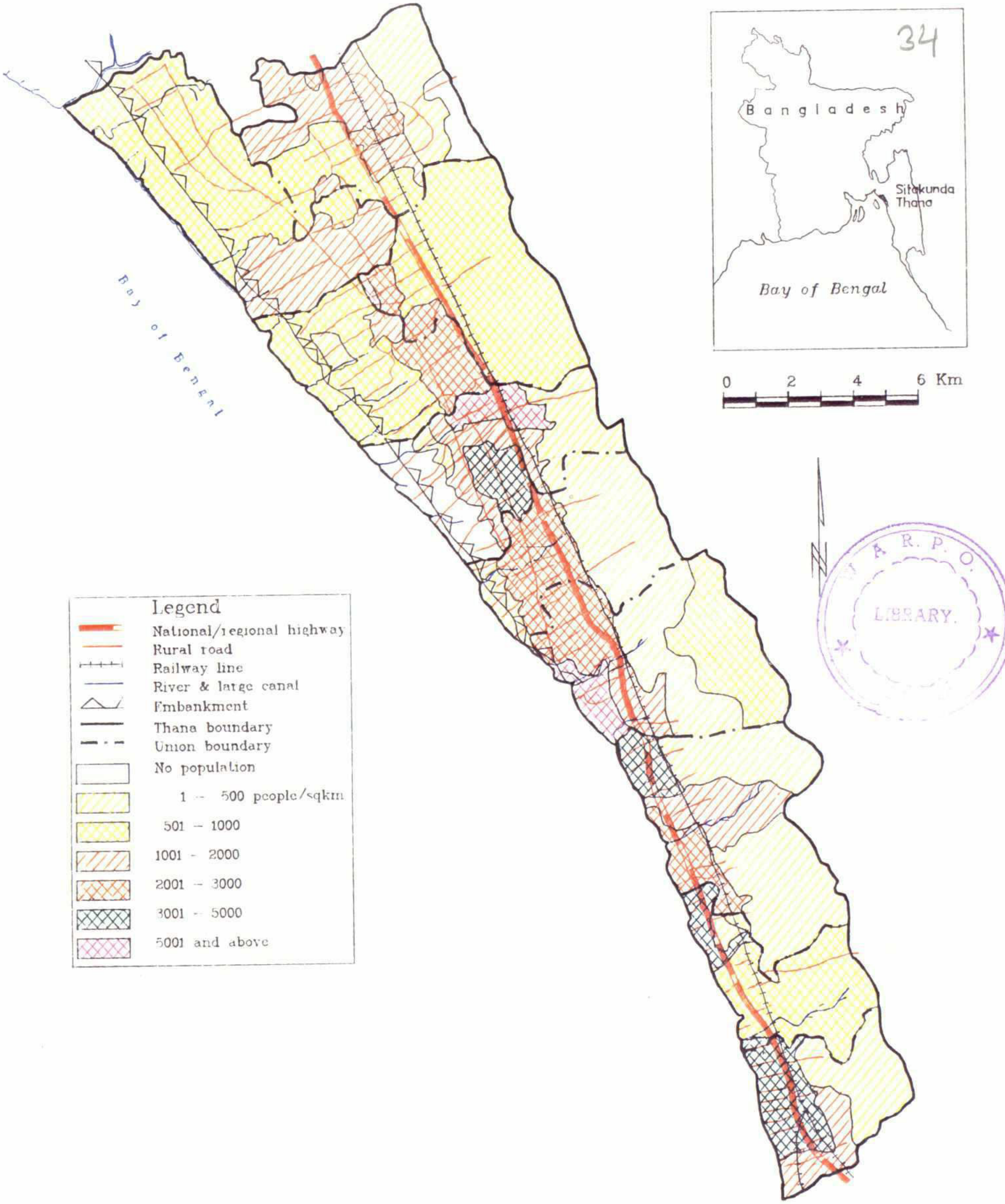

Figure 3.2 Population Density Map, Sitakunda Thana

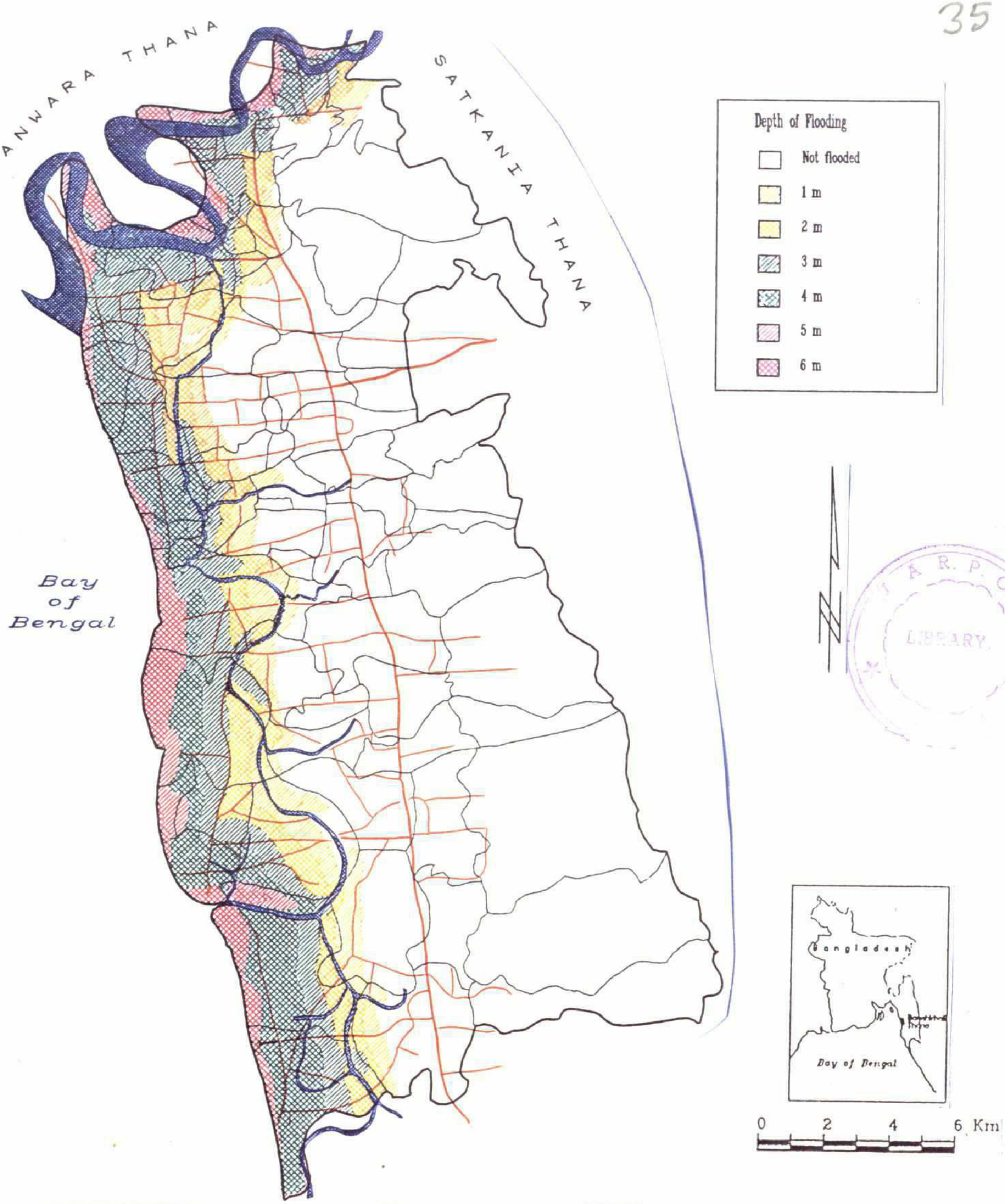

Figure 3.3 Storm Surge Inundation Model, Banshkali Thana

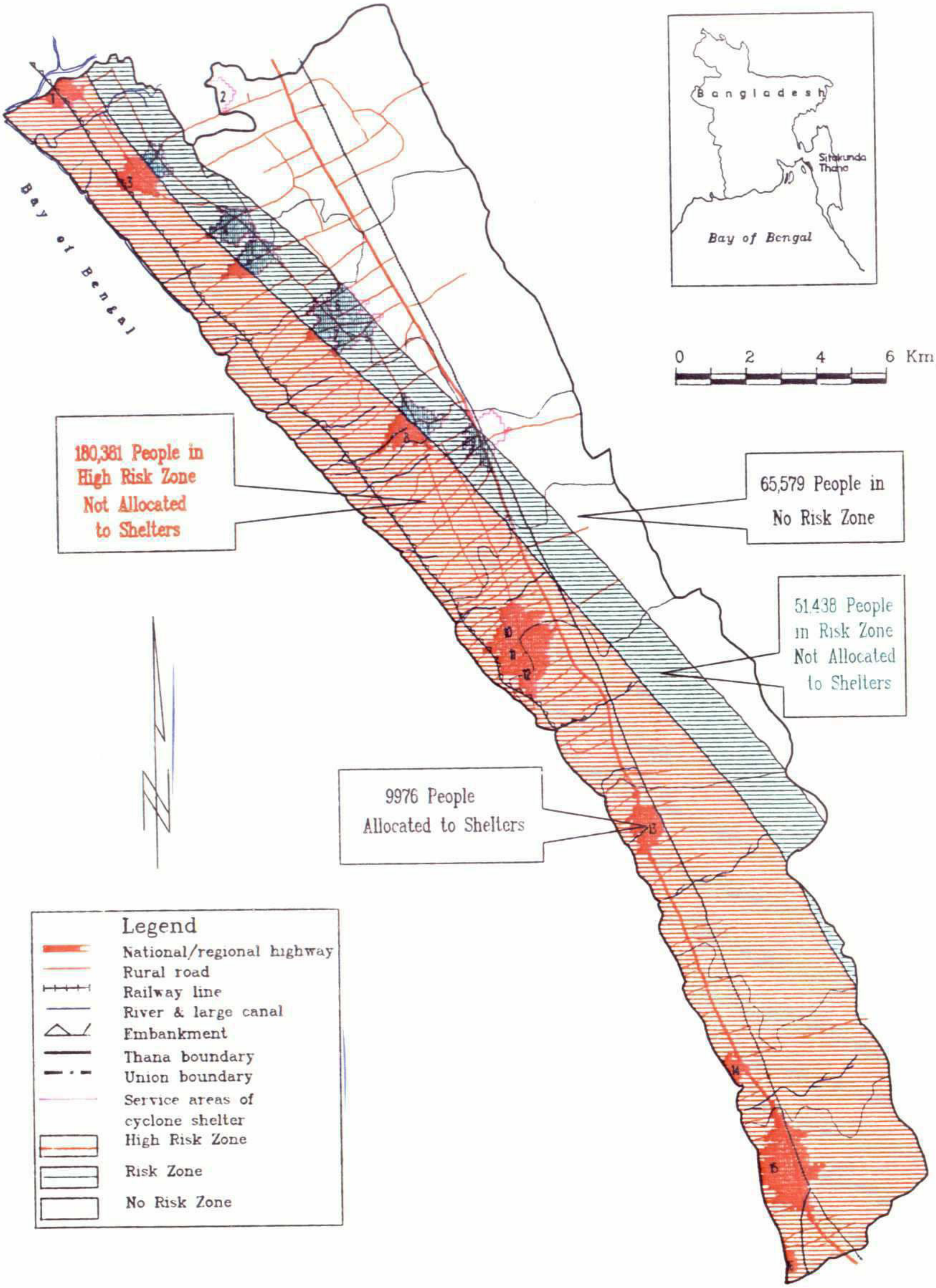

Figure 3.4 Cyclone Shelter Allocation and Vulnerable Zones, Sitakunda Thana

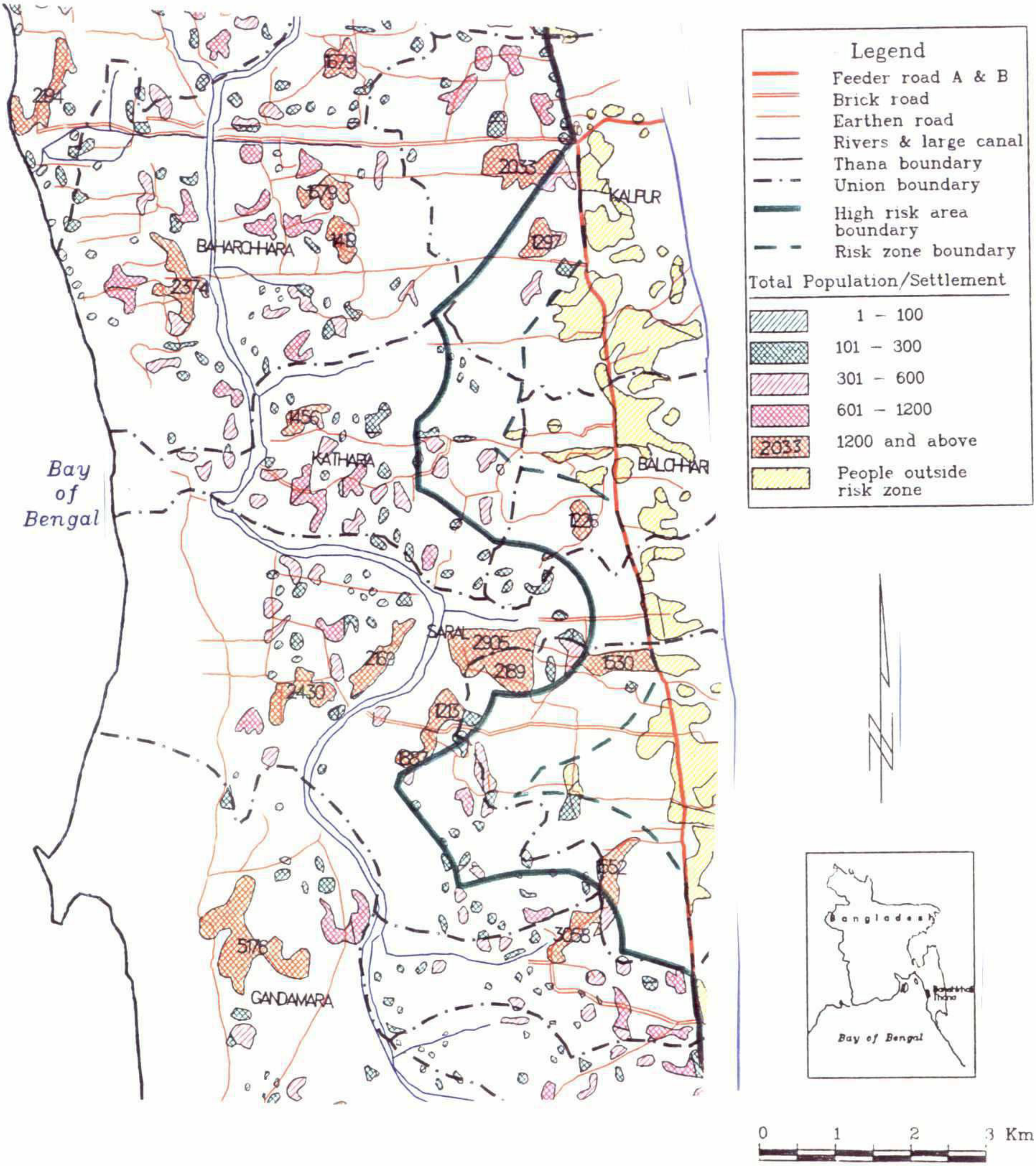

Figure 3.5 Population At Risk, Example from Banshkali Thana

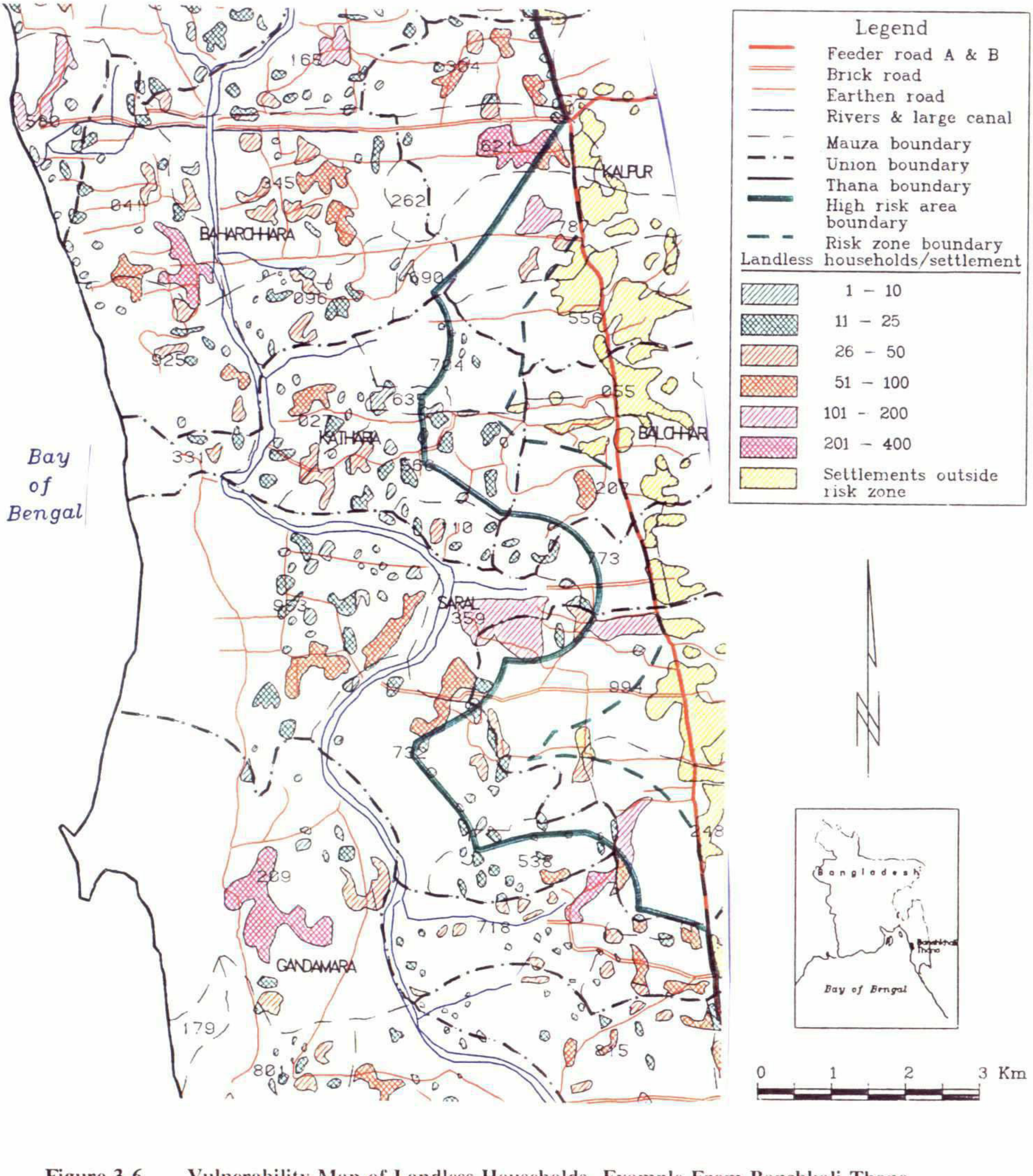

Figure 3.6 Vulnerability Map of Landless Households, Example From Banshkali Thana

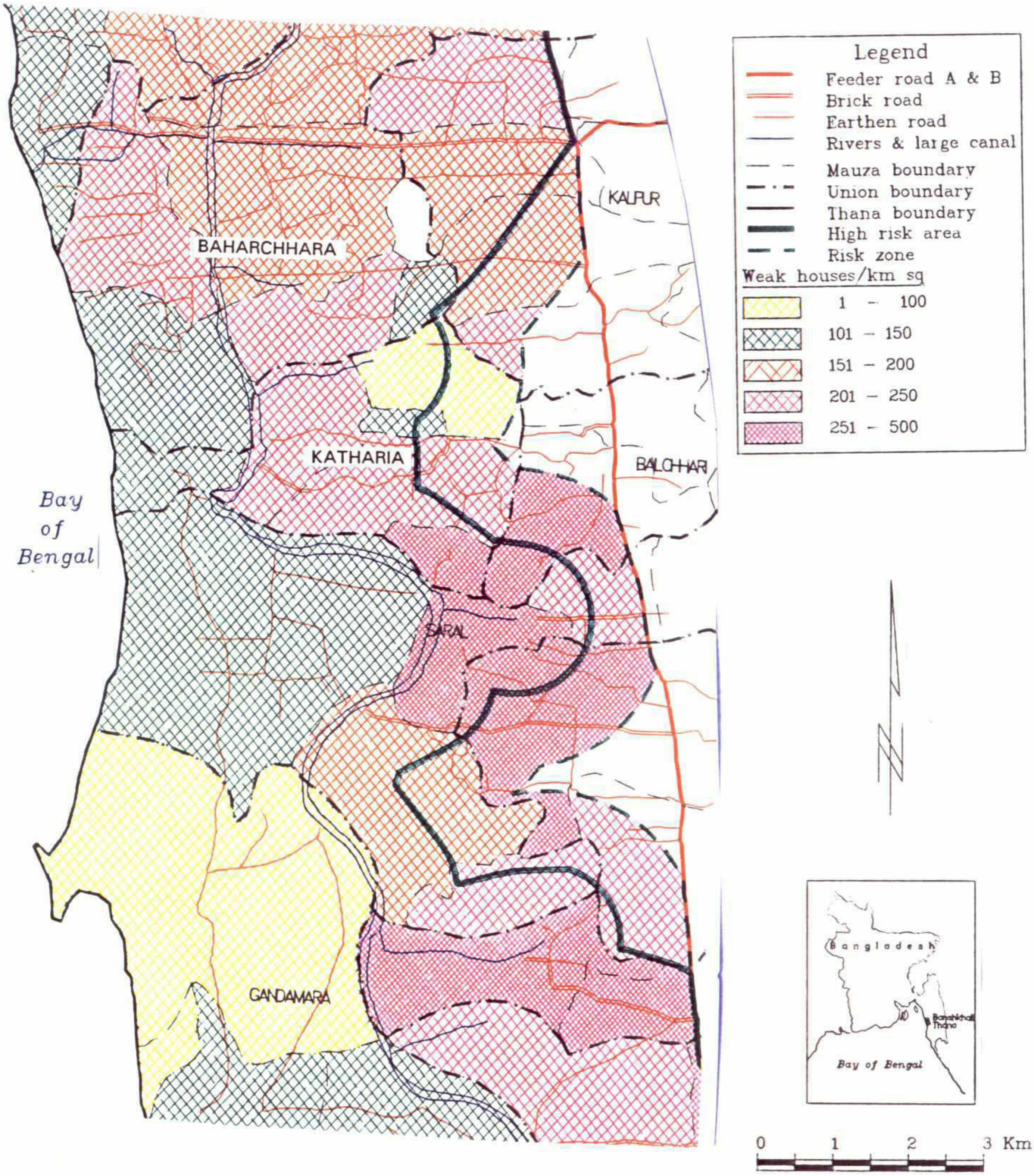

Figure 3.7 Vulnerability Map of Weak Housing, Example from Banshkali Thana

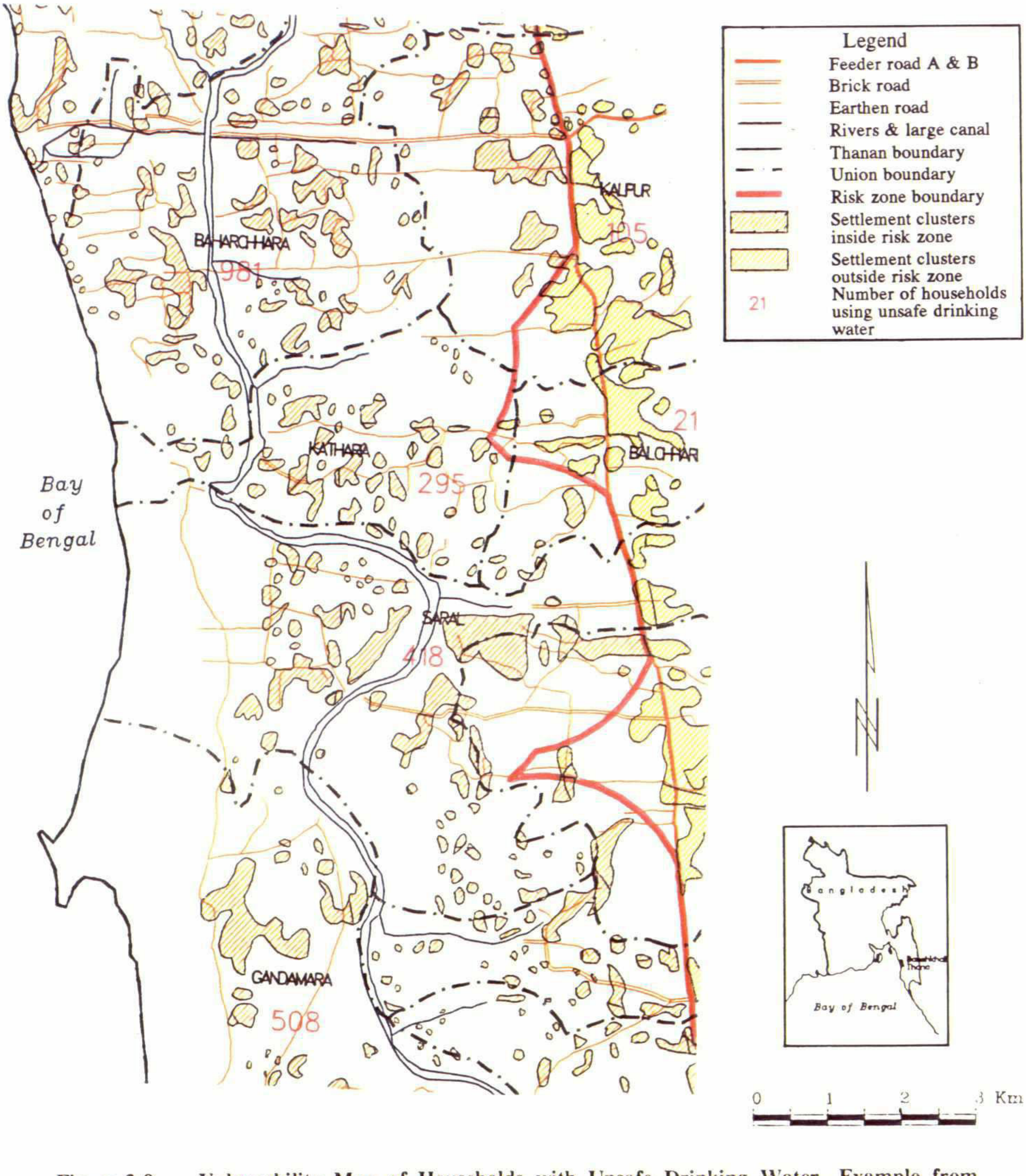

Figure 3.8 Vulnerability Map of Households with Unsafe Drinking Water, Example from Banshkali Thana

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 General

Reliable maps and data are critical to disaster management and relief distribution. An advantage of using GIS techniques is that they force the issue of data reliability; improperly constructed digital maps are immediately obvious in a GIS. Poor quality data and gaps in information are also highlighted. Digital modelling can utilize complex mathematical procedures that are impossible with conventional methods and allows a quantitative approach to analysis that can remove bias. Use of digital mapping and GIS requires an organized approach—in design, analysis, and in results or products. There are projects for which GIS is inappropriate; however, more often than not, use of GIS helps to identify weaknesses in the early project stages and opens up new perspectives in methods and in definition of data needs and analysis.

The suitability of GIS for disaster preparedness systems is self-evident in many aspects, and GISs are being implemented for this purpose worldwide. This pilot study is the first comprehensive application of GIS for cyclone disasters in Bangladesh. Because of the nature of the flood problem in Bangladesh and the availability, characteristics, and quality of the country's geographical data, there is a unique opportunity in Bangladesh for GIS to make a significant contribution to disaster management.

Successful implementation of GIS for disaster management in Bangladesh requires not only computer and digital mapping skills, but knowledge of the country's unique land and water resources. Along with such capability, the development of a GIS requires the direct and consistent involvement of disaster managers and/or planners in the government, NGOs, and the private sector.

4.2 Digital Databases, Mapping, and Software

The GIS digital database that was constructed for this pilot study can be used for a variety of complex analysis and modelling tasks, but its value as a mapping tool also should not be overlooked. The database can be used either in planning for disasters or for post-disaster activities such as relief allocation and routing, or simply to present updated damage information. Since the data was accurately portrayed and updated, and since it is in a digital form, any map theme can be combined with any other theme and plotted at any scale. Access to such capability is an important advantage of GIS techniques.

The MCSP database is unique in Bangladesh and is most valuable for disaster management activities. For use in a GIS, however, extensive manipulation of this data is required (as described in the technical annex). This study found that, due to locational errors, the digital data is unsuitable for GIS analysis and mapping at the subregional or thana level.

For a GIS-based approach to disaster management, it is recommended that the digital database created under this pilot study be extended to cover the entire coastal region. The methods used to build the

Banshkali GIS database should be employed. This would involve transferring MCSP data to a geographically correct base map, such as the SoB's 1:50,000 scale topographic map series or geocorrected satellite imagery. Verification and updating of data is recommended by field ground truth, including use of GPS and recent satellite imagery or aerial photography. Recommendations about the use of satellite imagery are in the technical annex.

An estimated 18 person days are required to build a comprehensive GIS data set for one thana. Another 10 person days are likely to be needed to verify and update data in the field. If LGED thana-level data become available for the coastal areas in digital form, this effort could be cut by about two-thirds. It is recommended that priority be given to cyclone-prone coastal areas; disaster planners should consider providing additional resources to LGED for this purpose.

4.3 Cyclone Shelter Siting

Selecting sites for cyclones shelters is an exercise involving numerous variables that are not easily quantified. If properly planned and implemented, GIS can be an important asset as a decision support tool, helping planners in site selection and in planning evacuation routes. The approach for shelter design and siting illustrated in this pilot study is unbiased, flexible, and effective. For future siting studies, use of these techniques should result in the selection of shelter numbers, location, and capacity that will ensure more efficient use of resources.

Field interviews conducted during this pilot study indicated that people may prefer a larger number of smaller cyclone shelters, or a strengthening of existing houses, so that almost all vulnerable settlements are served. This would minimize travel distances and help people feel that their homes were less vulnerable to robbery. They would, therefore, be more likely to use the shelters. GIS methods used in this pilot study could be used to assess the implications of such an approach.

4.4 Storm Surge Models

Modelling cyclonic storm surges is a complex endeavor. Extending the simple models used by MCSP and demonstrated in this pilot study will require specialized expertise in surge modelling. There are a number of tools GIS can offer, especially in terrain modelling and 3-dimensional representation of a storm surge front. Another benefit of using GIS in surge modelling is that a digital representation of a storm surge can immediately be combined with other spatial data in digital form to assess vulnerability or assess the impact of a particular event.

4.5 Vulnerability Analysis and Mapping

Use of GIS for combination of impact zones or flooding depths with vulnerable population, water supply, etc., can be useful for planning an appropriate disaster response. It can also serve in coordinating relief from the regional level down to field efforts on the ground. Indeed, if vulnerability information is to be available within hours of when disaster strikes, GIS techniques offer an informative and accurate method of doing so.

4.6 Institutional Issues

The application of GIS to disaster management is an interdisciplinary effort and requires the involvement and coordination of many different institutions. Disaster management planners, therefore, should be more actively involved in future GIS activities.

The institutionalization of GIS in disaster management organizations will require substantial training. GIS capability already exists in Bangladesh, but most of the trained people are in the private sector. From a long-term development perspective, the government should take the lead role in developing a National Disaster Information System. This may be best achieved through cooperative ventures among the government, NGOs, and the private sector. This will require implementing a comprehensive GIS training program with appropriate regional and local GIS networks.

4.7 Recommendation for Future Studies

This report documents a first level pilot study for applications of GIS in disaster management. Should there be interest to carry the results of this study further, then concerned organizations (e.g. DMB, CARE, FPCO others) may consider the following suggested tasks for a follow on program. The following are recommendations for the future, to help improve disaster management planning.

4.7.1 Digital Database, Mapping and Software

The first objective will be to demonstrate the full potential of hand-held global positioning systems (GPSs), which can reliably locate features to about ± 50 m. The task will involve detailed mapping of the alignment and condition of the coastal embankment and roads. To do this, a technician will walk or rickshaw the entire length of the coastal embankment and feeder roads in one thana encoding information in a GPS. Results will be downloaded into the GIS database, incorporated into the base map, and output on a color plotter.

A second task will be to more fully demonstrate the utility and flexibility of GIS mapping for disaster management. Additional hypothetical cyclone events will be modelled for different terrains. GIS will be used to update and display conditions in the affected area, including: simulations of road conditions; status of bridges and culverts; extent and duration of flooding; location of contaminated ponds; location of flooded villages and estimates of numbers of people displaced; salinization of agricultural lands; location and status of relief operations. Emphasis will be placed on rapid turnaround of dynamic conditions likely to be reported from simple field maps or via telephone as GPS coordinate data.

4.7.2 Storm Surge Models

GIS models should be developed to simulate land surface friction, and other physical characteristics affecting the decay of a surge front. With the cooperation of experts on cyclone surge modelling, and/or the collaboration of BWDB, SWMC, and MoR, the accuracy of predicted inundation for any given event can be improved. Required inputs for this effort would be a update of the digital elevation model for Banshkali Thana, accurate mapping of embankment and road locations and their condition, and land cover information. Tidal influence and schedules may also be required along with bathymetric information. Results should be linked with more detailed field investigations that would yield reliable estimates on extent of previous surge events for calibration and verification.

4.7.3 Risk Zone Mapping and Vulnerability Analysis

The risk zone concept, simulated in this pilot study for the 1991 cyclone, should be expanded by using similar modelling techniques for a series of events by return period (e.g., 1 in 5 year event, 1 in 10, etc.) or by a combination of wind velocity and storm surge heights using data such as that presented in Table 2.2. Each simulated event modelled would result in a series of maps showing levels of risk. Results would be compared with historic data available at the union level.

Vulnerability themes such as those presented above or other themes, such as loss of livelihood, damage to infrastructure, or interruption of normal business, would then be combined with the series of risk levels to produce a series of vulnerability maps and tables. These results could be used in many aspects of planning, such as cost-benefit analysis of cyclone shelters versus evacuation for various return periods or severity of events.

4.7.4 Decision Support for Early Warning

The existing early warning system relies on information from SPARRSO, the Meteorological Department, and international agencies to track cyclones and estimate their wind strength, direction, and likely point of landfall. This tracking system appears to work satisfactorily, but estimates of the area and extent of impact could possibly be improved. Better impact predictions should lead to more specific warnings with greater reliability. This would increase the confidence of evacuees who would be more likely to take shelter under warning of an approaching storm.

A pilot analysis would involve mapping an approaching storm, predicting a point of landfall, wind speed, etc. Predicted impact would require selection of the most representative model of storm surge risk zones as described in Section 4.7.3, and GIS linkage with digital union maps and data to predict the number of people affected. The GIS would be used to continually update the list of unions and affected population together with the severity of impact. An extension of this approach would be connection with concerned early warning authorities (MoR, Red Crescent, etc.) to assist in disseminating warning notices.

4.8 Applications Beyond the Pilot Stage

The following are areas in which GIS can prove useful but which are considered beyond the means or scope of this pilot study.

4.8.1 Cyclone Shelter Siting

Future cyclone shelter site selection and planning should incorporate methods similar to those outlined in this pilot study. In addition, review or monitoring of existing plans could also benefit from the GIS approach.

4.8.2 Estimation of Relief Needs

As soon as a cyclone crosses the coast people and property are affected by the associated storm surge. Before or during a cyclone, relief needs can be estimated and updated with each forecast. Under the early warning system described in Section 4.7.4, the GIS would produce an estimate of the affected population in a map and a listing by union. From such a list, relief needs would be generated automatically as a simple database operation. This list could then be compared with existing stocks held by all agencies concerned. Deficiencies would be highlighted in the database and map, leading to action plans to remedy any shortfalls. The procedures required could all be incorporated into a simple expert system providing reports and initiating actions according to the reliability of the information received. Research on this application would require investigation of "knowledge based" GIS techniques.

An automated system for estimating relief needs could be used either operationally or, perhaps more realistically, as a planning tool for establishing relief storage and distribution networks.

4.8.3 Optimization of Relief Supply—Routing and Priorities

As information on relief needs become available, coordinators must obtain sufficient transport and determine the best route for distributing relief. Transport decisions should be based on reliable information on the road and rail network and condition of ports, and after hazards have dissipated, information on sea and air conditions should also be considered.

Disaster-affected areas need to be considered in relation to the source of relief supplies. Road condition will be very important and distribution points for reaching the greatest number of people will need to be identified. GIS techniques, such as network analysis, can be used to allocate resources by the most efficient route. This application has been addressed in a cursory manner in this pilot study, but requires further investigation to define suitable procedures.

4.8.4 National Disaster Information System

The ultimate recommendation of this pilot study is that a National Disaster Information System be designed and implemented. Such a system would incorporate GIS technology, current geographical and socioeconomic databases, satellite image processing, and telecommunications links.

This would be a comprehensive package encompassing, in an operational mode, all of the disaster management modules described above for the cyclone-prone coastal regions and eventually for all areas susceptible to river flooding. Facilities would be available for routine data acquisition and dissemination including a digitizing facility and equipment for thematic map production as well as image processing and GIS analysis. Expertise and equipment for telecommunications links would also be required. Accurate databases that could be easily updated would be needed for relevant geographic and socioeconomic information.

Prerequisites for a disaster information system of this nature would be a sound institutional base and management cadre of well trained technicians and professionals.

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TECHNICAL ANNEX

1.1 Hardware and Software Requirements

1.1.1 Hardware Used for the Pilot Study

Several of the computers and peripherals of FAP 19 were used in this pilot project. The FAP 19 systems includes 386 and 486 microcomputers, two full-size tablet digitizers, a 9-track tape drive for reading satellite images, two color ink-jet printers, a color thermal wax printer, two image processing boards and display, and an 8-pen plotter.

1.1.2 Software Used for the Pilot Study

FAP 19 has several types of GIS software that are capable of constructing digital databases and performing analyses. This study used PC-based versions of ARC/INFO, IDRISI, and ERDAS.

PC ARC/INFO is a vector-based GIS program which composes all map features from lines or points and assigns each feature an identifier code (ID). Information describing each feature is stored in database files as an attribute and linked to the feature on the basis of the ID.

ERDAS and IDRISI are both raster-based GIS programs with some limited vector capabilities. In these programs a mapping theme is represented as a grid of picture elements (pixels). Features on the map are represented by groups or patterns of pixels, all with a unique value for each feature (e.g., roads may be assigned pixel value 101 and water may have value 10). IDRISI is a low-cost GIS software with some special analysis capability; ERDAS is relatively expensive but has a wide array of functions and supports FAP 19's high resolution monitors and color graphics printers.

Data conversion is relatively simple among these softwares, and for this pilot study all were used. Digitizing and data conversion was performed with ARC/INFO, as were vulnerability analyses. IDRISI was used for the cyclone shelter siting exercise. ERDAS was used for image processing and some color graphics output.

1.1.3 Recommendations

There are advantages and disadvantages to the various GIS software used in this pilot study and each type of software is recommended for aspects for which it is most suited: a vector GIS capability that has versatile data capture and map production features and linkage to a relational database; a raster GIS capability that has modelling and map production capacity; an image processing system with on-screen digitizing that interfaces with the GIS.

1.2 Satellite Imagery

Most of the base data for Banshkali Thana was taken from mapping done in the 1970s or earlier. Problems with the base data are particularly evident for actively changing features, such as river alignments or coastlines, or where mapping from different dates was integrated. To correct these errors, recent satellite imagery proved valuable.

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1.2.1 Map Correction Using Satellite Imagery

In the map shown in Figure 2.7, the alignment of the Sangu River was different on the SoB 1:50,000 sheet than on the Police Station map. In this case, both maps were reconciled to October 1990 Landsat Thematic Mapper imagery. This was achieved by displaying the mapping on a computer screen while using the satellite image as a backdrop. Road alignments and settlement boundaries were also checked against the imagery. The satellite imagery was georeferenced using control points from the SoB 1:50,000 sheet and GPS readings from field visits.

1.2.2 Recommendations

The most useful image type for map verification is the SPOT Panchromatic with a 10 meter by 10 meter ground resolution. The utility of these data is enhanced if combined with multispectral SPOT or Landsat TM images, particularly for mapping land use and land cover.

2.1 MCSP Data Conversion

The principal spatial data set used for the pilot study was developed by the MCSP for the entire coastal belt of Bangladesh. This digital data required conversion from AutoCAD format into ARC/INFO for use in FAP 19's GIS. The conversion process pointed up several shortcomings in this data set. The main problem arose from the fact that the MCSP spatial data was stored in units of digitizer coordinates rather than in universal map or geographic coordinates. This required an extensive georeferencing effort by FAP 19. Second, because of the AutoCAD data structure, many of the map features in the digital files required extensive editing or redigitizing after conversion. Design Development Consultants (DDC) provided advice on AutoCAD formats to improve the conversion where possible.

The important issues of the MCSP AutoCAD data and their conversion into ARC/INFO format for GIS application are as follows:

- Quality and accuracy of the source digital data
- AutoCAD layer concepts and standards
- Conversion procedures

2.1.1 AutoCAD Source Data

The source data were supplied in AutoCAD DXF format along with a set of hardcopy map sheets. The digital files included all the map elements including all annotations that are seen on the hardcopy map. The hardcopy map sheets were printed well and features were clearly readable.

The coordinate system used in referencing the digital files was reported by the DDC experts to be the digitizer coordinates. No georeferencing was used for preparing the digital data sets; therefore it was not possible to use a constant factor for transforming the data from digitizing coordinates to geocoordinates. Also the gradicules marked on the maps were in many cases difficult to interpret and locate.

It was found that some data marked on the hard copy maps do not appear in the digital files and vice versa. Most of these cases are linked with the proposed location of cyclone shelters. This was brought to the attention of DDC staff who indicated that these data would be further checked and edited.

2.1.2 AutoCAD Layering Concepts and Standards

Under this exercise, the basic layering concepts and standards followed during digitization of spatial information were investigated in detail. From this investigation, the following understanding and findings were recorded:

- A layer in AutoCAD basically refers to a group address of some AutoCAD graphics in a certain drawing. This implies that the entire list of drawing elements could be categorized into one or more groups i.e.

layer which could have a single identity (name), color and line type. However, under a specific layer more than one color and line type can be used and that should be done by selecting and changing the properties of specific elements separately.

- In case of using AutoCAD default point symbols, only one point symbol type can be used in certain AutoCAD drawings. This means in a single drawing, one cannot include more than one point type. However, insertion of different point symbols in a single drawing can be done by defined point blocks that could again be developed by combining AutoCAD default symbol sets (points, line, text, etc.).

- For preparing MCSP drawings, DDC developed and used a certain layer convention. This convention groups different features in separate layers. However, this feature-layer arrangement was not followed as a standard for all the thanas. This means that the same layer number in two different thanas contains different features.

2.1.3 Procedures Used for Conversion of MCSP Data to ARC/INFO

Step 1 Convert all the layers for all the existing features of a .DXF file into a single ARC/INFO coverage. For this purpose use DXFINFO command for information about the existing layer in the file. Prepare an SML that includes all the layer names and required feature types. Use the DXFARC command to convert the DXF file to a single ARC/INFO coverage.

Step 2 Identify and add at least four precisely located points on the digital files and also on the hardcopy maps the features should occur on both the map and the coverage and have known geographic coordinates. If any line marks of lat/long are present in both digital and hardcopy maps, these would be preferable for easy and better georeferencing. Those points will be used as reference TIC points.

Step 3 Create an empty coverage with the minimum four points (TICs) identified in Step 2 (in geographic coordinates) and convert the coverage to Bangladesh Transverse Mercator (BTM).

Step 4 Transform the existing coverage into the empty TIC coverage with known reference points.

Step 5 Using ARCEDIT module, identify each individual feature and add respective IDs to it. For unique IDs, follow the code list already developed and included in the work plan of the FAP 19 Pilot study.

Step 6 Split the coverage into two or three coverages for line and point features. This will facilitate easy handling of the coverage and assist in manipulation of the data.

2.1.4 Example of Conversion Process (Sandwip Thana)

- Two separate maps and DXF files were supplied for Sandwip which constitute the entire Sandwip thana.
- Each map contains a large number of arcs (the first one has more than 37,000). This large number of arcs was created from the AutoCAD dot filling pattern for sand bar islands. ARCEdit module of ARC/INFO cannot handle such high number of arcs.
- Because of the above mentioned problem, each map was again subdivided into three separate coverage and after manual editing of features (replacing thousands of lines for sand bars with a single line that represents the outer boundary of the islands). The process was a very time consuming exercise.
- For the above reason, same operation was to be executed several times.
- Computer time required for joining of two

maps was about 2.5 hours.

- Digitizing accuracy of outer boundary (for sandbars) was as good as the accuracy of visual estimates.
- The Tic adding operation was also a visual estimated work.
- The match-line in two coverages was drawn inside the edge but it would be better for mosaicing if it was drawn at the outer most edge.

2.1.5 Guidelines for AutoCAD-ARC/INFO Transfer

As a result of the problems described above, a guideline was prepared for AutoCAD users for preparing AutoCAD data and converting those into ARC/INFO format. This guideline may serve as a guide in developing different standards and establishing conventions for digitization in AutoCAD system so that this can be easily transferred into GIS.

It was found in converting AutoCAD data into ARC/INFO GIS that there are some symbological (graphics) problems and also lack of uniformity or standards that created major difficulties in use for GIS applications. For instance, user defined point symbols do not always convert and represent a point feature in ARC/INFO. Most of the problems are related to the digitizing operation and could be easily avoided by following specific standards and conventions.

Draft Guideline:

i) A feature-layer arrangement standard should be developed in close collaboration with RAJUK, LGED, and DDC. This standard will include a list which should tell us, "which layer should be reserved for each type of real-world feature".

ii) Generally, the AutoCAD developer should keep digitized drawings with default line symbol by following the standard layer convention in a separate archive before changing the default symbol into a user-defined one.

iii) Always digitize point features using default symbol set and put them into different layers according to the standards. An archive of that version of the drawing should be preserved before changing it into a different user-defined point symbol.

iv) For convenience, always preserve a version of the drawing with AutoCAD default text font. If the text used is in a non AutoCAD font, it should be converted to an AutoCAD font before converting to GIS (ARC/INFO) format.

v) For geo-referencing of an AutoCAD drawing, during digitization the developer should select the lower left and upper right corners of the drawing with known real-world coordinates as limits to the drawing's boundary and these should be recorded in a text (readme.txt) file. It should be noted that the nearest graticules from the drawing feature on the source map could be taken as the limits.

3.1 Raster Analysis Using IDRISI

The IDRISI GIS software package was used for certain analyses because it provided mathematical functions for producing travel cost surfaces and surge inundation modelling not readily available in the other software. Since procedures used in the analysis may require replication or alteration in the future, the steps are presented in detail. Software titles and command names are given in UPPERCASE letters.

3.1.1 Import of Thana Information From PC ARC/INFO

Point and Arc information was exported from ARC/INFO using UNGEN and imported into IDRISI using POINTRAS and LINERAS respectively.

Points and lines were rasterized into a file created with INITIAL using minimum and maximum extends from the ARC/INFO BND file. A cell size of 100 m was used.

Polygon information such as mauza boundaries was exported from ARC/INFO using the ARCDLGN command and imported into IDRISI using the DLG command.

3.1.2 Wind Direction Quadrants for Cyclone Shelter Catchments

Wind direction quadrants for each shelter were created in ARC/INFO and imported with ARCDLGN. As described in the report section 2.5.1.3?? each quadrant was assigned a different coefficient depending on ease of travel. The quadrant closest to the sea was given a friction value of 1 signifying no additional constraint to travel. The leeward quadrant was given a value of 2, since people there would be moving against the wind and water and also because people are very reluctant to run toward the sea in a cyclone. The remaining two quadrants were given values of 1.5.

The friction surface file was created from imported ARC/INFO features with, for example, a value of 1 assigned to roads, 5 for agricultural land, and -1 for barriers such as water. The friction surface file was then multiplied by the values in the quadrant surface file to adjust fnr difficulties in movement due to high winds and surge direction. Before multiplying the files with the OVERLAY command the pixel values in the friction surface file had to be modified to avoid negatives as -1 values caused the OVERLAY command to fail. The -1 values were changed to 11 with RECODE and then recorded to -1 after multiplication.

3.1.3 Travel Friction Surface for Cyclone Shelter Catchments

A distance/proximity surface representing the minimum effort in moving over a friction surface was then prepared using the COSTGROW command. The unit of measurement was grid cell equivalents (gce). The COSTGROW algorithm was applied in preference to the COSTPUSH algorithm because the former allows a maximum distance to be set to output buffer zones.

ALLOCATE was then used to assign each cell in the COST image to the nearest cyclone shelter.

3.1.4 Conversion of Results to ARC/-INFO

The catchment results were converted to ARC/INFO by the following steps:

ERDIDRISI to produce GIS file from IDRISI result
DSCEDIT to create descriptor
FIXHED to change classes
BSTATS to create trailer file
GRIDPOLY to convert to ARC/INFO with boundary values from IDRISI

3.1.5. Storm Surge Modelling

The storm surge modelling in IDRISI assumed that surge height at the coastline and 1 Km inland was 6m, thereafter surge height reduced linearly in the direction of flow. The surge was modelled using the DISTANCE function to measure the distance between each cell within the thana and a hypothetical line 1 Km inland from the coast. A new file was created by this process with pixel values representing the calculated distance. SCALAR was then used to multiply the distance values by a factor representing the reduction of surge height assuming a linear relationship from 1 Km to 5 Km inland. The coefficient applied was:

$$6\text{m surge} \times \frac{\text{Distance}}{4000\text{ m}}$$

$$= 0.0015 \times \text{Distance}$$

4.1 Representing Population for Settlement Areas

Population data was taken from the mauza-level census and, using the GIS software PC ARC/INFO, was manipulated so that populations were represented only in settlement areas. In addition to disaster management, population or other census data represented in this form could be used in many other applications. Therefore, the procedures are presented in detail.

These procedures were followed for Bashkhali thana. A coverage containing mauza polygons was attributed with mauza geocode. Another coverage was created including the settlement polygons delineated from the 1:50,000 topo sheet for survey of Bangladesh (SOB). A mauza based tabular database (in .dbf format) was built which contains 1991 census population statistics.

4.1.1 Input Data

Arc/Info coverage:

BASHMOUZ	Geocoded mauza (polygon) coverage for Bashkhali thana
SET_BASH	Settlement coverage containing settlement polygons. All the polygons are labeled with a fixed code (SETCODE = 99)
BASH_TBL.DBF	Population census database (created in dBase IV) which contains mauza population by sex and age group

4.4.2 Procedures

a. Add the census population data from the BASH_TBL.DBF file to BASHMOUZ coverage (PAT file) using Dbase-IV system. First, open the PAT and BASH_TBL files and establish a relation between these two database files. Then, use JOIN command to add the attribute (population) data from the BASH_TBL to PAT.

JOIN WITH <BASH_TBL> TO <TEMP> FOR <GEOCODE # ' '>

Close all the opened database files. Open the TEMP file and copy it to BASHMOUZ.PAT file. Then, quit Dbase and again, build the BASHMOUZ polygon topology in Arc/Info.

b. Clip the settlement coverage SET_BASH with the outer boundary coverage BASHOUTL of Bashkhali thana (to eliminate settlement polygons which are lying outside the Bashkhali thana). The clipped output coverage was saved into BASH_SET;

c. Overlay BASHMOUZ and BASH_SET coverage in Arc/Info using UNION command and save the intersected coverage into BASH_M_S;

d. Invoke Dbase-IV, open BASH_M_S\PAT.DBF and copy the PAT file to POSTEMP.DBF using the COPY command;

e. Index POSTEMP.DBF on {GEOCODE} and save the index file to POSTEMP.NDX using Dbase INDEX command;

f. Add 3 new fields (items) to POSTEMP.DBF {for population on settlement: POPONSET, population density on settlement: PDENONSET and settlement polygon percentage of overlaid polygons fallen into a certain mauza : AREAPER};

g. Keep open the POSTEMP.DBF file in sector A and in sector B, create a new database file OUTFILE.DBF which will have only two fields i.e. {GEOCODE} and {TOT_AREA}. Now, go to sector A and run a Dbase-IV program named POPONSET.PRG which will simply sum up total areas of all the settlement polygons (entire or part) which are fallen in different mauzas. This program will store all the summed up total areas for each of the mauza into the OUTFILE.DBF and will keep this output .DBF file in use for subsequent operations;

h. Establish relation between POSTEMP.DBF and OUTFILE.DBF through the key field {GEOCODE} using SET RELATION command in Dbase-IV;

i. Calculate percentage of area for each of the polygons and assign the percentage values to {AREAPER} by using REPLACE command in Dbase using the following formula :

AREAPER = 100 * (AREA / 1000000) / B->TOT_AREA FOR SETCODE = 99

(Note: The number 1000000 is used because {TOT_AREA} was in sq km and {AREA} is in sqm unit.)

j. Distribute the total population of a mauza proportionately to the area percentage to {POPONSET} by using REPLACE command using the following formula:

POPONSET = POPULATION * AREAPER / 100

k. Calculate and assign population density on settlement to the field {PDENONSET} by using REPLACE command according to the following formula:

PDENONSET = POPONSET / (AREA / 1000000)

l. Copy the POSTEMP.DBF file to BASH_M_S\PAT.DBF file and thus the PAT file of the coverage will include population densities on settlements.

As a result of above operations and calculations, a final coverage BASH_M_S containing population of mauzas distributed only to settlement areas will be ready for further use. Each of the polygons of the coverage represents either populated settlement areas (those have settlement code i.e. SETCODE = 99) or other areas (SETCODE = 0 or SETCODE = 100) covering agriculture lands, waterbodies and forest, etc.

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Appendix A
Estimate of Efforts Required for GIS Database Construction And Output

Input time includes efforts for data conversion, preparation, editing, digitizing of additional maps, map composing and final presentation. These estimates are based on experience of the pilot study for one thana, and are likely to change with more experience. Person days are assumed equally split between one GIS technician and one GIS analyst.

		person-days (per Thana)
1.	Basic Data Capture and Preparation	
	Data from SOB Topo sheet	
	Tracing & digitization of road network, etc. and making usable	1.0
	Tracing & digitization of settlement clusters	1.5
	Data from Satellite Image	
	Preparation of imagery	1.5
	Screen digitization of river network, etc.	0.5
	Subtotal	4.5
2.	Capture of Other Required Data (per thana)	
	Data from BWDB Elevation/Contour Map	
	Elevation points and building DEM	8.0
	Data from DLR Police Station and SAA Maps	
	Mauzas from PS maps	1.5
	Check plots & reconciliation with SAA and geocodes	1.5
	Attribute Data from BBS	
	Structuring database, demographics and other	3.0
	Subtotal	14 0
3.	Field Verification and Updating (per thana, incl. travel)	
	Road network from thana engineering office data & GPS	4.0
	Other field verification, updating	4.0
	Subtotal	8.0
4.	Baseline Map Composition and Output (per thana)	
	Designing output map compositions & generating maps	3.0
	Preparing final presentation of outputs	2.0
	Subtotal	5.0
	TOTAL	31.5