## *Detection, monitoring and management of small water bodies:: A case study of Shahjadpur Thana, Sirajgonj district, Bangladesh*

Huda, Khondaker Mohammod Shariful

# Detection, Monitoring and Management of Small Water Bodies: A Case Study of Shahjadpur Thana, Sirajgonj District, Bangladesh



***Khondaker Mohammod Shariful Huda***

B.Sc. and M.Sc. (Jahangirnagar), M.A. (Durham)

Thesis submitted for the degree of Doctor of Philosophy,
Department of Geography, University of Durham, UK

Durham, UK

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# DECLARATION

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***(Khondaker Mohammod Shariful Huda)***

## ABSTRACT

Bangladesh is a low-lying flood prone deltaic plain. Excavations are needed to create raised land for safe flood-free homesteads and water bodies for irrigation, and these result in the creation of doba, pukur, dighi and jola. All of these types of small water bodies are almost equally distributed all over the country, except for the beel, which is a natural, saucer shaped depression. For every eight people there is approximately an acre of small water bodies, which range in size from 25-400 sq.m. (doba), 150-1000 sq.m. (pukur), >750 sq.m. (dighi), >2000 sq.m. (jola) and >1000 sq.m. (beel). These small water bodies are commonly used for drinking, bathing and washing, fisheries and aquaculture, duck raising, irrigation, cattle feeding and washing. Despite the importance of small water bodies to the local economy there is no up to date inventory. For this purpose, in my research I have employed integrated participatory remote sensing, GIS and socio-cultural approaches. Although these have not been used before in Bangladesh, I argue that they are ideal for effective resource management and sustainable development planning.

This research investigated the historical development of the present spatial distribution and use patterns of SWB using Remote Sensing and GIS. This was at a regional scale in four mouzas of Shahjadpur Thana. The data sources were topographical maps, aerial photographs, satellite images, agricultural census data, in-depth questionnaire, focus group meetings and interviewing key informants. An integrated RS-GIS and social sciences methodology was employed to produce maps of change and overlays of the socio-cultural factors involved. Results show that the doba, pukur and dighi, when these are not obstructed by surrounding vegetation, can be detected easily in high resolution panchromatic CORONA satellite photography, IRS-ID Panchromatic image and aerial photography. Comparatively large pukurs, dighis and all jolas and beels are detected in all other optical sensors and the SIR-C radar imagery. Multi-temporal images are helpful for identifying the different types of small water bodies as well separating those from other seasonal large water bodies and flooded areas. It is hoped that the proposed computer assisted participatory management system, including some locally specific guidelines, may be applicable for the planning of other thanas (total 490) in Bangladesh. The proposed management system will facilitate the integration of local planning with the national level planning process, which has not been possible hitherto.

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*Khondaker Mohammod Shariful Huda*

## DEDICATION

**To my wife, twin sons and parents**

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|---|---|
| *Aam* | Mango |
| *Agrayan* | Eighth Bengali calendar month (Mid-November to mid-December) |
| *Aman dhan* | Paddy grows in Kharif two(monsoon), harvest in winter |
| *Ashar* | Third Bengali calendar month (Mid-June to mid-July) |
| *Ashwin* | Sixth Bengali calendar month (Mid-September to mid-October) |
| *Aus dhan* | Paddy grows in *kharif* one (early monsoon) harvest before Kharif-II |
| *Baba / Abba* | Father |
| *Badami* | Brown |
| *Bargi* | Sharecropping |
| *Bagoon* | Aubergine/egg plant |
| *Baishak* | First Bengali calendar month (Mid-April to mid-May) |
| *Band* | Embankment |
| *Baor* | Another name for *beel.* |
| BARC | Bangladesh Agricultural Research Council |
| *Bari* | Home for extended family |
| BARI | Bangladesh Agricultural Research Institute |
| *Batraj* | Water hyacinth |
| *B-aus* | Broadcast *aus* Paddy |
| *Bazar* | Regular local market (retail business place). |
| BBS | Bangladesh Bureau of Statistics |
| *Beel* | Saucer Shaped floodplain depression: containing perennial or semi perennial water body. (Natural lake) |
| *Beel-er thail* | Lowest point of the *Beel* |
| *Beeztola* | Seedbed (*beez*= seed , *tola* = bed) |
| *Bele* | Sandy |
| *Bhadra* | Fifth Bengali calendar month (Mid-August to mid-September) |
| *Bhat* | Boiled rice (Stable food) |
| *Bichar / Salish* | Justice (usually used local justice) |
| BIDS | Bangladesh Institute of Development Studies |
| *Bigha* | Local land measurement (I bihga = .33 acre) |
| *Bondor* | Port (Trading town, situated near any river, canal). |
| *Bonna/Bonnya* | Flood |
| *Bora aman* | Local deep water *aman* paddy |
| *Borgader* | Sharecropper |
| BRAC | Bangladesh Rural Advancement Committee-NGO |

| ITEM | Brief English Meaning and Explanation |
|---|---|
| BRDB | Bangladesh Rural Development Board |
| *Chai* | Ash |
| *Chaitra* | Twelfth Bengali calendar month (Mid-March to mid-April) |
| *Chak* | Agricultural land (adjacent to household) |
| *Char* | Sand bar |
| *Chash* | Ploughing |
| *Chasha* | Cultivator (farmer) |
| *Chitano* | Spreading manure or broadcasting of seeds |
| *Chora* | Specific area in the *Beel* |
| CPP | Compartmentalization Pilot Project, Fisheries Department |
| *Daag/plot* | See plot. |
| Decimal | 1 decimal = 40.48 square metres = 0.004048 hectares |
| *Deshi* | Local/Indigenous |
| DFID | Department of International Development |
| *Dhan* | Paddy |
| *Dighi* | Reservoir or large tank |
| *Doba* | Ditch or pit |
| DOF | Department of Fisheries, Government of Bangladesh. |
| *Do-fasli* | Double cropped |
| *Dokshin* | South |
| *Done* | Long scoop used in surface water irrigation |
| DTW | Deep Tube Well |
| *E etel / metel* | Clayey |
| *Ek-chohur* | Near 12-18 feet (measurement of beel water) |
| *Ek-fasli* | Single-cropped |
| *Eyeel* | Divider or the boundary marker of a agricultural plot and foot path. |
| FAP | Flood Action Plan |
| *Fasal* | Crop |
| FCD | Flood Control and Drainage |
| FCD/I | Flood Control, Drainage and / or Irrigation |
| FFWP | Food For Work Programme |
| *Gabar* | Cow Dung |
| Gamcha | Hand towel |
| GCP | Ground Control Point |
| GDP | Gross Domestic Product |
| *Ghor/ ghar* | Home |

| ITEM | **Brief English Meaning and Explanation** |
|---|---|
| GOB | Government of Bangladesh |
| *Gom* | Wheat |
| *Gorom kal* | Hot season (Gorom = Hot; kal = season) |
| *Gram* | Village |
| *Grisma* | Summer |
| *Haor* | Another name for *beel* |
| *Hat* | Local periodic market (normally one or two days a week) |
| *Hath* | Hand (length measurement unit = 18 inches) |
| *Hemonto* | Late autumn |
| *Household* | People/family members living together in one dwelling arrangement (common cooking: food same cooking arrangement) |
| HYV | High Yielding Varieties |
| IRRI | International Rice Research Instititue (HYV paddy) |
| IUCN | International Union for the Conservation of Nature |
| *J. L. No.* | Juridiction List Number (Numerical identifier of Mouzas for cadastral, revenue and administration) |
| *Jaishtya* | Second Bengali calendar month (Mid-May to mid-June) |
| *Jat* | Cultivar, Variety |
| *Jhur jhura* | Loose |
| *Jola* | Canal (local name for *khal*) |
| *Joma* | Deposition |
| *Jomi* | Plot / land |
| *Kachi* | Scikle |
| *Kachuripana* | Hyacinth/Duck weed |
| *Kal* | Season |
| *Kal Baishaki* | Thunder storm accompanied by heavy rain or hail occurs in Baishak. |
| *Kalche* | Blackish |
| *Kalo* | Black |
| *Kartik* | Seventh Bengali calendar month (Mid-October to mid-November) |
| *Katcha* | Non brick and concrete (cement for building and pitch for road) |
| *Katha* | Local land measurement (1 katha = .015 acre, 20 katha = 1 bigha) |
| *Kathal* | Jackfruit |
| *Khal Khonon/Kata* | Digging/Excavating Canal |
| *Khal/Jola* | Canal or channel (A tributary of the river) |
| *Kharif-I* | Pre monsoon crop and season (April-July) |
| *Kharif-II* | Monsoon crop and season (August-November) |
| *Khas* | The land that vested with government but temporarily used by locals |

| ITEM | **Brief English Meaning and Explanation** |
| --- | --- |
| *Khora* | Dry |
| *Kodal* | Spade |
| *Kola* | Banana |
| *Lalche* | Radish |
| *Langol* | Plough |
| *Lau/Laau* | Bottle gourd, Indian squash |
| *Lunghi* | Loin cloth for males |
| LWI | Land Water Interface |
| *Magh* | Tenth Bengali calendar month (Mid-January to mid-February) |
| *Man kachu* | Arum |
| *Mas* | Fish |
| *Mati* | Soil |
| *Mistikumra* | Pumpkin |
| *Moi* | Ladder |
| *Morich* | Chili |
| *Motamuti* | Medium / moderate |
| *Mound* | Weight measurement unit (1 mound means 37.5 kg) |
| *Mouza* | The smallest revenue unit of Bangladesh similar to village |
| *Mula* | Radish |
| *Mythal* | Ditch (Doba) excavated regularly for raising the homestead. |
| *Nadi* | River |
| NEMAP | National Environmental Management Action Plan (for Bangladesh) |
| NGO | Non-governmental Organisation |
| *Nichu jomi* | Low land (Nichu = low; jomi = land) |
| NRM | Natural Resources Management |
| NRSP | Natural Resources System Programme (of DFID) |
| ODA | Overseas Development Administration (Former DFID) |
| *Pagar* | Ditch (Doba) used for dumping materials and fish culture. |
| *Palan* | Homestead |
| *Panta vath* | Fermented rice |
| *Paribar* | Family |
| *Parishad* | Council |
| *Pashchim* | West |
| *Pat* | Jute |
| *Pat ash* | Jute fibre |
| *Pata kopi* | Cabbage |

| ITEM | **Brief English Meaning and Explanation** |
|---|---|
| *Paurashava* | Municipality Area (Shahjadpur is a rural characteristics without running water and proper sewerage and drainage system) |
| *Peara* | Guava |
| *Pepe* | Papaya |
| *Phalgun* | Eleventh Bengali calendar month (Mid-February to mid-March) |
| *Phul kopi* | Cauliflower |
| *Piaj* | Onion |
| PLA | Participatory Learning and Action |
| *Plot* | The lowest level of revenue collection, the boundaries of which are marked on a mouza map. In bangla 'daag'. |
| *Potol* | Pointed gourd |
| *Poush* | Ninth Bengali calendar month (Mid-December to mid-January) |
| PRA | Participatory Rural Appraisal |
| *Pradhan* | Headman of the *samaj* |
| *Pre-kharif* | Early rainy cropping season |
| *Pukur* | Pond |
| *Purba* | East |
| *Rabi/Robi* | Cropping season (Dry winter season, December-March) |
| *Rashun* | Garlic |
| *Samaj* | A neighbourhood social groupings protectors of norms and values within the community |
| *Sar* | Fertiliser |
| *Sarat* | Autumn |
| *Sarder* | Leader (A social status) |
| *Saree/sari* | Traditional long cloth for woman (about 6 yards; 12 hand) |
| *Sarisha* | Mustard / rape seed |
| *Sech* | Irrigation |
| *Sheet* | Winter |
| *Shokti* | Power / Energy |
| *Shukno* | Dry condition |
| *Sobha* | Meeting |
| SPARRSO | Bangladesh Space Research and Remote Sensing Organization |
| *Sraban* | Fourth Bengali calendar month (Mid-July to mid-August) |
| *STW* | Shallow Tube Well |
| *SWB* | Small Water Body (Ditch, Pond, Reservoir, Lake and Canal) |
| *Taka* | Bangladesh currency (£1 = 105 Taka in the year 2004) |
| *Tal* | Palm |

| ITEM | **Brief English Meaning and Explanation** |
|---|---|
| *Thana* | Police station |
| Thana | Larger administrative unit, equivalent to a sub district/upazila. |
| *Teel/Til* | Sesame |
| *Tin-fasli* | Triple cropped |
| *Tin sheet* | Galvanized corrugated iron sheet used for house roof and wall. |
| *Uchu* | High |
| *Union* | Fifth order administrative unit comprised of mouzas. |
| *Union Parishad* | The smallest local government electoral unit |
| *Upazila* | Former Thana consists of several unions. |
| *Uttar* | North |
| *Uzarbari* | Empty homestead (abandoned houses) |
| *Van* | Three wheeler, non-motorised cycle |
| *Vita* | Flood free high land usually used for home. |
| *Zamindar* | Landlords, who collected taxes for the Mughal and British East India Company |

# CHAPTER 1: INTRODUCTION

## 1.1 Introduction

The present water and wetland management systems in rural Bangladesh are complex and diverse. Agriculture and aquaculture are the dominant activities in rural life and both are dependent on successful water management; also, households need access to adequate and safe domestic water (Soussan, 2000). The waterways of Bangladesh still act as an important transport network and water is used extensively in many types of handicrafts and industrial production (Soussan, 2000). Water is also a vital component of ecosystems maintenance. Small Water Bodies (doba, pukhur, dighi, jola and beel: see Table 1.1 ) are one of the sources of water, a vital and common resource in rural areas.

**Table 1.1 Size and characteristics of different small water bodies.**

| Name | Size | Characteristics |
|---|---|---|
| Doba/Pagar (Ditch) | 25-400 sq.metre(Approx) | Man-made, retain water mainly in wet season. |
| Pukur (Pond) | 150-1000 sq.metre(Approx) | Man-made or natural, retains water throughout the year. |
| Dighi (Reservoir) | > 750 sq. metre (Approx) | Man-made/natural, retains water throughout the year. |
| Jola/Khal (Canal) | > 2000 sq. metre (Approx) | Man-made/natural, retains water throughout the year in some parts. |
| Beel | > 1000 sq. metre (Approx) | Natural, open inland water, saucer shaped depression, generally retains water throughout the year. |

**Source: Fieldwork, Author (2001).**

A researchable constraint in understanding the role of small water bodies in the lives of poor rural Bangladeshis is an appreciation of the dynamic nature of human-environment interaction. Experience has shown that there is a fundamental problem with any developmental work that invests without a knowledge of how the present situation has evolved or how it is likely to change in future. This study therefore investigates the historical development of the present spatial distribution and use patterns of Small Water Bodies. The research also assesses the applicability of different remotely sensed data in detecting small water bodies. This is at a regional scale at Mouza (village) level in Bangladesh. The data are from both primary and secondary sources. Maps of spatial distributions, monitoring changes and different uses patterns are produced using Geographical Information Systems and Remote Sensing. An integrated participatory GIS-RS management system is developed and proposed for appropriate resource management and sustainable development planning.

## 1.2 Background of the Research

I come from a part of Bangladesh that is on the central floodplains of the Ganges-Jamuna river systems. This is a dynamic region in terms of its physical geography, with active fluvial geomorphological processes causing the rapid erosion and deposition of quaternary sediments. Each year there is a high risk of floods, for instance in 2004 my home village was under water for several months. The magnitude of these floods is very variable and patterns are difficult to detect. In social and economic terms water is a key variable, not just in this region but throughout Bangladesh. It has extraordinarily complex consequences that are both positive and negative.

I have had an interest in the geography of water and wetland issues in Bangladesh from a young age. In 1991/2 I did my first masters thesis at Jahangirnagar University, Bangladesh on prediction of tropical cyclone rainfall from satellite. In 1995/6 I did my masters degree at the University of Durham in Geographical Information for Development, where I was trained in the use of Geographical Information Systems and learned some of the basics of remote sensing. It seemed to me at the time that these computer-based techniques have tremendous potential for the inventorying and analysis of resources in my country and I decided at that time to attempt a study at the land-water interface. I had spotted a research gap in work on water in South Asia. At the macro-scale, there is plenty of literature on river systems and flood defences, and, at the micro-scale, a great deal of work has been done on irrigation and moisture deficits. What is lacking is attention to the Small Water Bodies (SWB) that are so characteristic of the Bengali countryside and which, in my opinion, have a lot of potential for improved management and development. I would go so far as to say that the issue of SWB is a neglected but highly significant one for the future of rural Bangladesh.

## 1.3 Aim of the Research

The broad aim of this research is to understand the importance of SWB in rural Bangladesh's transition to sustainable development. I have also tested a number of mapping and monitoring methods against my personal knowledge of ground conditions and sought to develop an appreciation of how to interpret data in the use of SWB dynamics. The most appropriate methodology seems at present to be a combination of Remote Sensing, GIS and socio-economic survey work. Based on plot-level data, a participatory management system is formulated and proposed for SWB, in order to achieve environmentally sustainable development at the *Thana* level. It is hoped that this proposed participatory management system, including some locally specific guidelines, will be applicable for the planning of the other 490 thanas in Bangladesh. The management system facilitates the integration of local planning with the national level planning process, which has not been possible hitherto. It also gave the opportunity to verify the applicability of remotely sensed data in local level planning.

A secondary aim is to prove to the reader that it is possible to devise and execute a methodology that includes both the hard science of computer-based analytical techniques, such as those used in GIS and remote sensing, with the qualitative approaches of the social sciences/humanities. I am well aware that scholars from each side of this methodological divide will be sceptical of the both the need for such epistemological breadth and of the results that it delivers, but I hope that the reader will, by the end of the thesis, see that the fusion of human/physical techniques delivers interesting and valuable insights that could not have been accomplished otherwise.

### 1.4 Objectives of the Research

The broad objectives of the research are three-fold. In addition, there are objectives that will state at the beginning of each individual chapter.

1. To establish the best methods of detecting and interpreting the presence of small water bodies given the problems of maps, aerial photographs, cloud cover, etc.;

2. To study the most appropriate techniques for inventorying and monitoring change in small water bodies. This will involve establishing a link between ground truth data from field work and long term remote sensing images, using GIS approaches and Remote Sensing techniques.

3. To understand the different uses of small water bodies and associated socio-economic phenomena for sustainable management planning.

The research is unusual for its hybrid methodology, a combination of remote sensing, GIS and social science approaches. Although certain technical aspects are of considerable interest, for instance the problems associated with the measurement of small water bodies some of whose size is at or beyond the limit of the spatial resolution (e.g. Landsat TM 30m and SAR-C 25m) of many sensors, the technical and management side of the work is secondary to the ultimate aim of understanding the changing nature and use of SWB.

## 1.5 Research Questions

My personal field experience in the study area, and the literature that I have reviewed so far, suggest that the following indicative research questions have been answered in this research.

1. How significant are small water bodies as resources at the land/water interface?

2. To what extent can remotely sensed data, maps and GPS help in the identification of small water bodies?

3. Have the uses of small water bodies changed over the last 30 years and, if so, what is the nature of that change?

4. Is there any scope for the participation of the local people in the monitoring change detection process through the mapping of their memory of perceived historical changes?

5. What is the potential relevance of the result for planning by local authorities and perhaps more widely in Bangladesh?

## 1.6 Research Gap

This research is based on map data, census data, aerial photo images, satellite images, plot level GIS spatial and attribute data, GPS data and data collected from the field through Participatory Rural Appraisal (PRA), Focus Groups (FG) and participatory questionnaire. Figure 1.1 shows how the overall data has been integrated for this study in the light of research gaps and existing databases. Here, very raw methodological designs are illustrated for an understanding of the research.

All information derived from the remotely sensed satellite images (and the radar data which has not been explored) has been pre-processed and processed and integrated in a GIS environment for the proposed local level management system. This integrated GIS-RS management system is also fed by spatial information gathered from field work through the use of GPS and attribute information derived from participatory observation, questionnaire survey, interview and focus group meetings. This spatial and attribute data has enriched the management system and enabled the detection of shape, size and location of the SWB, multiple socio-economic uses and the significance of these types of land use as resources at the land/water interface.

| | | |
|---|---|---|
| Research Gap in Remote Sensing<br><br>1. Little use of Radar Data.<br>2. No use of Corona Satellite Data<br>3. No change detection of SWB<br>4. Little research on SWB<br>5. No empirical study on rural areas<br>6. No study on South Asian Countries | Plot Based<br><br>Spatial data<br><br>Attribute data | Research Gap in GIS<br><br>1. No use of plot based (Dag) data<br>2. No use on SWB.<br>3. No change detection<br>4. No research on SWB<br>5. No empirical study on rural areas<br>6. No study on South Asian Countries |
| Satellite/Radar - 1972-2003 - Change | Integrated GIS-RS Management | Updating - 1936-2001 - Maps |
| Research Gap in Field Work<br><br>1. No field 'integrated' field work.<br>2. No GPS survey.<br>3. None on small water bodies.<br>4. No questionnaire survey on SWB.<br>5. No Participatory Rural Appraisal (PRA)<br>6. No Focus Group Meeting | Data and Information<br><br>GPS, PRA, Questionnaire<br><br>Field Data | Research Gap in Conventional Map<br><br>1. No use of historical Maps.<br>2. No assessment of Planning map.<br>3. No integration with RS & GIS<br>4. No plot (Dag) level planning map.<br>5. No updating the socio-economic maps. |

**Source: Author, 2001**

**Figure 1.1 Research Gap and Framework.**

### 1.7 Organisation of the Thesis

Chapter 1 focuses on the background and statement of this research including the aim and objectives. I have highlighted the brief idea of SWB. Different research questions are briefly outlined for the study and various aspects of the sources of data and research gaps are also covered in this chapter.

The foundation of the thesis is Chapter 2. Without organising and planning of the vast databases, I could not have made any further progress in detecting, monitoring and developing a management system. Details of the sources of data used and their pre-processing and processing for the analysis are illustrated here. The chapter starts with a brief description of the context of the study area and ends with a description of each platform of different remotely sensed data used.

All aerial photo images, satellite images and radar data with the help of associated socio-cultural data are interpreted in Chapter 3 using different interpretation methods and ground truthing from field work. This gives the opportunity to test the applicability of different remote sensing data in detecting SWB. The results include spatial mapping of different types of SWB.

The main deliberation of Chapter 4 is to integrate socio-cultural data with the remote sensing. Integrating the GIS, RS and socio-economic approaches enhances our understanding of the different aspects of the uses of SWB in daily life of rural Bangladesh. Historical changes are also mapped through this integrated approach.

Chapter 5 gives specializes in the socio-economic conditions associated with the SWB in rural Bangladesh. The chapter is very important in understanding the different aspects and uses of SWB for management and planning purpose.

Chapter 6 is the final concluding section of the research. Different problems of water management are reviewed in this section. The overall scenarios of the thesis are discussed briefly, with some recommendations. Finally a computer-assisted participatory sustainable management system, integrating GIS, RS and social science approaches, is developed and proposed for use in other rural parts of Bangladesh with some local adjustments.

### 1.8 Conclusion

In summary, my thesis has used the case study of four mouzas in Shahjadpur Thana, Sirajgonj District, Bangladesh to illustrate a number of important points:

1. I wish to demonstrate that a management system for rural resources can be devised, with utility for planners, by the integration of Environmental Remote Sensing, Geographical Information Systems, and Social Science methodologies. It is hoped that this will be replicable in other parts of Bangladesh and perhaps further a field.
2. The thesis will add to our knowledge of SWB in the context of the human use of landscape and resources in rural Bangladesh. This is an important challenge for the future development of the country and especially for the sustainable use of its scare resources.
3. I also hope to make a contribution to the debate about the specialization of human and physical geography. It is my view that cross-over topics, such as the one considered in this thesis, are a valid application of geographical skills, and, although the integration of techniques has by no means been easy in my research, I consider the effort to have been worthwhile. In future I intend to encourage more work of this nature.

# CHAPTER 2: STUDY AREA AND BACKGROUND INFORMATION

## 2.1 Introduction

Every piece of empirical quantitative and qualitative research in geography needs a study site. There are different statistical methods that can be used for study site selection (Baxter and Eyles, 1997; Curtis et al., 2000; Kuzel, 1992; Miles and Huberman, 1994; Patton, 1990; Stake, 1994; Trost, 1986; Wainwright, 1997). Generally, the selection of study area is influenced by the theoretical framework of the research questions or based on the philosophy and theory of the study aims and objectives, which direct the data sources and types (Curtis et al., 2000).

## 2.2 Objectives

The objectives of this chapter are,

1. To understand the study area selection process depends on SWB's importance.
2. To understand the different contexts of the study area.
3. To outline the information that has been used to carry out this research.
4. To know the sources of data and their details.

## 2.3 Research Questions

This chapter will deal with different research questions given below:

1. Why and what methods were used for the study area selection?
2. What are the different issues of the study area for SWB?
3. What are the information compiled for this research?
4. Where from the data and information collected in this research?

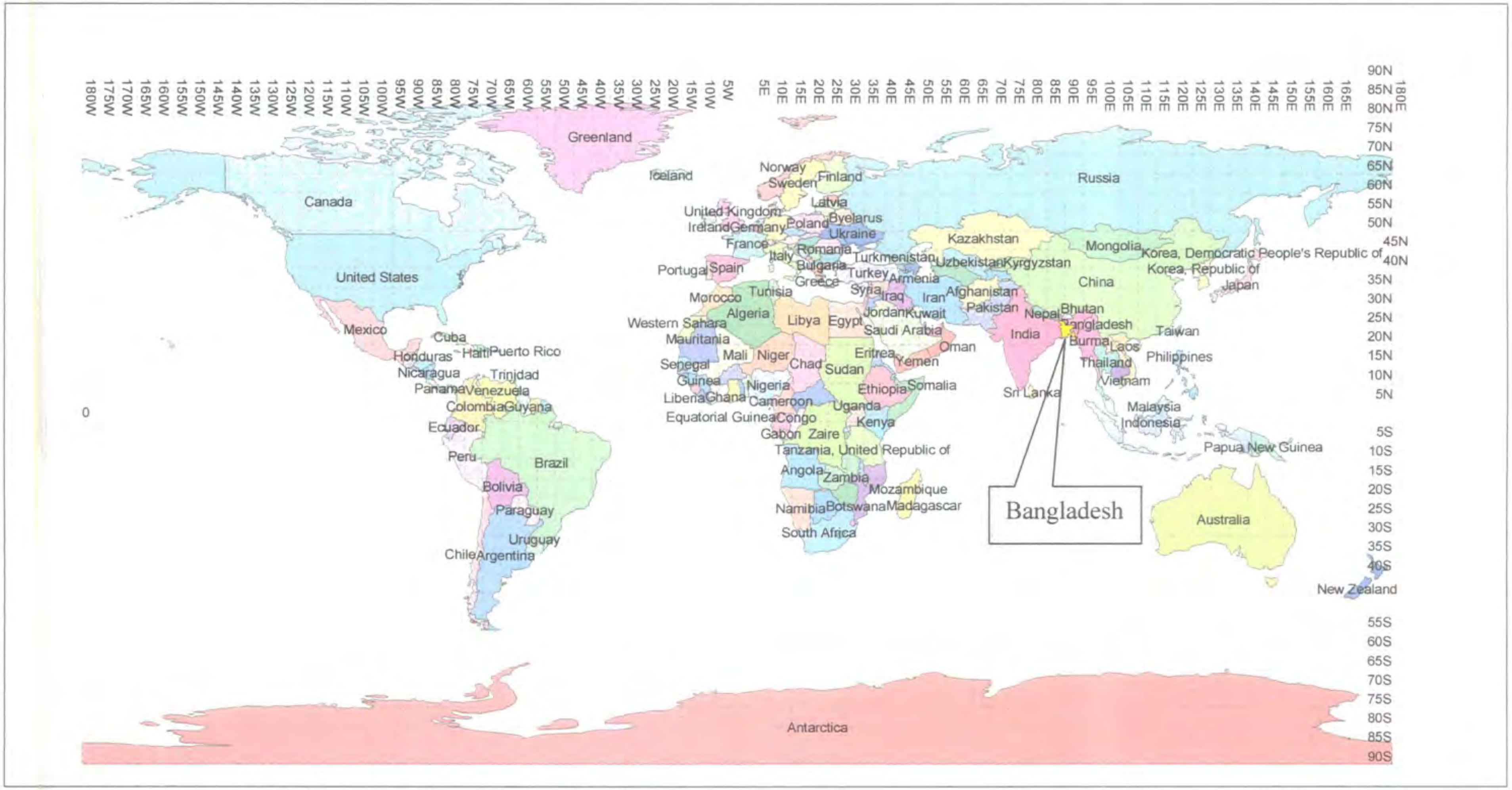



**Figure 2.1 Location of Bangladesh in the context of World.**

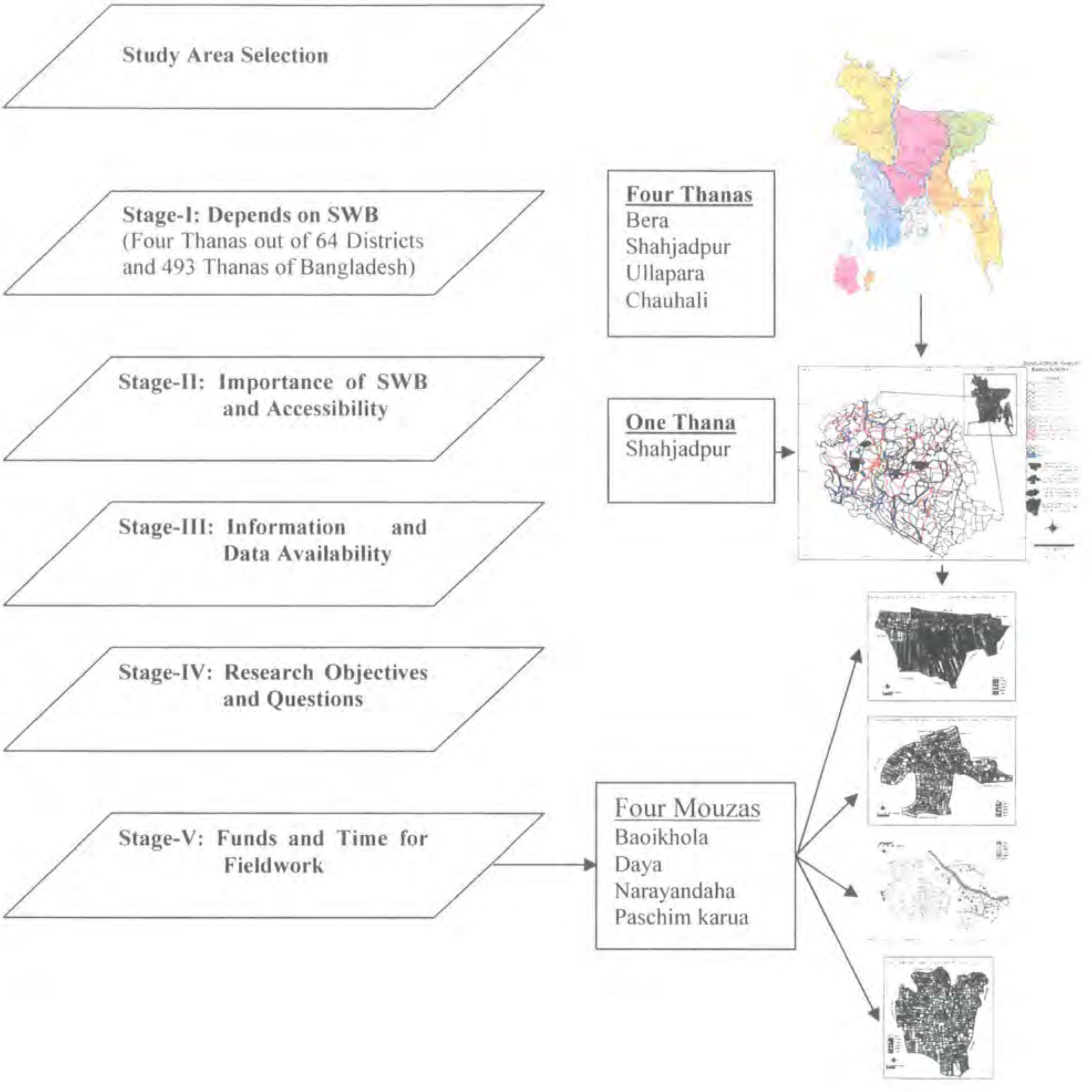
**Source: ESRI Data Base with ArcView 3.2 Software (1999).**

## 2.4 Justification of the Study Area

The study areas (four Mouzas) were selected based on a purposive sampling approach, according to their characteristics (Figure 2.2). This research is based in four Mouzas named Baoikhola, Daya, Narayandaha and Paschim Kharua under four different Unions named respectively Porzona, Shahjadpur (Habibullanagor) and Kayempur, under Shahjadpur Thana of Sirajgonj District, Bangladesh. These four mouzas represent Shahjadpur Thana. The mouza is the lowest administrative territory in Bangladesh just below the Union. Unions are under Thana/Upazila whereas Thana/Upazilas are under Districts and several districts make a Division. Bangladesh has 6 Divisions, 64 Districts, 493 Thana/Upazila, 4479 Unions and 59,990 mouzas (BBS, 2004).

The study areas were also selected due to the availability of data, ease of access to the researcher and the presence of moderately well distributed SWB (similar to other parts of lowland Bangladesh). These four mouzas are representative overall of the whole of Shahjadpur thana. It should also be mentioned that the researcher has a thorough knowledge of the area.

Figure 2.1 illustrates location of Bangladesh in the context of world.




**Source: Author (2004).**

**Figure 2.2 Study Area Selection Methods.**

## 2.5 History and Geographical Location

Shahjadpur, the most populous thana of Sirajgonj district, came into existence in 1910 (BBS, 1994). According to the district gazetteers, Hazrat Shah Mokhdum Shah Daulah, a shahjada (prince) of the kingdom of Yemen came to the place along with few followers to preach Islam and settled here. He was buried here after his death. He was reputedly a very pious man and religious leader during his life time. It is generally believed that the thana might have derived its name Shahjadpur from him. The great Nobel prize winning poet Rabindranath Tagoore also lived there and wrote several renowned poems specifically about a SWB.

Shahjadpur thana comprises 324 sq.km in 14 Unions and 185 Mouzas. It is located between 24°04′ and 24°25′ latitude and 89°31′ and 89°45′ longitude (Figure 2.3). Shahjadpur thana is bounded on the north by Ullahpara and Belkuchi thanas, on the east by Chowhali thana of Sirajgonj District and Nagarpur thana of Tangail District; on the south by Bera thana of Pabna district and Daulatpur thana of Manikganj District; and on the west by Faridpur and Sathia Thana of Pabna District. The thana is located near to the confluences of the Jamuna/Ganges and on the west bank of the Jamuna. In Figure 2.3 this is shown as the easterly most blue line running north-south. Note that during the wet season the Jamuna covers the whole of the south east margin of the study area (see Figure 2.5).

Specifically, *Baoikhola* mouza is under Porjana Union of Shahjadpur thana. Porjana union consists of 13 mouzas. The mouza Baoikhola comprise 157 hectares in 1587 plots. It is located between 24°10′ and 24°11′ latitudes and 89°39′ and 89°40′ longitude (Figure-2.3). Baoikhola is bounded on the north by Beltail mouza of Beltail Union; on the east by Mulkandi mouza of Jalalpur union and Kaijuri mouza of Kaijuri union; on the south by Ultadab and Ranikhola mouzas of Porjana Union; and on the west by Kakuria mouza and Porjana mouza of Porjana Union. This mouza lies in the north eastern part of central Shahjadpur thana (Figure 2.3).

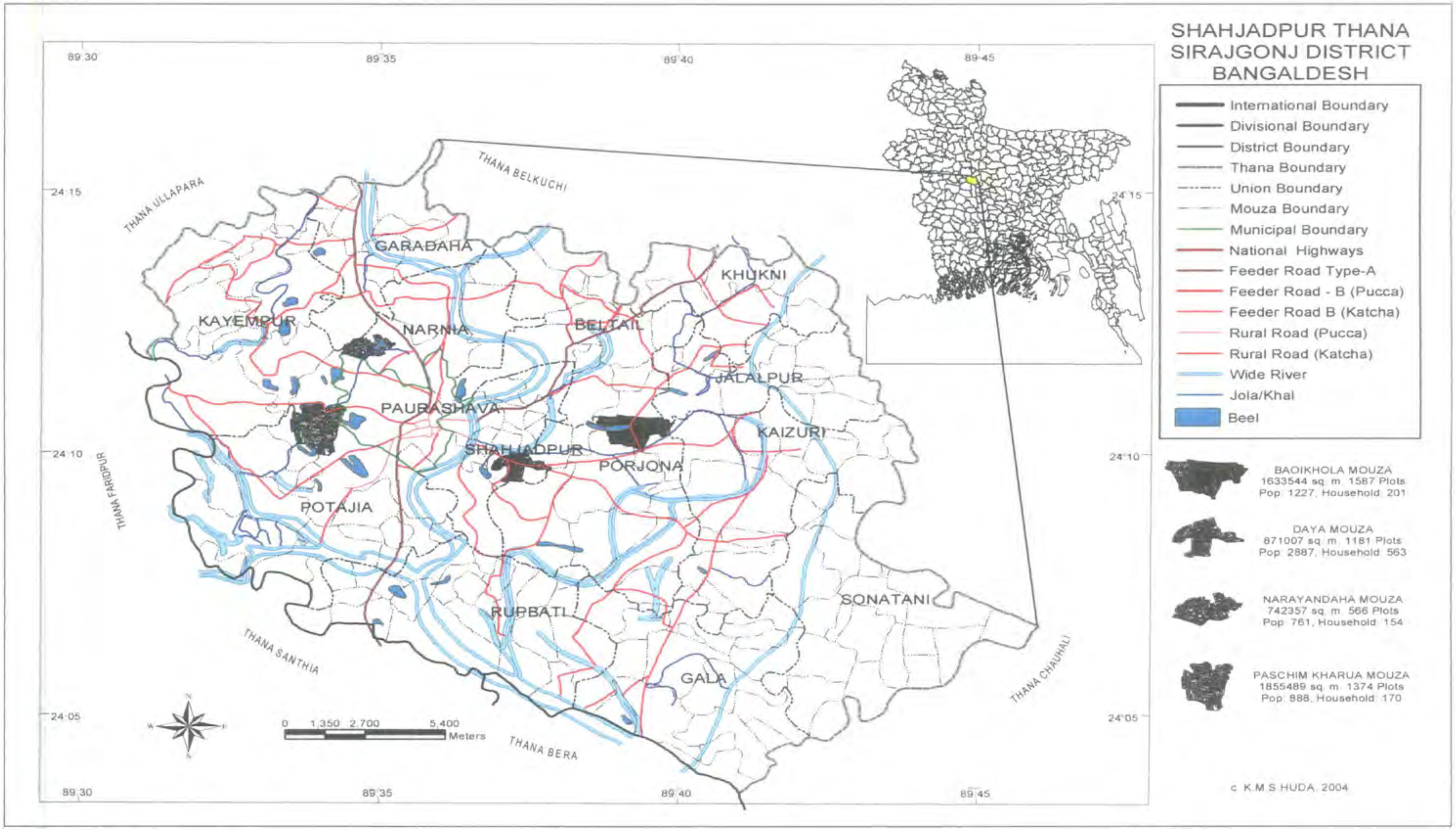



**Figure 2.3 Study Area.**

**Source: Modified and compiled from LGED (2003).**

*Daya* mouza is under Habibullahnagar (Shahjadpur) Union. Habibullahnagar union consists of 8 mouzas. The mouza Daya comprises 66 hectares in 1181 plots. It is located between 24°09′ and 24°10′ latitude and 89°37′ and 89°38′ longitude (Figure 2.3). Daya is bounded on the north by Kumirgoalia and Raipur mouzas of Habibullahnagar Union and Vagiroth Putia mouza of Porjona Union; on the east by Bera Kuchutia mouza of Habibullahnagar union; on the south by Hamlakhola mouza of Habibullahnagar and Nandalalpur mouza of Porjona Union; and on the west by Kumirgoalia and Hamlakhola mouzas of Habibullahnagar Union. This mouza lies in the south eastern part of central Shahjadpur thana (Figure 2.3).

*Narayandaha* mouza is under Narniah Union. Narniah union consists of 4 mouzas. The mouza comprises 65 hectares in 566 plots. It is located between 24°12′ and 24°13′ latitude and 89°34′ and 89°35′ longitude (Figure 2.3). Narayandaha mouza is bounded on the north by Mashipur mouza of Garadaha union and Parkola mouza of Shahjadpur Paurashava; on the east and south by Parkola mouza of Shahjadpur Paurashava; and on the west by Mashipur mouza of Garadaha union and Dariapur mouza of Shahjadpur Paurashava. This mouza lies in the north western part of central Shahjadpur thana (Figure 2.3).

*Paschim Kharua* mouza is under Kayempur Union, which comprises of 13 mouzas. The mouza Paschim Kharua comprises 179 hectares in 1374 plots. It is located between 24°10′ and 24°11′ latitude and 89°33′ and 89°34′ longitude (Figure 2.3). Paschim Kharua mouza is bounded on the north by Kharua Jangla mouza of Kayempur Union; on the east by Dariapur mouza of Shahjadpur Paurashava; on the south by Potajia mouza of Potajia Union; and on the west by Kharua Nandi mouza of Potajia Union. This mouza lies in the south western part of central Shahjadpur thana (Figure 2.3).

## 2.6 Population and Housing

The total population of Shahjadpur thana is 420,452 according to the Census of 1991 (BBS, 1996). Out of that 218,865 are male and 201,587 are female, which means 52 percent male and 48 percent female. There are 1,296 people per square kilometre (BBS, 1996) and 0.08 hectares of land per head. According to the population censuses of 1961, 1974 and 1981 the total population was respectively 202,426; 278,760 and 349,806 (SRDI, 1997), making annual rates of population increase for 1961-74, 1974-81 and 1981-91 of 2.9, 3.2 and 1.5 percent. Overall, the average literacy rate is 24.8 percent: 31.2 percent for males and 17.8 percent for females.

There are a total of 70,998 households according to the census of 1991 (BBS, 1996). The distribution of households by type shows that there are 99.12 percent dwelling units, 0.39 percent institutional units and 0.49 percent others. The average household size for the thana is 5.9 persons, and for the rural area slightly bigger at 6 persons (BBS, 1996). Only 4.79 percent of the dwellings have sanitary latrines, 3.75 percent in the rural area. A total of 90.64 percent of the households have non-sanitary latrines, rising to 91.89 percent in the rural area, and 4.57 percent households have no toilet facility of any kind. According to the 1991 census, only 13.05 percent of the total households and 12.72 percent of the dwelling households have an electricity connection. 99.70 percent of the dwelling households use a tubewell, different SWB and rivers as their main source of drinking water whereas only 0.28 percent use tap water.

**Table 2.1 Table shows the different Population Statistics of the four mouzas.**

| Items | Baoikhola | Daya | Narayandaha | Pashim Kharua |
|---|---|---|---|---|
| Population | 1227 | 2887 | 761 | 888 |
| Male | 667 (54%) | 1495 (52%) | 49% | 457 (51%) |
| Female | 560 (46%) | 1392 (48%) | 51% | 431 (49%) |
| Literacy | 17.6% | 20.5% | 33.7% | 10% |
| Male | 24% | 28.4% | 40.6% | 13.8% |
| Female | 10.6% | 11.19% | 26.9% | 6.3% |
| Household | 201 | 563 | 154 | 170 |
| Non sanitary latrines | 99.67% | 86.94% | 99.33% | 92.5% |
| Electricity | None | 14.74% | None | None |
| **Sources of Water** | | | | |
| TW & SWB | 100% | 99.33 | 100 | 100 |

**Source: Data compiled from BBS Census Report 1991.**

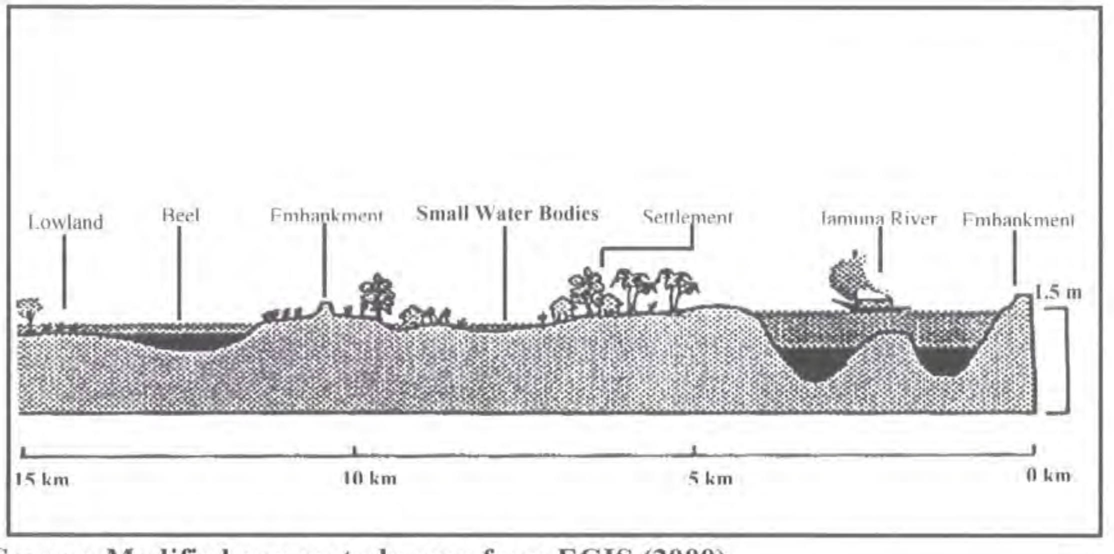
## 2.7 Communication network

The communication system is moderately good apart from remote and isolated charlands. This thana is situated beside the National Highway. It is connected via pucca roads to neighbouring thanas and Sirajgonj district headquarters (Figure 2.3). Also, there is good navigation through different rivers, especially via the Karotoa and Baral. In the dry season the thana headquarters is well connected by road with the unions and mouzas. In the rainy season it is the waterways that are used for communicating with the different parts of the thana.

The pucca National Feeder Road Type B that runs from the east of the thana to Shahjadpur Paurashava is a good quality road and gives the opportunity to neighbouring mouzas to have communications with the outside world. Baoikhola has benefited because the road runs immediately outside its southern boundary, as has Daya, which is also close to the eastern boundary of the municipality. However, proximity to Shahjadpur is not a guarantee of success, as witnessed by Narayandaha mouza, less than a kilometre from the centre but very poorly connected indeed, with no direct road access of any kind. Paschim Kharua is also close to the Paurashava boundary but has modest access via a katcha rural road.

## 2.8 Land type and Land use

Physiographically the thana lies in the Karatoya-Bengali and Brahmaputra-Jamuna flood plain basin. A schematic profile of the landscape is presented in Figure 2.4. Roughly 70 percent of the land is cultivated and the remainder is made up of homesteads and homestead forests, roads, and permanent water bodies like rivers and beels. Much of the land is inundated by rainfall and river water during the monsoon season; the extent of flooding is normally defined by topographic features within the flood plain. The flooding of low lying areas begins with pre-monsoon rainfall in May and June and it reaches a peak with over-bank river discharge in July and August.




**Source: Modified as per study area from EGIS (2000).**

**Figure 2.4 Schematic Profile of a Typical Landscape in Shahjadpur Thana.**

The majority of Shahjadpur thana lies in the Karatoya-Bangali flood plain. Only some southern parts fall in the Ganges floodplain. The topography of the thana is almost all plain and in some areas there is dry irregular relief or beels of the flood plain. The irregular dry lands are situated beside both banks of the river Karatoya, which flows through the middle of the thana. The beel in the western part of thana is very wide (SRDI, 1997). This thana can be divided in to four physiographic regions.

*Karatoya Bangali Floodplain:* A total of 23,924 hectares, that is 78 percent of the total area, lie in this physiographic region (SRDI, 1997). It consists of wide dry uplands and beels sized from small to large. In the past this plain was a part of the Tista flood plain and it now lies near the Bangali distributary of the Jamuna river (Rashid, 1991). The relief comprises broad ridges and basins. The uplands are inundated from a shallow to medium depth by floods and lower dry lands and beels are flooded medium to deep.

*Mixed Karatoya Bangali and Jamuna Floodplain:* The area is 1,604 hectares. (5 percent of the total) under this physiographic unit (SRDI, 1997). It lies outside of the embankment and is not vulnerable to floods or river bank erosion. The ridges are inundated to a shallow depth during the floods, whereas the beels are fully inundated.

*The Active and Young Jamuna Floodplain:* 19 percent of the total area of the thana lies in this physiographic unit, which is 6,120 hectares in size (SRDI, 1997). This region consists of permanent and temporary small and large chars in the Jamuna river, mostly situated in the eastern part of the thana. These areas can be deeply inundated by floods and are vulnerable to both floods and river bank erosion.

*The Old Ganges Floodplain:* The total area is 814 hectares, 3 percent of the total area of the thana (SRDI, 1997). The region has few ridges and consists mostly of beels. The ridges are inundated shallowly, whereas the beels can be deeply flooded in this zone.

Specifically Baoikhola and Daya mouzas lie in the Mixed Karatoya Bangali and Jamuna Floodplain physiographic region. Narayandaha and Paschim Kharua mouzas fall under the Karatoya Bangali Floodplain zone.

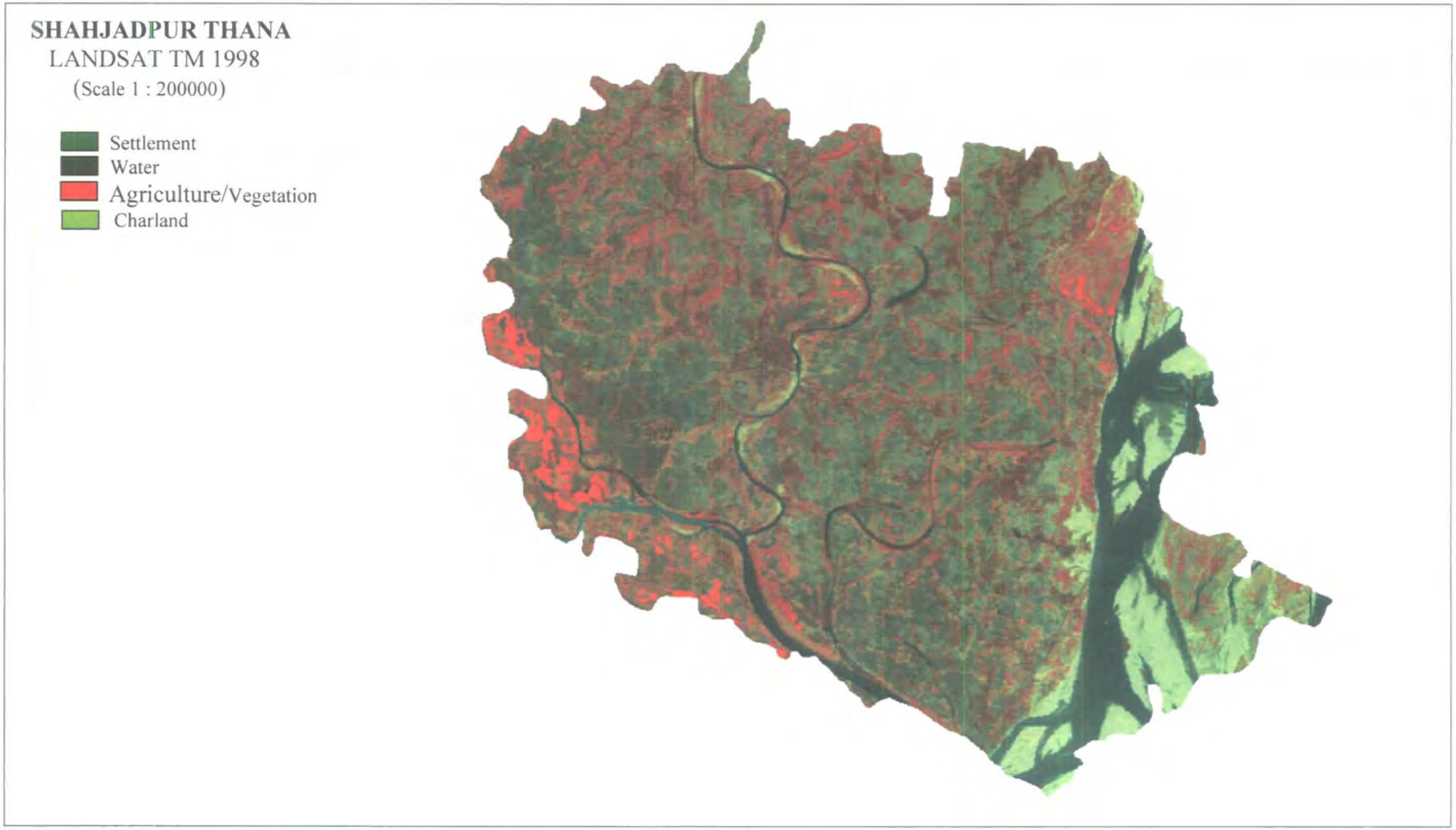



**Figure 2.5 Study Area (Landsat Image showing different landuse features )**
**Source: Author(2004).**

## 2.9 Soil

Different soil groups are present in Shahjadpur thana (Figure 2.6 and Table 2.2) According to SRDI (1997), the majority of the area is covered by Silmondi (7496 hectares), Savarbazar (6039 hectares) and Sonatola (4300 hectares). Other soil groups are Kazla (2152 hectares), Maldah (913 hectres), Kamarkhond (700 hectares) and Ghior (590 hectares). Still more groups named Daspara, Matia, Ishardi, Gopalpur, Belemati and Polimati of Jamuna are also found in this thana (SRDI, 1997). The varied characteristics of the different soil groups are illustrated in Table 2.3. The majority of soils are loamy or clayey loamy in texture. They are compact in hardness while some are loose i.e. Sonatola. They are mainly brown and pale to spotted grey colours and mildly alkaline. The drainage characteristics are poor.

Specifically, the majority part of *Baoikhola* consists of the Savarbazar soil group (SRDI, 1997). Also Sonatola and Silmondi are found in several places (Figure 2.6 and Table 2.2). Other soils present are Kamarkhond and Kazla. These soils are mainly clayey loamy and loamy in texture and mildly alkaline. These are compact in hardness and poor in drainage. Sonatola soil is present in the majority of the area of *Daya* (Figure 2.6 and Table 2.2). Silmondi and Savarbazar soils are also found in different parts of this mouza. These are mainly loamy, mildly alkaline, loose and slightly poor drainage in characteristics. *Narayandaha* consists of Sonatola and Savarbazar soils (Figure 2.6 and Table 2.2). A few areas are found with Kazla soils. These are clayey loamy and mild acid. These are compact in hardness and poor in drainage. Silmondi and Savarbazar dominates the Paschim Kharua (Figure 2.6 and Table 2.2). This area's soils are mainly clayey loamy and mildly alkaline. They are compact in hardness and poor in drainage.

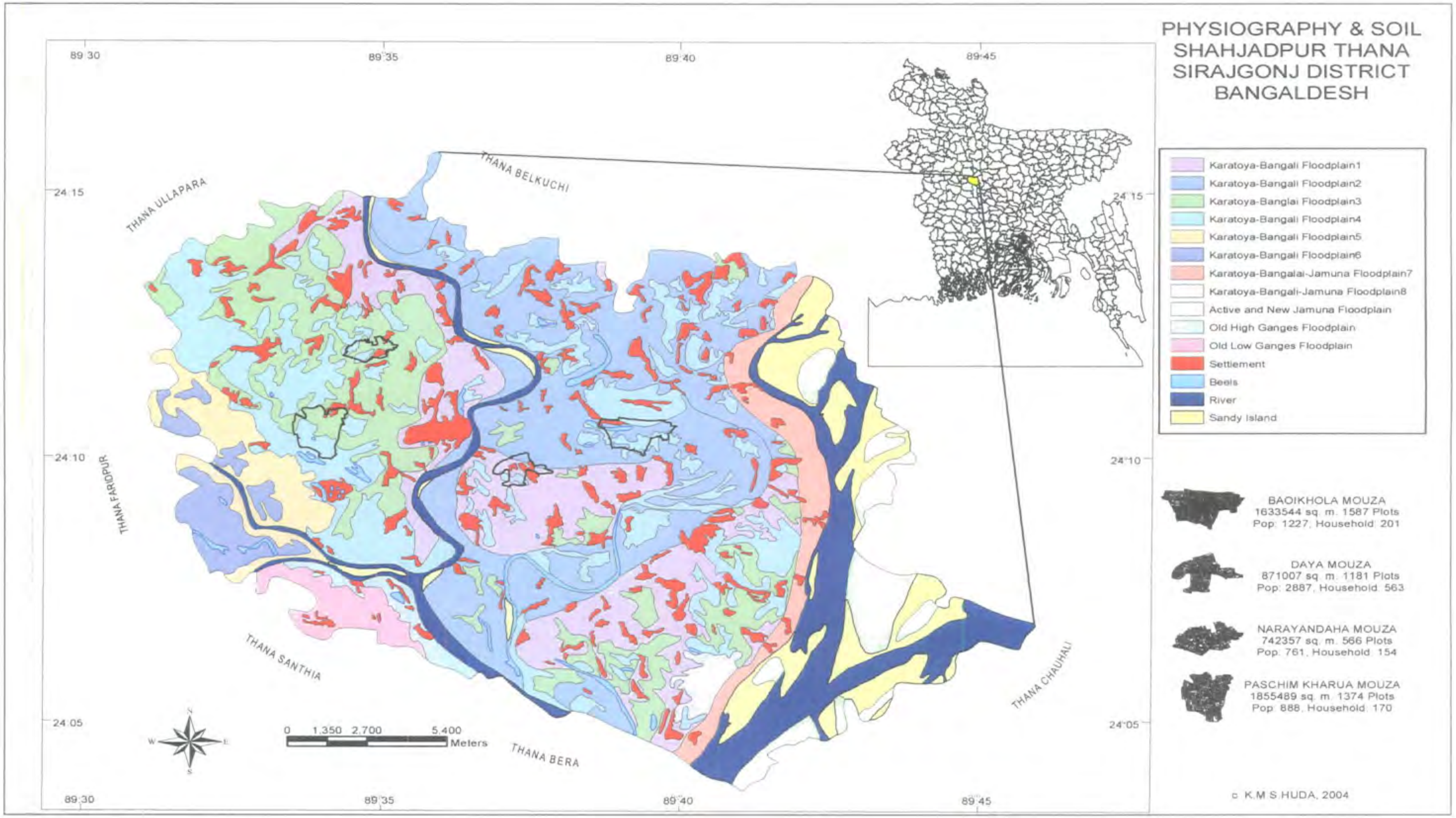



**Figure 2.6 Physiographic regions and Soil distribution in Study Area.**

**Source: Compiled from SRDI data base.**

**Table 2.2 Physiographic regions and Soil Types in the study Area.**

| Unit | Code | Physiographic Regions | Area | Fallow | Cultivable land: Landform | Land Type: Type | Land Type: Area | Soil Group: Name | Soil Group: Area | Characteristic: Drainage | Characteristic: Moisture | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | Karatoya - Bangali Floodplain | 5588 | 279 | Dryland | High | 559 | Sonatola | 559 | Well Advance | High | |
| | | | | | Dryland | Medium High | 4750 | Sonatola | 2235 | Advance | High | |
| | | | | | | | | Silmondi | 2515 | Advance | Medium | |
| 2 | 4 | Karatoya - Bangali Floodplain | 4864 | 243 | Dryland | High | 486 | Kamarkhond | 486 | Well Advance | High | Mainly uneven |
| | | | | | Dryland | Medium High | 4135 | Sonatola | 1459 | Advance | High | |
| | | | | | | | | Silmondi | 1946 | Advance | Medium | |
| | | | | | | | | Savarbazar | 730 | Advance | Medium | |
| 3 | 4 | Karatoya - Bangali Floodplain | 3780 | - | Dryland | Medium Low | 3780 | Silmondi | 2268 | Normal | Medium | |
| | | | | | | | | Savarbazar | 1512 | Normal | Low | |
| 4 | 4 | Karatoya - Bangali Floodplain | 5062 | 253 | Dryland | Medium Low | 506 | Silmondi | 506 | Normal | Medium | |
| | | | | | Beel | Low | 4303 | Savarbazar | 3797 | Normal | Low | |
| | | | | | | | | Kazla | 506 | Late | Low | |
| 5 | 4 | Karatoya - Bangali Floodplain | 1141 | 57 | Beel | Low | 970 | Matia | 228 | Normal | Medium | Flood Prone |
| | | | | | | | | Kazla | 742 | Late | Low | |
| | | | | | Beel | Very Low | 114 | Kazla | 114 | Late | Low | |
| 6 | 4 | Karatoya - Bangali Floodplain | 878 | 88 | Beel | Very Low | 790 | Kazla | 790 | Very late | Low | Flood Prone |
| 7 | 4 | Karotoya-Bangali-Jamuna Floodplain | 1068 | 53 | Dryland | Medium Low | 1015 | Kamarkhond | 214 | Normal | High | Flood Prone & River Bank Erosion |
| | | | | | | | | Maldah | 481 | Normal | High | |
| | | | | | | | | Silmondi | 214 | Normal | Medium | |
| | | | | | | | | Daspara | 106 | Normal | Medium | |
| 8 | 7 | Karotoya-Bangali-Jamuna Floodplain | 236 | - | Dryland | Medium Low | 236 | Sonatola | 47 | Normal | High | |
| | | | | | | | | Maldah | 95 | Normal | High | |
| | | | | | | | | Silmondi | 47 | Normal | Medium | |
| | | | | | | | | Belemati | 47 | Normal | Low | |
| 9 | 7 | Active Brahmaputra -Jamuna Floodplain | 1124 | 281 | Dryland | Medium Low | 674 | Maldah | 337 | Normal | High | Flood Prone & River bank erosion |
| | | | | | | | | Daspara | 224 | Normal | Medium | |
| | | | | | Dryland | Low | 169 | Belemati | 169 | Late | Low | |
| | | | | | | | | Polimati | 113 | Late | High | |
| 10 | 12 | Old High Ganges River Floodplain | 158 | 8 | Dryland | Medium High | 150 | Gopalpur | 47 | Advance | Medium | |
| | | | | | | | | Ishardi | 103 | Advance | Low | |
| 11 | 12 | Old Low Ganges River Floodplain | 656 | 66 | Beel | Medium High | 65 | Ghior | 65 | Normal | Low | Flood Prone |
| | | | | | Beel | Medium Low | 525 | Ghior | 525 | Late | Low | |
| | | | | | | | | | | | | |
| 81 | | Settlement | 2510 | 2259 | Dryland | High | 251 | Vitemati | 251 | Well Advanced | High | |
| 82 | | Sandy Island | 1941 | 1941 | | | | | | | | |
| 83 | | Water body/Pond | 401 | 401 | | | | | | | | |
| 84 | | River | 3055 | 3055 | | | | | | | | |
| | | | | | | | | | | | | |
| | | **Total Area (ha)** | 32462 | 8984 | | | 23478 | | | | | |

**Source: Data Compiled from SRDI (1997).**

## Table 2.3 Characteristics of Different Soils in Study Area

| Soil Group | Layer | Colour | Texture | Hardness | Reaction | Drainage |
|---|---|---|---|---|---|---|
| Sonatola | Upper | Pale Brown Spotted Grey | Loamy | Loose | Mild Acid(N) | Slight Poor |
| | Middle | Mixed Grey & Light Brown | Loamy | Loose | Mild Alkaline(N) | |
| | Lower | Brown Spotted Grey | Loamy | Loose | Mild Alkaline | |
| Silmondi | Upper | Pale Brown Spotted Grey | Clayey Loamy | Compact | Mild Acid | Poor |
| | Middle | Mixed Grey & Light Brown | Clayey Loamy | Compact | Mild Alkaline(N) | |
| | Lower | Pale Brown or Grey | Loamy | Loose | Mild Alkaline(N) | |
| Matia | Upper | Dark Grey | Clayey Loamy | Compact | Mild Alkaline | Poor |
| | Middle | Brown Spotted Grey/Dark Grey | Clayey Loamy | Compact | Mild Alkaline | |
| | Lower | Brown Spotted Dark Grey | Clayey | Compact | Mild Alkaline | |
| Savarbazar | Upper | Brown Spotted Grey | Clayey Loamy | Compact | Mild Alkaline | Poor |
| | Middle | Brown Spotted Grey | Clayey | Compact | Mild Acid(N) | |
| | Lower | Brown Spotted Grey | Clayey Loamy | Compact | Mild Alkaline(N) | |
| Kazla | Upper | Dark Grey | Clayey | Compact | Highly Acid | Poor |
| | Middle | Brown Spotted Dark Grey | Clayey | Compact | Mild Acid | |
| | Lower | Brown Spotted Dark Grey | Clayey | Compact | Neutral | |
| Maldah | Upper | Grey | Silty Loamy | Loose | Mild Acid | Poor |
| | Middle | Brown Spotted Grey | Loamy (stratified) | Loose | Mild Acid | |
| | Lower | Grey | Loamy (stratified) | Loose | Mild Acid | |
| Daspara | Upper | Grey | Loamy | Loose | Mild Acid | Poor |
| | Middle | Brown Spotted Grey | Clayey Loamy (stratified) | Loose | Neutral | |
| | Lower | Grey | Loamy/silty Loamy (stratified) | Loose | Neutral | |
| Kamarkhond | Upper | Pale Brown | Loamy | Loose | Neutral | Slight Poor |
| | Middle | Dark Brown Spotted Pale Brown | Loamy | Loose | Neutral | |
| | Lower | Brown Spotted Grey | Silty Loamy (stratified) | Loose | Neutral | |
| Belemati of Jamuna | Upper | Grey | Silty | unconsolidated | Neutral | Poor |
| | Middle | Grey | Silty (Stratified) | unconsolidated | Neutral | |
| | Lower | Grey | Silty (Stratified) | unconsolidated | Neutral | |
| Polimati of Jamuna | Upper | Grey | Loamy/Silty Loamy | Loose | Neutral | Poor |
| | Middle | Grey | Loamy (stratified) | Loose | Neutral | |
| | Lower | Grey | Silty Loamy (stratified) | Loose | Neutral | |
| Gopalpur | Upper | Pale Brown | Loamy/Clayey Loamy (Calcareous) | Loose | Mild Alkaline | Poor |
| | Middle | Pale Brown | Clayey Loamy (Calcareous) | Loose | Mild Alkaline | |
| | Lower | Pale Brown | Loamy/Silty Loamy (Calcareous | Loose | Mild Alkaline | |
| Ishardi | Upper | Pale Brown Spotted Grey | Loamy/Clayey Loamy (Calcareous) | Compact | Neutral | Poor |
| | Middle | Pale Brown/Brown | Clayey (Calcareous) | Compact | Mild Alkaline | |
| | Lower | Pale Brown /Grey | Clayey Loamy (Calcareous) | Compact | Mild Alkaline | |
| Ghior | Upper | Brown Spotted Dark Grey | Clayey | Compact | Neutral | Poor |
| | Middle | Brown or Dark spotted Dark Grey | Clayey | Compact | Neutral | |
| | Lower | Pale Brown/Brown Spotted Grey | Clayey | Compact | Mild Alkaline | |

**Source: Compiled from SRDI (2002).**

### 2.10 Rivers and Drainage

This large area covers six river basins: the Jamuna, Baral, Hurasagar, Karotoa, Kaikan, Hargila and Gohala (Figure 2.3). The meandering Karotoa flows through the middle of the thana from south to north. It is very rough in the monsoon and floods both banks. It has bank erosion also. The Hurasagar flows from the south to the north-eastern part of thana. It dries up during the dry season. The Baral flows from the south-eastern part towards the west. Both the Karatoya and the Hurasagar have connections with the Baral, which then falls into the mighty Jamuna on the eastern part of thana.

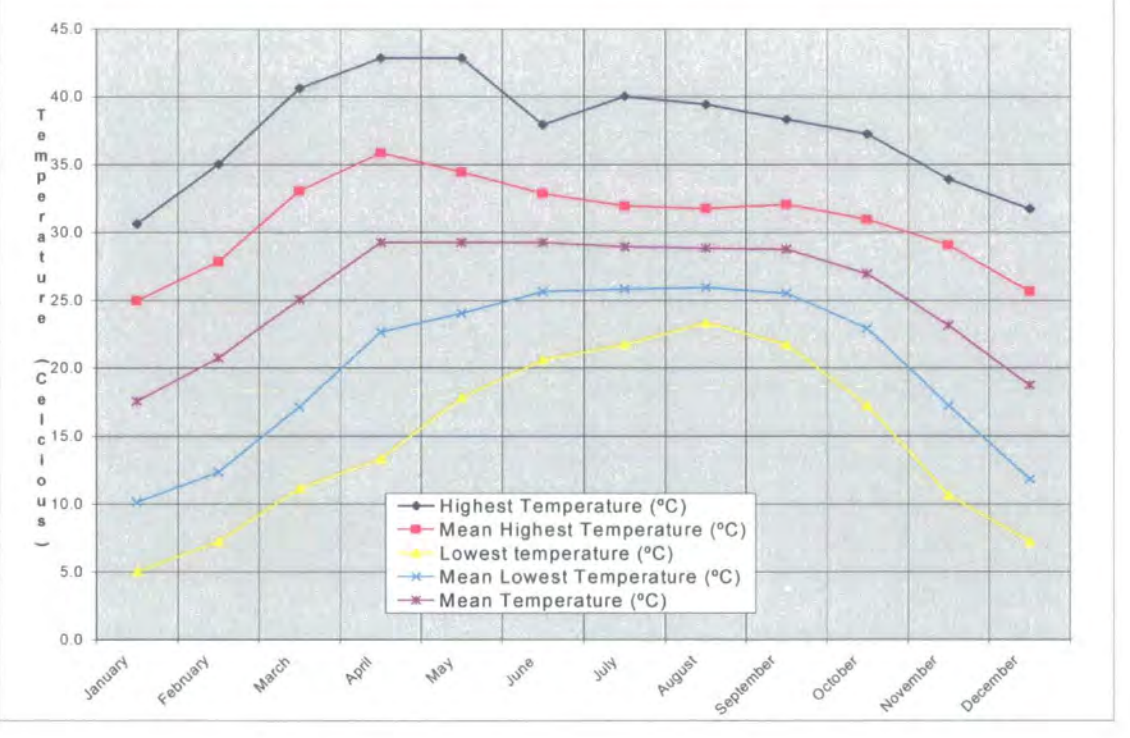
There are several jolas/khals connected to these rivers. These flow over different parts of the thana, specifically from the Karotoa River north east through Daya, to Beltail via a number of oxbow lakes (beels); eastwards from Daya to Porjona; and southwards from Narayandaha through Paschim Kharua, and then south westwards to the River Hargila. This interconnectedness of the drainage patterns and the phenomenal increase of discharge during the monsoon season, are the main features that set the hydrology of the region apart from the experience of a geographer from the United Kingdom.

Some parts of the jolas in Narayandaha and Paschim Kharua mouzas (Figure 2.3) dry up during January-March. The drainage system for the whole thana is poorly developed, specifically due to the characteristics of the soils. However, rivers, jolas, beels and ponds are major sources of water for agriculture and other domestic uses.

## 2.11 Climate

Shahjadpur thana has a tropical monsoon climate. Three seasons are clearly dominating among six. The monsoon prevails from May to October and 90 percent of the annual rainfall occurs during this period. Winter starts in November and ends in February. This season is very dry and cool. There is little rainfall in that period. March and April are the summer, when temperatures are very high and the humidity is low. Sometimes there are storms known as *Kal Baishaki*. Some hail storms occur also.

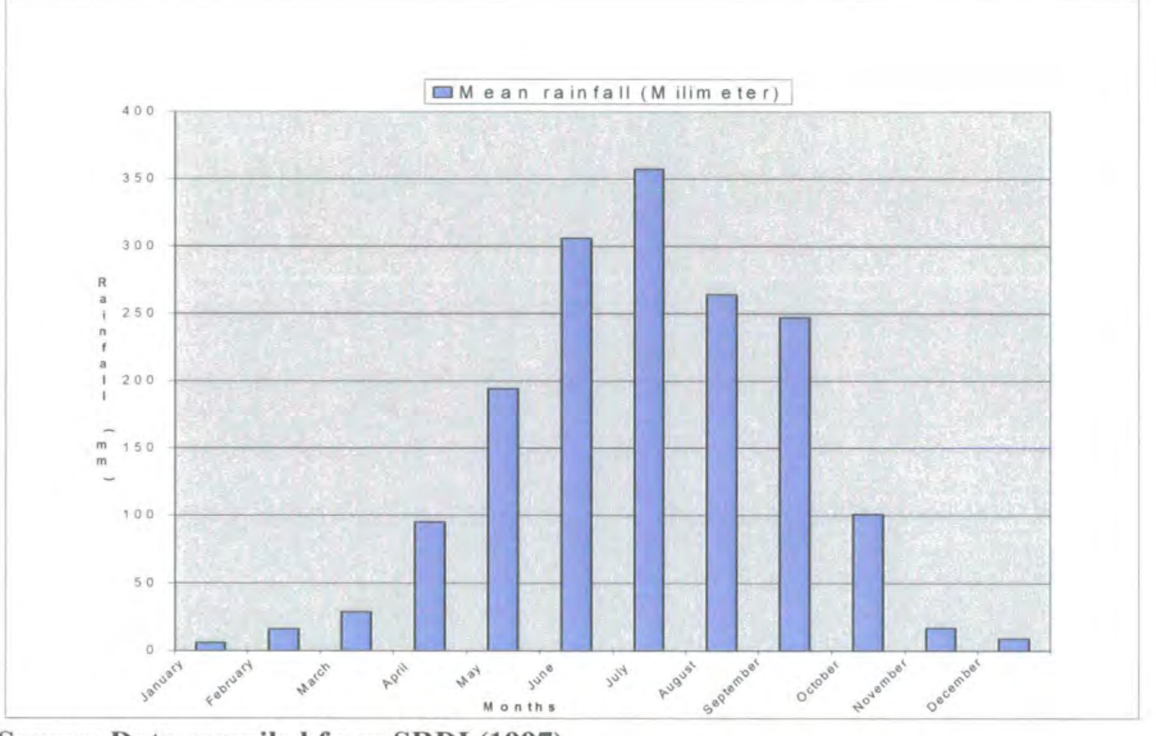
The minimum temperature can be seen during December and January (Figure 2.7). The mean of that period is 18° centigrade. The highest temperature of 42.8° centigrade can be seen in April or May. The lowest temperature of 5° centigrade occurs in January. April is the hottest month.




**Source: Data compiled from SRDI (1997).**

**Figure 2.7 Temperature in Study Area**

Rainfall is the major source of the water in this area. The mean rainfall in winter is 48 mm, although this amount is less than the evaporation rate. Long term records show that almost three to four months (November-February) stay dry. These months are named the dry season due to a rate of less than 75 mm of monthly mean rainfall. The highest rainfall occurs during May-September and the wettest month is July (Figure-2.8).




**Source: Data compiled from SRDI (1997).**

**Figure 2.8 Rainfall in the Study Area.**

Agro-climatic zones are highly dependent on this climate. Agricultural products are also directly dependent on yield season, numbers of dry days, heavy rainfall, high temperature and potential evapotranspiration. Shahjadpur thana has four agricultural seasons named Pre-Kharif (March-May), Kharif (May-December), Wet Kharif (June-October) and Rabi (October-February). Agriculture also relies on the irrigation system, and SWB play a vital role in this.

## 2.12 Agriculture

The agricultural system of Shahjadpur thana is totally dependent on water, especially rainfall and SWB as sources of water. 6,572 hectares of land is irrigated through different methods (SRDI, 1997). Rice is the dominant crop, while others include jute, wheat, mustard, sugarcane and pulses. Boro rice is cultivated with the help of irrigation in the medium low land with Savarbazar, Kazla, Ishardi and Ghior soils. With appropriate irrigation, wheat and mustard are cultivated on Sonatola and Silmondi soils. Mustard and maskalai are mainly cultivated in the Rabi season and Boro rice in the Kharif.

## 2.13 Economic Activity

Agriculture is the main livelihood of the thana, with milk production being a particularly prominent and successful activity. The local dairy cooperative, Milk Vita, and their associated factory is well-known nationally. They produce milk in packs, butter and a range of products that are traded across Bangladesh. Local farmers now have a substantial incentive to keep milch cattle and to restructure their agricultural system to accommodate the need for fodder. In addition, many jobs have been created in the factory, with the consequent multiplier effect in the spending power of the families concerned.

Handloom weaving is also prominent in some unions and mouzas of Shahjadpur. Saris, lunghis and ghamchas are produced and sold locally at a large twice-weekly clothes market in Shahjadpur Paurashava. Fishing from rivers and SWB is an important source of nutrition and income for the people in this area but does not have a national-level commercial status as do dairy products and textiles.

## 2.14 Data Sources

Different sources of data have been used for the research. From the beginning of this research I tried to explore as many as possible sources of data keeping in mind the research objectives and questions. A brief overview and justification of those sources of data can be seen in the Table 2.4 followed by their detailed description.

**Table 2.4 Different types of data sources and concerned chapters.**

| Data Sources | Purpose of Use | Used in chapters |
|---|---|---|
| Observation | Familiar with Study Area and research | All Chapters |
| Field Checking | Spatial Presence of SWB | All Chapters |
| GPS Survey | Geocorrection of Spatial Features | Chapter 2, 3 & 4 |
| Questionnaire Survey | Data for Landuse, SWB & Social | Chapter 5 & 6 |
| Ground Truthing | Remotely Sensed Data varification | Chapter 3 & 4 |
| Focus group Meeting | Data for peoples perception in management | Chapter 5 & 6 |
| Interviewing | Data for peoples perception in management | Chapter 5 & 6 |
| Country/District Map | Location & Familiar with Study Area | Chapter 1 and 2 |
| Thana/Union Map | Understanding Contexts of thana | Chapter 1 and 2 |
| Mouza Map | Plot level Data Insertion & Analysis | Chapter 3, 4 & 5 |
| Population Census | Socio-economic context | Chapter 2 & 5 |
| Agricultural Census | Socio-economic context | Chapter 2 & 5 |
| Published Literatures | Literature Review & Research Context | All chapters |
| Aerial Photo_1974 | Interpreting, Monitoring & Mapping | Chapter 2, 3 & 4 |
| Aerial Photo_1983 | Interpreting, Monitoring & Mapping | Chapter 2, 4 & 4 |
| Aerial Photo_1990 | Interpreting, Monitoring & Mapping | Chapter 2, 3 & 4 |
| CORONA_1972 | Detecting, Monitoring & Mapping | Chapter 2, 3 & 4 |
| IRS PAN 1999 | Detecting, Monitoring & Mapping | Chapter 2, 3 & 4 |
| IRS PAN 2003 | Detecting, Monitoring & Mapping | Chapter 2, 3 & 4 |
| IRS LISS-III 2003 | Detecting, Monitoring & Mapping | Chapter 2, 3 & 4 |
| SPOT HRV 1989 | Interpreting, Monitoring & Mapping | Chapter 2, 3 & 4 |
| Landsat TM 1997 | Detecting, Monitoring & Mapping | Chapter 2, 3 & 4 |
| Landsat TM 1998 | Detecting, Monitoring & Mapping | Chapter 2, 3 & 4 |
| ERS-1 1993 | Interpreting, & Mapping | Chapter 2, 3 & 4 |
| SIR-C 1994 | Interpreting, & Mapping | Chapter 2, 3 & 4 |
| X-SAR 1994 | Interpreting & Mapping | Chapter 2, 3 & 4 |

**Source: Author 2004**

All the sources of data are broadly divided into two major types named Primary and Secondary data depends on the characteristics of the sources.

### 2.14.1 Primary Data

#### 2.14.1.1 Data Collected during Field Work

My four months of fieldwork involved observation, interviewing, questionnaire surveys, focus group meetings, collecting unpublished documents, photography and video survey. Earlier, I prepared the necessary background paper work and preprocessing of remotely sensed images and hard copy prints for use in the field.

The main tasks done during field work were:

(1) Departure from Durham, UK and arrival in Dhaka on 30th of November, 2001;

(2) Visiting Jahangirnagar University (JU), selecting and briefing of field assistants;

(3) Buying and digitising of mouza maps and entry of basic attribute data;

(4) Observing selected mouzas and ice-breaking with local peoples;

(5) Identifying key informants and interviewing them;

(6) Participatory surveying selected mouzas and identifying land-use;

(7) Detailed survey on the Small Water Bodies (SWB);

(8) Surveying SWB with GPS and keeping tracts on printed maps;

(9) Surveying roads, infrastructures and land features with GPS and RS images;

(10) Collecting Aerial Photos and scanning these into a digital format;

(11) Meeting key informants with maps and images/getting necessary feedback;

(12) Focus group meeting;

(12) Ground checking of CORONA and other images and interpretations;

(13) Collecting published and unpublished materials/documents;

**2.14.1.2 Methods used for the collection of primary data**

Instead of a lengthy discussion here of data collections methods, it has been decided that this will be left to the appropriate sections of the later chapters. In brief, the methods are:

**a) Direct and Participatory Observation:** This is used in Chapters 2-5.

**b) General Plot-level Land use Questionnaire Survey:** See Chapters 4 and 5.

**c) Detailed Questionnaire Survey of Small Water Bodies:** See Chapter 4.

**d) Field Checking: Identifying co-ordinate/GC Points:** Chapters 3 and 4.

**e) Checking Boundaries of 4 Mouzas:** See Chapter 3.

**f) GPS Survey:** Chapter 3 and 4.

**g) Basic Image Processing:** Chapters 3 and 4.

**g) Basic Image Interpretation and Ground Truthing:** Chapters 3 and 4.

**h) Interviewing of key informants:** Chapter 5 and 6.

**i) Focus Group Meetings:** Chapter 5 and 6.

#### 2.14.2 Secondary Data

#### 2.14.2.1 Published Maps

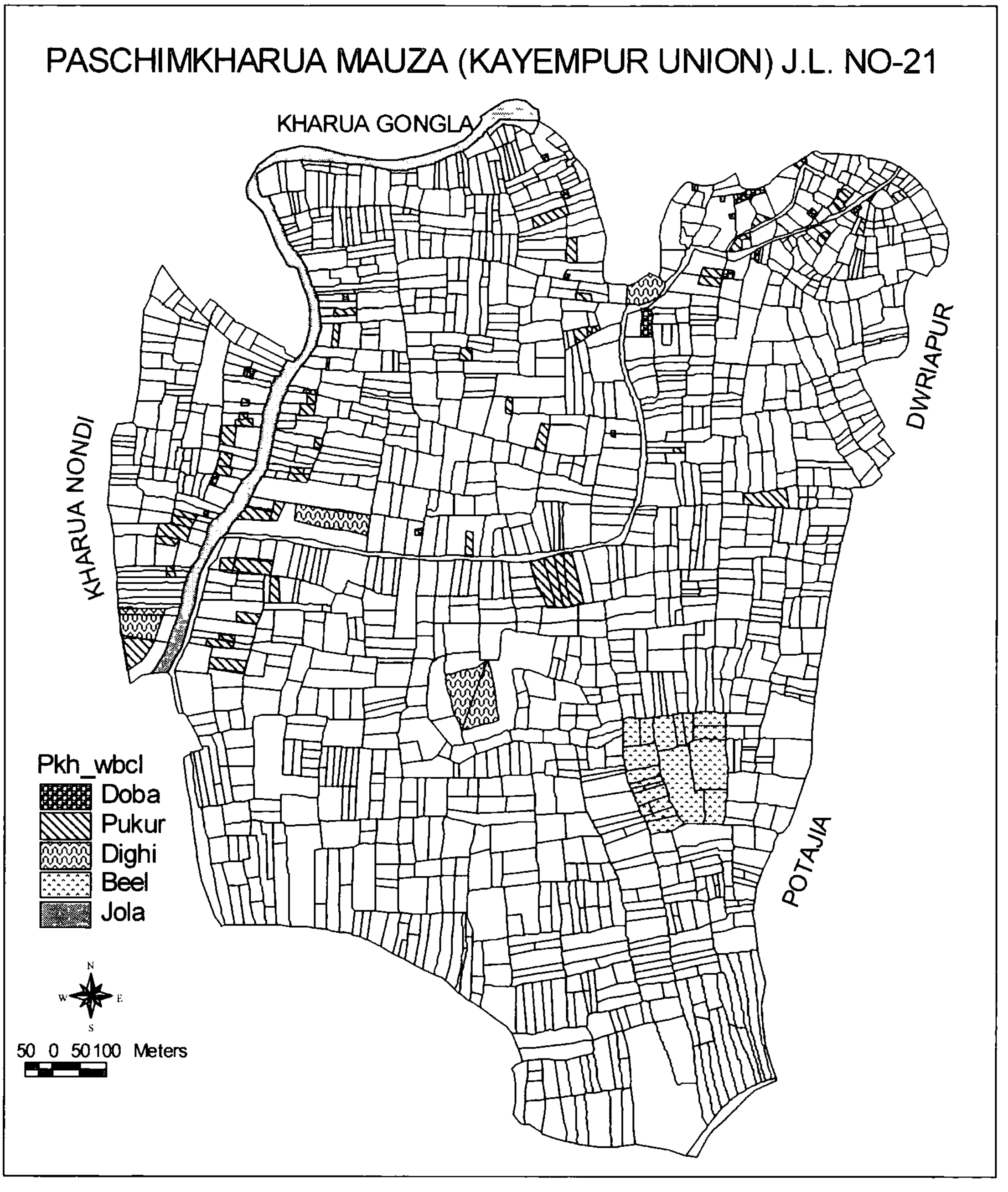
#### 2.14.2.1.1 Mouza Maps

Mouza maps are available from the Land Records and Surveying Department of Bangladesh. The detailed plot boundaries in each mouza were mapped either by ordinary plane table survey, or by offsets to the traverse, or by direct transfer of Thak boundaries (Rashid, 2003). Based on the above survey methods, the modern Cadastral Survey (CS) maps (16"=1 mile) up to plot level were developed to replace Todar Mall's $19^{th}$ century system which began in 1888 using the traverse survey (Hussain, 1995; Rashid, 2003). The Cadastral work showed the proper positions and the actual limits of all cultivators' fields or such subdivisions as required by the rules framed for 'the Settlement' work (Hussain, 1995). These accurate large-scale maps are now known as 'mouza maps'. The district settlement department reproduced these maps mechanically for revenue collection purposes (Rashid, 2003).

Since 1951, all mouza maps have been conserved by the Land Records and Surveying Department and mainly used for efficient revenue collection (Rashid, 2003). In the Pakistan period, after implementation of the State Acquisition Act, 1951, all mouzas were updated and resurveyed in the 1960s and were later known as Revenue Survey (RS) mouza maps (Rashid, 2003). The most recent survey was conducted in the 1990s but still it has not been implemented in Bangladesh. This survey is known as Bangladesh Survey (BS). However, there is absolutely no hesitation in saying that these maps are regarded as invaluable spatial-historical documents. They can be integrated with high resolution satellite images and aerial photos with the help of DGPS based GCPs (ground control points) data and can be considered as a milestone for the map-image relationship to understand the very dynamic deltaic SWB in Bangladesh. To understand and detect the SWB in detail, these mouza maps will play a significant and detailed role for further study and also help to map the changes at mouza level. Digital conversions of these maps can also be used in management, development, planning and monitoring systems in the country.

Figure 2.9 shows what a mouza map looks like and the information that is present. In the middle of the Paschim Kharua Mouza map the plot boundaries and identification numbers are also shown. In the map, we can observe that some plots are very big and some of them are small and they have irregular boundaries. In the real map, only one mouza or part of a mouza shows plot numbers at 16"=1 mile scale. The original mouza map does not show roads or land use pattern, or the inundation conditions. This map has been digitized from the original paper map using ArcInfo GIS software.

With the recent development of GIS systems and the advancement of mapping technologies, these mouza maps are very suitable for use with these modern approaches. Every plot has been marked with a plot number; every mouza has been recorded with a Jurisdiction list or Geocode number from the outset. To integrate all of the information from the primary, secondary, GIS and image interpretation techniques, a comprehensive data set has been developed by the author for each plot during the field survey.




**Source: Mouza map**

**Figure 2.9 Dizitized Mouza map of Paschim Kharua.**

#### 2.14.2.1.2 Topo Maps

Topo sheet no. 78 H/12 (Figure 2.11) was the first map that I acquired when I started my research and had no access to any other cartographic data. It is based on a colonial map corrected by air photographs produced by Messrs Air Survey Co. Ltd of London, who flew the region in 1952/3, and a ground survey in 1968/9. The sheet has been reprinted several times (Figure 2.11), but it has not been updated since the independence of Bangladesh in 1971. Therefore, at first I faced a considerable disadvantage in having no detailed, up-to-date topographical depiction of my study area and was forced to seek out alternative sources of information.

The following Figure 2.10 shows the numbering pattern of the topo sheets for identification.

| | | |
|---|---|---|
| 78 H/7 | 78 H/11 | 78 H/15 |
| 78 H/8 | 78 H/12 | 78 H/16 |
| 79 H/5 | 79 H/9 | 79 H/13 |

**Source: Topo map (1972)**

**Figure 2.10 Numbering Topo map.**

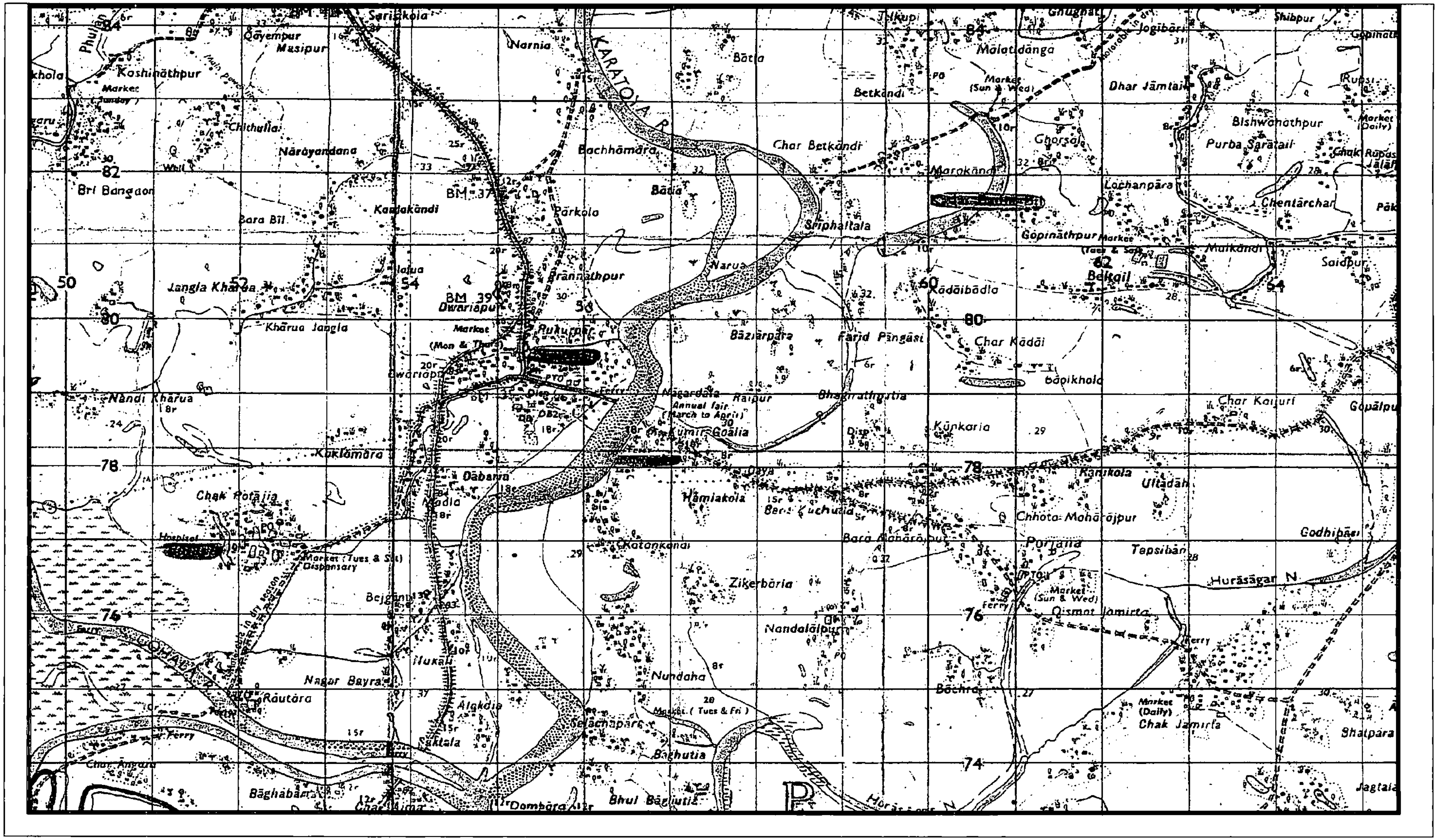



Figure 2.11 Study Area (TOPOMAP_1972)

Source: Author(2004).

#### 2.14.2.1.3 Other Maps

A number of maps of various ages and scales have been valuable during my research. The British map of Shahjadpur police station, Pabna District, surveyed in 1919-24 and corrected to 1936, although obviously out of date as a topographic map, was of a good quality.

Less inspiring was the Local Government Engineering Department Base Map of thana Shahjadpur, Zila Sirajganj, published in 1995 and based on aerial photography of 1983-84 and a SPOT image of 1989-90. This was part of Bangladesh's first GIS-based map series, which has since been used for planning purposes nationwide. It has gross errors in details such as the location of beels, the absence of mouza boundaries, and inconsistencies in the names of the mouzas. In the case of the mouzas, lists are published in the Small Area Atlas of Bangladesh (Mouzas and Mahallahs of Pabna District) in 1988. This illustrates well the problems faced by any researcher in Bangladesh, that different statistical and planning agencies do not integrate their databases, causing much confusion and waste of time in establishing the true situation.

The Bangladesh Bureau of Statistics produced a Mouza Geocode Map of Shahjadpur Upazila in 1988. Again, there are inconsistencies in the geocodes between this and the LGED map but neither organization, although informed of the problematic structure and accuracy of their data, was willing to make any amendments. I have therefore had to make my own arrangements in terms of creating a series of maps, which are as accurate as I can make them under these difficult circumstances.

### 2.14.2.2 Census Report

The Bangladesh population census of 2000 was surveyed only a short time before I was in the field from November 2001. I had already heard rumours about people claiming to have been left off the schedule and the usual explanation for this is that the collection of data was devolved to people who were not properly trained for the task. My experience suggests that these doubts are close to the mark. To take one example, I surveyed 100 households in Narayandaha, and my estimate is that this was approximately 40-50 per cent of the total population. This is borne out by the 1991 Census, published in 1996, which reported 144 households in that mouza and, taking natural population increase and migration into account, one might reasonably expect there to have been about 200 households in the year 2000. A preliminary manuscript version of the 2000 census report, which I have seen but at the time of writing remains unpublished, reported only 109 households, clearly incorrect. In Daya the 1991 figure was 536 households and my estimate is 650 for 2001, but the 2000 census reports only 313 households. Under these circumstances it is impossible to put one's faith in the census and at all times in the thesis I have used my own estimates of population and demographic characteristics.

#### 2.14.2.3 Other Materials

A variety of digital maps and GIS coverages were used for Shahjadpur Thana at an early stage of the research. An example is the Local Government Engineering Department's GPS survey of roads. In addition, I used clipped versions of digital maps of the whole country in my own GIS database. Where appropriate these sources are acknowledged in the text.

I found national and local newspapers valuable for the recent situation of SWB and also used a range of historical books and pamphlets about the thana. I also researched and collected most published and unpublished reports on SWB in Bangladesh and Bengal as a whole.

#### 2.14.2.4 Digital Coverages

The following digital coverages have been used in this thesis:

a) LGED Zila Boundary.

b) BBS Zila Boundary.

c) LGED Thana boundary.

d) BBS Thana boundary.

e) LGED Union boundary.

f) BBS Union boundary.

g) LGED Mouza boundary.

h) Author produced Baoikhola plot boundary.

i) Author produced Daya plot boundary.

j) Author produced Narayandaha plot boundary.

k) Author produced Paschim Kharua plot boundary.

l) Author produced Shahjadpur thana soil map compiled from SRDI.

m) Author produced SWB boundary for Baoikhola mouza (different years).

n) Author produced SWB boundary for Daya mouza (different years).

o) Author produced SWB boundary for Narayandaha mouza (different years).

p) Author produced SWB boundary for Paschim Kharua mouza (different years).

### 2.14.3 Remote Sensing data

Different forms of remotely sensed data used in this research. Table below shows the brief justification of using those data and concerned chapters.

**Table 2.5 Summary of remotely sensed data chapters in which used.**

| Platforms of RS | Purpose of Use | Used in chapters |
|---|---|---|
| Aerial Photo_1974 | Landuse and monitoring mapping | Chapter 2, 3, 4 and 6 |
| Aerial Photo_1983 | Landuse and monitoring mapping | Chapter 2, 3, 4 and 6 |
| Aerial Photo_1990 | Landuse and monitoring mapping | Chapter 2, 3, 4 and 6 |
| CORONA_1972 | Monitoring & Change Detecting SWB | Chapter 2, 3, 4 and 6 |
| IRS PAN 1999 | Monitoring & Change Detecting SWB | Chapter 2, 3, 4 and 6 |
| IRS PAN 2003 | Monitoring & Change Detecting SWB | Chapter 2, 3, 4 and 6 |
| IRS LISS-III 2003 | Monitoring & Change Detecting SWB | Chapter 2, 3, 4 and 6 |
| SPOT 1989 | Understanding Study Area and monitoring | Chapter 2, 3, 4 and 6 |
| Landsat TM 1997 | Monitoring & Change Detecting SWB | Chapter 2, 3, 4 and 6 |
| Landsat TM 1998 | Monitoring & Change Detecting SWB | Chapter 2, 3, 4 and 6 |
| ERS-1 1993 | Understanding Study Area and monitoring | Chapter 2, 3, 4 and 6 |
| SIR-C 1994 | Understanding Study Area and monitoring | Chapter 2, 3, 4 and 6 |
| X-SAR 1994 | Understanding Study Area and monitoring | Chapter 2, 3, 4 and 6 |

**Source: Author 2004**

#### 2.14.3.1 Aerial Photos

Unlike in most developed countries, aerial photos in Bangladesh are still very confidential and prevented by law for general public use and research. In some developed countries APs can be acquired from different authorised websites (e.g., www.streetmap.co.uk or www.multimap.co.uk) and other authorities, e.g. the Ordnance Survey in the UK. It is paradoxical that in Bangladesh APs are prohibited, although anybody can buy or collect from different sources even better quality high resolution satellite images in digital format from commercial image data suppliers (e.g. Quickbird or Ikonos image data).

Like other researchers, getting hold of or purchasing Aerial Photographs (AP) in a proper way from the government authority was difficult. However, I managed to acquire APs covering my study area for 1974, 1983 and 1990 (Figure-2.12) from a variety of undisclosed sources, who considered my situation and were convinced that my use of APs was solely for research purposes. They also understood that my work will not be harmful for the national interest; on the contrary the methods and results of this research will be useful for our country's sustainable development and resource management planning.

The archiving and record keeping management system of the APs in Bangladesh is poor. Because of this we are losing valuable historical evidence and data as lots of old APs are already damaged and misplaced. It is time to realise that they need to be preserved properly as they represent an important source of historical data for identifying changes, resource management and related research. Finally, APs should be made easily available for different research and educational purposes with as little bureaucracy as possible.

The first APs were acquired by the then Pakistan Government in 1953 in panchromatic form at a 1:30,000 scale, primarily to implement its land reforms, natural resource management and agricultural developments (Rashid, 2003). The Bangladesh Government surveyed and acquired APs in order to update topographic map sheets and defence purposes twice in 1984 and 1989. These APs have been used for different purposes earlier by other researchers but this is the first time for the detection of SWB.

The quality of the CORONA satellite images for the study area was evaluated by comparing with the APs. A great amount of data was generated from these APs. They were scanned using a high quality photogrammetric scanner in grey scale and saved digitally in Tag Image File Format (TIFF), as this format is convenient and compatible with image processing software. These digital APs have been manually geo-corrected by the author with help of ground control points acquired during field work and calibrated using the geoprocessing module of Erdas Imagine Software. This pre-processing helped the APs to be compatible with other RS data to be analysed and compared in the same platform. Different aspects of these APs can be seen in table 2.6.

**Table 2.6 Technical Summary of Aerial Photography.**

| Variables | Aerial Photo_1974 | Aerial Photo_1983 | Aerial Photo_1990 |
|---|---|---|---|
| Resolution | 1:30,000 | 1:30,000 | 1:40,000 |
| Source | Hard Copy | Hard Copy | Hard Copy |
| Mode/Band | Black and White | Black and White | Black and White |
| Digitalizing | Scanned geocorrected | Scanned geocorrected | Scanned geocorrected |

**Source: Author (2001-2).**

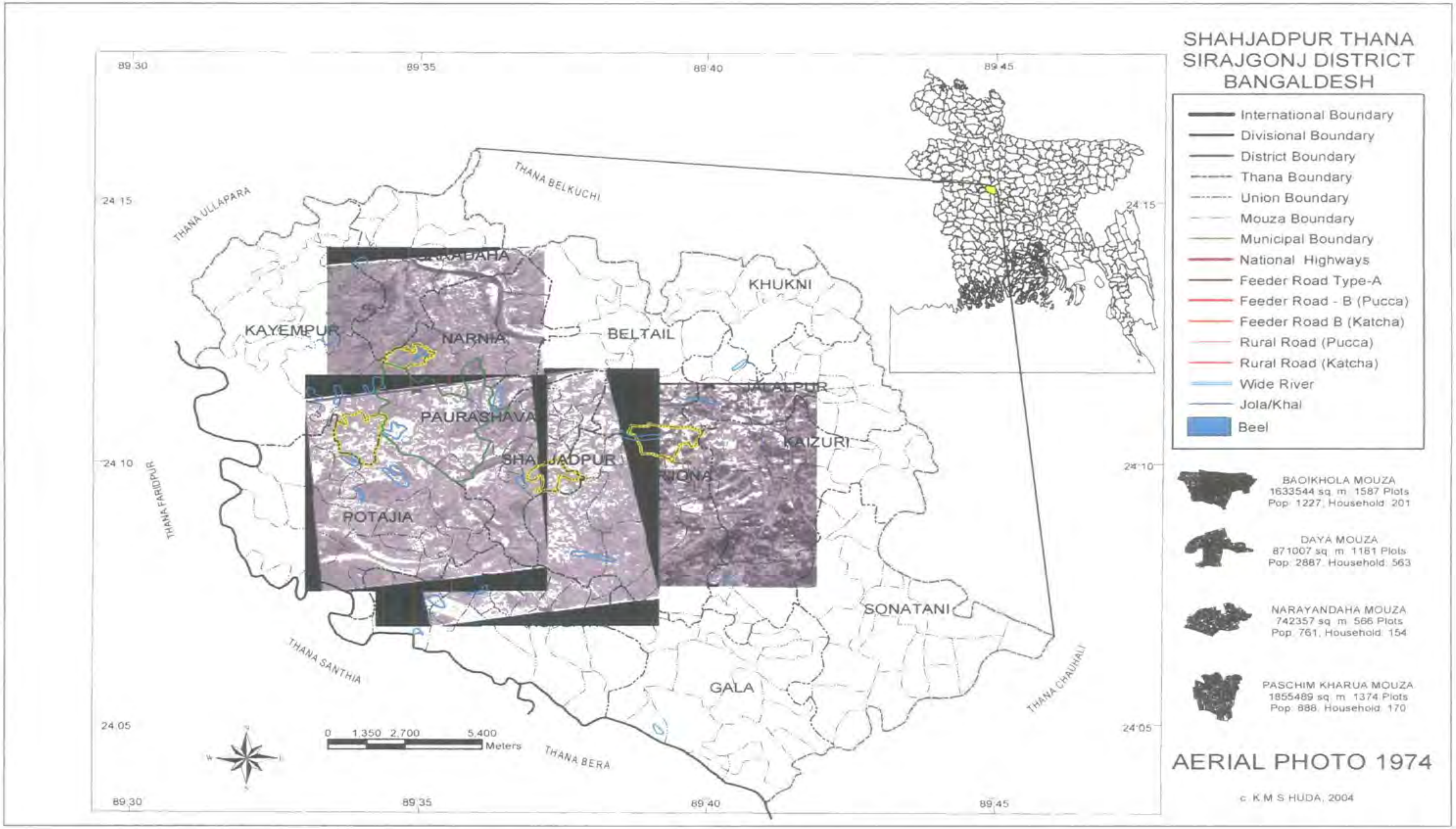


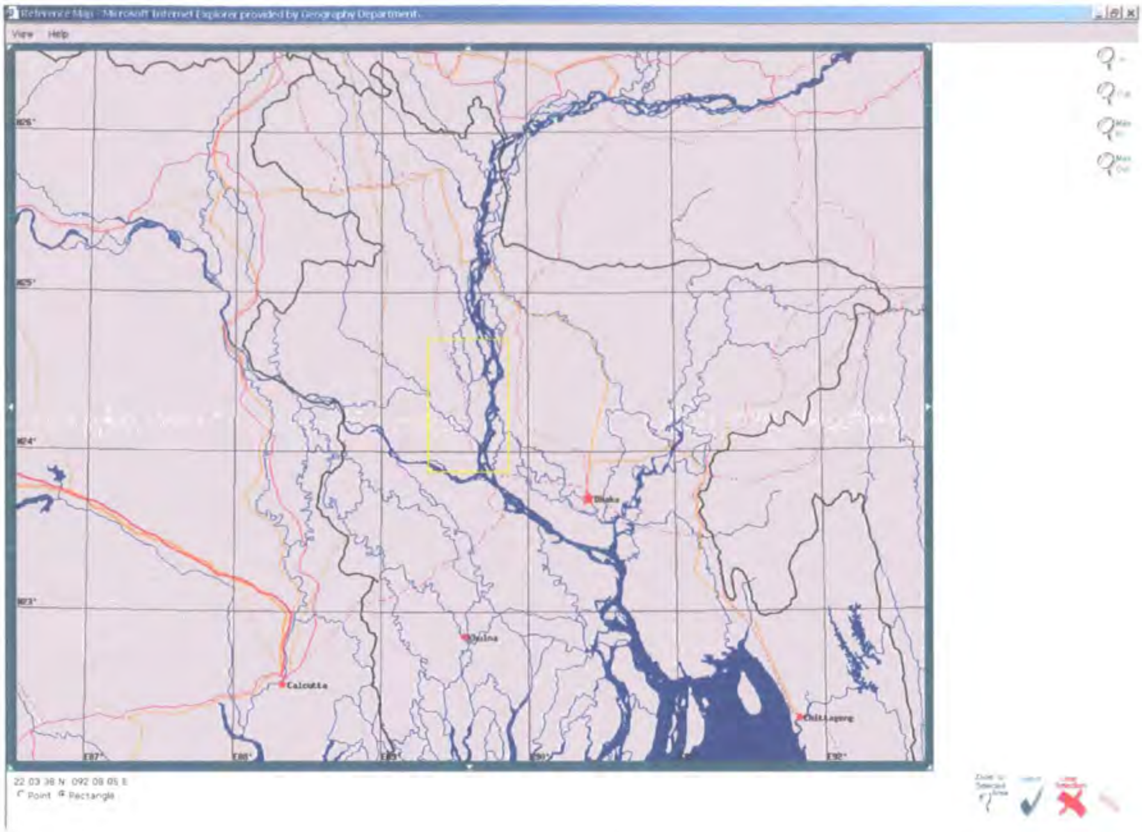

**Figure 2.12 Study Area (Aerial Photo 1974)**

**Source: Author(2004).**

### 2.14.3.2 CORONA Intelligence Satellite Photography

For this research I had the chance to incorporate recently declassified American military intelligence satellite photography for the detection of SWB in Bangladesh for first time. The data are rather different from the more familiar commercial satellite images and aerial photographs. President Clinton of the United States in 1995 directed the declassification of intelligence imagery collected between 1960 and 1972 by the first generation of US photo-reconnaissance satellites and the programme was code-named CORONA, Argon and Lanyard (Campbell, 2002; Rashid, 2003). The intelligence community used the designators KH-1, KH-2, KH-3, KH-4, KH-4A and KH-4B for the CORONA systems (http://edcwww.cr.usgs.gov/glis/hyper/guide/disp, 2002).

To achieve the goal of the study, high-resolution images were needed for the historical change detection study and CORONA KH-4B imagery for 1972 was purchased as high quality filmstrips. Out of a total of 148 known spy missions between 25 June 1959 and 25 May 1972, 8 negative microfiches (2.25" x 29.8") from Sequence Roll no 6145 and 6134 of one mission were selected for the study of Shahjadpur Thana. The selected mission number was 1116-1 of 22 April 1972 acquired by CORONA KH-4B. The strip is 13.8 km in width and 188 km long. The films are of approximately 2 metre ground resolution.



**Source: (http://edcwww.cr.usgs.gov /glis/hyper /guide/disp, 2002).**

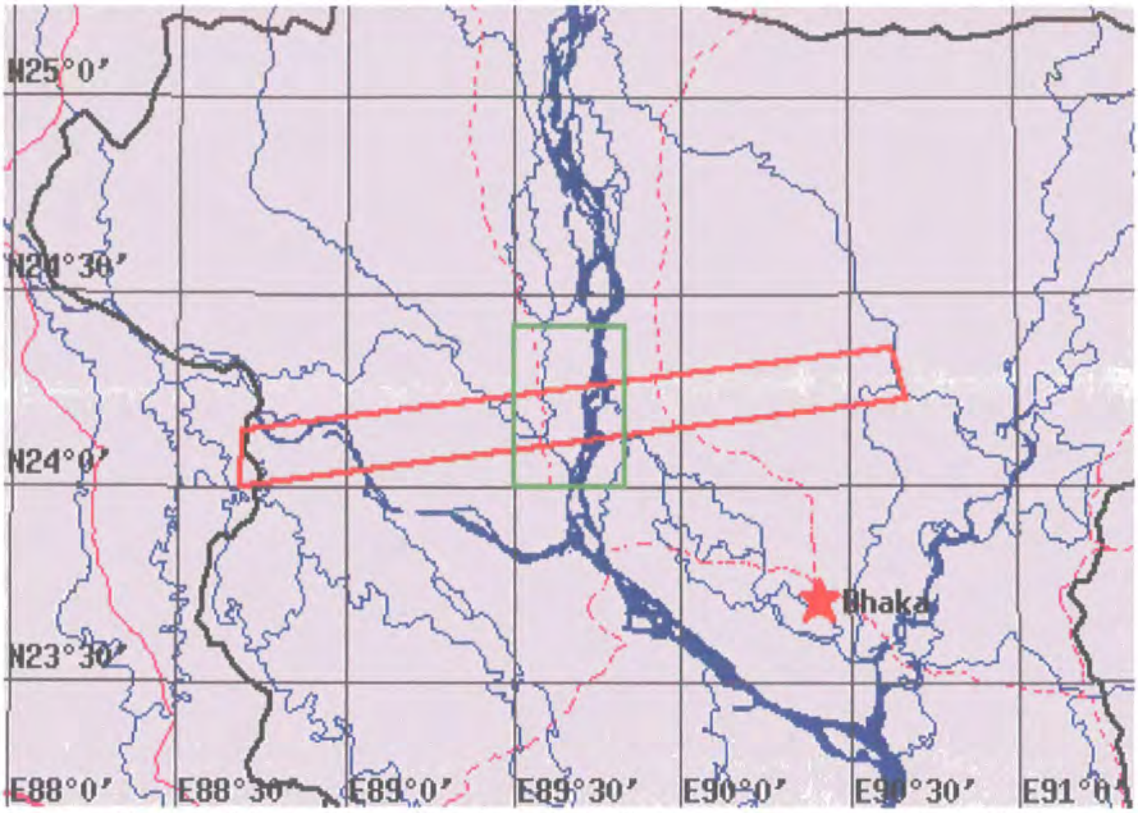
**Figure 2.13 Corona Film Strip selection procedure for the study area in web.**

The selected filmstrips were ordered using the internet (http://edc.usgs.Gov /Webglis/glisbin/submitorder.pl) from the Customer Services of USGS/EROS Data Centre (47914 252nd Street, Sioux Falls, SD 57198-0001, USA attn: GLIS Order). The study area was marked on the negatives and was scanned using a photogrammetric optical scanner at 7.5 micron resolution by SDS (Survey and Development Services Ltd, http://www.sds.co.uk). The total size of the study area after the scanning was a more than 2 gigabytes. This means that an entire microfilm contains about 18 gigabytes of digital data at 7.5 micron scan resolution.

The image preparation steps of the aft and back looking panoramic CORONA photography were:

1. Surfing USGS web site;
2. Selecting CORONA negative films;
3. Purchasing films;
4. Identifying study sites;
5. Contacting a company with a suitable photogrammetric scanner;
6. Scanning at 7.5 microns;
7. Geo-referencing using GPS based ground control points;
8. Digital image processing and integrating with GIS;
9. Adding field attributes and data; and
10. Mapping and interpreting.

The example in Figure-2.14 shows the location of the CORONA 1972 KH4B given a narrow and long red strip of Bangladesh territory (bold black boundary) with the actual images and metadata details available for each film. The strip was elongated from west to east. The small green box is the rectangular extent of Shahjadpur Thana. Each negative filmstrip (red rectangular on the map) covers 13.8km x188 km (about 2594.4 $km^2$) of Bangladesh, which means that the filmed area is about 9 times larger than the area of Shahjadpur, with about a 2-metre ground resolution and 160 lp/mm or 8000 dpi film resolution. Parts of four strips were required to cover the study area in order to carry out this research.




**Source: Data and image compiled from http://edcwww.cr.usgs.gov/glis, 2001.**

**Figure 2.14 Selection of Area and film Strip.**

Film Reference: DS1116-1039DF055 1116-1 039D 59 1972/04/22 Y F 5

**Source: http://edcwww.cr.usgs.gov/glis, 2003.**

**Figure 2.15 Example of CORONA KH-4B Satellite Film of 1972 of Bangladesh.**

**Metadata**

| | |
|---|---|
| Entity Id: DS1116-1039DF056 | Area Indicator: Entity partially covers the search area |
| Mission Number: 1116-1 | Northwest Latitude: N24 08 |
| Frame Number: 56 | Northwest Longitude: E088 41 |
| Acquisition Date: 1972/04/22 | Northeast Latitude: N24 22 |
| Camera Type: FORWARD | Northeast Longitude: E090 38 |
| Camera/Resolution: STEREO HIGH | Southeast Latitude: N24 14 |
| Revolution: 039D | Southeast Longitude: E090 40 |
| Image Type: BLACK and WHITE | Southwest Latitude: N24 00 |
| Film Type: 70mm PANORAMIC | Southwest Longitude: E088 41 |
| Generation: 2 | Browse Availability: YES |
| Polarity: NEGATIVE | Browse Path:1116-1/039D/F/DS1116-1039DF056.jpg |

**Source: Data and image compiled from http://edcwww.cr.usgs.gov/glis, 2001.**

**Table 2.7 Various types of the CORONA sensors and their configurations.**

| CORONA System | KH-1-4* | KH-4A | KH-4B | KH-5 | KH-6 |
|---|---|---|---|---|---|
| Camera Type | Panoramic | Panoramic | Panoramic | Frame | Panoramic |
| Film Width | 70 mm | 70 mm | 70 mm | 5 in | 5 in |
| Approx. Frame Format (in. x in.) | 2.18x29.8 | 2.18x29.8 | 2.18x29.8 | 4.5 x 4.5 | 4.5 x 25 |
| Focal Length (inches) | 24 | 24 | 24 | 3 | 66 |
| Best Resolution of Film (lines/mm) | 50-100 | 120 | 160 | 30 | 160 |
| Enlargement Capability | <10 times | 16 times | 16 times | 8 times | 16 times |
| Best Ground Resolution (approx.) | 25 ft | 9 ft | 6 ft | 460 ft | 6 ft |
| Nominal System Altitude (naut. miles) | 90-250 | 100 | 81 | 174 | 93 |
| Nominal Photo Scale | 1:505000 | 305000 | 1:247500 | 1:4250000 | 1:100000 |
| Nominal Ground Coverage/ Image Frame (miles) | 9.5X130 to 26X360 | 10.6X144 | 8.6X117 | 300X300 | 7.5 X 40 |
| Nominal Ground Sample Distance of GLIS** Browse Image (feet/pixel) | 530 | 530 | 430 | 4000 | 180 |

* The KH-1, KH-2, KH-3, and KH-4 are grouped together for describing camera-related features. The KH-4 designator was sometimes used by the Intelligence Community to refer to the entire group.

** GLIS - Global Land Information System

**Source:Data compiled from http://edcwww.cr.usgs.gov/glis/hyper/guide/disp, 2002.**

A total of 8 CORONA black and white negative films were sent to SDS Ltd., Scotland for digital scanning at 7.5 micron accuracy. The proposed scanning areas were marked by non-adhesive red tape on the films and on film covers respectively with instructions to scan only within the marked area. The original printed numbers of negatives are located on either side border. More particularly, the digits beginning with D are negative numbers. The original spatial resolution of the 1972 negatives (D039 series) is very high (approximately 3 microns or 8000 dpi or 160 lines/mm). Monochrome film scanned at 7.5 microns as mentioned in the RH file used by SDS Ltd. for each CORONA Microfiche, in April 2001. Figure 2.16 illustrates the CORONA satellite image used for the research.

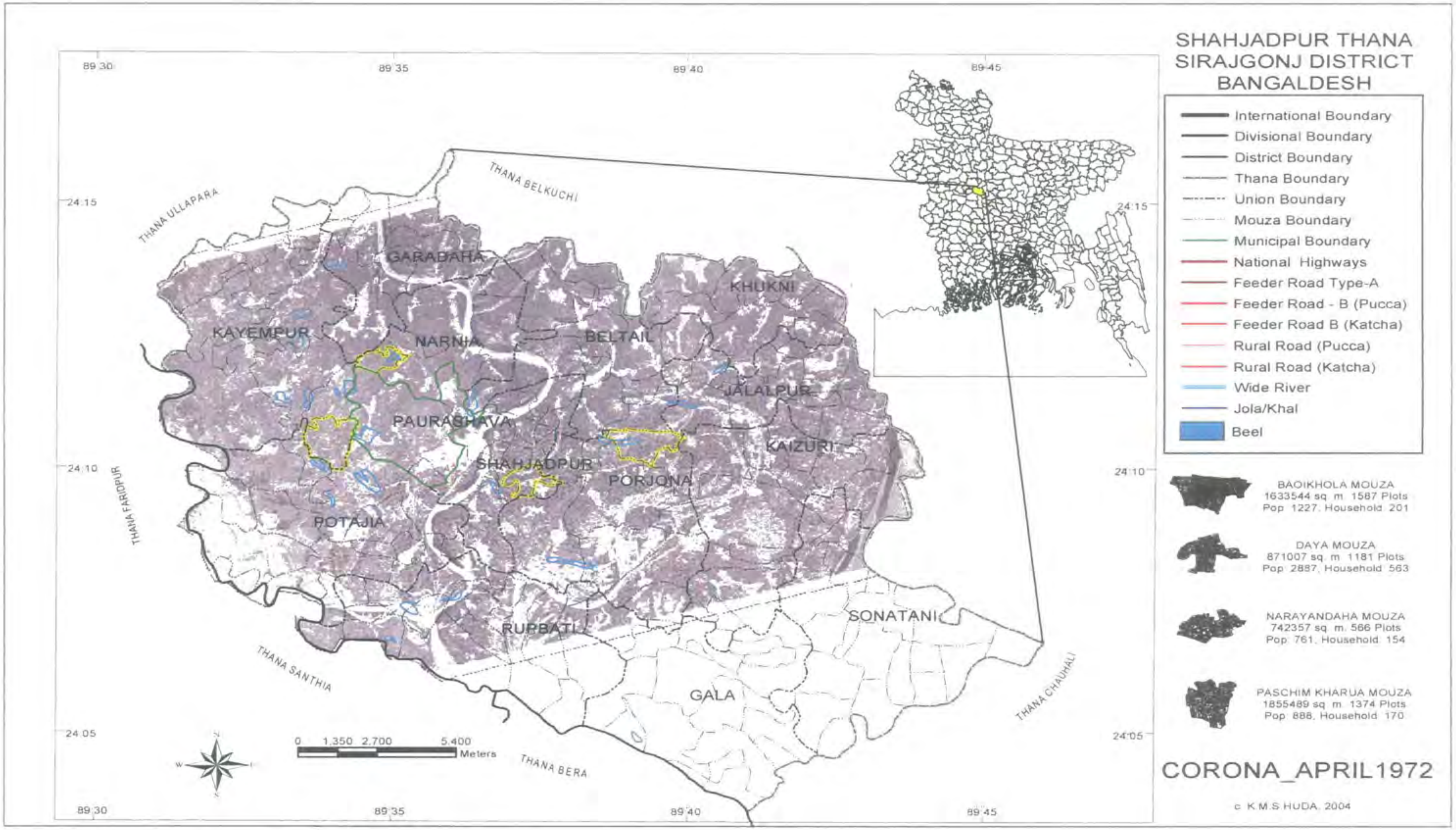



**Figure 2.16 Study Area (CORONA 1972)**

**Source: Author(2004).**

#### 2.14.3.3 Indian Remote Sensing Satellite

India launched four India Remote Sensing (IRS) satellites between 1988 and 1997. IRS-1A was launched on 17 March 1988; IRS-1B on 29 August 1991; IRS–1C on a Russian launched vehicle on 28 December 1995; and IRS-1D on a PSLV launch vehicle in 29 September, 1997 into polar orbit (2001; Eurimage, 2003; ISRO, 2004; Jensen, 2000; Sabins, 1996). The payload for IRS-1C was activated in the first week of January 1996 (Eurimage, 2003; NRSA, 2004). The systematic and repetitive acquisition of data of the Earth's surface is the primary objective of the IRS satellites. Figure 2.17 shows the IRS LISS-III image of the study area of March 2003 used in this research.

**Table 2.8 Technical Summary of IRS.**

| Variables | IRS-IC | IRS-ID |
|---|---|---|
| Satellite Launch Date | 28-Dec-95 | 29-Sep-97 |
| Altitude | 817 Km | 874 x 824Km |
| Inclination | 98.69° | 98.653° |
| Orbits/cycle | 341 | 358 |
| Revisit at equator | 24 days | 25 days |
| Sensors | PAN, LISS-III and WiFS | PAN, LISS-III and WiFS |

**Source: Data compiled from ISRO, NRSA and Eurimage website.**

IRS–IC operates in a circular, sun-synchronous, near polar orbit with an inclination of 98 .69°, at an altitude of 817 km in the descending node (Eurimage, 2003; ISRO, 2004; Jensen, 2000). The satellite takes 101.35 minutes to complete one revolution around the earth and completes about 14 orbits per day. It takes 341 orbits during a 24 day cycle to cover the entire Earth (Table 2.8). Successive orbits are shifted westward by 2820 km at the equator (Eurimage, 2003; ISRO, 2004; Jensen, 2000). IRS-IC and ID do not have the same reference system as they have slightly different orbits. The mean equatorial crossing time in the descending node is 10.30 a.m. ±5 minutes. The ground trace pattern is controlled within ±5 km of the reference ground trace pattern (Eurimage, 2003).

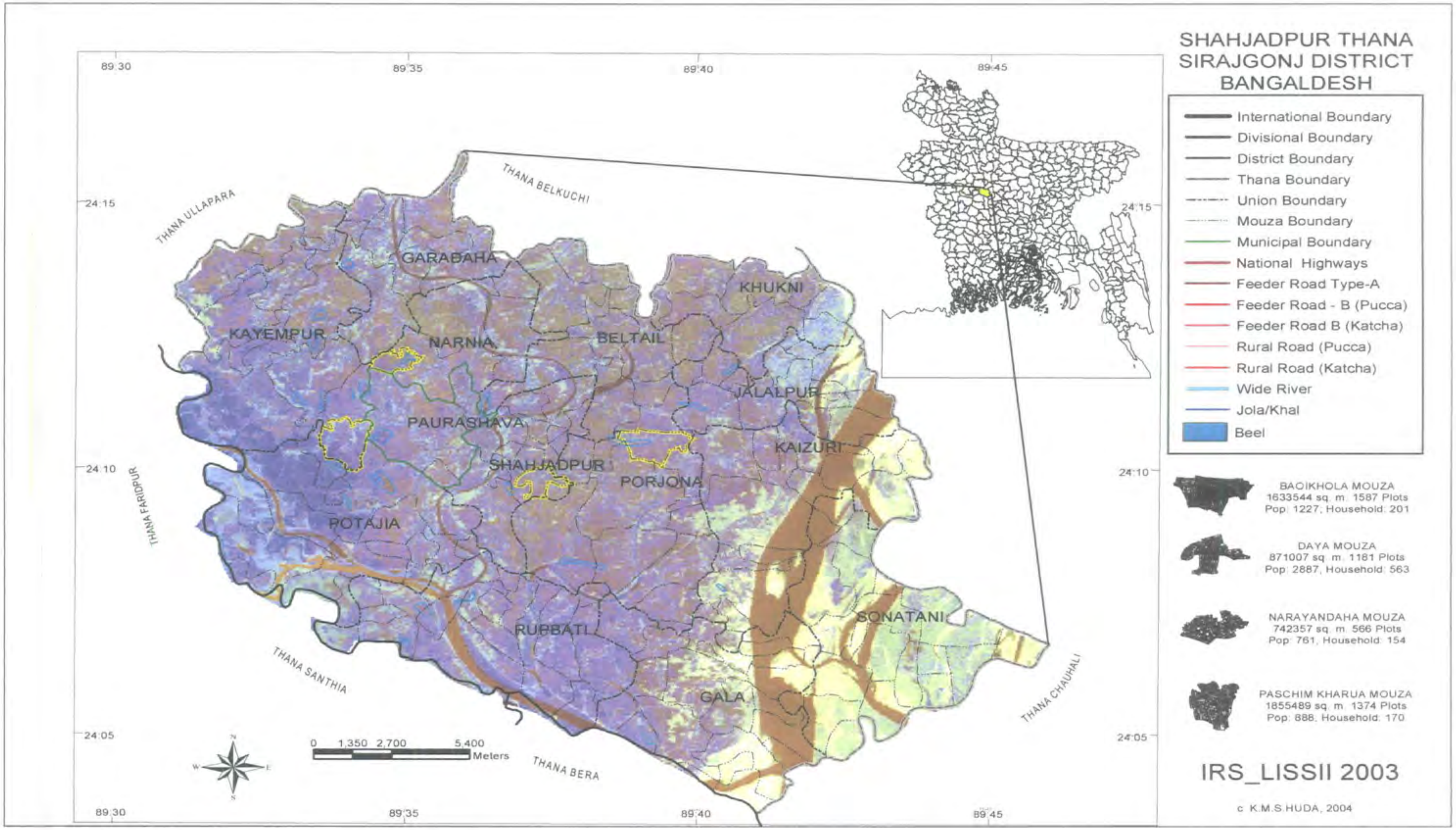



**Figure 2.17 Study Area (IRS LISS-III 2003)**

**Source: Author(2004).**

Details of the three sensors: PAN, WiFS and LISS-III are given in Table 2.9. The tilt angle of the PAN sensor is set to either +2° or −2°, approximately during acquisition (ISRO, 2004; Jensen, 2000). These settings guarantee full coverage of the entire area within 2 cycles, that is 2*24/25 days (Eurimage, 2003; NRSA, 2004). The WiFS referencing scheme is based on LISS-III scene centres. Due to the large coverage of each WiFS scene, there is an overlap between adjacent WiFS passes (ISRO, 2004).

**Table 2.9 Sensor and Band Technical Summary for IRS.**

| Sensor | Band | µM | Quantification | Pixel Size (M) | Swath (KM) |
|---|---|---|---|---|---|
| PAN | 1 | .5 - .75 | 6 bits | 5.8 (resampled to 5) | 63-70 |
| WIFS | 3 (red) | .62-.68 | 7 bits | 188 | 728-812 |
| | 4 (NIR) | .77-.86 | | | |
| LISS-III | 2 (green) | .52-.59 | 7 bits | 23 | 127-141 |
| | 3 (red) | .62-.68 | | | |
| | 4 (NIR) | .77-.86 | | | |
| | 5 (SWIR) | 1.55-1.70 | | | |

**Source: Data compiled from ISRO, NRSA and Eurimage website.**

In my research I have also used IRS-ID Pan for 19 March 1999 (Figure 2.18), 8 March 2003 and LISS-III of March 2003. I collected these from EGIS. These images were preprocessed and analysed in an Erdas imagine image analysis environment. These up-to-date image data sets gave me the opportunity to evaluate this sensor for detecting and monitoring changes of SWB characteristics in the study area.

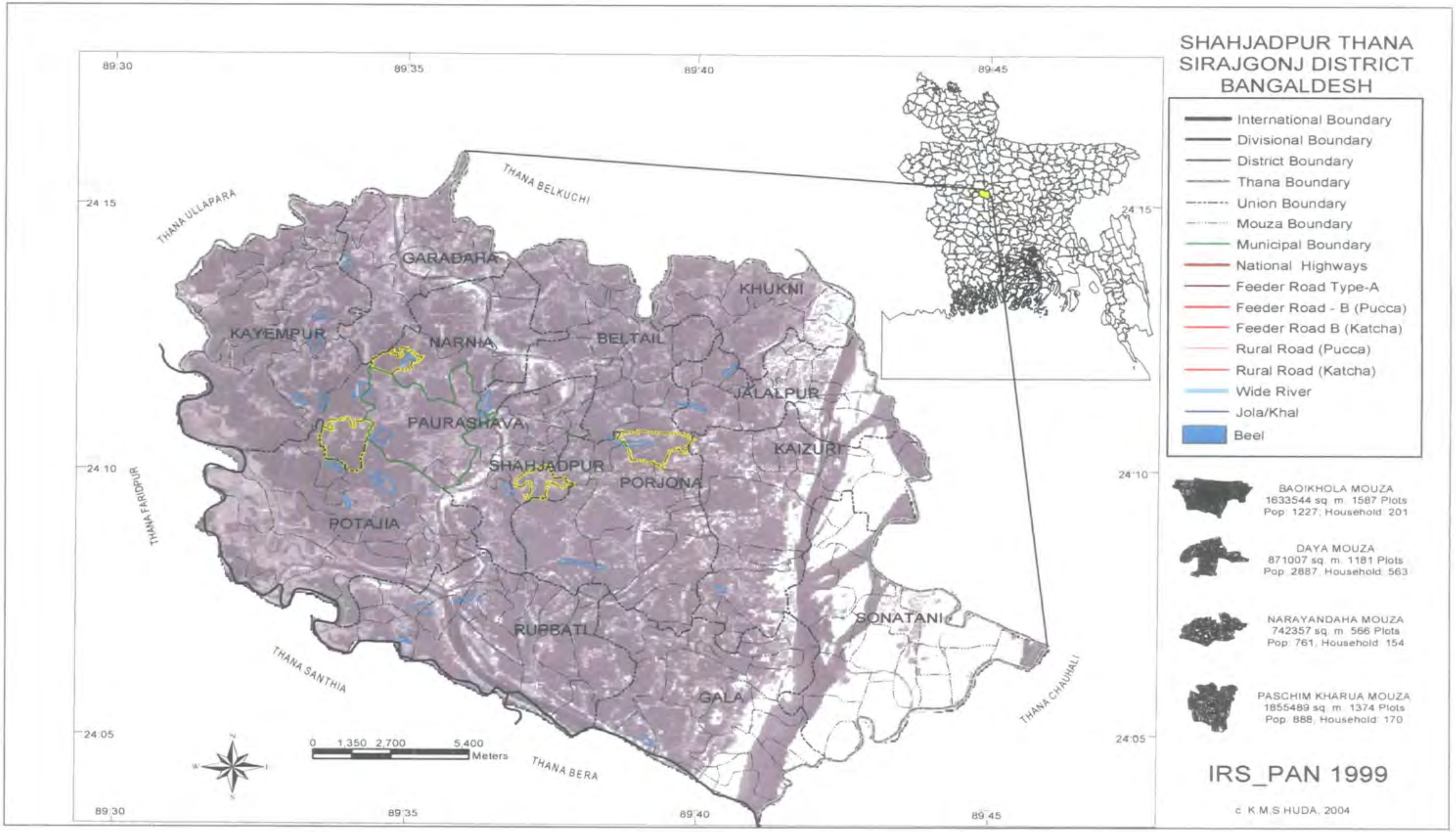



**Figure 2.18 Study Area (IRS PAN 1999)**

**Source: Author(2004).**

### 2.14.3.4 Systeme Probatoire d'Observation de la Terre (SPOT)

The SPOT (Systeme Probatoire d'Observation de la Terre) satellite was first launched on 21 February 1986 by France (Jensen, 2000; Sabins, 1996). Four more satellites have been successfully launched since 1986. The SPOT system has always produced high-quality imaging data from medium-high resolution sensors. It has a special-sensor design, and stereoscopic capability. The latest satellite in this series SPOT 5 was launched on 3 May, 2002 (Eurimage, 2003; Jensen, 2000). This has a higher resolution plus a new stereo instrument. To capture a full earth coverage, all of the SPOT missions have repetitive, circular, near-polar orbits. To acquire the same area or simultaneously for a bigger swath it has sensors which are steerable and can be moved independently (Eurimage, 2003; Jensen, 2000).

In my research I have also interpreted the SPOT HRV image of 1989 (Figure 2.19) and tested capabilities of identifying SWB in my field. Table 2.10 shows the different technical aspects of SPOT system.

**Table 2.10 Technical Summary**

<table>
<tr><td>Variables</td><td>SPOT 1</td><td>SPOT 2</td><td>SPOT 3</td><td>SPOT 4</td><td>SPOT 5</td></tr>
<tr><td>Launch Date</td><td>22/02/86</td><td>22/01/90</td><td>26/9/93</td><td>24/3/98</td><td>3/5/02</td></tr>
<tr><td>End Mission</td><td>Stand-by since SPOT 5 launched</td><td>Operational</td><td>14/11/98</td><td>Operational</td><td>Operational</td></tr>
<tr><td>Orbit</td><td colspan="5">822 km / 98.7°</td></tr>
<tr><td>Revisit</td><td colspan="5">(nadiral, at equator) 26 days</td></tr>
<tr><td>Sensors</td><td colspan="3">2 x HRV</td><td>2 x HRVIR, vegetation 1</td><td>2xHRG, HRS Vegetation 2</td></tr>
<tr><td>Recording capacity</td><td colspan="3">2 x 120-Gbit recorders<br>(~ 280 images)</td><td>2 x 120-Gbit recorders</td><td>2 x 120-Gbit;<br>1 x 9-Gbit</td></tr>
<tr><td>Onboard IP</td><td colspan="4">Two images acquired simultaneously, then downlinked or recorded</td><td>Up to 5 acquired simultaneously ; 2 downlinked in real time; 3 stored</td></tr>
</table>

**Source: Data compiled from Eurimage website, Jensen (2000) and Sabins (1996).**

Each SPOT satellite flies over the same ground track every 26 days (Eurimage, 2003). It makes an integer number of revolutions in one complete track cycle during this period. The satellite performs 14 + 5/26 revolutions per day (Eurimage, 2003; Jensen, 2000). SPOT can image any area within a 900 kilometre swath oblique viewing. Viewing frequency can be increased for a given point during a given cycle by using this oblique viewing capability (Eurimage, 2003; Jensen, 2000). The frequency varies with latitude. At the equator, a given area can be imaged 7 times during the same 26 day orbital cycle (Eurimage, 2003; Jensen, 2000). In higher latitudes, a given area can be imaged 11 times during the orbital cycle, i.e. 157 times yearly and an average of 2.4 days, with an interval ranging from a maximum of 4 days to a minimum of 1 day (Eurimage, 2003).

The collection of SPOT satellites increases due to the unique revisit capability: any point on 95 percent of the Earth may, in the absence of cloud cover, be imaged any day by at least one of the three satellites (Eurimage, 2003; Jensen, 2000). The satellites are sun-synchronous, so that all acquisitions over the same area occur at the same time. The equatorial crossing time during descending passes (ascending passes are night ones) for all missions is 10:30 AM local time (Eurimage, 2003; Jensen, 2000).

Each payload comprises two identical optical imaging instruments, one or two tape recorders for image data, and a payload telemetry package for image transmission to ground receiving stations (Eurimage, 2003; Jensen, 2000). The position of each instrument's entrance mirror can be commanded by ground control to observe a region of interest. Thus, each instrument offers an oblique viewing capability. Panchromatic and multi-spectral acquisition are available. Both instruments can operate in either mode, either simultaneously or individually (Eurimage, 2003). The size of each scene is 60 km x 60 - 80 km, depending on the viewing angle (Eurimage, 2003; Jensen, 2000).

**Table 2.11 Sensor Summary.**

| Sensor | Band Number | Spectral Range (µm) | Pixel Size (m) | Absolute Location Accuracy (RMS) |
|---|---|---|---|---|
| HRV SPOT 1,2,3 | P | .50 – .73 | 10 | < 350 m* |
| | B1 | .50 – .59 | 20 | |
| | B2 | .61 – .68 | 20 | |
| | B3 | .78 – .89 | 20 | |
| HRVIR SPOT 4 | P | .61 – .68 | 10 | < 350 m* |
| | B1 | .50 – .59 | 20 | |
| | B2 | .61 – .68 | 20 | |
| | B3 | .78 – .89 | 20 | |
| | B4 | 1.58 – 1.75 | 20 | |
| HRG SPOT 5 | P | .48 – .71 | 2 x 5 m, combined: 2.5 m (Supermode) | < 50 m* |
| | B1 | .50 – .59 | 10 | |
| | B2 | .61 – .68 | 10 | |
| | B3 | .78 – .89 | 10 | |
| | B4 | 1.58 – 1.75 | 20 | |
| HRS SPOT 5 | P | .49 – .69 | 10 | < 15 m* |
| Vegetation-1 SPOT 4 | B0 | .45 –. 52 | 1 km | < 350 m* |
| | B2 | .61 – .68 | | |
| Vegetation-2 SPOT 5 | B3 | .78 – .89 | 1 km | < 50 m* |
| | B4 | 1.58 – 1.75 | | |
| *No ground control points, flat terrain. The higher positional accuracy of SPOT 5 images is due to the presence of a star-tracker. | | | | |

**Source: Data compiled from Eurimage website, Jensen (2000) and Sabins (1996).**

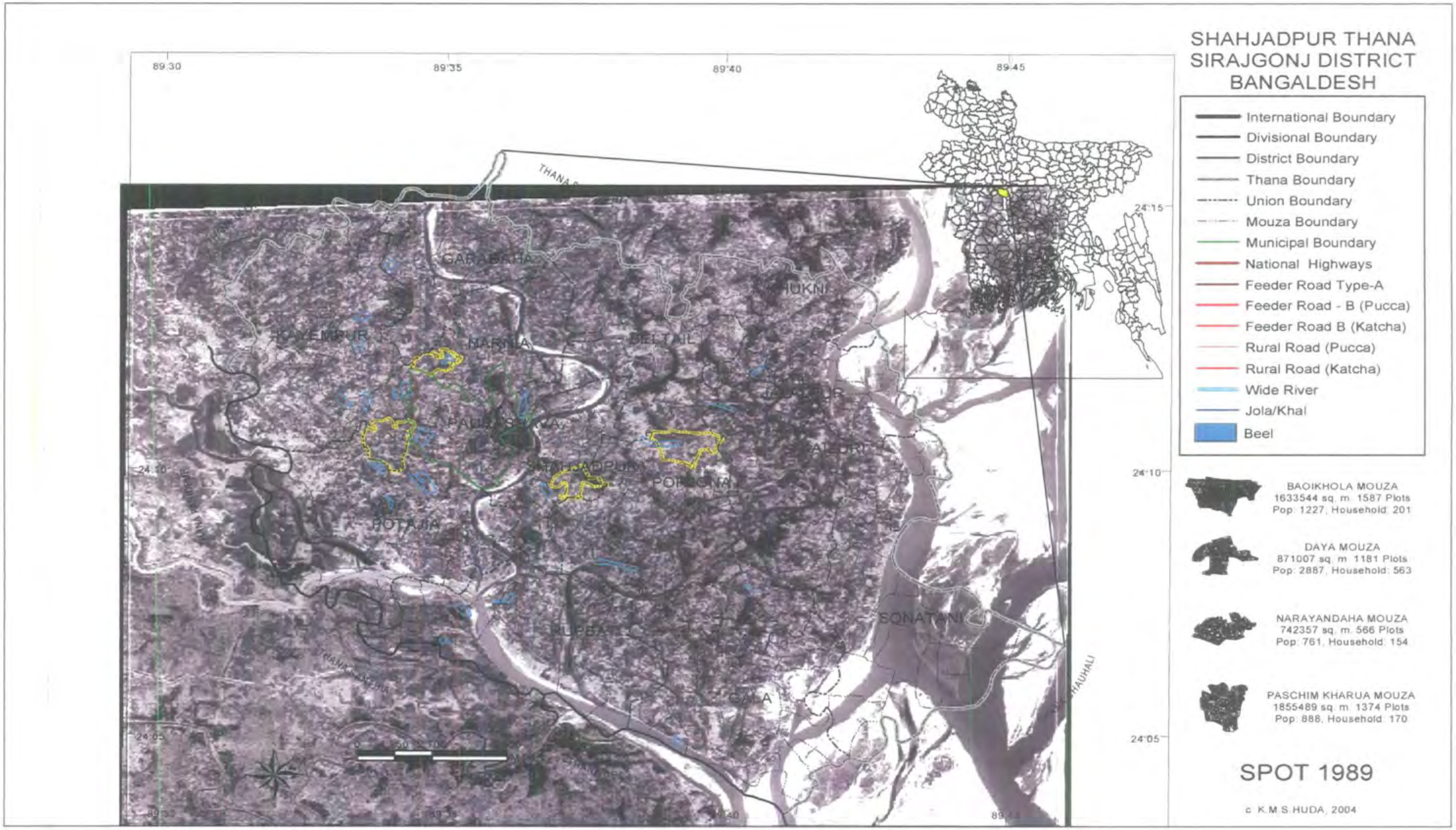



**Figure 2.19 Study Area (SPOT 1989)**

**Source: Author(2004).**

*Supermode* - yields a 2.5m image from two 5m black-and-white images acquired simultaneously by oversampling. This image sampling process is unique to SPOT 5. This new concept was patented by the French space agency CNES (Eurimage, 2003).

*Onboard Processing* - imagery is acquired by two dedicated arrays of CCD detectors vertically and horizontally offset by one half-pixel (2.5 m) in the focal plane (Eurimage, 2003). The instrument thus generates two 5m images that are downlinked separately.

*Ground Processing*: Final Supermode products are generated in three steps:

- *interpolation* consists in interlacing the two images acquired by the offset arrays and interpolating "missing" pixels to obtain an image that is twice as sharp (Eurimage, 2003).

- *deconvolution* compensates for blurring introduced by the instrument by applying a filter representing the instrument's inverse transfer function (Eurimage, 2003).

- *noise removal* reduces the noise in the image (amplified by deconvolution) to an acceptable preset level (Eurimage, 2003).

SPOT 5 is able to acquire two images simultaneously – one forward and one aft of the satellite - for near-instantaneous acquisition of stereo pairs due to the HRS (High Resolution Stereoscopic) instrument on board (Eurimage, 2003; Jensen, 2000). On one satellite pass, the forward-looking telescope acquires images of the ground at a viewing angle of 20° ahead of the vertical. One minute and 30 seconds later, the aft-looking telescope images the same strip at an angle of 20° behind the vertical (Eurimage, 2003).

The quality and accuracy of HRS digital elevation models are a vital advantage. They depend on the automatic correlation process and is made it easier by the fact that the images' radiometric parameters are identical (Eurimage, 2003; Jensen, 2000). Simultaneous stereopair acquisition is a great advantage for The Base to Height ratio (B/H) of the HRS instrument is fixed to 0.84 (Eurimage, 2003). The area covered is also particularly extensive: with 72,000 km per segment (600 km x 120 km), 30 million sq. km of HRS data can be achieved per year (Eurimage, 2003; Jensen, 2000).

The Vegetation programme co-funded by the European Union, Belgium, France, Italy and Sweden and led by French space agency CNES marks a significant advance in the ability to monitor crops and the flora and fauna (Eurimage, 2003; Jensen, 2000). The Vegetation instrument flying on SPOT 4/5 provides global coverage on an almost daily basis at a resolution of 1 kilometre, making it an ideal tool for observing long-term environmental changes on a regional and worldwide scale (Eurimage, 2003). Data acquired by the Vegetation instrument is stored in a centralized global archive accessible to users for mapping vegetation cover, forecasting crop yields etc. thematic applications (Eurimage, 2003; Jensen, 2000).

This research had a opportunity to incorporate the SPOT image of 1989 for detection and monitoring of SWB. The existing thana base maps of the LGED in Bangladesh are basically based on 1989 SPOT images.

**2.14.3.5 LANDSAT**

LANDSAT is designed specifically for collecting synoptic and repetitive multispectral images for monitoring resources and environments. It operates in the international public domain (Sabins, 1996). Prior to 1974 it was called ERTS (Earth Resources Technology Satellite). The first Landsat satellite was launched on 23 July, 1972 (Avery and Berlin, 1985). Five more satellites in the LANDSAT family have been put into orbit since 1972. Landsat 7 is the latest in the series. It has an Enhanced Thematic Mapper (ETM+) sensor, which provides 7 bands of multi-spectral data at 30 metres resolution, plus a panchromatic band at 15 m, over a swath 183 km wide (Avery and Berlin, 1985; Eurimage, 2003). There is also a 60 m thermal infrared band. A Solid-State Recorder holds 500 full scenes of data. It has inclination of 98.2° on 705 km altitude (Avery and Berlin, 1985). The operational Landsat 5 TM was launched on 1st March 1985 and Landsat 7 on 15 April 1999 (Avery and Berlin, 1985; Eurimage, 2003).

The Landsat satellite provides full coverage between 81°N and 81°S (Avery and Berlin, 1985; Eurimage, 2003). It has repetitive, sun-synchronous, near-polar orbits, The sensors always scan the ground from the satellite nadir. Due to the sun-synchronous orbit it can acquisition a area at the same repetitive time (Avery and Berlin, 1985; Eurimage, 2003). The equatorial crossing time during descending passes (ascending passes are at night) is, for all Landsat Missions, between 9:30 and 10:00 local time (Eurimage, 2003). A Landsat track is 183km wide. At the equator there is a 7.6 percent overlap between adjacent tracks (Avery and Berlin, 1985; Eurimage, 2003), which gradually increases near the poles, reaching 54 percent at 60° latitude. The repeat cycle for Landsats 1, 2 and 3 was 18 days, and for Landsat 4, 5 & 7 was reduced 16 days (Avery and Berlin, 1985; Eurimage, 2003).

Four different types of sensors have been used in various combinations. Landsats 1 - 3 carried a Return Beam Vidicon (RBV) and the Multi-spectral Scanner (MSS). The second generation of Landsat 4 satellites launched in 16 July, 1982 (Avery and Berlin, 1985; Eurimage, 2003). Landsat 4, carried a Thematic Mapper (TM) in addition to the MSS. Landsat 7 is equipped with an enhanced Thematic Mapper (ETM+). Quantisation is 8 bits for all data (Eurimage, 2003). ETM+ has a number of advantages. It has a panchromatic band with 15 metres resolution basically registered with the multispectral bands. The thermal infrared resolution has improved to 60 m (see table 2.12). There is an on-board Solid State Recorder (SSR) with 378 Gb (500 full scenes) of data capacity (Avery and Berlin, 1985; Eurimage, 2003; Sabins, 1996). I had opportunity to test the detection capabilities of SWBs using LANDSAT XS of 1997 and 1998 (Figure 2.20).

**Table 2.12 Technical Summary of LANDSAT.**

| Sensor | Band Number | Spectral Range (μm) | Pixel Size (m) |
|---|---|---|---|
| MSS | 4 | .5 – .6 | 80 |
| | 5 | .6 – .7 | 80 |
| | 6 | .7 – .8 | 80 |
| | 7 | .8 – 1.1 | 80 |
| TM | 1 | .45 - .52 | 30 |
| | 2 | .52 - .60 | 30 |
| | 3 | .63 - .69 | 30 |
| | 4 | .76 - .90 | 30 |
| | 5 | 1.55 – 1.75 | 30 |
| | 6 | 10.42 – 12.50 | 120 |
| | 7 | 2.08 – 2.35 | 30 |
| ETM+ | 1 | .45 - .52 | 30 |
| | 2 | .52 - .60 | 30 |
| | 3 | .63 - .69 | 30 |
| | 4 | .76 - .90 | 30 |
| | 5 | 1.55 – 1.75 | 30 |
| | 6 | 10.42 – 12.50 | 120 |
| | 7 | 2.08 – 2.35 | 30 |
| | 8 (PAN) | .52 - .90 | 15 |

**Source: Data compiled from Euro Image website, Jensen (2000) and Sabins (1996).**

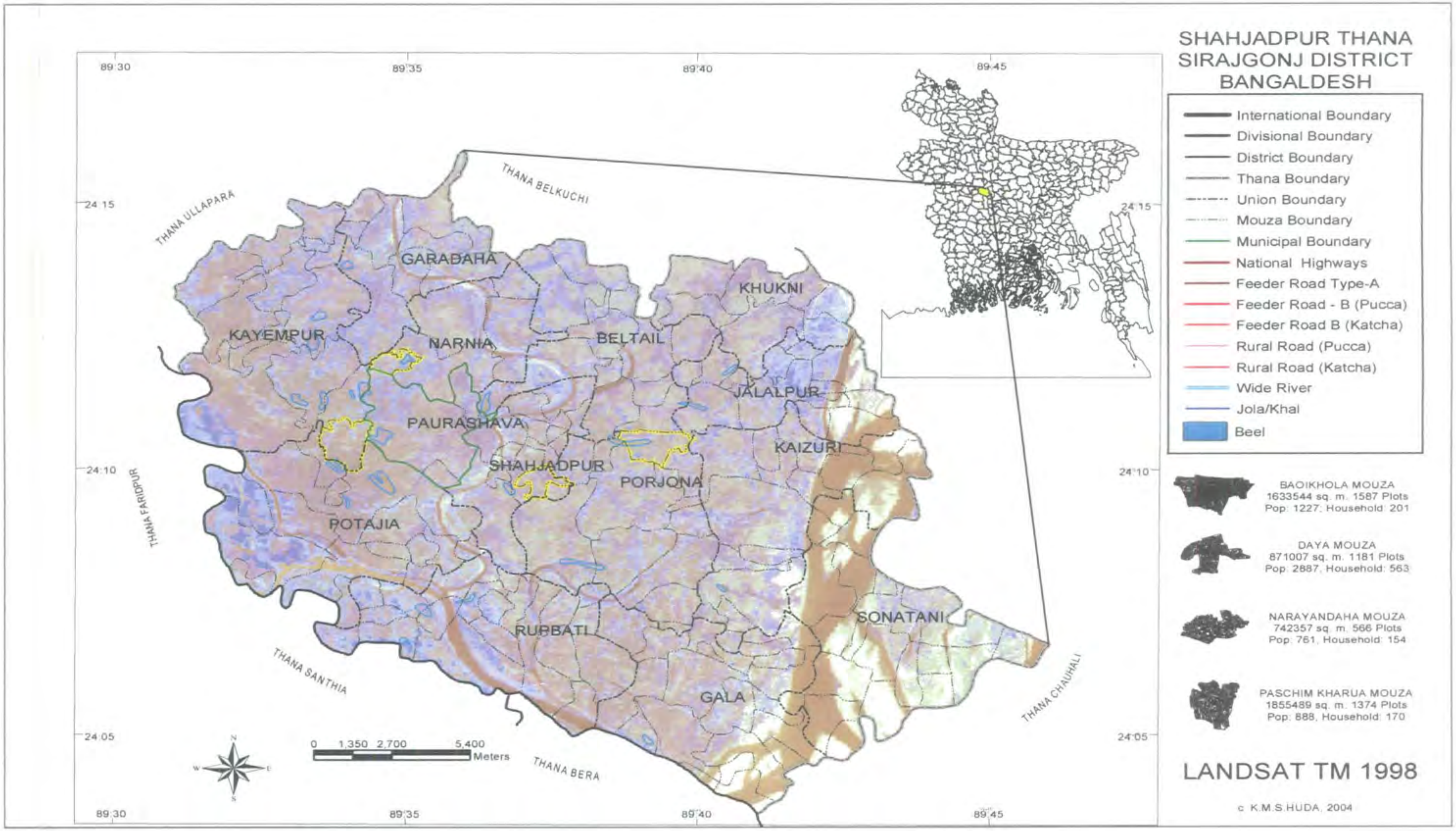



**Figure 2.20 Study Area (LANDSAT 1998)**
**Source: Author(2004).**

#### 2.14.3.6 ERS-1

European Resource Satellite-1 (ERS-1) was launched in 1991 (Jensen, 2000) and is operated by the European Space Agency (ESA). The ERS satellites are the first commercial missions acquiring microwave Synthetic Aperture Radar data. They offer new opportunities for all weather remote sensing applications. The RADAR images are independent of lighting or weather conditions. They can measure wave height and frequency, wind speed and direction (Campbell, 2002; Eurimage, 2003). ERS-1 operated regularly from 25/7/1991 to 10/3/2000 (DEOS, 2001; Eurimage, 2003; Jensen, 1996). ERS-2 started regular acquisitions in May 1995 and it is still operational (see table 2.13). ESA launched ENVISAT in March 2001, carrying advanced versions of the SAR and ATSR instruments, plus several new sensors (Eurimage, 2003; Jensen, 1996).

ERS-1 images of 24 July (Figure 2.21) and 28 August 1993 has been interpreted for detecting and monitoring SWB. These particular images were tested for Flood monitoring in Bangladesh by EGIS and achieved fair result.

**Table 2.13 Technical Summary of ERS-1 and ERS-2**

| Variables | ERS-1 | ERS-2 |
|---|---|---|
| Launch date | 25/7/91 | 20/04/95 |
| End Mission | 10/3/00 | |
| Altitude | 785 km | 785 km |
| Repeat Cycle | 35 days | 35 days |
| Sensors | AMI, ATSR, MWR, RA | AMI, ATSR, MWR, RA, GOME |

**Source: Data compiled from Euro Image and DEOS website.**

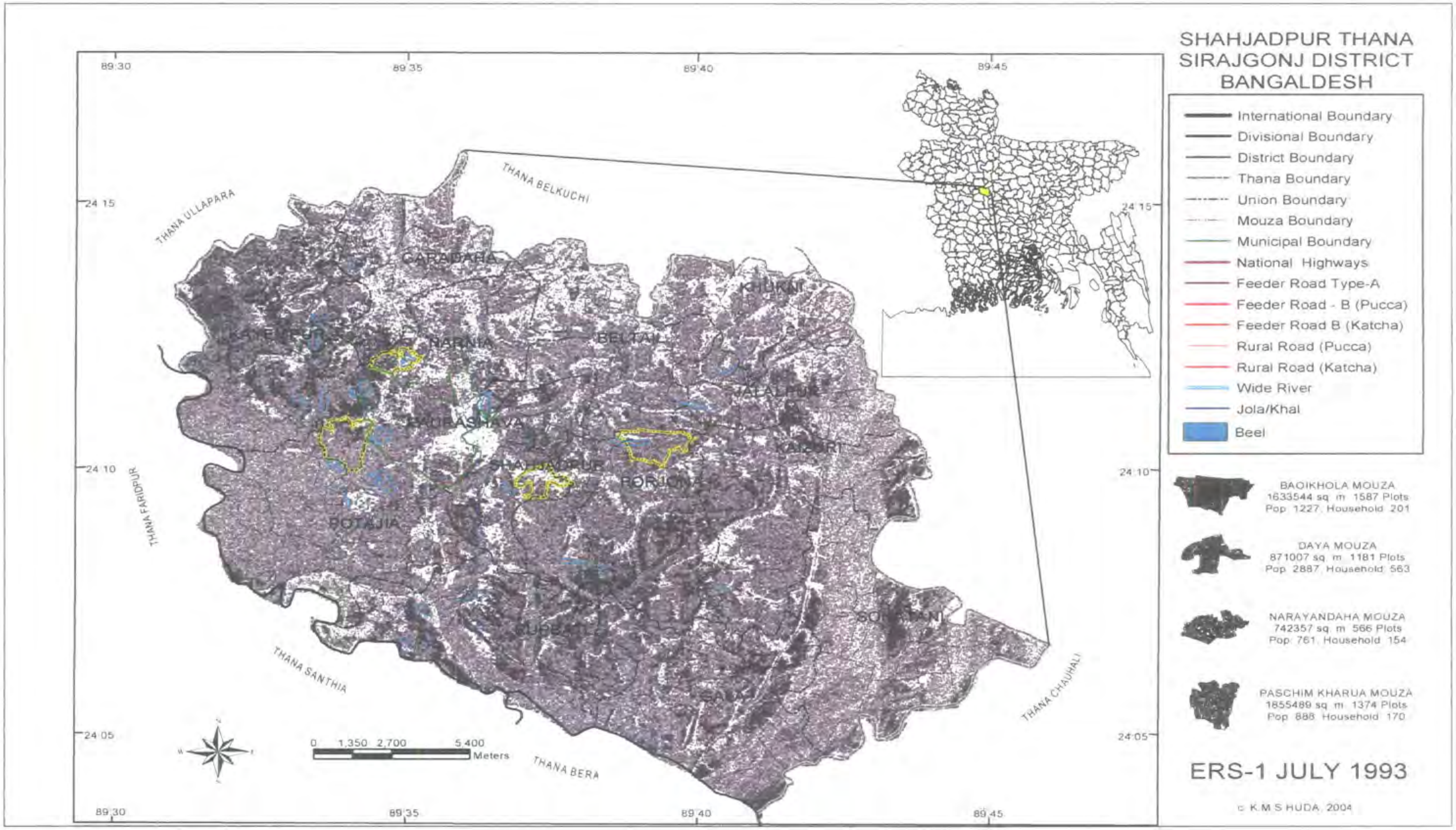


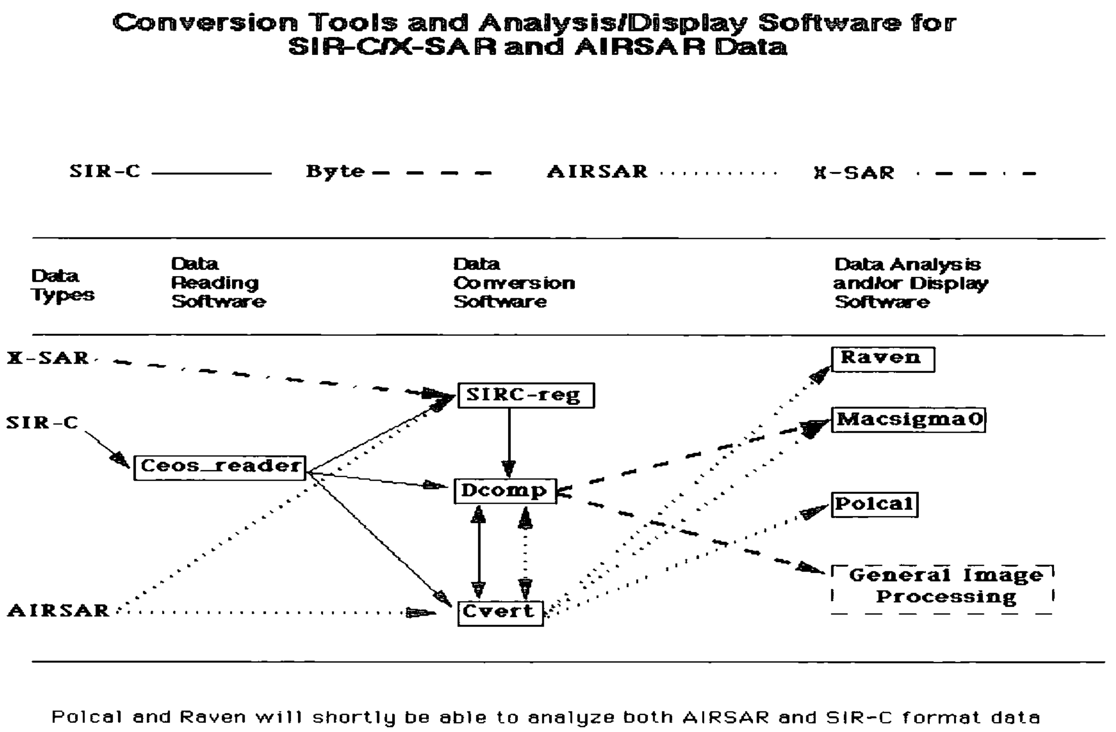

**Figure 2.21 Study Area (ERS-1 1994)**

**Source: Author(2004).**

2.14.3.7 Shuttle Imaging Radar

2.14.3.7.1 SIR-C

SIR-C stands for Spaceborne/Shuttle Imaging RADAR (Radio Detection And Ranging) –C (Campbell, 2002; ENVI, 2001). It is a polarimetric synthetic aperture RADAR that uses two microwave wavelengths: L-band: 23.5cm and C-band: 5.8cm (Campbell, 2002; ENVI, 2001; Sabins, 1996). As an active remote sensing technique, SIR-C has the great advantage over visible-wavelength imagers of independence of daylight conditions and cloud cover. SIR-C is the third in a series of JPL shuttle RADAR instruments. The SIR-C radar system was flown as a science experiment on the Space Shuttle Endeavour in April as SRL-1 and October 1994 as SRL-2 (ENVI, 2001). Frequency: 1.25GHz (L band) and 5.3GHz (C band). Polarization: HH, VV, HV, VH. Incidence angle: 15-55° (L band) and 20-55° (C band). Spatial resolution: 40m (L band) and 25m (C band). Swath width: 40 km. SIR-C data (Figure 2.23) was collected from JPL in 8mm tape and converted using the CEOS software (see figure 2.22).




**Source: CEOS Data Processing Manual (1999).**

Figure 2.22 SIR-C/X-SAR Preprocessing.

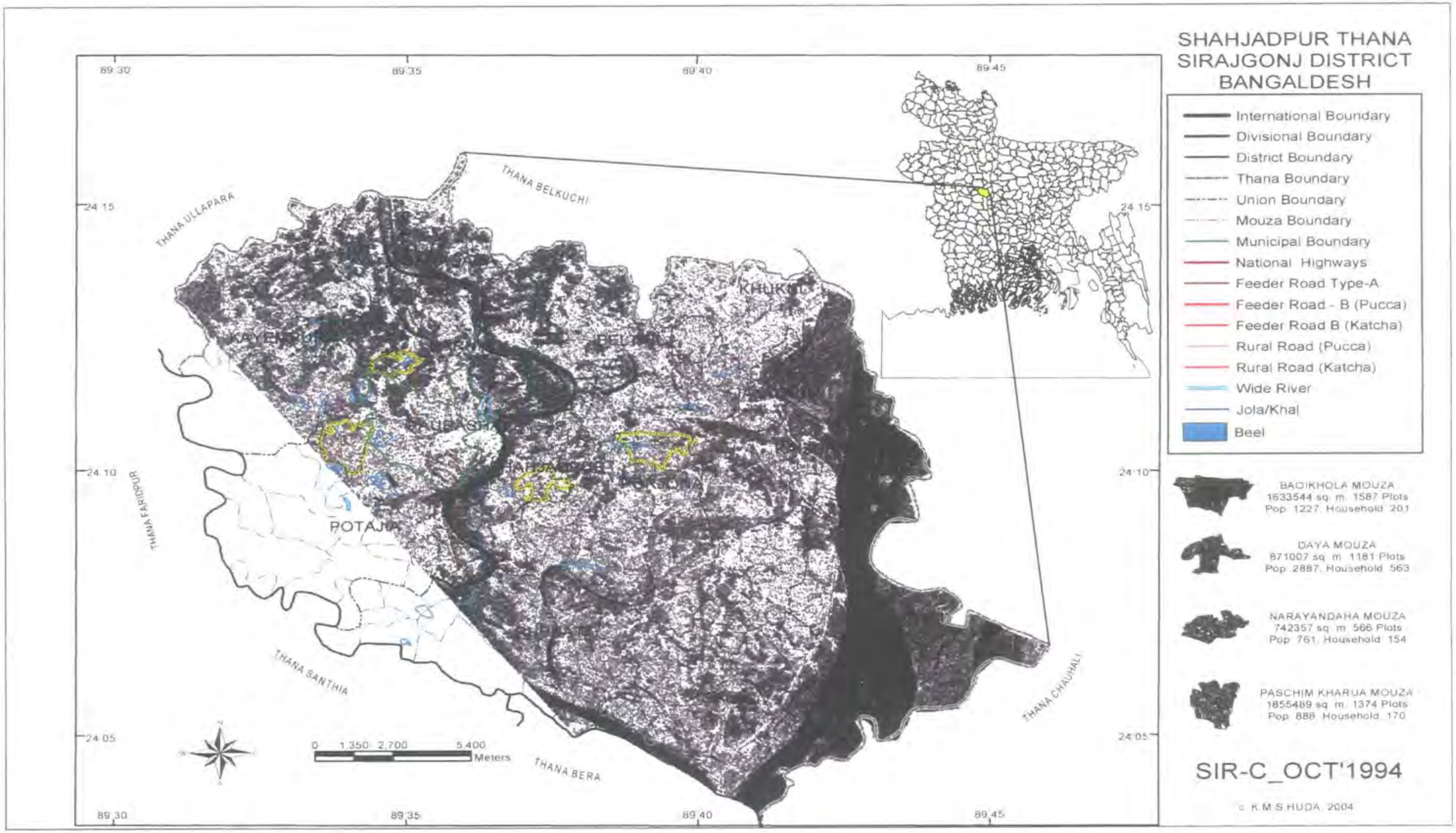



**Figure 2.23 Study Area (SAR-C 1994)**
**Source: Author(2004).**

#### 2.14.3.7.2 X-Sar

The X-SAR instrument was built by the aerospace organization (DLR) to be carried on the NASA Space Shuttle along with the JPL Shuttle Imaging Radar (SIR-C). Missions were 9-20 April 1994; 30 September-11 October 1994 (Campbell, 2002; ENVI, 2001; Sabins, 1996). The orbit was circular at 225km altitude. Inclination was 57°. Frequency: 9.6GHz. Polarization: VV. Incidence angle: 20°. Spatial resolution: 30m. Swath width: 15 to 45 km (Campbell, 2002; ENVI, 2001; Sabins, 1996). X-Sar data collected and processed could not evaluated as it only covered a part of study area (Figure 2.24).

Optical satellite images such as Landsat, SPOT and IRS are of good radiometric and geometric quality. The multispectral nature of these data allows landcover types to be mapped very efficiently using digital image processing techniques. However, these satellite data are limited by cloud cover and their moderate spatial resolution, which severely limit their ability to resolve objects such as SWB. On the other hand the use of *RADAR* (X-SAR and SAR-C) which is an active remote sensing technique that has the great advantage over visible-wavelength imagers of being able to acquire data day and night. RADAR can also penetrate through cloud and at certain frequencies through a vegetation canopy. In the long term, RADAR data offers the most promise for detecting SWB but the technology needs to be properly evaluated against ground truth.

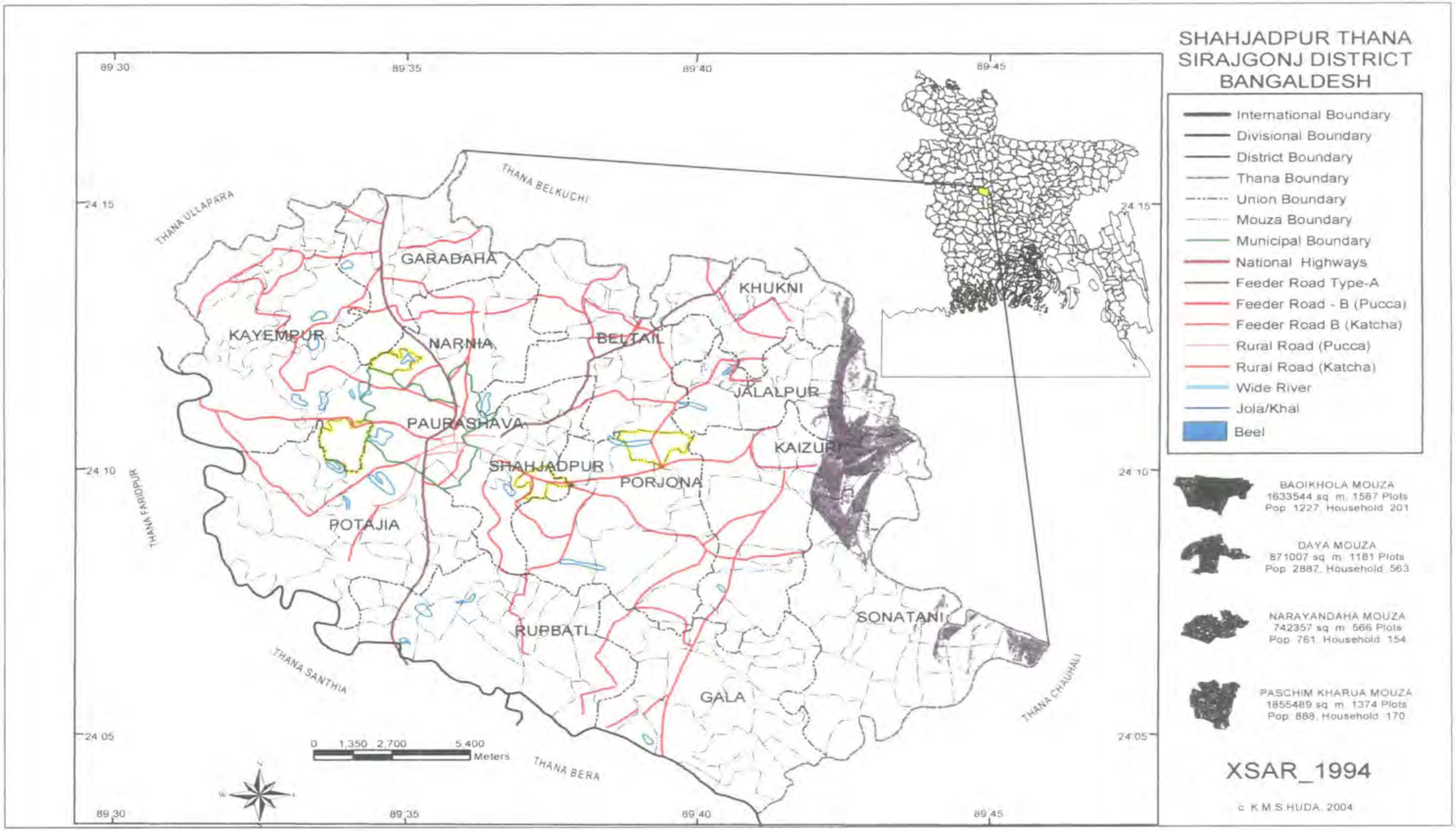



**Figure 2.24 Study Area (X-SAR 1994)**

**Source: Author(2004).**

## 2.15 Conclusion

This chapter discussed the study area, its geographical context and relevant datasets for the whole of Shahjadpur thana. Many datasets had to be converted into digital format and careful planning was required to make them compatible with the associated attribute data. I have prepared a list of information used for this study and this has been vital for an understanding of the dynamic nature SWB and associated phenomena. I have not discussed the methods of collecting information of each aspects here but they can be found in the chapters concerned.

The chapter had a number of purposes. I have described the physical and human conditions of the thana. It is a region typical of the floodplains of Bangladesh, with a dynamic environment and a rural population that achieves a meagre existence from the agricultural resources.

My fieldwork was planned with a view to collecting further data beyond official, published statistics and to provide a context within which I could interpret the remotely sensed images effectively. I decided that a time series was desirable and the images collected range over thirty years from 1972 to 2003.

The planning of the fieldwork and data acquisition went well. I was able to generate what might reasonably be called a 'vast' database. A number of comments seem appropriate at this point:

(1) In retrospect I have collected more data than I have been able to analyse in depth. Were I to start the research again, I would target my image analysis more selectively.

(2) Learning the various image analysis software packages has been very time-consuming. There was no alternative to this.

(3) The RADAR side of my work will be commented on in Chapters 3 and 4.

(4) The integration of remote sensing with human geography fieldwork has been exceptionally valuable and a great intellectual inspiration but, again, very time-consuming and logistically complex. This will be discussed in Chapter 4.

# CHAPTER 3: DETECTING AND MAPPING WATER BODIES

## 3.1 Introduction

The water management systems in Bangladesh are complex and diverse. Agriculture and aquaculture are the dominant activities in rural life and both are dependent on successful water management. Access to adequate and safe domestic water and sources of water for the maintenance of livestock for at least subsistence purposes are part and parcel of rural life. Water is also a vital component of ecosystems maintenance. Vital sources of water are the SWB (doba, pukhur, dighi, jola and beel) common in rural areas. A researchable constraint in understanding the role of SWB in the lives of poor rural Bangladeshis is an appreciation of the dynamic nature of human-environment interaction. Experience has shown that there is a fundamental problem with any developmental work that invests without an up-to-date inventory of resources. Therefore the aim of the chapter is to detect, record and map the past and present spatial distribution patterns of SWB using integrated remote sensing, GIS and participatory field methods.

## 3.2 Remote Sensing of Water

Water is all source of life. Approximately 74 percent of the Earth's surface is covered by water (Jensen, 2000). Almost 97 percent of the Earth's volume of water is in the great saline oceans and only about 0.02 percent of the Earth's water is found in freshwater streams, rivers, lakes and reservoirs (Campbell, 2002; Jensen, 2000). The remaining water is contained in underground aquifers (0.6 percent), and the permanent ice-cap approximately 2.2 percent (Jensen, 2000). Water can be found in various states on Earth, including freshwater, saltwater, water vapour, rain, snow and ice (Jensen, 2000). Water scientists devote their research lives to measuring, monitoring and predicting the spatial distribution, sources, volume and movement of water as it progresses through the hydrologic cycle (Jensen, 2000). Monitoring water and associated aspects depends largely upon measurements made at specific points or the collection of samples from discrete locations.

Measurements of various hydrological (water) parameters such as precipitation, water depth, temperature, salinity, velocity, volume etc. at very specific locations on the Earth are common. For example, the Water Development Board in Bangladesh maintains a dense network of *in situ* river flow gauges on major streams and rivers that provide continuous record of river stage (height) and velocity for flood monitoring. The Department of Public Health Engineering Dept. is often mandated to collect water quality samples from rivers, beels, khals, dighi, ponds, doba and tubewells for determining the arsenic pollution. These point measurements are very important. If enough are collected throughout a region, it is possible to interpolate between the points of observation and inter regional geographic pattern (Jensen, 2000). Unfortunately there are usually not enough point observations in Bangladesh to create a statistically significant distribution map. According to Jensen (2000), it is often difficult to obtain regional spatial information using *in situ* point observations for a number of the most important hydrological variables, including: a) water surface area (seas, rivers, streams, canals, lakes, ponds, reservoir and ditches), b) water constituents (organic and inorganic), c) water depth (bathymetry), d) water surface temperature, e) cloud cover, f) precipitation and g) water vapour.

Therefore, a significant amount of research has been undertaken to develop remote sensing methods that can obtain quantitative, spatial measurements of these important hydrological variables (Asrar and Dozier, 1994; Ikeda and Dobson, 1995; Jensen, 2000). This research also inventoried different aspects of SWB.

### 3.3 Rationale and Objectives

There is no existing resource database on the number, size and distribution of SWB such as doba, pukur, dighi, beel and jola in the study area. A national inventory of ponds was conducted in the mid-1980s by the Bangladesh Space Research and Remote Sensing Organization (SPARRSO) using aerial photographs and satellite images but this did not produce any specific results or statistics for the study area or at the thana or mouza level. There was also a pilot project in Tangail district in 1996. Since the national-level work was completed, there have been two main developments that call for a new inventory, (i) the number of SWB has increased dramatically, and, (ii) more appropriate remote sensing data is now available and the techniques for interpreting, analyzing and classifying these data also have improved. Thus, there is a persuasive rationale for developing and demonstrating appropriate techniques for conducting a new inventory specifically to map the different types and spatial distribution of SWB at the mouza level. This chapter is designed to determine appropriate methods for detecting and inventorying SWB, and has following objectives.

1. To establish the best methods for identifying water bodies.

2. To study the most appropriate techniques for mapping the spatial distribution of SWB. This will involve establishing a link between ground truth data from participatory field work and multi-temporal remote sensing images.

### 3.4 Research Questions

My research is unusual for its hybrid methodology, a combination of remote sensing, GIS and social science approaches. Certain technical aspects are of particular interest, for instance the problems associated with the measurement of water bodies whose size is at or beyond the limit of the spatial resolution of many sources of remotely sensed data.

Specific research questions which has been addressed in this chapter are:

1. To what extent can remotely sensed data, maps and GPS help in the identification of SWB?

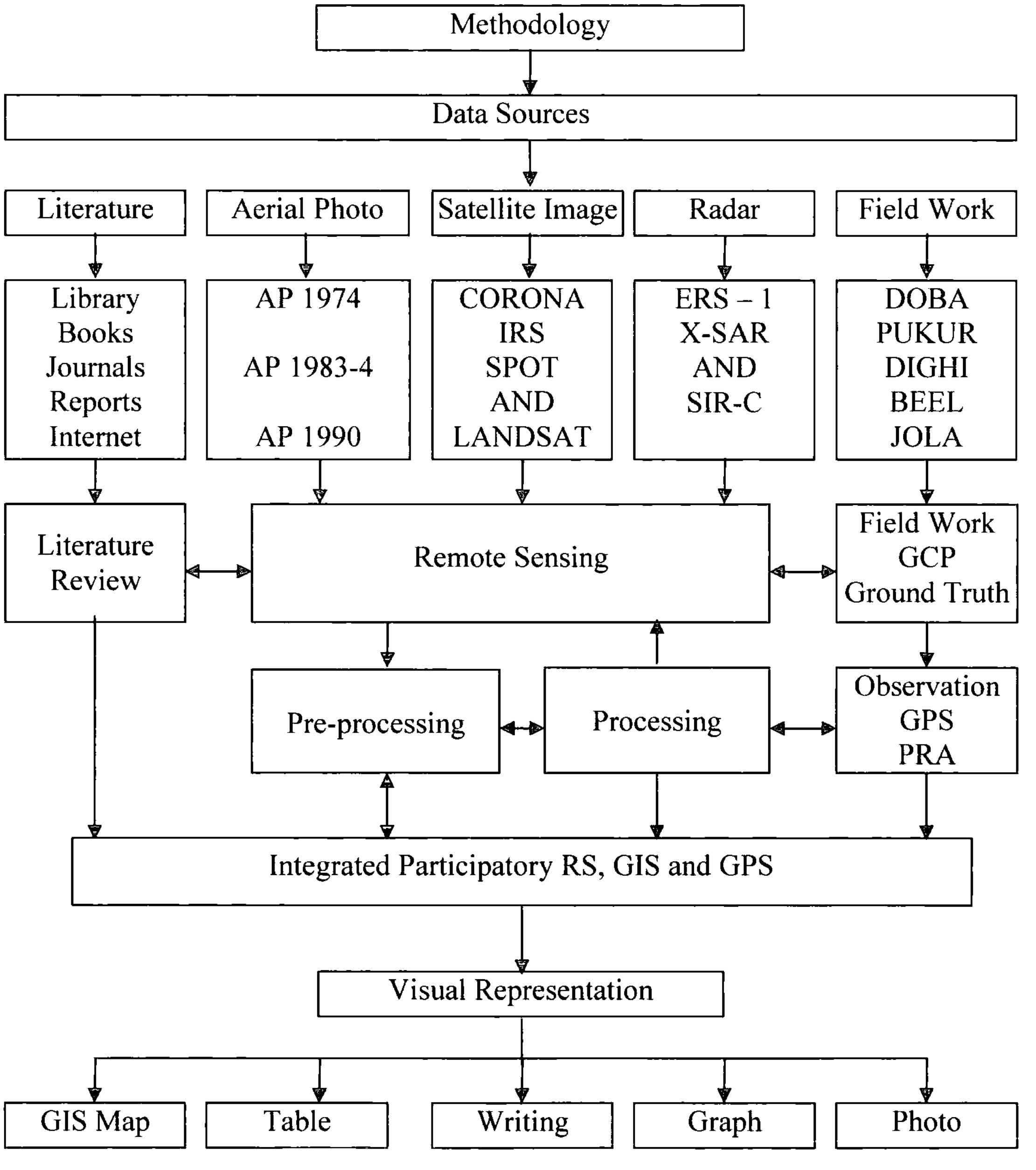
2. What is the best remote sensing method for detecting and inventorying SWB?

3. What is the most appropriate methodology for mapping the SWB?

4. What is the potential relevance of the results for planning by local authorities and perhaps more widely in Bangladesh?

### 3.5 Methodology

In this thesis I have used a wide range of data sources and the methodologies have also been varied (Figure 3.1). Manual interpretation, automated classification with ground truthing, participatory observation and use of GPS gave me the opportunity to engage with the data at several levels. These approaches will be described in this chapter.




**Source: Author, 2003.**

**Figure 3.1 Data Sources and Methods used in this Chapter.**

### 3.5.1 Data Source

I have used multi-spectral and panchromatic satellite data with the highest available resolution for this chapter. Previous studies have identified the need for high spatial resolution sensors for SWB detection (Vonders and Clevers, 1999). Based upon this requirement and the availability of images, a range of different satellite photos, images and aerial photography were evaluated (see Table 3.1). Details of these data are given in chapter 2. A visual (on screen) interpretation was performed to assess manual on-screen digitizing methods for identifying and mapping the SWB. In addition, the images were digitally classified, using various methods, to identify the water bodies in the area. The classified images were verified using available GIS data and data on the size of the water bodies to derive the potential SWB. Finally, the results were compared with the ground truth data collected during the fieldwork.

**Table 3.1 Remote Sensing data used in this chapter.**

| Platform name | Sensor | Year | Mode | Media | Resolution/Scale |
|---|---|---|---|---|---|
| CORONA | KH-4B | 1972 | Panchromatic | Film | 6 feet |
| Aerial Photography | ---- | 1974 | Black and White | Printed | 1:30,000 |
| Aerial Photography | ---- | 1983 | B&W-Infrared | Printed | 1:30,000 |
| Aerial Photography | ---- | 1990 | B&W-Infrared | Printed | 1:40,000 |
| SPOT-3 | HRV | 1989 | Panchromatic | Digital | 1:50,000 |
| ERS-1 | SAR | 1993 | C-Band | Digital | 12.5 metre |
| SIR-C | SAR | 1994 | X-Band | Digital | 30 metre |
| X SAR | SAR | 1994 | C-Band | Digital | 25 metre |
| Landsat 5 | TM | 1997 | Band 2-4 | Digital | 30 metre |
| Landsat | TM | 1998 | Band 2-4 | Digital | 30 metre |
| IRS | ID | 1999 | Panchromatic | Digital | 6 metre |
| IRS | ID | 2003 | Panchromatic | Digital | 6 metre |
| IRS | LISS | 2003 | XS | Digital | 23 metre |

**Source: Author, 2002-3**

#### 3.5.1.1 Aerial Photographs

Black and white aerial photographs of 1974, 1983 and 1990 in 1:30,000 and 1:40,000 scale prints were used for the field operations (see Chapter 2). Although the photos were not recent, they were very useful for my field survey. During the field work the SWB were plotted on the aerial photograph and digitized afterwards as point data for linking with other collected attributes acquired during the field operation.

#### 3.5.1.2 Optical satellite imagery

Satellite data such as CORONA Panchromatic, IRS ID Panchromatic and LISS-3 multispectral, SPOT HRV Panchromatic, and Landsat TM were used for the study. There is always an issue for remote sensing scholars of the cost-effectiveness of their data collection against the precision and appropriateness of the analytical output. In my case there was a tension between the modest resources available for purchasing data and my need for adequate coverage at high resolution for the detection and spatial mapping element of my research. In retrospect the available range of data was satisfactory. For further detail of the individual datasets, see Chapter 2.

#### 3.5.1.3 Radar Data

ERS-1, X-SAR and SIR-C RADAR data were obtained and evaluated in this study (see Chapter 2). RADAR imagery has been used widely for the study of floods in Bangladesh at times of year when the cloud cover is extensive but it has not been used for SWB mapping. Microwave can also penetrate same vegetation canopies and so it was important to investigate its potential for detecting SWB, which in the Bangladesh context are frequently surrounded by bamboos or homestead fruit trees.

### 3.5.2 Literature Review

There is an extensive literature on remote sensing applications for the identification of natural water features and related land cover, such as wetlands. Some papers discuss the particular application for detecting water bodies. These include Pramanik et al., SPARRSO and Schepel and Kamal who tried to examine the reliability of low resolution data for identifying water bodies in Bangladesh (Pramanik, 1990; Schepel and Kamal, 2000; SPARRSO, 1984; SPARRSO, 1993; SPARRSO, 1996).

Schepel and Kamal found a combination of multi-date low resolution merged images as the most efficient for water body detection (Schepel and Kamal, 2000). The study area was in the CPP area of Tangail District under a water management and controlled flooding programme. They suggested using multi-temporal imagery for differentiated ponds from seasonal open water bodies. In this study smaller ponds were not reliably detected. I saw this project report when I was in the field and it gave me a chance for further expansion and testing of methods for using with different remote sensing data.

One study used LANDSAT TM and SPOT HRV multi-spectral satellite imagery to delineate the water extent in different seasons for monitoring the seasonal fluctuation of inland water bodies (SPARRSO, 1993). The study used visual interpretation of maps created at 1: 100,000 scale from single bands 4 and 5 from LANDSAT TM and a false colour composite of bands 3, 4 and 5. Both IRS-XS and Landsat TM succeeded in delineating water area and seasonal fluctuation. The study focused on natural water features and did not specify how far delineation of SWB was possible with the methods used.

Another study used remote sensing data for mapping areas of shrimp farming in Bangladesh (Pramanik et al., 1990). The details of the shrimp farms and mangrove forest areas have been shown. Visual and stereoscopic interpretation methods were employed on enlarged LANDSAT MSS and TM imagery and manually traced. This method was combined with stereoscopic interpretation of black and white and Infrared Colour (IRC) aerial photographs. Results were prepared on maps at 1:50,000 scale by interpretation, which were then verified in the field. Finally a digital planimeter was used to measure the areas of shrimp farms and mangrove forest.

SPARRSO, ISPAN, EGIS and other different organizations in Bangladesh have conducted several pilot studies to map the extent, condition and location of different types of water bodies. A range of optical satellite remote sensing data and aerial photography were used in these studies. So far these studies have succeeded in identifying only the relatively larger water bodies including the naturally created *beels, haors, baors,* and rivers. A reliable method or approach for detecting SWB or for an actual inventory and spatial distribution was not established from these surveys, although estimates were made of approximately 10-15 million or more SWB in Bangladesh.

Studies in Bangladesh have been mainly conducted with specific objectives in mind related to fisheries data collection or fisheries management. They have mostly used sampling and estimation techniques in the survey of water resources. The total number of ponds has been estimated at 1.86 million through a field survey conducted by the Non Crops Statistics Section of the Agricultural Statistics Wing of the Bangladesh Bureau of Statistics (BBS, 1984). This survey was conducted in 420 thanas (sub-districts) out of 493 and included mostly managed ponds.

Another survey was conducted by SPARRSO in 1984 to collect data on water bodies using satellite imagery and aerial photographs at the request of the Bangladesh Fisheries Department (SPARRSO, 1984). This survey estimated the total area of water bodies suitable for fish production in the country. The study divided all the water bodies of Bangladesh into 'small' or 'large'. The SWB included ponds and tanks with water areas less than 25 ha. Colour infrared aerial photographs of 1983 and 1984 were used to identify and locate the SWB. The study identified about 122,000 ponds, covering an area of 13,900 ha in 40 selected thanas (SPARRSO, 1984). These did not include Shahjadpur thana or any other thana of Sirajgonj district. The total number of ponds in Bangladesh was estimated through extrapolation to be 1.3 million, covering an area of 164,000 ha. The survey showed the pond density to be 2 to 35 ponds per sq km and the water coverage 0.13-2.9 $ha/km^2$ (SPARRSO, 1984).

A survey work plan was incorporated in the Second Phase Agricultural Census Project (1985-90) in Bangladesh (BBS, 1994). This was carried out in 1989 to obtain a comparison with the earlier survey of 1982, and had the objective of establishing for the first time comprehensive statistics on inland fisheries resources. The result was published in 1994 and had been disaggregated into twenty regions due to the small size of the sample. Unfortunately neither Shahajdpur thana nor Sirajgonj district were included and nationally the results only specified managed ponds. The total number of ponds was estimated at 1,949,055 (BBS, 1994).

Another ponds survey was carried out in the Tangail area by the Compartmentalization Pilot Project (CPP, 1996) and for South Hatia Island in the Bay of Bengal (MES, 1998). This survey found similar figures and categories of ponds as the BBS, that is 15 per cent ponds are derelict. They used classifications as 'cultured', 'culturable' and 'derelict'.

Apart from Bangladeh, Kapetsky used satellite data to demonstrate the capabilities of a high-resolution sensor for aquaculture siting and planning (Kapetsky, 1988; Kapetsky et al., 1987). Meaden and Kapetsky have given an overview of the use of GIS and RS in inland fisheries and aquaculture (Meaden and Kapetsky, 1991). Travaglia used LANDSAT Multispectral Scanner (MSS) data to map commercially harvested algae and to monitor their growth in a coastal lagoon (Travaglia, 1989). Mooneyhan explained how to define optimum sites for aquaculture by taking into account physical factors such as distance from water to a settlement or a roadway or a vegetation type (Mooneyhan, 1985).

### 3.5.3 Remote Sensing

Low altitude colour infrared aerial photographs are probably the best remotely sensed data for the delineation of SWB (Schepel and Kamal, 2000). Spectral resolution of black and white aerial photos limits their application. However, aerial photos that could be used for SWB surveys are not available for most of Bangladesh and, as I have noted, the most recent comprehensive surveys of ponds (not using APs) were conducted in 1984 and 1989.

Digital classifications of remotely sensed data in identifying water bodies are limited through the spectral and spatial resolutions, combined with the spectral characteristics of the images (Schepel and Kamal, 2000). With the digital classification of satellite imagery, objects with an approximate size of 2.5 times the ground resolution can be identified (Jensen, 1996). This identification capability depends on the size, shape, the contrast of the object with surrounding features, and other factors that influence the object's signature in the digital imagery (Schepel and Kamal, 2000). Relatively high levels of energy absorption at the near infrared to infrared wavelengths of electromagnetic energy is the most distinctive spectral characteristic of water (Campbell, 2002; Jensen, 2000; Lillesand and Kiefer, 2000). According to Schepel and Kamal (2000) the classification of water bodies with remote sensing data is most effective in the infrared wave bands because of the absorption property. They also found that clear water absorbs relatively little energy in wavelengths less than about 0.6 μm and transmittance is at a maximum in the blue green portion of the spectrum (Schepel and Kamal, 2000).

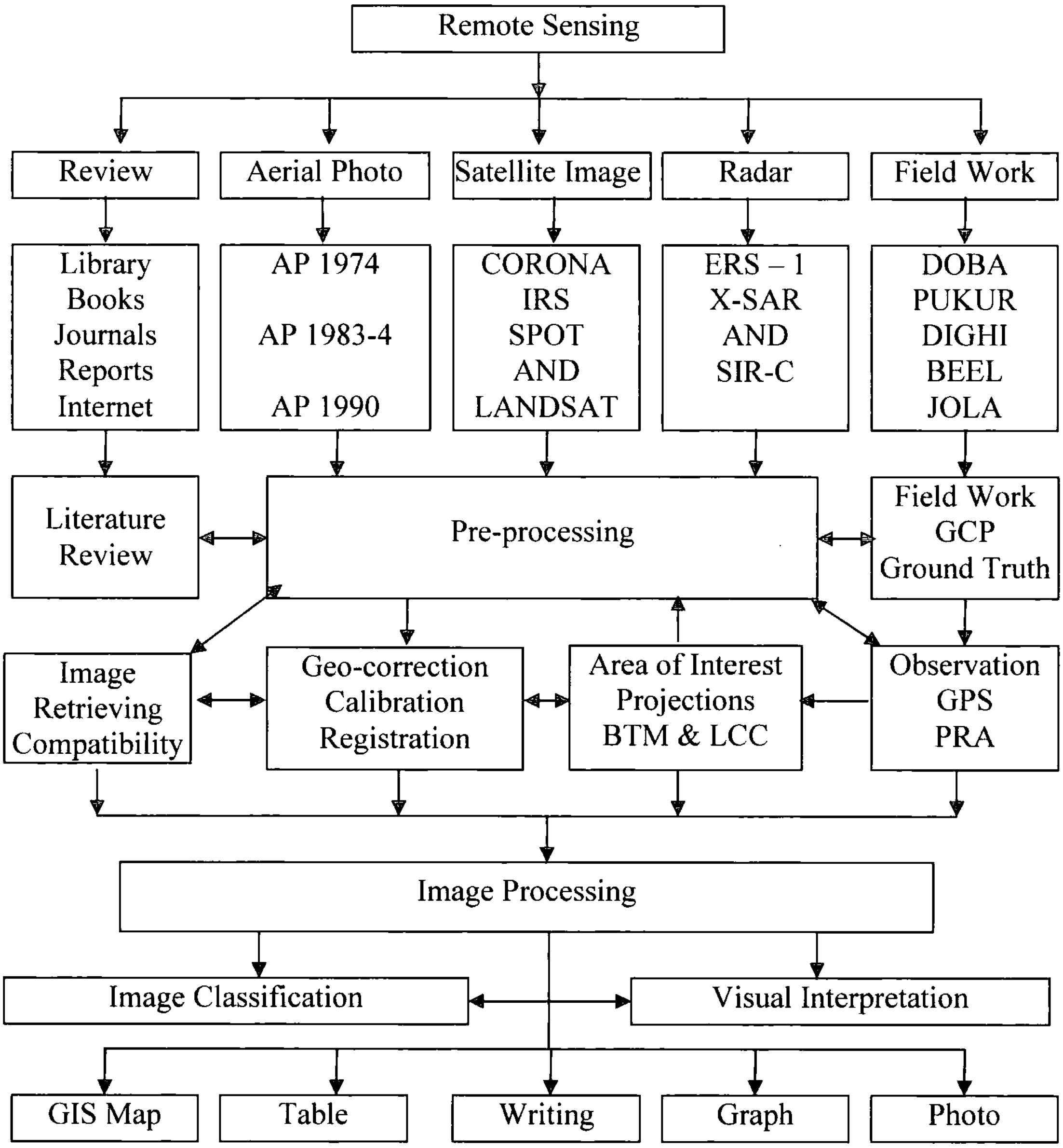
Reliable digital satellite image classification of typical SWB in the study area could be expected down to about 200 sq. metres in size. This assumes the use of the highest resolution of CORONA satellite photography and Aerial photo, with a ground resolution of 2 metres. According to Cliche, et al. (1985) integration of SPOT HRV panchromatic imagery, with a ground resolution of 10 metres, with multispectral imagery has been shown to enhance feature separation. With the Indian Remote Sensing (IRS) satellite's 6 metre ground resolution, more enhancement can be expected through merging with multi spectral imagery such as IRS LISS3 and SPOT (Chavez et al., 1991; Muralikrishnan et al., 1993) or with increased temporal coverage. It was likely that SWB could be identified using above approach under certain conditions.

My study indicated that the signature of water in multispectral images was mostly determined by size, but also by shape, clarity or turbidity of the water surface, tree canopy and surface vegetation, and by the spectral characteristics of surrounding areas. Table 3.2 gives the electromagnetic and spatial resolution of several satellite data sets used in this study

**Table 3.2 Characteristics of Available Satellite Imageries.**

| Satellite | Image Mode | Spatial Resolution(metres ) | Band Description | Spectral resolution ($\mu m$) |
|---|---|---|---|---|
| Aerial Photo | | 1.8 | Panchromatic | Photo |
| CORONA | KH-4B | 2 | Panchrmatic | Photo |
| Spot 4 | | | Short Wave Infrared | 1.58 - 1.73 |
| | Pan | 10 | Panchromatic | 0.51-0.73 |
| IRS ID | Pan | 5.8 | Panchromatic | 0.50 - 0.75 |
| | | | Blue | 0.45 -0.52 |
| | | | Green | 0.52 - 0.59 |
| | LISS-3 | 23 | Red | 0.62 - 0.68 |
| | | | Near Infrared | 0.77 - 0.86 |
| | | | Blue | 0.45 - 0.52 |
| | | | Green | 0.52 - 0.6 |
| LANDSAT 4, 5 &7 | (E)TM | 30 | Near Infrared | 0.76 - 0.90 |
| | | | Short Wave | 1.55 - 1.75 |
| | | | Infrared | |

**Source: After (Richards and Jia, 1998)**




**Source: Author, 2003.**

**Figure 3.2 Methods used for Remote Sensing.**

#### 3.5.3.1 Image Pre-processing

##### 3.5.3.1.1 Geometric correction and registration

Geometric correction and registration includes the removal of geometric distortion in an image and transforming it to suitable map projections. Forms of geometric distortion may include panoramic distortion, scan skew, Earth rotation, altitude of the sensor platform (roll, pitch and raw), and changes from one projection to another (Ramsey, 2003). My image data were corrected for geometric distortion with the use of the Ground Control Points (ESRI, 2001). The purpose of this correction is to allow image features to be located on a map. When using multitemporal images like in this research, it is fundamental to geo-reference the images to the base map coordinate system. This helps later in accurate spatial and socio-economic data integration.

Steps I used for the geometric registration of the various remote sensing images were as follows: a) selection of ground control points (GCPs), b) performing the transformation, and c) accuracy assessment. There are several processes for geometric corrections based on GCPs. According to Schepel and Kamal (2000), it is necessary to select about 10 times the minimum required number of GCPs (determined by the order of transformation) and to have a relatively equal distribution of the GCPs over the data set. It was necessary to weight the GCPs according to reliability (e.g., corners of ponds and road intersections are typically more reliable than the corner of a patch of vegetation or settlements) and sort them in a stepwise manner. In several studies it has been observed that the corner of a large pond is a distinct feature for use as a ground control point (Schepel and Kamal, 2000). Schepel and Kamal (2000) also suggested that high order transformation is not necessary for most areas which are relatively flat, and where there is no strong indication of instability of the imaging platform. In this study ground control points were collected with reference to the 1972 CORONA and 1998

LANDSAT 5 TM mosaic of Bangladesh, which is standardized for further geometric correction of the images. A 1st order polynomial was used with a nearest neighbour re-sampling algorithm to re-project the image in a modified Transverse Mercator Projection, known as the Bangladesh Transverse Mercator (BTM) and Lambert Conformal Conical (LCC) data preparation module of Erdas Imagine. These projections have the following parameters:

Projection: Bangladesh Transverse Mercator (BTM) : Everest

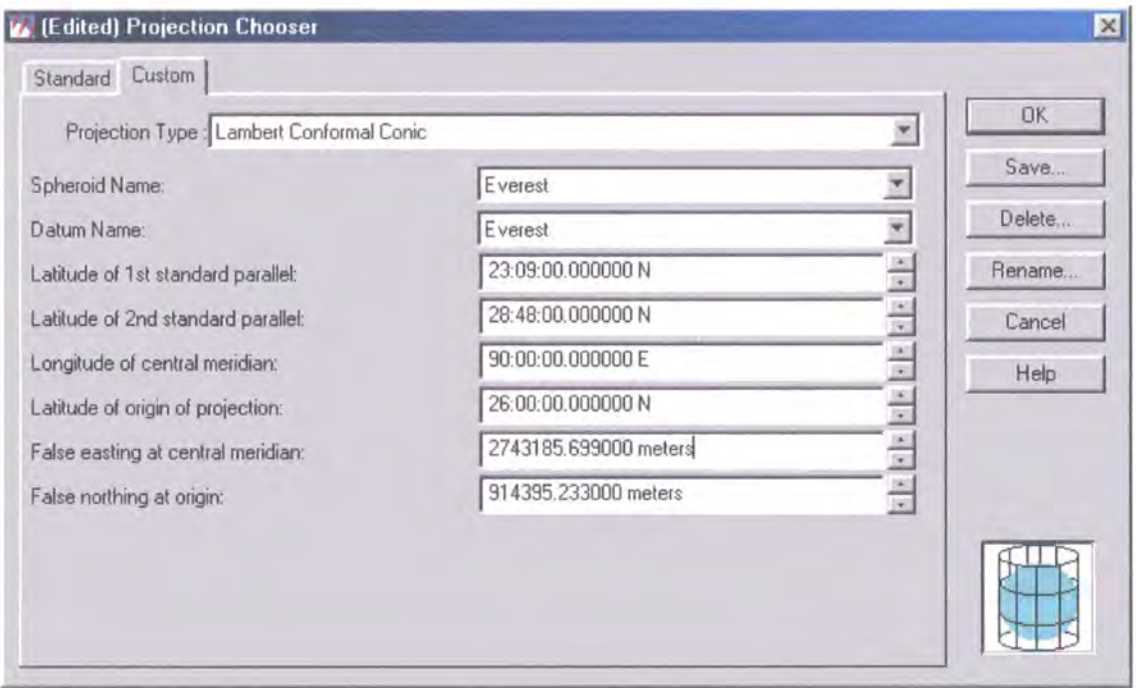
Spheroid Name: 90.00 Degree

Longitude of Central Meridian Latitude of origin: 00.00 Degree

Scale Factor at Central Meridian: 0.9996

False Easting: 500000

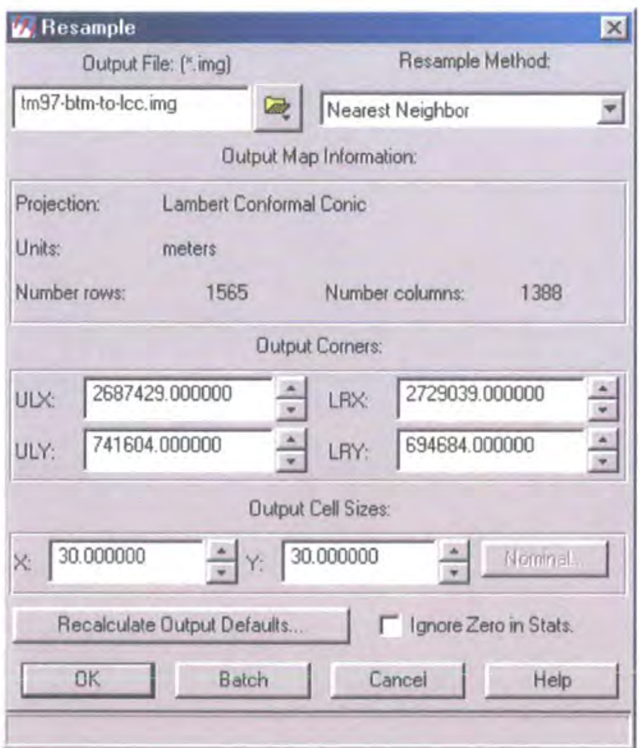
False Northing: -2000000




**Source: (ESRI, 2000) and Author, 2002.**

**Figure 3.3 Projection Conversion.**

The nearest neighbour interpolation method replaces the brightness value of the nearest pixel in the input image to the output grid co-ordinate at the warped pixel location (Schepel and Kamal, 2000). It is also found that output values are the original input values, whereas other methods of re-sampling tend to average surrounding values as described by Schepel and Kamal (2000). This was an important consideration to discriminate small objects from neighbouring bigger objects. Since the original spectral data are retained, this method is usually recommended before classification (Ramsey, 2003). Besides the above mentioned advantages, this method is easy to use and fast to compute. In the geometric correction process of the present study the Aerial Photo was first corrected with the mentioned LANDSAT TM Mosaic of Bangladesh and then the other two CORONA scenes were coregistered with the projected panchromatic scene. An accuracy assessment was done for the geometrically registered images by comparing the location of some clearly identifiable points of the registered images with the referenced image mosaic.




**Source: (ESRI, 2000) and Author, 2003.**

**Figure 3.4 Geometric Correction and registration.**

### 3.5.3.2 Image Processing and Analysis

#### 3.5.3.2.1 Photo/Image Interpretation

Photo/image interpretation can be defined as 'the examination of images for the purpose of identifying objects and judging their significance' (Lillesand and Kiefer, 2000; Phillipson, 1997). When image data is available in digital form, several methods can be used to extract information. According to Jensen (2000), firstly software can be employed to evaluate each pixel based upon its spectral attributes and this can be termed quantitative interpretation since pixels with like attributes are often counted to give area estimates. A second method involves the interpretation of information by the visual inspection of an image. Humans are adept at interpreting the images of objects and with suitable instruction we can become excellent image analysts (Jensen, 2000; Lillesand and Kiefer, 2000). According to Jensen (2000) there are several reasons in justifying photo or image interpretation as a scientific method, including; i) the aerial/regional perspective, ii) three-dimensional depth perception, iii) knowledge beyond our human visual perception, and iv) the ability to document change from a historical image.

**i) The aerial/regional perspective:**

According to Jensen (2000), a vertical or oblique aerial photograph or other type of visible/near-infrared image represents one particular view of reality and a single image usually covers a much larger geographical area than we would have able to visit on a given day if we had been undertaking field work (Jensen, 2000). A single 9 x 9 inch 1:63,360 scale vertical aerial photograph records approximately 81 square miles at one time (Jensen, 2000). Table 2.7 in chapter two shows that my 1972 CORONA KH-4B photo at a nominal scale of 1:247,500 covers a frame of 8.6 x 117 miles (1,006.2 square miles).

According to Jensen (2000), interpretation of the Earth's resources from an aerial perspective allows researchers to identify objects, patterns and human-land interrelationships that may only be incompletely understood from a terrestrial viewpoint. In one sense, it does not matter whether the aerial perspective is from a high-flying spy plane, the space shuttle or a satellite platform (Warner et al., 1996). A remotely sensed image represents unique spatial terrain information, which would not be possible to extract through other approaches (Jensen, 2000).

The interpretation of vertical and oblique imagery needs care. From our usual terrestrial viewpoint, we do not have a general idea of how the objects might be seen when they are acquired from a vertical or oblique perspective (Haack et al., 1996). Our normal line of sight on the ground is less than a kilometre and we are definitely not familiar with looking at and interpreting the significance of several square kilometres of terrain at once (Jensen, 2000). Therefore, regional analysis of vertical and oblique image requires training and practice (Jensen, 2000).

**ii) Three-Dimensional Depth Perception:**

Using our visual skills, a single aerial photograph or image can be viewed and the spatial distribution of features in the landscape is identifiable (Jensen, 2000). It is also possible to get a three-dimensional view of landscape features, so that it seems as if we are looking from on high (Jensen, 2000). The three-dimensional effect is accomplished by obtaining two photographs or images of the landscape from two slightly different viewpoints (Jensen, 2000). We can train our eyes to view these two images of the landscape simultaneously (Jensen, 2000). This stereoscopic information is processed as a three-dimensional model of the landscape that we perceive as being real (Caylor and Lachowski, 1988).

Sometimes it is important to measure the size and shape of an object, as well its height, depth and volume. The analysis of stereoscopic imagery allows an appreciation of the three dimensional nature of the undulating terrain, slope and aspect of the land (Jensen, 2000). In addition, the process of stereoscopic analysis usually exaggerates the height or depth of the terrain, allowing us to grasp the very fine differences in object height and terrain slope and aspect that we are unable see from a vantage point on the ground (Jensen, 2000).

**iii) Obtaining Knowledge Beyond our Human Visual Perception:**

The human eye is sensitive to blue, green and red light that is 0.4-0.7 μm (Jensen, 2000). That is why we are able to sample a very limited portion of the electromagnetic energy which is actually in the environment and interacting with soil, rock, water, vegetation, the atmosphere, and urban structure (Jensen, 2000; Lillesand and Kiefer, 2000). On the other hand, sensors can measure the activity of X-rays, ultraviolet, near-infrared, shortwave-infrared, thermal infrared, microwave, and radiowave energy (Jensen, 2000). Remotely sensed data, carefully calibrated, gives entirely new information about an object that might never be able to detect in any other way (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000).

**iv) Historical Image Record and Change Detection Documentation:**

An aerial photograph or satellite image captures the Earth's surface and atmosphere at a particular point in space and time that cannot to be obtained again (Jensen, 2000). These photographs or images are valuable historical documents of the spatial distribution of natural and human-made features (Campbell, 2002; Jensen, 2000). The new photographs and imagery could be compared with those historic photographs and imagery to detect if there are any subtle, dramatic, or particularly significant changes by acquiring multiple images of the Earth (Cowen and Jensen, 1998). The study of inventory and change using remote sensing increases understanding about the physical and human-induced dynamic processes in the landscape (Jensen, 2000). Knowledge about spatial and temporal dynamics allows us to develop estimation and predictive models about what has happened in the past and what will be in the future (Lunetta and Elvidge, 1998). Estimation and visibility study is one of the vital component and objectives of present research. Remote sensing image interpretation is playing an increasingly important role in detection, inventorying and estimation of land cover (Moran et al., 1997; Vane and Goetz, 1993).

***(a) Elements of Image Interpretation:***

While performing a regional spatial analysis of any physical feature such as SWB, the landscape is usually viewed in the three dimensions. Images may then be interpreted in terms of spatial variations of the electromagnetic spectrum, which assists in the identification of the feature that is changing (Jensen, 2000; Lillesand and Kiefer, 2000). The principles of image interpretation have been developed through empirical experience over more than 150 years (Estes et al., 1983; Rabben, 1960; Schott, 1997). According to Jensen (2000) most fundamental principles are the elements of image interpretation that are routinely used in the interpretation of aerial photographs or of satellite photography (CORONA). These elements are location, size, shape, shadow, tone and colour, texture, pattern, height and depth, and site, situation, and association (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000; Lillesand and Kiefer, 2000). The brief explanations used with each of these elements are summarized in Table 3.3. To evaluate an feature with respect to these elements can be a complex process and there is usually no substitute for experience and local knowledge of the area (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000; Lillesand and Kiefer, 2000).

**Table 3.3 Elements of Image Interpretation.**

| Elements | Quantitative and Qualitative Comments |
|---|---|
| Location and Position | X and Y coordinates, Longitude and latitude or metres easting and northing in a BTM or LCC projection.<br>North, South, East, West, Upper, Lower and middle part. |
| Size | Length, width, perimeter, Area ($m^2$)<br>Small, medium and large |
| Shape | Geometrical expression: linear, curvilinear, circular, elliptical, radial, square, rectangular, triangular, hexagonal, pentagonal, star, amorphous, zigzag, etc. |
| Shadow | A silhouette caused by solar illumination from the side.<br>Absent and Present<br>North, South, East, West, Right, Left, Upper and Lower. |
| Tone and Colour | Grey Tone: light (nearly white and bright), intermediate (grey) and dark (blackish).<br>Colour: HIS = Intensity, Hue and Saturation.<br>RGB = Red, Green and Blue. |
| Texture | Characteristic placement and arrangement of repetitions of tone or colour: Smooth, intermediate (medium), rough (coarse), mottled and stippled. |
| Pattern | The spatial arrangements of SWB on the landscape: systematic, unsystematic or random, clustered, linear, curvilinear, rectangular, circular, elliptical, parallel, centripetal, serrated, striated, braided and zigzag. |
| Height | z-elevation (height measured in suitable unit e.g. metres)<br>High, medium and low. |
| Depth | Bathymetry in metres<br>Highest, medium and lowest |
| Volume | Cubic metres<br>Bigger, smaller and lower |
| Slope and Aspect | Degree.<br>Steep, narrow, slopy, |
| Site | Exposure (elevation, slope and aspect)<br>Adjacency to household, homestead, road and utilities. |
| Situation | SWB are placed in a particular order or orientation relative to other features of landscape. |
| Association | Surrounding features are generally present. |

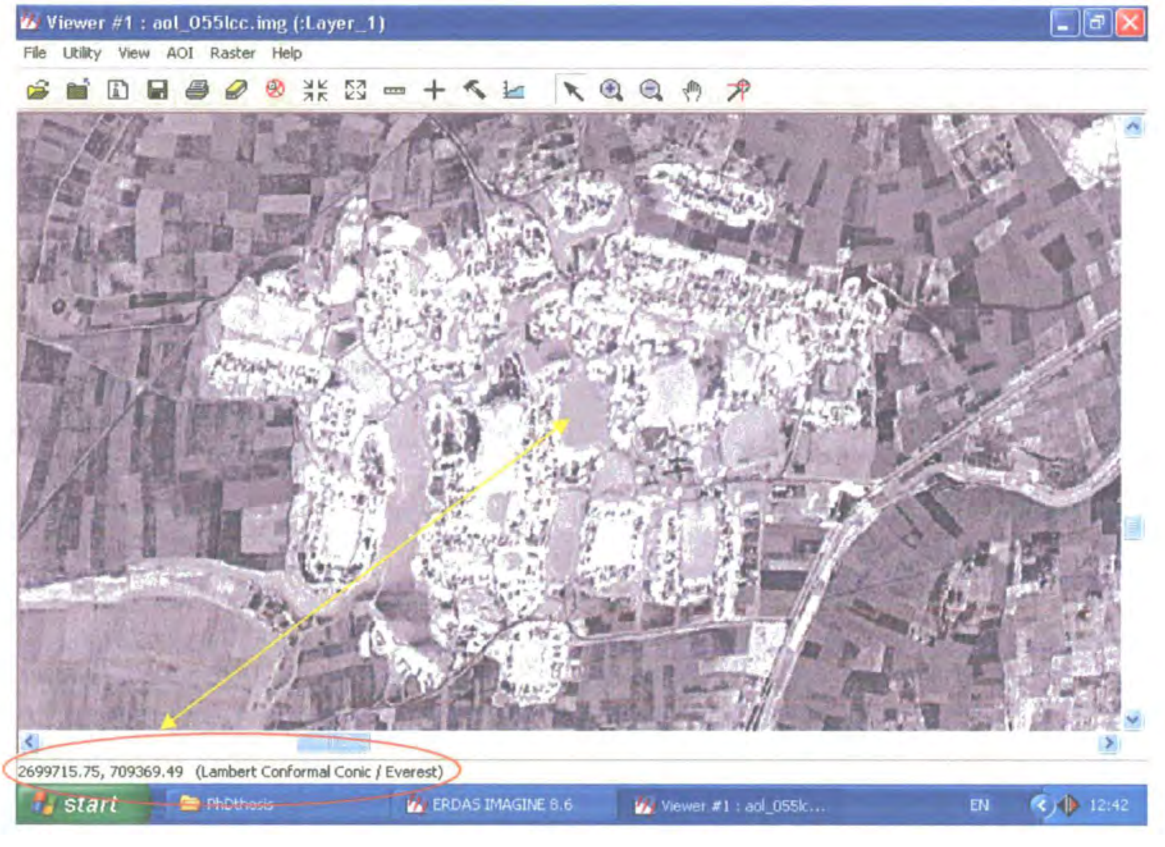
**Source: After Jensen (2000)**

**(i) Location and position:**

According to Jensen (2000), there are two primary methods for obtaining precise x and y location or positional coordinate information about a object: 1) survey it in the field using traditional surveying techniques and GPS, or 2) collect remote sensor data (photos and images) of the study area, register (rectify) the image to a base map, and then extract the x and y coordinate information directly from the image. If option one is selected, most researcher/interpreter now use relatively inexpensive GPS instruments in the field to get a precise position of an object's location in degrees of longitude and latitude on the Earth's graticule or in metres of eastings and northings in a map grid such as the Bangladesh Transverse Mercator (BTM) and Lambert Conformal Conic (Jensen, 2000). The coordinates of the point (e.g., a specific water body location) or polygon (e.g., the perimeter of a small pond) are then transferred on to accurate planimetric maps (Jensen, 2000). In the United States they normally use the U.S. Geological Survey's 7.5-minute quadrangle map and in Britain an Ordnance Survey map (Jensen, 2000).

Most modern aircraft or spacecraft now have an in-built GPS receiver that collects positioning data (Jensen, 2000). This allows the RS instrument onboard to obtain exact x, y and z GPS coordinates at each photograph exposure station or each line scan (Jensen, 2000; Lillesand and Kiefer, 2000). GPS information collected by the sensor (and perhaps some collected on the ground) can also be used to register (rectify) the uncontrolled photo or image to a BTM or LCC map projection (Jensen, 2000). According to Jensen (2000), corrections also can be made for the relief displacement of the topography, then the image becomes an *orthoimage* with all of the metric qualities. (Jensen, 2000). He also mentioned coordinates (x,y) of points and polygons can then be extracted directly from the rectified image. (Jensen, 1996).

Both methods described above were used to obtain precise x and y location or positional coordinate information for each SWB within each of the four mouzas. Ground truthing using both direct and participatory observation and global positioning system (GPS) gave the precise location and position of each SWB. I collected remotely sensed data (photos, images and RADAR) of the study area, geocorrected and registered it to a base map using ArcView and ArcGIS, and then extracted the x and y coordinate information directly from the image using Erdas Imagine software (see figure 3.5).




**Source: Author 2004.**

**Figure 3.5 Location and position of the SWB.**

**(ii) Size (Length, Width, Perimeter and Area):**

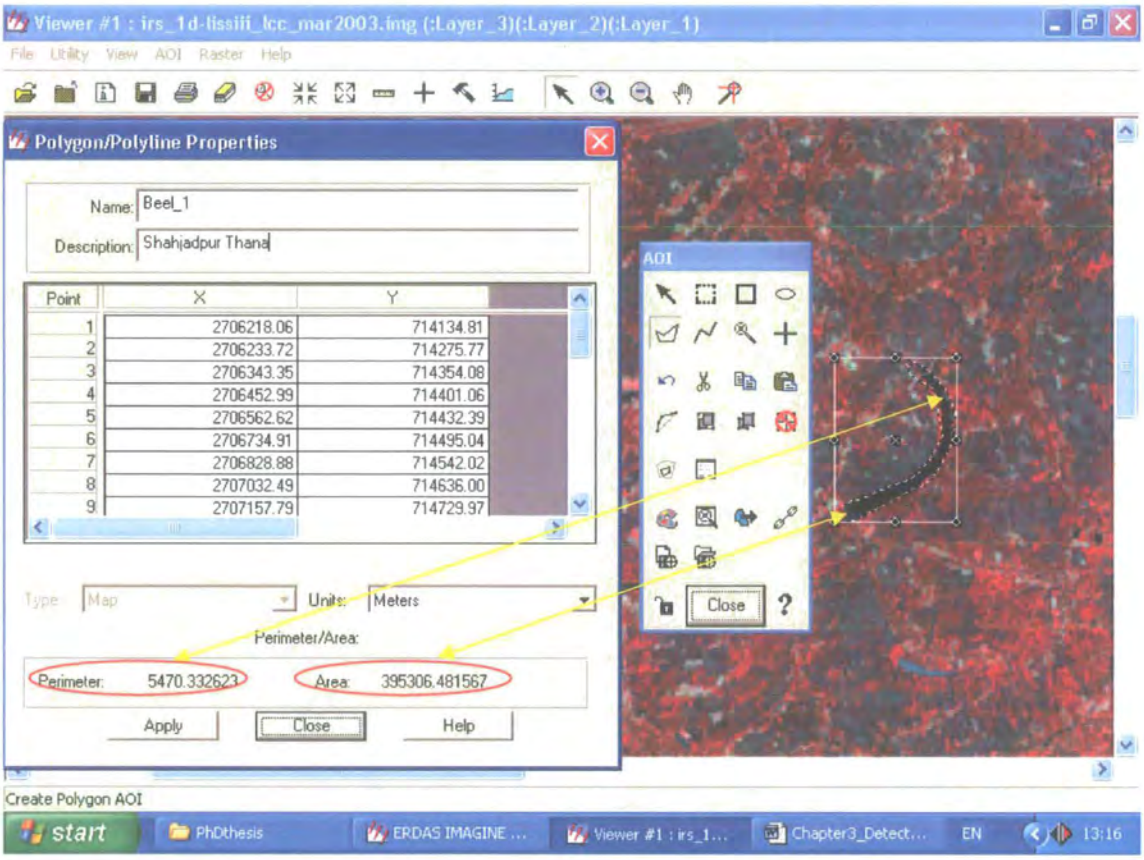
In two-dimensional space, size is a measure of surface dimensions of a feature. The size of SWB is one of their most distinguishing characteristics and one of the most important elements of image interpretation. The most commonly measured parameters are length, width, perimeter, area and occasionally volume (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000). Relative size comparison plays a vital role in identifying objects. Comparative size is also an important aid for identifying different types of SWB. According to Jensen (2000), the interpreter routinely measures the size of unknown objects. He mentioned that to do this it is necessary to know the scale of the photography (e.g., 1:30,000 for a photograph and in the case of digital imagery, it is necessary to know the spatial resolution or point spread function of the sensor system (e.g., 2 x 2 metres for the CORONA Satellite).

According to Jensen (2000), measuring the size of an unknown feature allows the interpreter to rule out many possible alternatives. Special measures should be taken as all of the phenomena in remote sensor data are at a scale of less than 1:1, and we are not usually looking at a miniature version of a feature that may measure only a few centimetres in length and width on the image (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000). Identifying the size of a few well-known features in an image such as a pond, road and jola width, or the size of a typical house/hut in the area, etc., allowed me to judge the size of unknown objects in the image and eventually to detect them. According to Jensen (2000), there are also several subjective, relative size adjectives, such as 'small', 'medium', and 'large'. These adjectives have been used for representing the differences between SWB interpretation.

Jensen (2000) also suggested features that have unique sizes can be used to judge the size of other objects in the scene. For example, in my study area mid-sized ponds are approximately 12 ft long and 12 ft wide. Ponds might be different in size in other places of world. It should be possible to differentiate between other types of water bodies like doba and dighi. The coarse line which separates water areas and banks gives some indication as to the high spatial resolution of this aerial photography and CORONA satellite photography. If these objects are visible within an image, it is possible to determine the size of other objects in the scene by comparing their dimensions with those of the known object's dimensions (Jensen, 2000).

Incorrect information could be obtained in measuring the precise length, perimeter, and area of objects on unrectified aerial photography or other types of unrectified remote sensor data (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000). The landscape is rarely completely flat as captured in an aerial photograph or other type of image. This happens because points that are higher than the average elevation are nearer to the sensor and points those are lower than the average elevation are further from the sensor system (Jensen, 2000). Palan (homestead), agricultural land, and SWB have significantly different scales than those at the average elevation within the photograph (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000).

According to Jensen (2000), the optimum situation is where the aerial photography or other image have been geometrically rectified and terrain-corrected to become, in effect, an orthophotograph or orthoimage where all objects are in their proper planimetric x,y location. He also mentioned measuring the length, perimeter and area of features using polar planimeter, tablet digitization, dot-grid analysis, or digital image analysis (Figure 3.6) are justifiable on geometrically rectified and terrain-corrected photo/images.

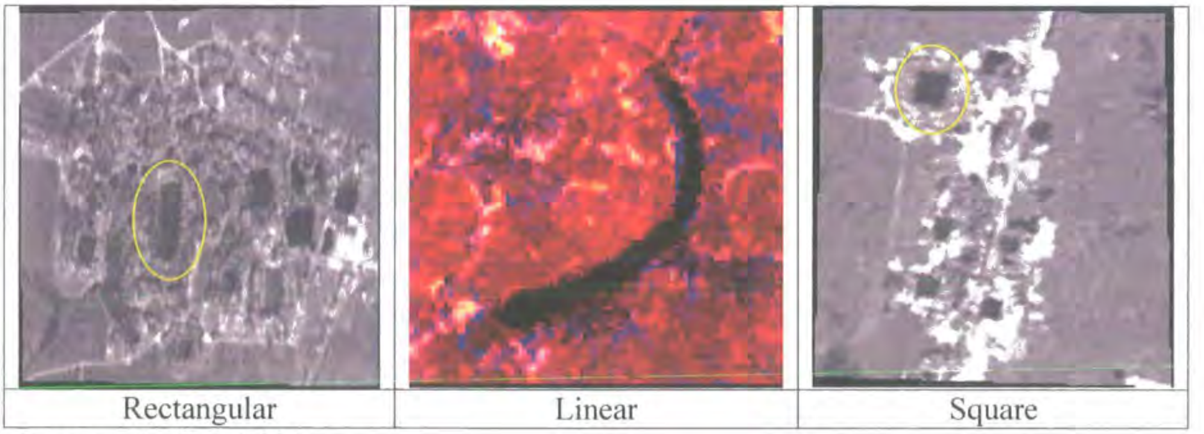



**Source: Author 2004.**

**Figure 3.6 Size (perimeter and Area) of the SWB.**

**(iii) Shape:**

The element of shape describes the external form or configuration of a landscape object (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000). Generally cultural phenomena have geometrical shapes and precise boundaries. On the other hand natural features tend toward irregular shapes with irregular boundaries. According to Jensen (2000), it would be easier for the analyst if everything had a unique shape and could easily be detected from a vertical or oblique perspective. He also mentioned that it is sometimes difficult even identifying the shape of a feature, much less appreciating the planimetric (x and y) shape of natural and man-made features recorded in aerial photography or other imagery. Lots of features do have unique shapes. According to Jensen (2000), there are also different adjectives to distinguish each from other such as linear, curvilinear, circular, elliptical, radial, square, rectangular, triangular, hexagonal, star, elongated and amorphous (no unique shape). There are an infinite variety of uniquely shaped natural and human-made objects in the real world. I had to spend a great amount of time in the field viewing, ground truthing and appreciating the different types of SWB and their shapes (Figure 3.7). Only then I was in a good position to understand how these shapes appear when recorded on vertical or oblique imagery.



| Rectangular | Linear | Square |
|---|---|---|

**Source: Author 2004.**

**Figure 3.7 Different shapes of the SWB in Shahjadpur Thana.**

**(iv) Shadow:**

Shadows cast by oblique illumination are important in the interpretation of remotely sensed data (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000). The shapes of shadows provide profile views of certain features that can help in detecting and identifying. Most remote sensor data is collected within $\pm 2$ hours of solar noon to avoid extensive shadows in the imagery (Jensen, 2000). This is because shadows from objects can obscure other objects that might otherwise be detected and identified (Jensen, 2000). On the other hand, the shadow or silhouette cast by an object may sometimes be the only real clue to an object's identity (Jensen, 2000).

According to Jensen (2000), very small scale photography or imagery usually does not contain shadows of objects unless they project a great distance above surrounding landscape such as mountains, extremely tall buildings, etc. Shadows can provide clues about the height of an object when the image interpreter does not have access to stereoscopic imagery e.g. shadow of house provide valuable information about the relative height of a house above the ground, e.g. a one-storey single-family house/hut.

Jensen (2000) suggested that, it is better to orient the imagery so that the shadows fall toward the interpreter. This will evade experiencing pseudoscopic illusions where low points appear high and vice versa (Jensen, 2000). Shadows on RADAR imagery are completely black and contain no information (Jensen, 2000). This doesn't happen with shadows on aerial photography. Usually it is relatively dark in the shadow area, but there may still be sufficient light scattered into the area by surrounding objects to illuminate the terrain to some degree (Jensen, 2000).

**(v) Tone and Colour:**

The reflective characteristics of objects within the photographic spectrum determine tone or colour and the wavelength region of sensitivity is a function of film type and filtration (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000). According to Avery and Berlin (1985), the ability of an object to reflect radiation at a given wavelength interval is dependent upon its surface composition and physical characteristics plus the intensity and angle of illumination. Real-world surface materials such as vegetation, water, and bare soil often reflect different proportions of energy in the blue, green, red, and near-infrared portions of the electromagnetic spectrum. We can plot the amount of energy reflected from each of these materials at specific wavelengths and create a spectral reflectance curve, which is called a spectral signature. Spectral reflectance curves of selected materials provide insights of why they appear on black-and-white or colour imagery. Greyscale tones are briefly discussed below.

***Tone:*** The tonal contrasts to be found in black-and-white photography, and hue, chroma and value qualities in colour photography, play an important role in the detection and identification of features (Jensen, 2000). A band of electromagnetic energy (e.g., green light from 0.5 - 0.6 μm) recorded by a remote sensing system may be displayed in shades of grey ranging from black to white (Jensen, 2000). According to Jensen (2000), we may interpret the image feature with adjectives e.g. "this part of an image has a 'bright' tone, this area has 'dark' tone, and this feature has an intermediate 'grey' tone." He also mentioned that the degree of darkness or brightness is a function of the amount of light reflected from the scene within the specific wavelength interval (band). Red light does not penetrate well into a water column, so the water has a slightly dark tone, especially in the deeper channels. As expected, sandy areas have bright tones (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000).

In black-and-white image recording only the near-infrared energy (0.7 - 0.92 μm), vegetation is displayed in bright tones (Jensen, 2000). According to Jensen (2000) healthy vegetation reflects much of the incident near-infrared energy. He also mentioned that the brighter the tone from a vegetated surface, the greater the amount of biological matter (biomass) present. Conversely, water absorbs most of the incident near-infrared energy, causing the water to appear dark. There is a great contrast between the bright upland consisting of vegetation and sand, and the dark water. Therefore, the near-infrared region is considered to be the best for discriminating between the upland and water interface (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000).

Jensen (2000) mentioned that our eye can differentiate approximately 40-50 individual shades of grey in black-and-white photographs or remotely sensed images and it takes practice and skill to extract useful information from broad-band panchromatic black-and-white images or black-and-white images of individual bands (Jensen, 2000). Often it is very difficult to identify features like SWB, if the scene is composed of very high or low contrast information.

***Colour:*** Jensen (2000) suggested that we may use additive colour-combining techniques to create colour composite images from the individual bands of remote sensor data and this introduces hue and saturation in addition to greyscale tone (intensity). Most researchers prefer to acquire some form of multi-spectral data so that colour composites can be made. This may be the collection of natural colour aerial photography, colour-infrared aerial photography, or multi spectral data, where perhaps many individual bands are collected and a select few are additively colour-combined to produce colour images (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000).

**(vi) Texture:**

Texture is the visual impression of coarseness, roughness and smoothness caused by the variability or uniformity of image tone or colour (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000). It is the characteristic placement and arrangement of repetitions of tone or colour in an image (Jensen, 2000). According to Jensen (2000), in an aerial photograph, it is created by tonal repetitions of groups of objects that may be too small to be discerned individually. As suggested by Jensen (2000), sometimes two features that have very similar spectral characteristics (e.g., similar black-and-white tones or colours) display different texture characteristics that allowed me to distinguish between them. Jensen (2000) also mentioned textural adjectives: smooth (uniform, homogeneous), intermediate and rough (coarse, heterogeneous).

**(vii) Pattern:**

Pattern relates to the spatial arrangement of objects in the land use dynamic (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000; Lillesand and Kiefer, 2000). The objects may be arranged randomly or systematically and they may be natural, as with a drainage pattern or man-made, as creating SWB. Pattern is a very diagnostic characteristic of many features (Jensen, 2000). Different adjectives are used to interpret the pattern i.e. random, systematic, circular, centripetal, oval, curvilinear, linear, radiating, rectangular, hexagonal, pentagonal, octagonal, etc (Avery and Berlin, 1985; Campbell, 2002; Jensen, 2000; Lillesand and Kiefer, 2000).

**(viii) Height and Depth:**

According to Jensen (2000) the ability visually to appreciate and measure the height (elevation) or depth (bathymetry) of a feature is one of the most diagnostic elements of image interpretation. He also mentioned that stereoscopic parallax is introduced to remotely sensed data when the same object is viewed from two different vantage points. Jensen (2000) found that viewing these overlapping photographs or images using stereoscopic instruments is the optimum method for the visual understanding of the three dimensionality of the terrain and for extracting accurate x,y, and z topographic and/or bathymetric information. He also thinks that there are monoscopic cues that we can use to appreciate the height or depth of an object. For example, any object such as a building or a SWB that protrudes above or below the local datum will exhibit radial relief displacement outward from the principal point of aerial photograph(Jensen, 2000).

**(ix) Site, Situation and Association:**

Site, situation, and association characteristics play important role when trying to interpret features (Jensen, 2000). We know that every site has unique physical and/or socioeconomic characteristics. According to Jensen (2000) the physical characteristics might include elevation, slope, aspect, and type of surface cover (e.g., bare soil, grass, shrub/scrub, rangeland, forest, water, crop, housing, etc.) and socioeconomic site characteristics might include the value of the land and the land-tenure system.

Situation refers to how certain features in the image are situated relative to each other (Jensen, 2000; Lillesand and Kiefer, 2000). It can be found that usually certain raw materials, houses, settlements, and roads are situated in a logical, predictable manner (Jensen, 2000). I observed the SWB are situated usually either beside the house or middle of the agricultural field and surrounded by homestead vegetation.

Association refers to the fact that when a certain feature invariably encounters related or associated features or activities (Jensen, 2000) e.g. Jolas/khals has embankment and linear shape. Site, situation, and association elements of image interpretation are rarely used independently when analyzing an image. Rather, they are used synergistically to arrive at a logical conclusion.

### *(b) Methods of Search/Detection*

According to Jensen (2000), over the years since the first successful aerial photograph taken by Gaspard Felix Tournachon (Nadar) in France in 1858, scientists have developed some valuable approaches to interpreting remotely sensed data, including: 1) utilizing collateral (anciliary) information, 2) converging the evidence, and 3) applying the multi-concept in image analysis (Jensen, 2000).

#### (i) Using Contextual Information:

Jensen (2000) found that the trained image interpreters rarely interpret aerial photography or other remote sensor data in isolation rather; they collect as much collateral (often called ancillary) information about the subject and the study area as possible. Cotextual information used in my image interpretation are collected from mouza map and other maps like LGED thana map, local informants, government and non-government offices, published an unpublished literature Some of these data were inserted as attribute in GIS for easy retrieval and overlay with remotely sensed data.

#### (ii) Convergence of Evidence:

It is generally a good practice to start interpreting from the known feature to the unknown (Jensen, 2000). For example, I was having difficulty identifying a particular SWB in aerial photograph but managed to detect while I found the nearest one.

According to Jensen (2000) careful examination of known features, surrounding and influencing the feature of interest justify the identifications. A careful interpretation of the settlement characteristics (length, width, height, orientation), the surrounding land-use pattern (e.g., homestead garden and agricultural land), site slope and aspect, site drainage characteristics, unique utilities coming into or out of the facility (sewerage), bushes and vegetation increased the capability of SWB detection. I tried to use as much as ancillary knowledge that I can in the interpretation problem and considered the various types of evidence together to identify and detect the SWB.

**(iii) The Multi-concept:**

According to Jensen (2000), Robert Colwell of the Forestry Department at the University of California at Berkeley introduced the multiconcept in image interpretation in the 1960s (Colwell, 1997; Phillipson, 1997). He also mentioned that Colwell (1997) suggested the most useful and accurate method of scientific image interpretation consisted of performing the following analysis: multispectral, multidisciplinary, multiscale, and multitemporal.

Jensen (2000) argues that single-date remote sensing investigations can yield important data but they do not always provide information about the processes at work. He also mentioned that a multi-temporal remote sensing investigation obtains more than just an image of an object. Jensen (2000) agreed with other authors that monitoring the phenomena through time allows us to understand the processes at work and to develop predictive models (Lunetta and Elvidge, 1998; Schill et al., 1999). He also reported that a trained image analyst understands the phenological cycle of the phenomena is interpreting and uses this information to acquire the optimum type of remote sensor data on the optimum days of the year (Jensen, 2000).

Above methodological discussion enriched the understanding of the image interpretation. I have utilized this to interpret carefully and analyze aerial photography, CORONA satellite photography, IRS panchromatic satellite image and other types of optical (blue, green, red, and near-infrared wavelength) remote sensor data. Based on this foundation, I was prepared to progress to more sophisticated image analysis techniques for the extraction of quantitative information from remote sensor data.

#### 3.5.3.2.2 Image classification

Digital image classification was performed on the geocorrected and registered images. They were classified to extract the water classes. The images were classified in two steps using an unsupervised algorithm. The first step of this process classified the images into a number of classes. Some of the classes appeared to match water bodies when were checked against ground survey and map data. Other potential water body classes did not fully discriminate between other non water classes; the pixels corresponding to these uncertain classes were extracted from the digital image and resubmitted to the classification process and reclassified into a few classes using Erdas Imagine software.

The signature statistics of the classes thus derived were evaluated to help define a set of final water categories. The resultant categories consisted of several water classes, based on various levels of surface water appearances. In some cases, two additional classes were added to segregate water from the vegetation canopy (i.e. recently planted rice paddy fields).

1. **Defining the Nature of Classification**
   - ✓ Locating Area of Interest (AOI)
   - ✓ Defining the Classes of Interest (i.e. Water Bodies)

2. **Collection of RS and Ground Reference Data**
   - ✓ Selection Remote Sensing Platforms
     - ➢ Spatial, spectral, temporal and radiometric resolution.
     - ➢ Environmental: atmospheric, soil moisture, phonological cycle etc.
   - ✓ Ground Referenced Data Collection
     - ➢ Detailed Knowledge of the Study Area.

2. **Thematic Data Extraction Processes**
   - ✓ Radiometric Correction (or normalization)
   - ✓ Geometric Rectification
   - ✓ Image Classification Algorithm
     - ➢ Unsupervised
       - ❖ Chain method.
       - ❖ Multiple pass ISODATA
     - ➢ Supervised
       - ❖ Parallelpiped and/or minimum distance
       - ❖ Maximum Likelihood
     - ➢ Hybrid combining ancillary information
   - ✓ Data extraction from initial training site
   - ✓ Appropriate band selection
   - ✓ Extracting training statistics
   - ✓ Thematic data Extraction
     - ➢ Label pixels (unsupervised)
     - ➢ By class (supervised)

3. **Error Evaluation for Quality Assurance**
   - ✓ Cross check with field data
   - ✓ Statistical Assesement

4. **Presentation of Results**
   - ✓ Digital Output
   - ✓ Interpretation and Justification
   - ✓ Hard copy printing
   - ✓ Thesis

**Source: After Jensen (2004).**

**Figure 3.8 Generalized image classification procedure.**

### 3.5.4 Geographical Information System (GIS)

Several sets of GIS data were used at different stages during the study. Some of them were directly obtained from the field and the others were prepared from the satellite data used for this study. All the boundaries of plots in the Mouzas were digitized from hard copy map and used. A coverage of perennial water bodies within the study area was used to mask the perennial waters from the classified images. This water body coverage was visually interpreted from 1:50000 scale maps prepared from a SPOT multi-spectral image by LGED. A road network coverage of the study area was digitized through on-screen visual interpretation and compared with the GPS-derived data.

### 3.5.5 Field work for ground truthing and accuracy assessment

The field information was used in two ways: for documenting properties such as shape, size, depth of water, seasonal variation, location relative to other landscape features, etc. for assessing the results of the study. Considering the available budget and time available, it was decided to make an extensive survey in four mouzas. Within these mouzas all the SWB were investigated in order to make an assessment of the errors of interpretation and classification using various methods. The field survey was conducted from December 2001 to March 2002 considering the season and availability of cloud free satellite imagery.

Information was collected using a pre-designed field observation Sheet (Appendix 1-3). The collected field data from the four mouzas for each SWB are as follows: Size, Water area, Percentage covered by water weeds, Percentage covered by tree or other vegetation canopy, Water depth in dry and the wet season, Seasonality of the water and date when the pond dries out, Appearance of the water. Besides these data, photographs and a video were taken of each SWB during the field survey to visualize the size, shape, water quality and surroundings. Although the field data from these four mouzas contained information on a total of 287 different SWB, the limitation of the collected data was the accuracy of the GPS readings, because the location of the water body was very significant to assess the image.

### 3.5.6 Global positioning system (GPS)

A hand-held Magellan 5000 Pro Global Positioning system was used to measure the perimeter and locate the field locations of a number of SWB. The readings from the GPS were useful to get the relative location, however the inaccuracies were more than several metres in some cases. These inaccuracies are attributed to the fact that a differential GPS was not used, and likely too there were errors by the survey team, who were not fully trained to operate the GPS systems.

### 3.5.7 Integrated Method (Extraction and detection)

For each of the images were overlaid with existing GIS data to identify and manually on screen digitize the extent of known visible SWB (e.g. Jola, beel, dighi, pukur or doba). The other water body types in the area are wetlands, rivers and the water in the irrigated paddy fields. Beside the image classification resultant mixed classes; these corresponded with shade from vegetation, roads and other feature. Some feature classes, which were misclassified as roads and associated features, were eliminated using the existing road coverage. A GIS coverage of settlements was useful as a backdrop to the classified and non classified image. This process of onscreen manual editing and digitizing was very useful and necessary to interpret the remote sensing data. It took a skilled remote sensing analyst several hours for the onscreen manual editing and digitizing for identifying the SWB of the study area.

The integrated methodology in terms of practical steps was as follows:

1. The remote sensing data was collected and analysed as described.
2. Mouza maps were used for the identification of land use and plot boundaries, which enabled the location and identification of individual SWB.
3. With my research assistants I visited each plot with a SWB to get an idea of the spatial extent of the water body and an idea of the surrounding land use context.
4. Each SWB was then surveyed via participatory observation using the CORONA image and aerial photographs as a guide for local people to orientate themselves.
5. All of the SWB in each of the four mouzas were then mapped and tabulated (see Table 3.4 and Figure 3.11-3.14).
6. The precise boundary identification and area measurements were then performed using different ground observation methods (Table 3.6).
7. In Durham the detailed remote sensing analysis was completed and it was then possible to compare this with the participatory and direct observational data, the local people's historical perceptions, and the GPS data. For further information concerning the results of this, see Chapter 4.

### 3.6 Software

ERDAS Imagine software was used for image processing and analysis. Windows NT workstation based ARC/INFO and ArcView and ArcGIS was used for various GIS analyses and vector data management. ArcView 3.2, Stata 8.2, MS Office 2000 and XP software were used for field data entry, analysis and visual presentation of results.

### 3.7 Results and Discussion

The field survey of four mouzas found 287 SWB. The largest SWB surveyed was 34,812.8 sq metres and, at the lowest end, the minimum doba size is about 1 decimals (40.48 sq metres). 20 SWB were reported as dry during the field survey and of these, ten were also dry during December 2001. The distribution pattern over the different class sizes follows more or less the pattern as observed for the whole study area.

The survey was carried out during the dry season when the SWB were not completely filled with water. The remote sensing techniques were used to estimate the SWB area. The field data contained information on both the total of SWB area as well as the water area. The relation between SWB area from groundtruthing and obtained from remote sensing techniques was examined.

The criteria were assessed from the database, video and the photograph of the SWB. These could be easily located on the image and the resulting GIS attribute table was extremely useful during the comparison of results.

**Table 3.4 Data Collected Through Participatory Observation, questionnaire and ground truthing.**

| ITEM/MOUZA | BAOIKHOLA | DAYA | NARAYANDAHA | PASCHIMKHARUA | TOTAL |
|---|---|---|---|---|---|
| AREA (SQ.METRES) | 1633544 | 871006.9 | 742357 | 1855489 | 5102396.9 |
| NO OF PLOTS | 1587 | 1181 | 566 | 1374 | 4708 |
| **NO. OF DOBA** | **28** | **67** | **20** | **22** | **137** |
| SMALLEST SIZE(SM) | 40.48 | 40.48 | 80.96 | 60.72 | 40.48 |
| LARGEST SIZE(SM) | 485.76 | 728.64 | 647.68 | 485.76 | 728.64 |
| AVERAGE SIZE(SM) | 157.872 | 161.92 | 221.83 | 162.73 | 177.71 |
| **NO. OF PUKUR** | **20** | **48** | **19** | **44** | **131** |
| SMALLEST SIZE(SM) | 182.16 | 80.96 | 121.44 | 161.92 | 80.96 |
| LARGEST SIZE(SM) | 1335.84 | 1012 | 1012 | 2428.8 | 2428.8 |
| AVERAGE SIZE(SM) | 597.48 | 311.7 | 440.83 | 690.18 | 610.44 |
| **NO. OF DIGHI** | **1** | **2** | **0** | **5** | **8** |
| SMALLEST SIZE(SM) | 2428.8 | 1619.2 | N/A | 1983.52 | 1619.2 |
| LARGEST SIZE(SM) | 2428.8 | 2347.84 | N/A | 12144 | 12144 |
| AVERAGE SIZE(SM) | 2428.8 | 1983.52 | N/A | 6152.96 | 5532.4 |
| **NO. OF JOLA** | **2** | **3** | **1** | **1** | **7** |
| SMALLEST SIZE(SM) | 2631.2 | 3643.2 | 4048 | 34812.8 | 2631.2 |
| LARGEST SIZE(SM) | 4331.36 | 5869.6 | 4048 | 34812.8 | 34812.8 |
| AVERAGE SIZE(SM) | 3481.28 | 4992.3984 | 4048 | 34812.8 | 11455.84 |
| **NO. OF BEEL** | **3** | **0** | **0** | **1** | **4** |
| SMALLEST SIZE(SM) | 18782.72 | N/A | N/A | 26716.8 | 18782.72 |
| LARGEST SIZE(SM) | 80960 | N/A | N/A | 26716.8 | 80960 |
| AVERAGE SIZE(SM) | 42153.17 | N/A | N/A | 26716.8 | 38294.08 |
| **GRAND TOTAL** | **54** | **120** | **40** | **73** | **287** |

**Source: Author, 2001-2.**

Table 3.4 summarizes the results from the direct and participatory observation in 2001/2. It shows the total number of SWB to be 287: 137 dobas (ditches), 131 pukurs (ponds), 8 dighis (reservoirs), 7 jolas (canals) and 4 beels (lakes), in approximately ascending order of size. All of these are human-made or human-modified, except for the beels, which are residual oxbow lakes formed by rivers changing course. The data on area are based on rough calculations made in collaboration with the local people, using customary measures such as pacing.

The digital images were processed to derive a SWB map of the study area. From the preliminary assessment of the images it was observed that there was often a confusion between vegetation in the settlements and water of the SWB. Haze also significantly influenced the spectral properties of the image and had an effect on the classification results. The months from December to March are normally the middle stage of the irrigated paddy cultivation and ideally low and medium high lands are covered with paddy. These irrigated paddy fields added big clusters of scattered water pixels to the croplands.

Table 3.5 summarises the results of the remote sensing interpretation in terms of the smallest SWB that was detected, in square metres. The reader will immediately notice the wide variation of the total and for the individual mouzas. This is the result of the different resolution of the sensors and their ability to distinguish SWB from surrounding noise. The smallest SWB were detected by the IRS ID for 1999 and 2003, although we must remember that SWB are continually being created or re-excavated and the surrounding vegetation grows or is cut, and comparing sensors through time therefore has the disadvantage that the set of targets is not stable. For a further discussion of this complex point about analysis, see Chapter 4.

Table 3.5 Smallest SWB Detected in the Study Area (square metres)

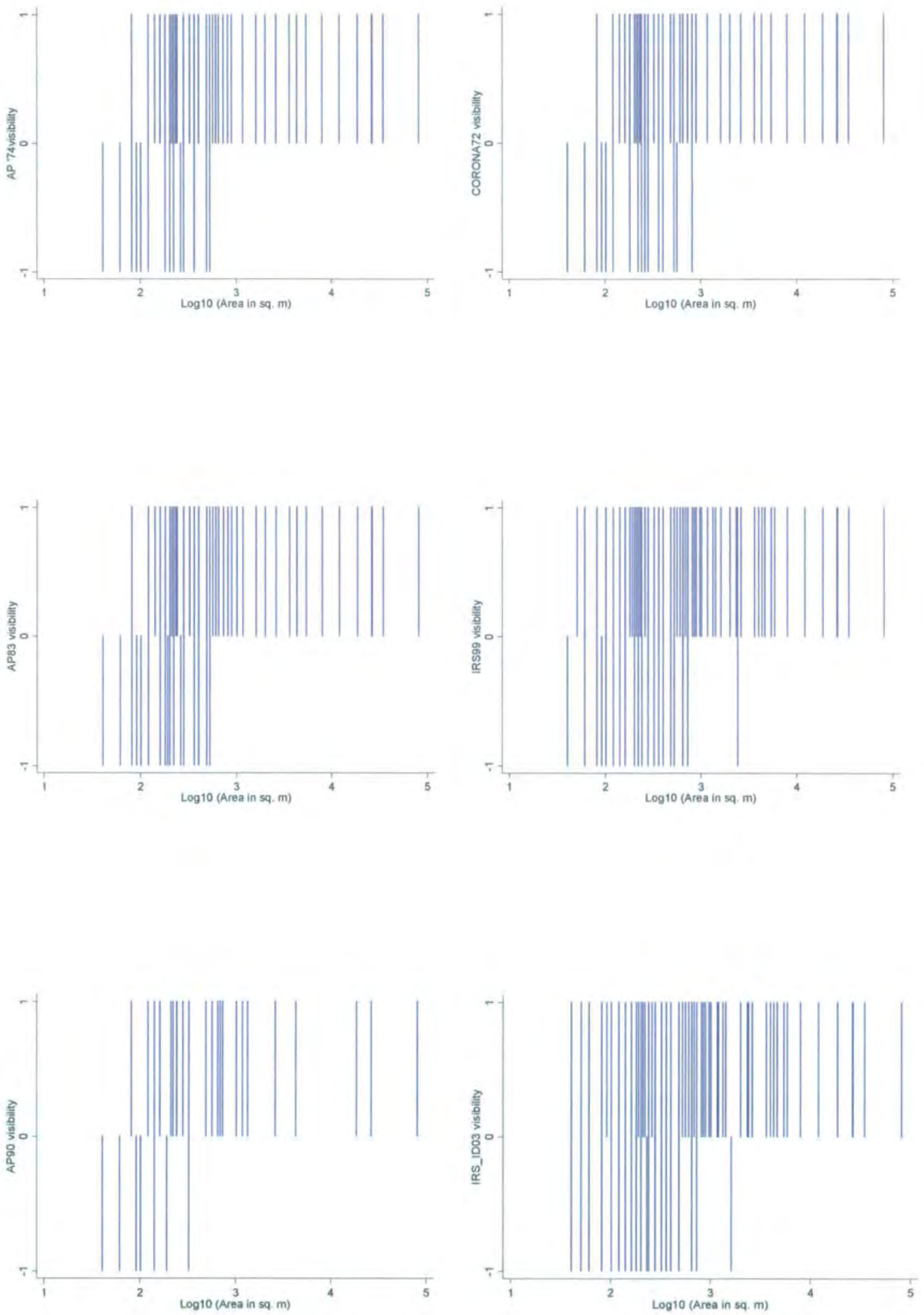
| RS/MOUZA | Year | Sensor | Resolution (m) | BAOIKHOLA | DAYA | NARAYANDAHA | PASCHIMKHARUA | ALL MOUZA |
|---|---|---|---|---|---|---|---|---|
| Corona | 1972 | Panchromatic | 2 | 79.62 | 93.94 | 83.22 | 129.35 | 79.62 |
| Aerial Photo | 1974 | AP | 1.5 | 75.28 | N/A | N/A | N/A | 75.28 |
| Aerial Photo | 1983 | AP | 1.5 | 74.37 | N/A | N/A | N/A | 74.37 |
| SPOT, HRV | 1989 | Panchromatic | 16 | N/A | N/A | N/A | N/A | N/A |
| Aerial Photo | 1990 | AP | 1.5 | 78.82 | N/A | N/A | N/A | 78.82 |
| ERS1 | 1993 | RADAR | 16 | N/A | N/A | N/A | N/A | N/A |
| SIR-C | 1994 | RADAR | 13 | N/A | N/A | N/A | N/A | N/A |
| Landsat TM | 1997 | Multispectral | 30 | N/A | N/A | N/A | N/A | N/A |
| IRS ID | 1999 | Panchromatic | 5.8 | 85.91 | 73.62 | 86.44 | 86.13 | 73.62 |
| IRS ID | 2003 | Panchromatic | 5.8 | 84.69 | 78.73 | 85.22 | 87.36 | 78.73 |
| IRS LISSIII | 2003 | Multispectral | 23 | 800.31 | 812.65 | 865.23 | 833.96 | 800.31 |

Source: Author, 2001-4

Figure 3.9 shows the interpreted visibility pattern of the remotely sensed data from aerial photographs for 1974, 1983, and 1990; CORONA satellite images for 1972; and IRS images for 1999 and 2003. They are all panchromatic (black and white) images and their resolutions range from 1.8 metres up to 5.8 metres. For ease of comparison, the aerial photographs are grouped on the left of the figure, with the satellite images to the right. These are all high resolution images and the figure plots the log of the area of each of the SWB created on the X axis against visibility (+1) or invisibility (-1) on the Y axis. This in effect is a qualitative yes/no plot and is a powerful visual representation of the effectiveness of each platform in detecting each measured SWB. The reader can instantly get an impression of the capability of each sensor by comparing the number of bars above and below the zero line and by looking in the top left-hand corner to see how many of the smallest are visible. The IRS-ID Pan sensor results are consistent between both image data sets used apart from one SWB. IRS shows similar capability to1:30,000 scale air photography.

On a technical point, please note that the maximum value below the line on each plot is important. It represents the largest SWB that was invisible to each sensor. Now looking vertically above the line and to the left gives us the smallest SWB that are visible. However, it is important to note that this visibility is often compromised by surrounding vegetation and therefore precision of areal measurement is problematic.

Another important caveat should be entered for the aerial photography of 1990. This only covered Baoikhola mouza and is therefore not as full as the other years. Also, with the IRS for 1999 and 2003, it should be remembered that many new SWB have been created in recent years and therefore comparison with the other platforms is not strictly possible in terms of the numbers of features that are in/visible.

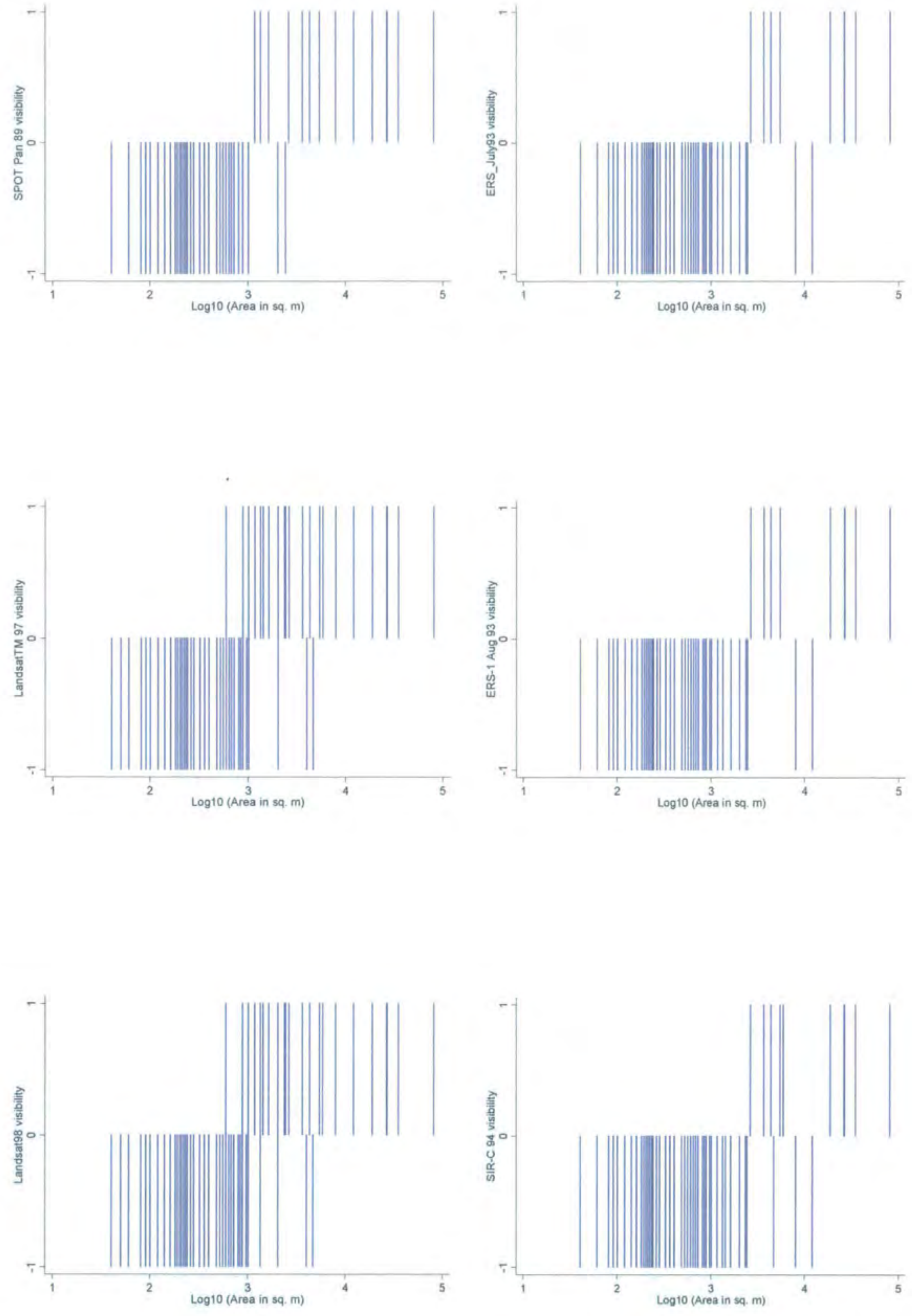



**Source: Author 2004**

**Figure 3.9 Interpreted visibility pattern of high resolution remotely sensed data.**

Figure 3.10 covers the lower resolution optical sensors: SPOT 3 HRV Pan 1989; Landsat TM 1997; and Landsat TM 1998. It is no surprise to note that there are fewer bars above the line in these plots and that there is significantly more white space in the top left corner of each. They detected larger SWB such as beels and jolas but were less successful with dighis, dobas and pukurs. The resolution of SPOT images has now improved (5m Pan) and they will therefore become more useful for this kind of study, not least because the unit price of a SPOT image is less than other high resolution equivalents.

Figure 3.10 also compares synthetic aperture RADAR imagery; ERS-I July 1993; ERS-I August 1993 and NASA SIR-C 1994. RADAR also show poor detection capability for the smaller SWB. It can be concluded that these sensors cannot identify all the types reliably. However, they may be helpful for understanding changes especially the larger water bodies e.g. above 1000 $m^2$. Particularly, in the case of RADAR data which can be acquired day or night and through cloud. Two further points may be mentioned. First, acquiring the necessary skills for the interpretation of RADAR images is difficult because relatively little relevant literature exists by way of example. Second, the technology of RADAR is including its ground resolution likely to improve to the extent that it may become appropriate for this type of study in future. e.g. RADARSAT-2.



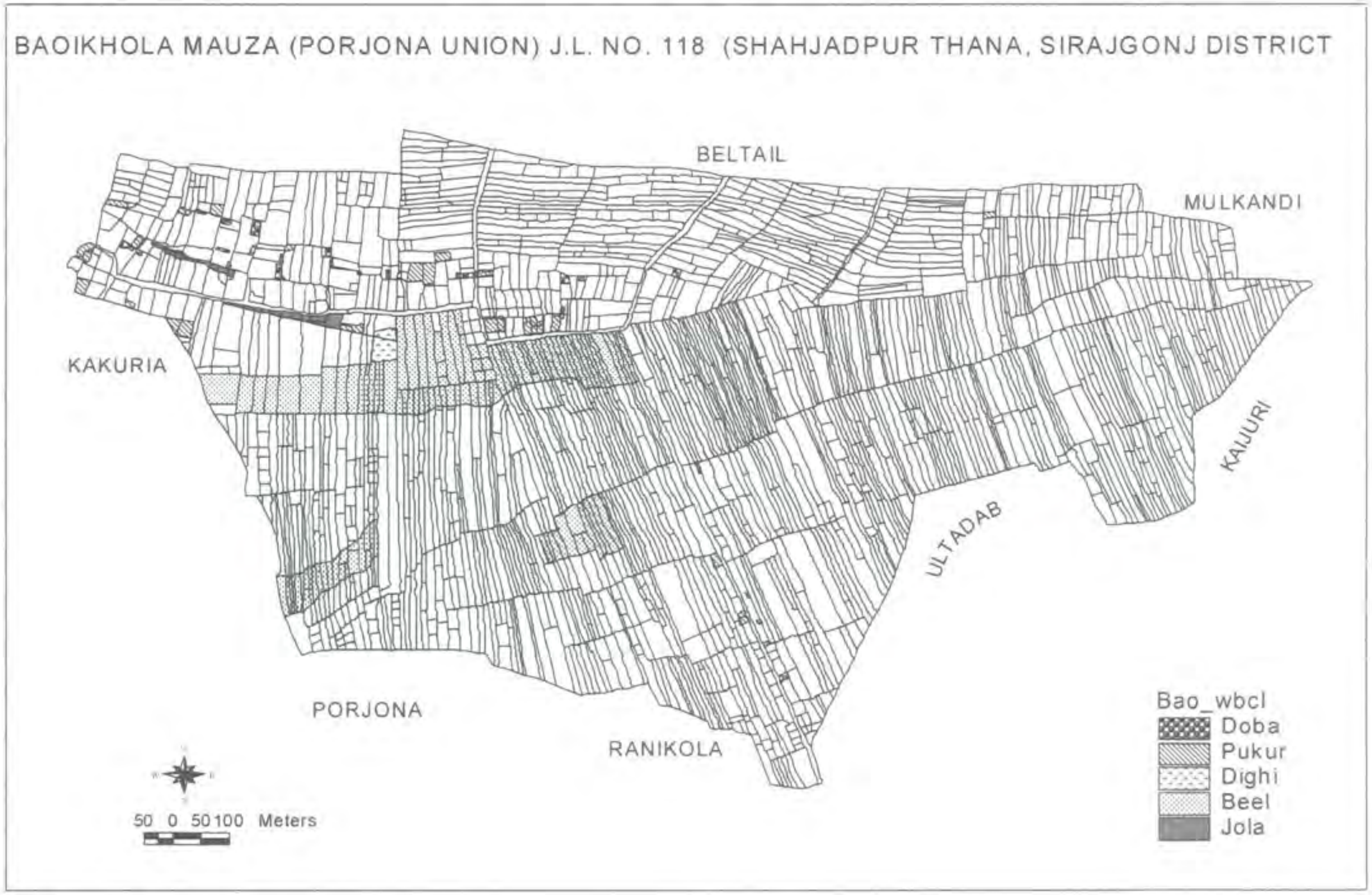

**Source: Author 2004**

**Figure 3.10 Interpreted visibility pattern of low resolution remotely sensed data.**

**Table 3.6 Results of Remote Sensing Image Interpretation (Baoikhola Mouza)**

| SWB | Platforms | CORONA72 | AP_74 | AP_83 | SPOT_89 | AP_90 | ERS1_93 | ERS1_93A | SIRC_94 | LSAT_97 | LSAT_98 | IRS_99 | Survey_02 | GPS_02 | IRS_03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Created | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | Visible | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 2 |
| Jola | Percentage | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100 | 0.00 | 100.00 |
| | Smallest_Dec | 31.43 | 42.47 | 36.04 | N/A | 35.02 | N/A | N/A | N/A | N/A | N/A | 62.83 | 65.00 | N/A | 47.72 |
| | Smallest_Sq m | 1272.42 | 1719.12 | 1459.00 | N/A | 1417.66 | N/A | N/A | N/A | N/A | N/A | 2513.31 | 2631.2 | N/A | 1908.85 |
| | | | | | | | | | | | | | | | |
| | Created | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | Visible | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 0 | 3 |
| Beel | Percentage | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100 | 0.00 | 100.00 |
| | Smallest_Dec | 281.01 | 276.84 | 284.75 | N/A | 289.92 | N/A | N/A | N/A | N/A | N/A | 316.18 | 464.00 | N/A | 293.59 |
| | Smallest_Sq m | 11375.38 | 11206.68 | 11526.85 | N/A | 11735.84 | N/A | N/A | N/A | N/A | N/A | 12798.83 | 18782.72 | N/A | 11743.68 |
| | | | | | | | | | | | | | | | |
| | Created | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Visible | N/A | N/A | N/A | N/A | N/A | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 |
| Dighi | Percentage | N/A | N/A | N/A | N/A | N/A | 0.00 | 0.00 | 0.00 | 100.00 | 100.00 | 0.00 | 100.00 | 100.00 | 0.00 |
| | Smallest_Dec | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 60.00 | 68.42 | N/A |
| | Smallest_Sq m | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 2428.8 | 2736.77 | N/A |
| | | | | | | | | | | | | | | | |
| | Created | 6 | 6 | 10 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 17 | 20 | 20 | 20 |
| | Visible | 6 | 6 | 10 | 2 | 13 | 0 | 0 | 0 | 2 | 2 | 12 | 20 | 14 | 14 |
| Pond | Percentage | 100.00 | 100.00 | 100.00 | 15.38 | 100.00 | 0.00 | 0.00 | 0.00 | 14.29 | 14.29 | 70.59 | 100.00 | 70.00 | 70 |
| | Smallest_Dec | 4.56 | 4.63 | 4.68 | N/A | 4.71 | N/A | N/A | N/A | N/A | N/A | 6.27 | 4.50 | 5.48 | 5.40 |
| | Smallest_Sq m | 184.50 | 187.62 | 189.61 | N/A | 190.78 | N/A | N/A | N/A | N/A | N/A | 250.67 | 182.16 | 219.38 | 216.00 |
| | | | | | | | | | | | | | | | |
| | Created | 11 | 11 | 14 | 16 | 16 | 17 | 17 | 17 | 18 | 22 | 27 | 28 | 28 | 28 |
| | Visible | 4 | 7 | 9 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 16 | 28 | 3 | 18 |
| Doba | Percentage | 36.36 | 63.64 | 64.29 | 0.00 | 56.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 59.26 | 100.00 | 10.71 | 64.29 |
| | Smallest_Dec | 1.97 | 1.86 | 1.84 | N/A | 1.95 | N/A | N/A | N/A | N/A | N/A | 2.15 | 1.00 | 2.80 | 2.12 |
| | Smallest_Sq m | 79.62 | 75.28 | 74.37 | N/A | 78.82 | N/A | N/A | N/A | N/A | N/A | 85.91 | 40.48 | 111.84 | 84.69 |

**Source: Author, 2001-2004**




**Source: Author, 2001-2002**

**Figure 3.11 Detecting and Mapping Small Water Bodies in Baoikhola Mouza.**

### 3.7.1 Mouza results

Using the remote sensing results in table 3.4 to 3.9, we can see the smallest water bodies that could be detected by the various sensors. The jolas appear to have a stability over the years but this is a function in this linear SWB of the difficulty of the high ratio of banks to water, with the result that vegetation may mask the water's edge. It is only with the advent of the higher resolution IRS platforms in 1999 and 2003 that the figure has dropped. Although of different shapes and sizes, the same comment about sensor resolution applies to beels, dighis, and pukurs.

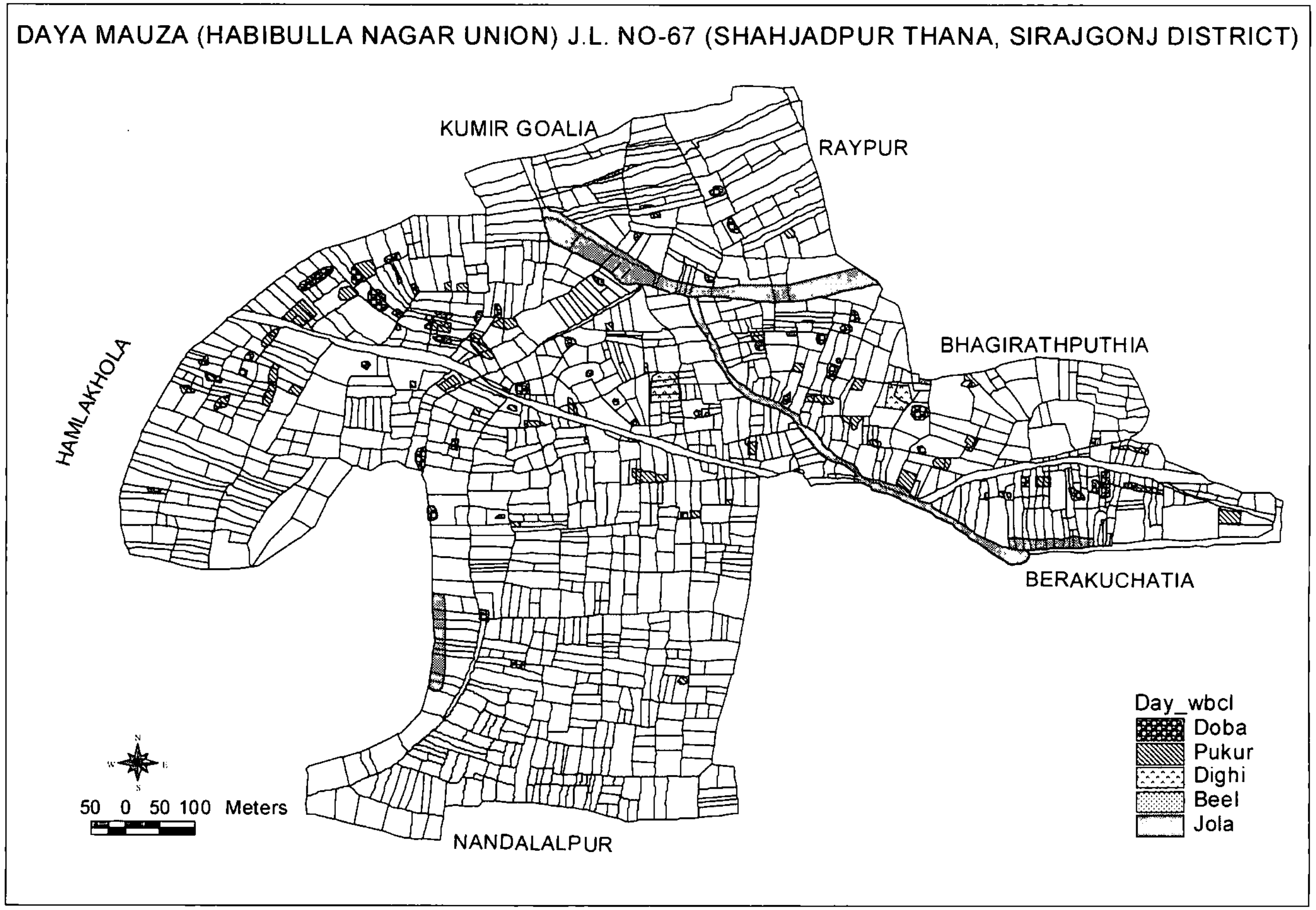
Two problematic features are notable. First, the most difficult SWB apparently to detect were dobas. Even aerial photographs and the CORONA image detected no more than two thirds of these and the SPOT HRV pan and LANDSAT XS images found none at all. Second, the results of the RADAR ERS-1 and SIR-C images in 1993 and 1994 are disappointing, with only jolas and beels being visible.

Spatial distribution of SWB maps (see figure 3.11-3.14) has been produced for each mouza using integrated method which are very helpful for further research on monitoring and changes.

**Table 3.7 Results of Remote Sensing Image Interpretation (Daya Mouza)**

| SWB | Platforms | CORONA72 | AP_74 | AP_83 | SPOT_89 | AP_90 | ERS1_93 | ERS1_93A | SIRC_94 | LSAT_97 | LSAT_98 | IRS_99 | Survey_02 | GPS_02 | IRS_03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Created | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | Visible | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 0 | 3 |
| Jola | Percentage | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 0.00 | 100.00 |
| | Smallest_Dec | 284.82 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 154.95 | 90 | N/A | 154.83 |
| | Smallest_Sq m | 11529.35 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 6197.99 | 3643.2 | N/A | 6193.21 |
| | | | | | | | | | | | | | | | |
| | Created | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Visible | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Beel | Percentage | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | Smallest_Dec | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | Smallest_Sq m | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | | | | | | | | | | | | | | | |
| | Created | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | Visible | 1 | 1 | 1 | 2 | 1 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 1 | 2 |
| Dighi | Percentage | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 0.00 | 0.00 | 0.00 | 100.00 | 100.00 | 100.00 | 100.00 | 50.00 | 100.00 |
| | Smallest_Dec | 30.81 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 31.43 | 90 | 31.50 | 31.48 |
| | Smallest_Sq m | 1247.25 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 1257.22 | 3643.2 | 1259.89 | 1259.22 |
| | | | | | | | | | | | | | | | |
| | Created | 9 | 9 | 11 | 14 | 16 | 25 | 25 | 29 | 32 | 38 | 39 | 48 | 48 | 48 |
| | Visible | 3 | 6 | 6 | 0 | 10 | 0 | 0 | 0 | 8 | 8 | 38 | 48 | 7 | 46 |
| Pond | Percentage | 33.33 | 66.67 | 54.55 | 0.00 | 62.50 | 0.00 | 0.00 | 0.00 | 25.00 | 21.05 | 97.44 | 100.00 | 14.58 | 95.83 |
| | Smallest_Dec | 3.84 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 3.33 | 2 | 2.05 | 3.46 |
| | Smallest_Sq m | 155.48 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 133.06 | 80.96 | 82.16 | 138.26 |
| | | | | | | | | | | | | | | | |
| | Created | 11 | 11 | 13 | 14 | 21 | 34 | 34 | 37 | 43 | 59 | 64 | 67 | 67 | 67 |
| | Visible | 5 | 5 | 8 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 34 | 67 | 7 | 35 |
| Doba | Percentage | 45.45 | 45.45 | 61.54 | 0.00 | 66.67 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 53.13 | 100.00 | 10.45 | 52.24 |
| | Smallest_Dec | 2.32 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 1.84 | 2 | 1.07 | 1.97 |
| | Smallest_Sq m | 93.94 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 73.62 | 40.48 | 42.95 | 78.73 |

**Source: Author, 2001-2002**




**Source: Author, 2001-2002**

**Figure 3.12 Detecting and Mapping Small Water Bodies in Daya Mouza.**

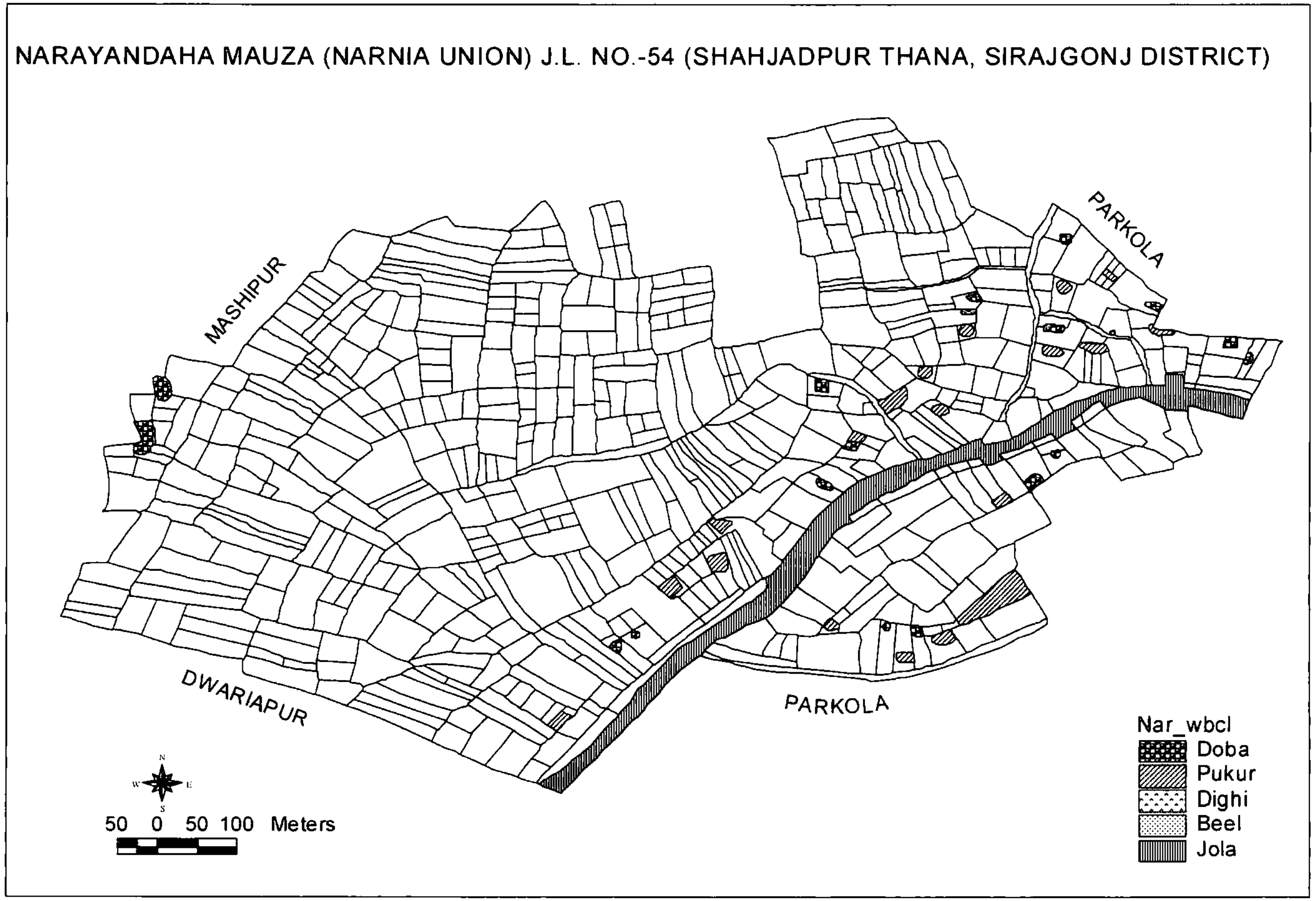
The results of the study were compared with the ground data that was collected during the fieldwork using different participatory and GPS methods. Images were also visually interpreted, manually digitized on the screen and compared with the other collected data. All the results show that the use of high resolution panchromatic imagery and AP demonstrate better detection capability. Table 3.5 summarizes the results from the different remote sensing platforms. Tables 3.6 to 3.9 show number of SWB are visible and detected from the different mouzas by types. From the remote sensing point of view dry SWB are not detectable. Table 3.6 to 3.9 also shows the percentages of the number of SWB are visible and detected from the different images of four mouzas.

One of the important points is that there is a difference in the SWB area detected and number of SWB created, even when considering the larger SWB. In some cases, these SWB are visually detectable in the image and careful knowledge-based editing may provide better accuracy. In addition to this, the large SWB are often situated along the extreme edge of settlements and bordered by lowlands. Because there is frequent water-logging in the lowlands, correct identification becomes more difficult as the low-lying areas can be confused with the SWB signature.

Table 3.8 Results of Remote Sensing Image Interpretation (Narayandaha Mouza)

| SWB | Platforms | CORONA72 | AP_74 | AP_83 | SPOT_89 | AP_90 | ERS1_93 | ERS1_93A | SIRC_94 | LSAT_97 | LSAT_98 | IRS_99 | Survey_02 | GPS_02 | IRS_03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Created | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Visible | 1 | 1 | 1 | 1 | N/A | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| Jola | Percentage | 100.00 | 100.00 | 100.00 | 100.00 | N/A | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 0.00 | 100.00 |
| | Smallest_Dec | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 105.753 | 100.00 | N/A | 107.9 |
| | Smallest_Sq m | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 4230.12 | 4048.00 | N/A | 4316.00 |
| | | | | | | | | | | | | | | | |
| | Created | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Visible | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Beel | Percentage | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | Smallest_Dec | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | Smallest_Sq m | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | | | | | | | | | | | | | | | |
| | Created | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Visible | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Dighi | Percentage | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | Smallest_Dec | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | Smallest_Sq m | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | | | | | | | | | | | | | | | |
| | Created | 10 | 10 | 13 | 15 | 15 | 16 | 16 | 16 | 16 | 17 | 19 | 19 | 19 | 19 |
| | Visible | 6 | 5 | 6 | 0 | N/A | 0 | 0 | 0 | 0 | 0 | 13 | 19 | 13 | 13 |
| Pond | Percentage | 60.00 | 50.00 | 46.15 | 0.00 | N/A | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 68.42 | 100.00 | 68.42 | 68.42 |
| | Smallest_Dec | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 5.32 | 3.00 | 4.88 | 5.24 |
| | Smallest_Sq m | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 212.62 | 121.44 | 195.37 | 209.51 |
| | | | | | | | | | | | | | | | |
| | Created | 10 | 10 | 11 | 16 | 16 | 18 | 18 | 18 | 18 | 18 | 18 | 20 | 20 | 20 |
| | Visible | 8 | 8 | 9 | 0 | N/A | 0 | 0 | 0 | 0 | 0 | 11 | 20 | 8 | 12 |
| Doba | Percentage | 80.00 | 80.00 | 81.82 | 0.00 | N/A | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 61.11 | 100.00 | 40.00 | 60.00 |
| | Smallest_Dec | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 3.05 | 2.00 | 2.10 | 3.00 |
| | Smallest_Sq m | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 121.82 | 80.96 | 84.06 | 120.10 |

Source: Author, 2001-2004




**Source: Author, 2001-2002**

**Figure 3.13 Detecting and Mapping Small Water Bodies in Narayandaha Mouza.**

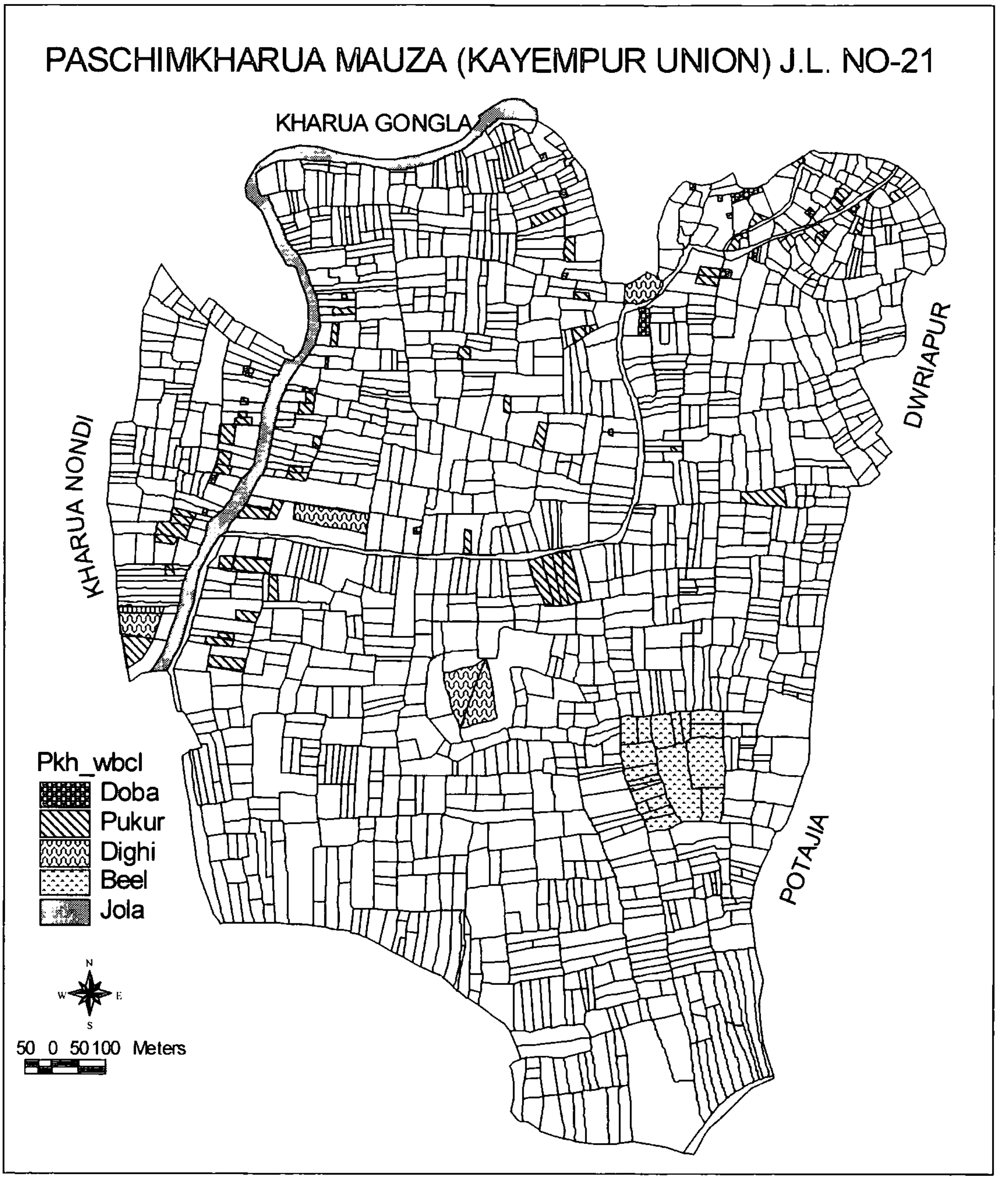
The smallest SWB area calculated based on the screen digitized AOI SWB polygon which does not represent the exact extend of those SWB on the field. Area of the SWB depends on the seasonal water extent and physical appearance in the field and on the other side the resolution and reflectance properties of the sensor. The relationship between the SWB area detected and the extent in the field derived from a limited amount of data with only a few larger SWB. Probably the relationship will be a different when applied to other areas with different physical characteristics, e.g. soils, homestead vegetation patterns, settlement distribution and obviously characteristics of SWB. It can be concluded that seasonal variations of the water level within the SWB are very significant for the identification. From this study it was found that the best time for making an inventory of the SWB is the period from November to February.

The multi-date temporal images combined with the aerial photographs shows the highest potential for detecting, inventorying and monitoring SWB. This can be deduced from the overall accuracy (the number of SWB remotely detected compared with the number of SWB observed in the field). it can be concluded that the combination of AP with CORONA and IRS is the most suitable. This has a high overall potential and a high score in the probability classes, especially when looking at the smallest SWB. However, this integrated method can be applied and tested for the inventory and spatial mapping of SWB for other parts of Bangladesh.

**Table 3.9 Results of Remote Sensing Image Interpretation (Paschim Kharua Mouza)**

| SWB | Platforms | CORONA72 | AP_74 | AP_83 | SPOT_89 | AP_90 | ERS1_93 | ERS1_93A | SIRC_94 | LSAT_97 | LSAT_98 | IRS_99 | Survey02 | GPS_02 | IRS_03 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jola | Created | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Visible | 1 | 1 | 1 | 1 | N/A | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| | Percentage | 100.00 | 100.00 | 100.00 | 100.00 | N/A | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | N/A | 100.00 |
| | Smallest_Dec | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 903.24 | 860.00 | N/A | 883.18 |
| | Smallest_Sq m | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 36129.67 | 34812.80 | N/A | 35327.18 |
| | | | | | | | | | | | | | | | |
| Beel | Created | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Visible | 1 | 1 | 1 | 1 | N/A | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| | Percentage | 100.00 | 100.00 | 100.00 | 100.00 | N/A | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | N/A | 100.00 |
| | Smallest_Dec | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 629.82 | 660.00 | N/A | 633.18 |
| | Smallest_Sq m | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 25192.83 | 26716.80 | N/A | 25327.31 |
| | | | | | | | | | | | | | | | |
| Dighi | Created | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 4 | 4 | 4 | 4 | 4 | 4 |
| | Visible | 2 | 2 | 2 | 2 | N/A | 0 | 0 | 0 | 2 | 2 | 4 | 4 | 3 | 4 |
| | Percentage | 100.00 | 100.00 | 100.00 | 100.00 | N/A | 0.00 | 0.00 | 0.00 | 50.00 | 50.00 | 100.00 | 100.00 | 75.00 | 100.00 |
| | Smallest_Dec | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 70.27 | 50.00 | 68.45 | 70.07 |
| | Smallest_Sq m | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 2810.73 | 2024.00 | 2738.19 | 2802.91 |
| | | | | | | | | | | | | | | | |
| Pond | Created | 9 | 9 | 9 | 13 | 17 | 29 | 29 | 32 | 33 | 39 | 42 | 45 | 45 | 45 |
| | Visible | 9 | 9 | 9 | 1 | N/A | 0 | 0 | 0 | 8 | 8 | 34 | 45 | 10 | 36 |
| | Percentage | 100.00 | 100.00 | 100.00 | 7.69 | N/A | 0.00 | 0.00 | 0.00 | 24.24 | 20.51 | 80.95 | 100.00 | 22.22 | 80.00 |
| | Smallest_Dec | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 3.53 | 4.00 | 5.01 | 3.45 |
| | Smallest_Sq m | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 141.26 | 161.92 | 200.28 | 137.81 |
| | | | | | | | | | | | | | | | |
| Doba | Created | 3 | 3 | 3 | 8 | 9 | 10 | 10 | 13 | 15 | 18 | 20 | 22 | 22 | 22 |
| | Visible | 3 | 3 | 3 | 0 | N/A | 0 | 0 | 0 | 0 | 0 | 13 | 22 | 5 | 15 |
| | Percentage | 100.00 | 100.00 | 100.00 | 0.00 | N/A | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 65.00 | 100.00 | 22.73 | 68.18 |
| | Smallest_Dec | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 2.15 | 1.50 | 2.32 | 2.18 |
| | Smallest_Sq m | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 86.13 | 60.72 | 92.85 | 87.36 |

**Source: Author, 2001-2004**




**Source: Author, 2001-2002**
**Figure 3.14 Detecting and Mapping Small Water Bodies in PachimKharua.**

### 3.8 Conclusion and Recommendation

This study has used visual interpretation and digital processing of remotely sensed imagery combined with the participatory field observation to develop a reliable, efficient and cost effective integrated method for detecting, inventorying and finally mapping the spatial distribution of SWB in the four mouzas of Shahjadpur Thana, Bangladesh. The study used the spectral, spatial and multi-temporal properties of remotely sensed data to differentiate SWB from the other land surface features with the support of information and knowledge acquired from fieldwork under GIS-RS environment. It has found that SWB of less than 200 sq metres were not reliably detected using the best combination of spatial and temporal resolution. It was observed that the panchromatic image of the CORONA and aerial photographs, although it has a very high resolution, lacked the necessary spectral information to detect the SWB using automated digital classification but achieved best performance in identifying through manual visual interpretation and on screen digitizing.

Successful visual interpretation needs concentration and adequate knowledge of the feature on the real world. I tried to use as much as ancillary knowledge that I can in the interpretation problem and considered the various types of evidence together to identify and detect the SWB. The mentioned integrated method gives full control and knowledge over the visual interpretation of the SWB in the study area. Once the SWB is identified and detected successfully then the extent and area of the SWB acquired from manual on screen digitizing. This gives an opportunity to map the spatial distribution pattern. It also gave advantages of using that spatial extent for further digital classification and other quantitative and qualitative analysis of associated information under GIS_RS environment.

The spatial resolution of the imagery plays vital role in interpreting and identifying the SWB. From Figures 3.9 and 3.10 we can get an idea of visibility according to size distribution. About two-thirds of the number of SWB has an area that is less than 800 sq. m. The study showed that the remote sensing methods are not suitable for the inventory of SWB with a size of less than 200 sq metres and are not capable of detecting more than a portion of SWB with size less than 80 sq metres. SWB signatures have the tendency to get mixed up with other land surface features. Surrounding homestead vegetation is the noisiest element for detection. The date and season when the remote sensing data are obtained is also important. In the early dry season SWB are full of water and a minimum number of SWB will be dry. More SWB were found to be dry while revisiting the SWB later February and begin of March 2001. SWB are re-excavated for homestead rising. Dry and newly excavated SWB are not detectable and difficult to interpret in remote sensing data.

During this study a relationship was found between the derived SWB and the actual SWB area found in the ground. It is only valid for the images and field data used in this study. The smallest SWB area measured based on the screen digitized AOI SWB polygon which not represent the exact extends of those SWB on the field. Visual interpretation method gave nearly as accurate results as the ground observation. The influence of the resolution was very noticeable; higher resolution image resulted in a more accurate visual interpretation. Percentages of successful identification can be improved using as much as ancillary information. Futher monitoring of the SWB has been discussed in the next chapter 4.

A band combination that is image fusing/merging among the different resolution could be worthwhile investigating. The combination of a IKONOS/Quickbird and IRS panchromatic image with a MODIS or similar image may give better result. This fused image in a multi-temporal combination of a high-resolution (panchromatic) image with a multispectral image could be promising. Unfortunately, this methodology was not tested during this study because a choice had to be made between different promising methodologies and time.

Since the completion of the field work and image analyses of this study, the new era of very high resolution, commercially available satellite images has begun. The IKONOS and Quickbird satellites launched and transmitting high-quality imagery with 1 m panchromatic resolution and 4m multispectral resolution (See also table 3.1). Using the merging techniques with very high-resolution imagery should provide a method to identify most of the SWB in Bangladesh. However, the listed price for this high resolution imagery and the computer storage processing resources are to be taken under consideration. It is expected that the cost of these data will be reduced as other high-resolution satellites begin operating in the coming years.

Apart from the launch of high resolution satellite, the computer based storage, processing and analytical software has also developed promisingly. ERDAS Imagine 8.6 image analyst software build in GIS functions is very much capable in handling both image and associated information. Windows NT workstation based ArcGIS is also recomended for spatial analyses, vector and attribute data management. Basically all the image data and ancillary information can be combinedly analysed under above software. Stata 8.2 gives the flexibility of data analyis and visual presentation of the results.

The integrated methods used and developed in this study are reasonably reliable and cost-efficient when compared to other techniques that have been used in the past for purposes of inventory and spatial mapping of resources. This method is therefore applicable and recommended for future inventories or studies of similar nature. The advantages of this method are that the spatial distribution of all the SWB are digitized to use in GIS_RS environment and all of the characteristics are collected through different participatory observation methods fed as attribute data. It is recommended that GIS-RS should be used for inventory of SWB in other regions of Bangladesh. These GIS-RS environment gives great advantages of regular information updating which is helpful for planning a sustainable management system.

# CHAPTER 4: CHANGE DETECTION AND MONITORING

## 4.1 Introduction

During recent years parts of rural Bangladesh have undergone significant change of land-use, usually without any prior planning or evaluation. This leads to complex, and often serious problems such as: increased risk of flooding deforestation, declining aquaculture, potential agricultural failure and soil erosion. Monitoring changes using remotely sensed data provide valuable tools for scientist, resource managers, policy makers and others to enable efficient detection, monitoring, mapping and modelling of resources.

Monitoring changes to SWB is one of the most important types of land-use change in rural Bangladesh due to explosive growth in population and high demand of water for multipurpose uses. Especially, recent arsenic contamination and scarcity of water for irrigation and household uses drew attention for proper exploitation of surface water resources. The monitoring of change provides valuable information on the resources like SWB at risk and can be used in to identify the cause of changes.

The launch of the first Earth observation satellite was a major advance in monitoring the environment from space. Since that time temporal remotely sensed data have been used extensively to assess land cover changes. The recent advancement of remote sensing platforms with the launch of new generation satellites aimed at increasing spectral, spatial, temporal and/or radiometric resolution and advances in image processing to compare multi-resolution and multi-temporal image data gives opportunities to use and evaluate the capability in detecting and monitoring land cover features in developing country like Bangladesh.

Change detection and monitoring is the routine process of identifying differences in the state of a feature by observing it at different times. Current change detection systems use a variety of image processing tools to make changes visible, but typically rely on manual interpretation to delineate the change area. Complex remote sensing change detection procedures can be simplified by the selection of a single sensor series, by low cloud cover and the use of images with matching dates (Daryaei, 2003). The difference in two images with different spatial resolution and spectral band pass of dates acquired with two sensors complicates the direct comparison of data to detect and monitor changes (Yuan et al., 1999).

Monitoring and change detection of different SWB using multi-resolution and multi-temporal image data requires more research that would involve new approaches of multi-scale analysis. In this study an unsupervised and supervised classification and an on-screen digitizing method for image interpretation were used to monitor and detect changes in small water bodies using panchromatic, multi-resolution and multi-temporal image data.

### 4.2 Aim and Objectives

The aim of this research chapter is to test a number of monitoring and change detection methods against personal knowledge of ground conditions. The objectives of this chapter are:

1. To review the techniques currently used in change detection procedure.
2. To study the most appropriate techniques for monitoring changes in small water bodies. This involves establishing a link between ground truth data from field work and long term remote sensing images, using integrated participatory GIS approaches and RS techniques.
3. To detect the changes of small water bodies?
4. To develop a participatory monitoring and change detection procedure.

This chapter is unusual for its hybrid methodology, a combination of remote sensing, GIS and participatory social science approaches. Although certain technical aspects are of considerable interest, for instance the problems associated with the measurement of water bodies whose size is at or beyond the limit of the spatial resolution (e.g. Landsat TM 30m and SAR-C 25m) of many sensors, the technical side of the work is secondary to the ultimate aim of understanding the changing nature of small water bodies.

### 4.3 Research Questions

My personal field experience in the study area, and the literature that I have reviewed so far, suggest that the following indicative research questions are important:

1. What are the currently used change detection techniques?
2. What are the advantages and disadvantages of each technique?
3. Which resolution and which type of output is suitable for SWB monitoring?
4. Is it possible to compare the multi-scale results for SWB monitoring using integrated methods?
5. Have the SWB changed over the last 30 years and, if so, what is the nature of that change?
6. Is there any scope for the participation of the local people in the change detection process through the mapping of their memory of perceived historical changes?
7. What is the potential relevance of the results, for planning by local authorities and perhaps more widely in Bangladesh, in developing a participatory monitoring and change detection procedure?

## 4.4 Methodology

### 4.4.1 Literature Review

The practical significance of landuse change over time in response to economic, social and environmental forces is obvious. Change detection study permits identification of trends in time and space and the formation of policy in anticipation of the problems regarding resource management (Campbell, 2002; Estes and Senger, 1972). According to Lillesand and Keifer, change detection involves the use of multitemporal data sets to discriminate areas of land cover change between dates of imaging (Lillesand and Kiefer, 2000). Hoffer has defined the temporal effects as the variation in spectral response in situations where the spectral characteristics of the vegetation or other cover type in a given location change over time (Hoffer, 1978). Later, Singh described change detection as a process that observes the differences of an object or phenomenon at different times (Singh, 1989). A study described in a SPARRSO publication (1996) used remote sensing data to investigate the mangrove ecosystem of the Chokoria Sundarbans. The study identified shrimp ponds and monitored their temporal changes and impact on the mangrove ecosystem. The study used aerial photographs, taken in 1975, 1981 and 1983, for mapping the shrimp ponds and for studying change, as well as LANDSAT digital data from 1976 and 1980 (SPARRSO, 1996).

Since the launch of ERTS-1 in 1972, various methods and techniques have been developed and used to detect and monitor changes in the land cover using remotely sensed data. Digital change detection methods can be divided into two broader divisions: firstly pre-classification spectral change methods and, secondly, post-classification change detection (Nelson, 1983; Pilon et al., 1988; Singh, 1989; Yuan et al., 1999).

#### 4.4.1.1 Pre-classification spectral change detection

This approach relies on the principle that land cover changes result in persistent changes in the spectral signature of the affected land surface (Yuan et al., 1999). According to Yuan and co-authors, two images of different dates are transformed into a new single-band or multi-band image in spectral change detection approach, which contains the spectral changes. They also suggested processing the resultant change detected image using other analytic methods to assign the changes to specific land cover types (Yuan et al., 1999). These methods are sensitive to image registration and co-registration accuracy based on pixel-wise or scene-wise operations. Discrimination of change and non-change pixels is of the greatest importance in successful performance of these methods (Daryaei, 2003). The use of a statistical threshold is the common method for discrimination (Yuan et al., 1999). In this method a careful decision is required to establish threshold boundaries to separate the area of change from no-change (Singh, 1989). The following are the various pre-classification spectral change detection approaches.

##### 4.4.1.1.1 Temporal raw image differencing

Most of the spectral change detection techniques are based on some style of image differencing, which is the spectral distance between pixels, or image pixel similarity, which is ratios, inner products and correlation (Weismiller et al., 1977; Yuan et al., 1999). Accurate image coregistration is critical for this method. Two co-registered image dates are subtracted pixel by pixel in each band to produce a new change image between two dates in this image differencing change detection method (Jensen, 1996; Singh, 1989; Yuan et al., 1999). A pixel with no-change between two dates has the value of zero in the resultant change image, and pixels of change have a value lower or higher than zero, yielding a differenced distribution for each band (Jensen, 1996;

Lillesand and Kiefer, 2000). Jensen and Toll described no-change pixels (or minor radiance values) distributed around the mean, and pixels of significant change distributed in the tails of the distribution (Jensen and Toll, 1982).

Weismiller and co-authors found better results despite a few errors in not identifying small area change detection by using raw image differencing in Texas coastal zone (Weismiller et al., 1977; Yuan et al., 1999). Miller and co-authors succeeded in mapping of changes in tropical forest cover in northern Thailand (Miler et al., 1978; Yuan et al., 1999). Singh also successfully used this raw image differencing method for monitoring changes in a tropical forest environment in India (Singh, 1986; Yuan et al., 1999). Riordan criticised the method, pointing to image misregistration with the existence of mixed pixels, and to radiometric differences between the input images in this method (Riordan, 1980; Yuan et al., 1999).

#### 4.4.1.1.2 Spectral Change Vector Analysis

This change detection procedure is a conceptual extension of image differencing (Lillesand and Kiefer, 2000). Yuan et al. (1999) defined a change vector of a pixel as the vector difference between the multi-band digital vector of the pixel at two different dates. Malila introduced the concept of spectral change vector analysis (Malila, 1980; Yuan et al., 1999). A spectral change vector describes direction and magnitude of change from date one to date two (Yuan et al., 1999). The output encompasses two images, one containing the magnitude of the change vector, the other its direction. Comparison of magnitude of changes with a specified threshold determines the change and the direction of change vector represents the type of change (Singh, 1989). This method is also sensitive to misregistration of images, mixed pixels and radiometric differences between input images (Daryaei, 2003; Yuan et al., 1999).

Zhan and co-authors used the change vector in land cover change detection in the red and near-infrared reflectance space (Zhan et al., 1998). Bruzzone and Prieto (2000) proposed a novel adaptive parcel-based technique for unsupervised change detection, and compared it with a change vector analysis (CVA) using two TM image dates. The comparison showed the effectiveness of the proposed method in reducing the overall change detection error. They concluded that the adaptive nature of parcels caused a considerable reduction in noise and an accurate location of the change area border (Bruzzone and Prieto, 2000).

#### 4.4.1.1.3 Inner product analysis

The spectral values of a pixel in an image are again considered as multispectral vectors in the inner product change detection analysis (Inamura et al., 1982). The difference between the two multispectral vectors is measured as the cosine of the angle between them (Yuan et al., 1999). According to Yuan et al. (1999), the concept behind this approach is that if two multispectral vectors coincide with each other, their inner product would be equal to one (1). Inamura et al, (1982) successfully used this method for land cover change detection. Similar to other pixel-wise technique this method has a limitation of misregistration (Yuan et al., 1999).

#### 4.4.1.1.4 Correlation analysis (Spectral signature similarity)

Conceptually, the correlation method is similar to the inner product method (Yuan et al., 1999). According to Yuan et al. (1999), the difference between the correlation method and the inner product method is that correlation takes into account the means of the multispectral vectors. This method has the potential of reducing scene-to-scene radiometric influence on the analysis induced by differences in total solar irradiance, sun angles, atmosphere effects and sensors (Yuan et al., 1999). Yasuoka and co-authors used this method for detecting land cover change from remotely sensed images (Yasuoka and al, 1988). Coiner also succeeded in using the correlation method to monitor land cover changes (Coiner, 1980). In his study he compared the effectiveness of this method with that of the inner product method.

#### 4.4.1.1.5 Temporal Image Ratioing

This method computes the ratio of the data from two dates of imaging (Lillesand and Kiefer, 2000). Like the previous method, two co-registered image dates are ratioed pixel by pixel in each band in the image ratioing change detection approach (Yuan et al., 1999). Ratio values close to 1 are represented by the no-change area. Depending on the nature of changes between two dates, changed areas will have higher or lower values (Singh, 1989). These methods are user-friendly though have disadvantages. One of them is unavailability of from-to change classes (Jensen, 1996). Jensen (1996) also mentioned the requirement to select the place of threshold boundary for change or no-change. According to Singh, image differencing may generate misleading data, as the same change values, i.e. the difference between pixels, may belong to different classes or phenomena (e.g., 150-130=20 and 50-30=20) (Singh, 1989). Misregistration and mixed pixels are also noticed by using these methods (Daryaei, 2003). A better method was developed by Stow (1999) for solving misregistration. Stow (1999) tested the method on multi-temporal Thematic Mapper (TM) images for a rapidly urbanizing landscape using the image differencing method. The misregistration compensation model enhances land change features at or near pixel scale, and reduces noise caused by misregistered multi-temporal data (Daryaei, 2003; Stow, 1999).

Todd, identified 91.4% of the urban change in Atlanta using this method (Todd, 1977; Yuan et al., 1999) Quarmby and Cushnie (1999) used on SPOT (HRV) data and detected changes at the urban fringe in South-east England. They illustrated the successful detection of changes from rural to urban development (Quarmby and Cushnie, 1989). Fung (1990) used image differencing, principal component analysis, and tasseled-cap transformation in land-cover change detection. The study found that near infrared reflectance or greenness detects changes in crop type and change between vegetative and non-vegetative features (Fung, 1990). Differenced image bands 1, 2 and 3 created similar information in detecting changes due to rural-to-urban conversion (Daryaei, 2003; Fung, 1990).

Nelson used this image ratio along with image differencing and vegetation index differencing to delineate forest area change (Nelson, 1983). Another study by Howarth and Wickware detected ecological changes by band ratioing of MSS bands 5 and 7 (Howarth and Wickware, 1981). Howarth and Boasson (1983) reported that simple overlay of one band from two dates represents the changes (Howarth and Boasson, 1983). They found that the band image ratio only emphasized major changes, and the vegetation index was successful in identifying vegetated to non-vegetated changes, clear definitions of the urban boundary and major road networks (Howarth and Boasson, 1983). Beeber and Nerem also demonstrate how to detect urban changes using both the image ratio and differencing methods (Beeber and Nerem, 2003).

Weydahl found that this image ratioing approach is less sensitive than differencing to multiplicative noise in SAR imagery (Weydahl, 1991). Robinson also criticized this method as it is based on a non-normal distribution (Lillesand and Kiefer, 2000; Robinson, 1979).

#### 4.4.1.1.6 Vegetation Index Differencing

This method involves the differencing of combinations of two or more bands aimed at enhancing vegetation features (Deer, 2003; Tian, 1989). The ratio known as vegetation indices is used to enhance the spectral differences between strong reflectance of vegetation in the near-infrared part of spectrum and chlorophyll-absorption band (red part) of the spectrum (Singh, 1989). Typical vegetation indices include: Ratio Vegetation Index, Normalized Vegetation Index, and Transformed Vegetation Index (Daryaei, 2003). According to Derring and Haas, the development of vegetation indices from red and near-infrared multispectral values is based on the differential absorption and reflectance of solar energy by green vegetation (Derring and Haas, 1980; Lillesand and Kiefer, 2000).

Lyon et al. (1998) compared 7 vegetation indices: 1) Difference Vegetation Index (DVI), 2) Normalized Difference Vegetation Index (NDVI), 3) Perpendicular Vegetation Index (PVI), 4) Ratio Vegetation Index (RVI), 5) Soil Adjusted Ratio Vegetation Index (SARVI), 6) Soil Adjusted Vegetation Index (SAVI) and 7) Transformed Soil Adjusted Vegetation Index (TSAVI) for change detection of vegetation and land cover. They found firstly. seven vegetation indices could be grouped in three categories with respect to computational procedures if a normalization technique was used; secondly among all the indices only NDVI showed a normal distribution histogram, thirdly the NDVI group was least affected by topographic factors and finally, all groups could clearly differentiate between land, waters and cloud covers and the NDVI demonstrated the best vegetation change detection (Daryaei, 2003; Lyon et al., 1998).

#### 4.4.1.2 Image Regression

The image to image regression method assumes that pixels from time T1 are a linearly related to those from time T2. It considers differences in the mean and variance between pixel values from two dates (Singh, 1989). Ridd and Liu (1998) produced three change images (change in brightness, greenness and wetness) using four algorithms. These are image differencing, image regression with a tasseled cap transformation and a chi-square transformation. They observed that visible bands 1, 2 and 3, and the shortwave-infrared bands (TM 5,7) were useful in detecting urban changes, and that TM band 4 (near-infrared) was suitable in detecting changes from green farmland to dry farmland in the study area (Ridd and Liu, 1998).

#### 4.4.1.3 Multi-date Principal Component Analysis

Principal component analysis (PCA) is one of the most popular multivariate analysis methods for change detection on reduced data (Lillesand and Kiefer, 2000). Basically, two image dates of the same area are superimposed and analysed as a single image in this approach. A number of literature observed that the major component images show the albedo (reflectance) and radiometric differences, and that minor component images reveal the local changes and minor changes (Byrne et al., 1980; Richardson and Milne, 1983; Yuan et al., 1999). Li and Yeh (1998) found this method useful to monitor rapid land-use changes and urban expansion in comparison with the post classification method. They carried out a principal component analysis on two images from different dates, and an interactive supervised classification of land-use change was done on the compressed PCA image (Li and Yeh, 1998). Toll and co-authors found poor results for urban change detection (Lillesand and Kiefer, 2000; Toll et al., 1980). Singh and Harrison have reported significantly different outcomes between standardized and nonstandardized variables (Lillesand and Kiefer, 2000; Singh and Harrison, 1985).

#### 4.4.1.4 Principal Component Comparison

Individual PCA results can be used for change detection in principal component comparison (PCC). Yuan et al. explained that the result of PCA of image data of each date can be further analysed by other change detection techniques, such as image differencing and regression under PCC methods (Yuan et al., 1999). This method is good for global comparisons of various image data and is not sensitive to image registration, but needs experience and knowledge about the applied data for interpretation (Daryaei, 2003; Lillesand and Kiefer, 2000).

Kwarteng and Chavez (1998) reported on the detection of changes using PCA as a change detection algorithm. They used a high frequency spatial filter with a large kernel to enhance the high frequency information in bright desert and dark urban areas, (Kwarteng and Chavez, 1998). They also used an edge detection filter to sharpen the textural information. Urban development, vegetation growth (natural and crops) and coastal wetland differences were identified using PCC.

This method is good for global comparison of multitemporal image data and is insensitive to image registration (Lillesand and Kiefer, 2000). However, its interpretation often requires experience and knowledge of the particular data used. It needs further visual or analytic analysis, such as the differencing or the ratioing method to extract change information (Lillesand and Kiefer, 2000).

#### 4.4.1.5 Post-classification Technique

This method involves the classification of each of the images independently, followed by a comparison of the corresponding pixel labels to show areas of change (Daryaei, 2003; Deer, 2003; Jensen, 1996; Singh, 1989; Yuan et al., 1999). Either supervised or unsupervised classifications methods are used in this process. The individual classification of two image dates minimizes the problem of normalizing for atmospheric and sensor differences between two dates (Singh, 1989). The comparison of separately classified images can be carried out visually, or by computer. Computers are better at quantitative analysis whereas humans are able to recognize patterns and shapes (Deer, 2003). Jensen and co-authors used this approach to detect inland wetland changes (Jensen et al., 1987). Accuracy of the classification results is the main disadvantage of this method. Poor classification accuracy of individual classification leads to uncertainties in the change map (Daryaei, 2003).

Shi and Ehlers (1996) described the uncertainty sources in change detection as errors of the source image, classification methods, and determination of changes. They explained three main error sources in Maximum Likelihood (ML) classification-based change detection: (1) the process of training data collection is subjective; (2) the ML classifier assumes that the probability distribution of each class is normal; and, (3) the method used to determine changes is based on amount of uncertainties (Daryaei, 2003; Shi and Ehlers, 1996). A confusion matrix can be used to derive error indicators, such as error of commission, error of omission and total accuracy of classification. These indicators represent the classification accuracy (for the whole classification and for each category), but do not indicate the classification uncertainty for each pixel, which is required to determine change detection uncertainties (Daryaei, 2003; Shi and Ehlers, 1996). Shi and Ehlers (1996) suggested an approach to determine uncertainties and their propagation.

#### 4.4.1.6 Direct multi-date classification methods

These methods perform a single analysis of a combined data set of two or more dates to identify areas of change (Deer, 2003; Lillesand and Kiefer, 2000; Singh, 1989; Yuan et al., 1999). Either a supervised or an unsupervised classification procedure is applied. In the supervised classification, training sets pertaining to change and no change areas are used to derive statistics to define sub-spaces of the feature (normally spectral) space (Deer, 2003). On the other hand, in the unsupervised approach, spectral classes are determined by cluster analysis, and subsequent monitoring gives the change detection results (Deer, 2003). According to Deer (2003), change classes are expected to display significantly different statistics from no-change classes. As a disadvantage, these methods need a very complex classification, involving many classes (Daryaei, 2003).

Weismiller et. al. (1977) used a direct multidate classification method for coastal change detection. They found the best harmony to be with the ground post-classification comparison results (Lillesand and Kiefer, 2000; Weismiller et al., 1977; Yuan et al., 1999). Soares and Hoffer (1994) used this method for detecting eucalyptus forest change. Their study achieved an accuracy of 90.6% for a full (12-band) image and 90.4% for a principal components reduced 6-band image (Deer, 2003; Soars and Hoffer, 1994). Chan et al. (2001) compared four algorithms to detect the nature of change in urban area. They are: 1) multi-layer perceptions (MLP); 2) Learning Vector Quantization (LVQ); 3) Decision Tree Classification (DTC); and, 4) ML classification (Chan et al., 2001). They found that a one-pass classification of merging multi-spectral images is simpler with higher accuracy in comparison with conventional methods of classification of two images individually (Chan et al., 2001; Daryaei, 2003).

#### 4.4.1.7 Change Detection Using Write Function Memory Insertion

Jensen (1996) found that the changes could be visually revealed in the remotely sensed data by insertion of the individual bands of two image dates (one band of each date) in the digital image processing system. He explained, for example, that the insertion of one band of T1 image in red and one band of the T2 image in green under image processing system to visually identify can show change area in red, green and the area of no-change in yellow (Jensen, 1996). There is an advantage in visual change identification between two and even three dates of imagery at the same time using this procedure. The main disadvantage is that it cannot quantify the amount of change. Alternatively, manual on screen digitizing can give the spatial extent of the changes.

#### 4.4.1.8 Manual On-screen Digitization

This method is usually suitable for high-resolution remote sensor data like Ikonos, IRS and scanned CORONA and aerial photographs. It also helps in updating vector databases using on-screen photo interpretation of high-resolution imageries (Jensen, 1996). The image analysis software, Erdas Imagine, has a feature called 'Area of Interest' in the 'Data Preparation' module that allowed the identification of SWB via a polygon feature and the accurate measurement of their area. Then the area calculated from muti-temporal and multi resolution images can be compared for changes. This was an important tool for the detection and monitoring change detection of the SWB and their associated land uses through time and space.

#### 4.4.1.9 Statistical Tests

This method can be applied to two or more image files of the same area taken at different times (Deer, 2003). Eghbali used the Kolmogorov-Smirnov test to determine whether two samples of two dates of imagery of same location have been drawn from the same population (Eghbali, 1979). Other statistical test methods of correlation coefficient between the data sets from the two dates and semivariance that is the sum of the squares of the differences in pixel values can be used to understand the nature of changes (Deer, 2003). Ancillary data can also analyzed statistically for example the relationship between ground survey and other dates imagery to understand the changes. Deer found statistical tests do not yield specific spatial extent of change in the image but can justify statistically that significance changes occurred in an image (Deer, 2003).

### 4.4.2 Data Sources

Different sources of primary and secondary data used for this chapter (see table 4.1). The descriptions of those data can be seen in chapter two: Study Area and Data Sources.

**Table 4.1 Sources of Data**

| |
|---|
| **Primary Sources:** |
| **a) Remote Sensing Data:** Optical, Radar and Panoramic Satellite Images and Aerial Photos; |
| **b) Map Data :** Both Published and Unpublished (from plot to district level maps); |
| **c) Field Data:** Based on RRA and PRA/Questionnaire /Interviewing/ field checking/ observation /ground checking; and |
| **d) GPS Data:** Based on extensive fieldwork with Global Positioning System (GPS) techniques and ground truthing. |
| **Secondary Sources:** |
| **a) Census Data:** Agricultural data collected during , 1983-84, 1986-87 and 1989-90; |

**Source: Author, 2003**

### 4.4.3 Rapid Rural Appraisal and Participatory Rural Appraisal

It is the present author's contention that the highly technical methodologies reviewed and described so far can profitably be coupled with socio-economic data collected in the field. This helps to provide checks for the remote sensing method and facilitate a more accurate insight into SWB monitoring through time. Such a hybrid approach is advocated by various authors in Liverman et al. (1998). Rapid Rural Appraisal (RRA) emerged in the 1970s as an efficient and cost-effective way of learning by outsiders, particularly about resource monitoring, management and planning systems through large-scale social surveys. It drew on many of the insights of social activities of the 1930s-1950s, emphasized the importance and relevance of situational local knowledge, and the importance of getting the big things broadly right rather than achieving spurious statistical accuracy (IISD, 1999). It developed a style of listening research, and a creative combination of iterative methods and verification, including "triangulation" of data from different sources - using two different methods to view the same information. Its chief techniques, employed in this research, are a) review of secondary sources, including aerial photos, even brief aerial observation; b) direct observation, foot transects, familiarization, participation in activities; c) interviews with key informants, focus group interviews, workshops; d) mapping, diagramming; e) local histories; and f) rapid report writing in the field.

Participatory Rural Appraisal (PRA) is an especially helpful family of methods, which enable local people to share, enhance and analyse their knowledge of life and conditions, and to plan, act, monitor and evaluate their environment. Its extensive and growing menu of methods includes visuals such as mapping and diagramming. According to (Chambers, 1999) practical applications of PRA have proliferated, especially in natural resources management, agriculture, health and nutrition, poverty and livelihood programmes. In this research the Focus Group technique was used for collecting historical data on changes and to know the different uses of small water bodies in the study area. An in-depth questionnaire survey was also conducted during the field work in the four selected mouzas to interpret the socio-economic uses of these small water bodies and to know the extent of their changes. There was one questionnaire associated with each of the 287 SWB in my four mouzas. Looking at the full number rather than a sample helped to increased the depth of the author's knowledge about the subject. I trained 8 male and 8 female assistants who helped with this task. While the gender issue was recognised to be of significance, it was very difficult to give it prominence in view of the conservative attitude of rural Bangladeshis towards male research assistants talking to women.

The choice of mouzas and respondents depended upon the size, density and use patterns of small water bodies. Purposive sampling was employed to achieve a representative view of water use and management. This combined various strategies to achieve the desired sample. It helped in triangulation, allowed for flexibility, and met multiple interests and needs. When selecting a sampling strategy it is necessary that it fits the purpose of the study, the resources available, the question being asked and the constraints being faced. This holds true for sampling strategy as well as sample size. A frequency distribution for different sizes and types of small water bodies were included in the sampling framework.

#### 4.4.4 Global Positioning System (GPS) and Ground Truthing

The basic premise of the Global Positioning System (GPS) is the same as that of any surveying system. The coordinates of new points are found by making observations with respect to points of known coordinates. The only difference here is that the known points are in orbit, and are not stationary. The orbits are chosen to ensure that at least four satellites are above the horizon at any time for any observer. The satellites are at a nominal altitude of 20200 km (orbital period 718 minutes). The determination of the coordinates of these satellites is therefore a continuous process, and is achieved by the control segment of GPS, which consists of a world wide network of monitoring and control stations dedicated to the task of determining the orbital paths of the satellites and monitoring the health of their signals. It is then possible to predict the orbit of a satellite a short way into future, and to upload this information to the satellite itself. In this way, the satellite is able to broadcast its position for the user to determine their own positions in real time (Iliffe, 2000; Rees, 1999).

A hand-held GPS was used for plotting the position of the principal types of SWB. This gave useful results where each point has a nominal accuracy of $\pm 3$ metres. Results could have been improved by using Differential Global Positioning System (DGPS), which employs a triangulation net to provide very high accuracy for the coordinates. Unfortunately, due to the unavailability of more than one GPS this was not possible. In fact, this proved to be one of the most frustrating parts of my fieldwork since institutions in Bangladesh were unwilling to help and, on return to Durham, I then had temporary technical difficulties in recovering and processing the GPS data that it had been possible to collect, before eventually succeeding and gaining a full dataset to analyse.

Conventional maps are not adequate for geocorrection of high accuracy, because they may have acquired distortions from the scanner and photocopier. GPS-based geocorrection seems to be the best technique to be applied for the satellite and radar data, since it is more accurate than map-based geocorrection (Cook and Pinder III, 1996; Kardoulas et al., 1996). Data collected through a GPS are helpful in detecting the changes by comparing with the data collected from the multi temporal satellite images through manual on screen digitizing. These data are also compared with the peoples' perception for understanding the dynamics behind the change processes.

### 4.4.5 Integration of GIS, GPS, Remote Sensing and Participatory Methods

The final methodological approach keeps in mind a degree of integration "by mining the pixels using both remote sensing and GIS approaches" (Geoghegan et al., 1998). Mining the pixel involves seeking the social meaning in imagery. Social data collected through PRA and in-depth questionnaire survey, in this case, allows an inductive exploration of different types of small water bodies and their uses that may provide clues to the underlying dynamics involved. Geoghegan et al. (1998) coined the term 'socialising the pixel and pixelising the social' for making remote sensing, in general, more relevant to the social, political and economic problems and theories pertinent to land use and land cover change; in this case census data could also play a significant role. This objective involves methods and tools, 'predominantly GIS that are relevant to the analysis of spatial imagery and 'gridded' data in general for exploring the underlying human model. Given the spatial data and GIS capabilities, hypotheses have been drawn to understand spatial patterns.

An emerging trend in GIS applications is the use of multiple systems and diverse data sets in a single study. Recently, much emphasis has been placed on the integration of remotely sensed imagery from image analysis systems (IAS) with other digital spatial data from GIS. It is widely recognised that this type of synergism has the potential to open new avenues for both (Estes, 1985; Goodenough, 1988; Jackson and Mason, 1986; Piwowar and LeDrew, 1990). In fact, many are already using a number of different IAS and GIS in a single project to take advantage of the processing capabilities that some systems have and others do not (Abel, 1989). In practice, sharing spatial data among systems is difficult because of the way in which each system stores and processes its data. Recent version of Erdas Imagine 8.6 is the true picture of combined GIS and Remote Sensing data handling in a single platform.

GIS provides the facility to integrate multi-disciplinary data for dedicated interpretations in an easy and logical way. This integrated approach is both time-saving and cost-effective. By studying detection changes in the pattern of small water bodies using remotely sensed data based on the comparison of the time sequential images, differences in surface phenomena over time was determined, and evaluated visually, using digital techniques (Grag et al., 1998; SAC(ISRO), 1990). Change detection using satellite data is efficient for timely and consistent estimates of changes in small water bodies, and has the additional advantages of ease of social data capture into a GIS.

To develop a GIS, databases for existing small water bodies were captured from different conventional map and digital sources. *Mouza and Plot* boundaries and plot *(Daag)* numbers based on the lowest administrative units were digitized in a GIS format. The database also deals with physical resources based on Soil Resources Development Authority (SRDI) and Local Government Engineering Department

(LGED) databases to understand the physiographic background and natural setting of the study area. Plotting the road network and the other major infrastructures as influencing factors for the agricultural land use and vegetation cover in general are also incorporated, and a trend analysis was performed using statistical and overlay techniques on the spatial distribution with respect to the surrounding context. Then, all information derived from the satellite, radar data, attribute GIS format and the referenced data from GPS, ground truthing, PRA and questionnaire survey are integrated. The most important points here in their integration are common map references; a relational database to assist further analysis; the ability to program different change detection methods; and satisfactory methods of error tracking.

## 4.5 Results and Discussions

### 4.5.1 Changes in Number of Small Water Bodies

Table 4.2 represents our best estimate, integrating every available source and technique, of the number of SWB in the four mouzas combined. Given the detailed and intensive approach adopted in this thesis, it seems likely that these data are as accurate as any previous study of SWB in Bangladesh. The overall number of SWB has increased dramatically from 74 in 1960 to 287 in 2002, and possibly 308 in 2003. I say possibly because the data for 2003 is taken from remote sensing only and has not been ground truthed. I put less reliance upon the 2003 figure because I am convinced, as I have said before, that the best approach to monitoring SWB is to combine the remote sensing data with ground thruthing through fieldwork.

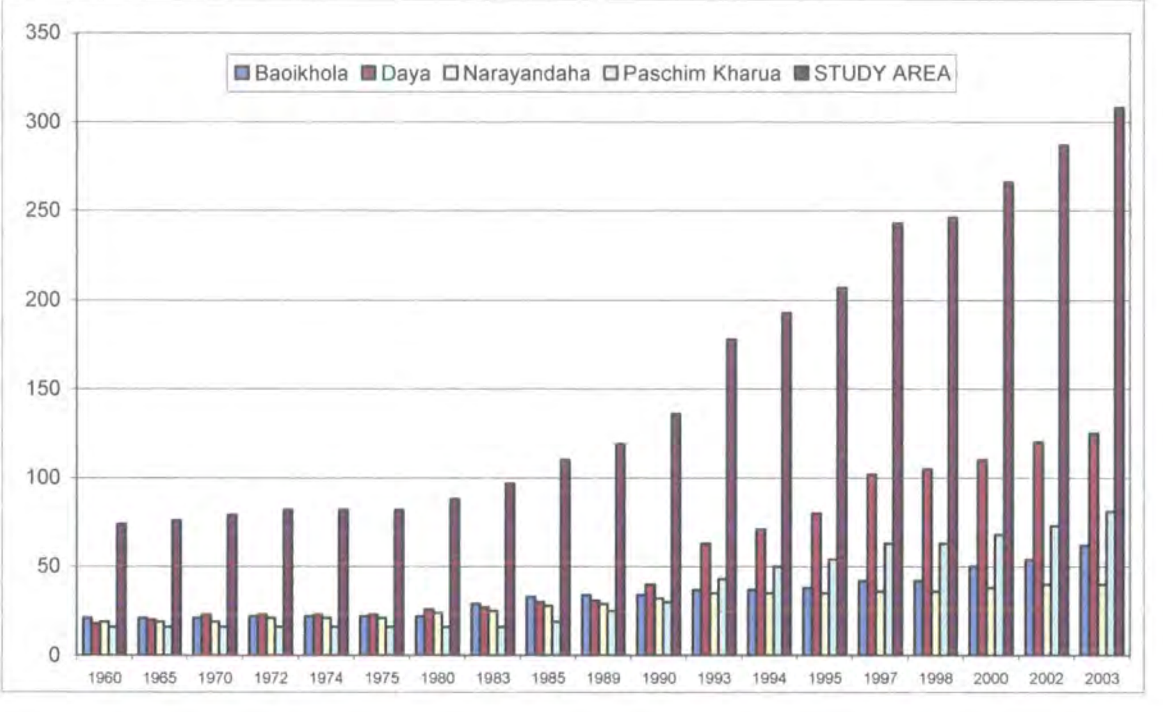
The figure of 287 in 2002 is remarkable, not least because a substantial proportion of the increase has taken place within the last ten years. Note also that much of the increase has been in dobas, associated with homesteads and therefore representing the domestic convenience of the local people, and in pukurs (ponds), which are mainly used for economic purposes such as fishing. In other words, the acceleration in the making over of the landscape into managed water features has been a function of an increase in activity by the local people. Population increase plays its part here but the major thrust is a hitherto undocumented form of grassroots resource management and planning.

**Table 4.2 Changes in number of SWB.**

| Mouza | SWB Type | 1960 | 1965 | 1970 | **1972** | **1974** | 1975 | 1980 | **1983** | 1985 | **1989** | **1990** | **1993** | **1994** | 1995 | **1997** | **1998** | 2000 | 2002 | **2003** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Baoikhola** | Jola | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | Beel | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | Dighi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Pond | 5 | 5 | 5 | 6 | 6 | 6 | 6 | 10 | 13 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 17 | 20 | 24 |
| | Doba | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 14 | 15 | 16 | 16 | 17 | 17 | 18 | 22 | 22 | 27 | 28 | 32 |
| | **Total** | **21** | **21** | **21** | **22** | **22** | **22** | **22** | **29** | **33** | **34** | **34** | **37** | **37** | **38** | **42** | **42** | **50** | **54** | **62** |
| **Daya** | Jola | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | Beel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Dighi | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | Pond | 8 | 8 | 9 | 9 | 9 | 9 | 11 | 11 | 13 | 14 | 16 | 25 | 29 | 32 | 38 | 41 | 41 | 48 | 51 |
| | Doba | 7 | 9 | 11 | 11 | 11 | 11 | 12 | 13 | 14 | 14 | 21 | 34 | 37 | 43 | 59 | 59 | 64 | 67 | 69 |
| | **Total** | **18** | **20** | **23** | **23** | **23** | **23** | **26** | **27** | **30** | **31** | **40** | **63** | **71** | **80** | **102** | **105** | **110** | **120** | **125** |
| **Narayandaha** | Jola | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Beel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Dighi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Pond | 9 | 9 | 9 | 10 | 10 | 10 | 12 | 13 | 14 | 14 | 15 | 16 | 16 | 16 | 17 | 17 | 19 | 19 | 19 |
| | Doba | 9 | 9 | 9 | 10 | 10 | 10 | 11 | 11 | 13 | 14 | 16 | 18 | 18 | 18 | 18 | 18 | 18 | 20 | 20 |
| | **Total** | **19** | **19** | **19** | **21** | **21** | **21** | **24** | **25** | **28** | **29** | **32** | **35** | **35** | **35** | **36** | **36** | **38** | **40** | **40** |
| **Paschim Kharua** | Jola | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Beel | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Dighi | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 4 | 4 | 4 | 4 | 4 | 4 |
| | Pond | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 10 | 13 | 17 | 29 | 32 | 33 | 39 | 39 | 42 | 45 | 49 |
| | Doba | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 5 | 8 | 9 | 10 | 13 | 15 | 18 | 18 | 20 | 22 | 26 |
| | **Total** | **16** | **16** | **16** | **16** | **16** | **16** | **16** | **16** | **19** | **25** | **30** | **43** | **50** | **54** | **63** | **63** | **68** | **73** | **81** |
| **STUDY AREA** | Jola | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| | Beel | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| | Dighi | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 5 | 6 | 7 | 7 | 7 | 7 | 7 | 7 |
| | Pond | 31 | 31 | 32 | 34 | 34 | 34 | 38 | 43 | 50 | 54 | 61 | 84 | 91 | 95 | 108 | 111 | 119 | 132 | 143 |
| | Doba | 30 | 32 | 34 | 35 | 35 | 35 | 37 | 41 | 47 | 52 | 62 | 79 | 85 | 94 | 117 | 117 | 129 | 137 | 147 |
| | **Total** | **74** | **76** | **79** | **82** | **82** | **82** | **88** | **97** | **110** | **119** | **136** | **178** | **193** | **207** | **243** | **246** | **266** | **287** | **308** |

**Source: Author 2001-4**

By way of example, Table 4.3 and Figure 4.1 are a case study of Daya. They show that this Mouza has the most extreme amount of change in SWB from 1960 to 2002. This is explicable in terms of its density of population and its proximity to the Paurashava, from which it draws some features of the 'urban'. One might expect the early stages of densely populated pseudo-urban land use to exclude the possibility of SWB but, on the contrary, more people mean more demand for water and, in the absence of a mains water supply, there has been a proliferation of dobas and pukurs. By comparison, comparatively little change has occurred in the less accessible and less densely populated environment of Narayandaha.




**Source: Author 2001-4**

**Figure 4.1 Graph showing trend in changes of SWB.**

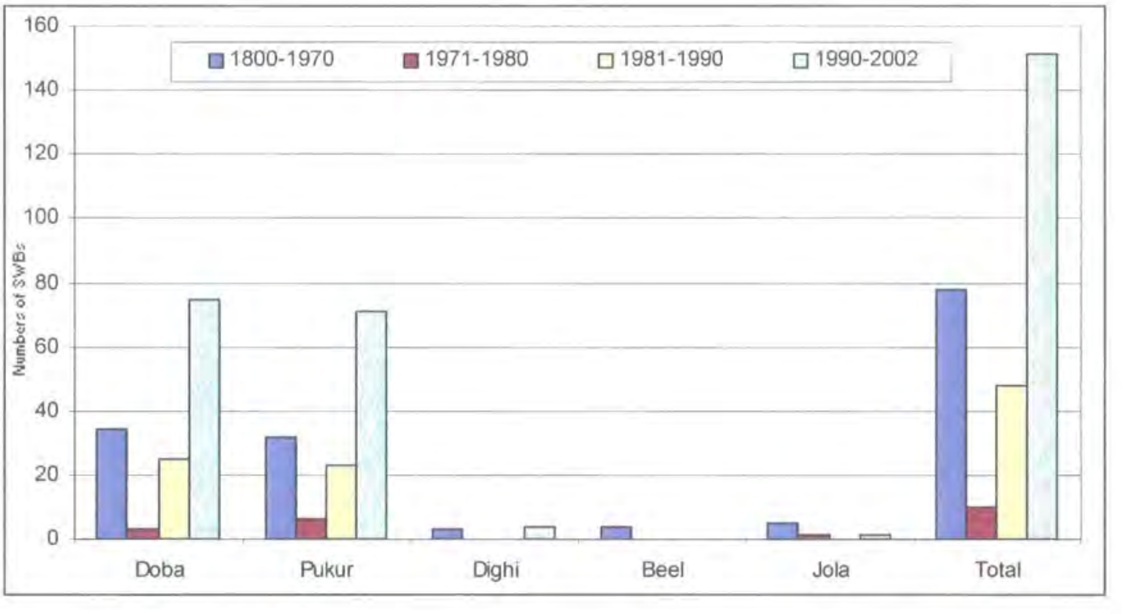
**Table 4.3 Year of Creation**

| BAOIKHOLA | Doba | | Pukur | | Dighi | | Beel | | Jola | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Quantile Class** | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage |
| 1800-1970 | 11 | 39.29 | 5 | 25.00 | 0 | 0.00 | 3 | 100.00 | 1 | 50.00 | 20 | 37.04 |
| 1971-1980 | 0 | 0.00 | 1 | 5.00 | 0 | 0.00 | 0 | 0.00 | 1 | 50.00 | 2 | 3.70 |
| 1981-1990 | 5 | 17.86 | 7 | 35.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 12 | 22.22 |
| 1990-2002 | 12 | 42.86 | 7 | 35.00 | 1 | 100.00 | 0 | 0.00 | 0 | 0.00 | 20 | 37.04 |
| **Total** | 28 | 100 | 20 | 100 | 1 | 100 | 3 | 100 | 2 | 100 | 54 | 100 |
| **DAYA** | Doba | | Pukur | | Dighi | | Beel | | Jola | | Total | |
| **Quantile Class** | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage |
| 1800-1970 | 11 | 16.42 | 9 | 18.75 | 1 | 50.00 | 0 | 0.00 | 2 | 66.67 | 23 | 19.17 |
| 1971-1980 | 1 | 1.49 | 2 | 4.17 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 3 | 2.50 |
| 1981-1990 | 9 | 13.43 | 5 | 10.42 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 14 | 11.67 |
| 1990-2002 | 46 | 68.66 | 32 | 66.67 | 1 | 50.00 | 0 | 0.00 | 1 | 33.33 | 80 | 66.67 |
| **Total** | 67 | 100 | 48 | 100 | 2 | 100 | 0 | 0 | 3 | 100 | 120 | 100 |
| **NARAYANDAHA** | Doba | | Pukur | | Dighi | | Beel | | Jola | | Total | |
| **Quantile Class** | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage |
| 1800-1970 | 9 | 45.00 | 9 | 47.37 | 0 | 0.00 | 0 | 0.00 | 1 | 100.00 | 19 | 47.50 |
| 1971-1980 | 2 | 10.00 | 3 | 15.79 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 5 | 12.50 |
| 1981-1990 | 5 | 25.00 | 3 | 15.79 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 8 | 20.00 |
| 1990-2002 | 4 | 20.00 | 4 | 21.05 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 8 | 20.00 |
| **Total** | 20 | 100 | 19 | 100 | 0 | 0 | 0 | 0 | 1 | 100 | 40 | 100 |
| **PASCHIM KHARUA** | Doba | | Pukur | | Dighi | | Beel | | Jola | | Total | |
| **Quantile Class** | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage |
| 1800-1970 | 3 | 13.64 | 9 | 20.00 | 2 | 50.00 | 1 | 100.00 | 1 | 100.00 | 16 | 21.92 |
| 1971-1980 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| 1981-1990 | 6 | 27.27 | 8 | 17.78 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 14 | 19.18 |
| 1990-2002 | 13 | 59.09 | 28 | 62.22 | 2 | 50.00 | 0 | 0.00 | 0 | 0.00 | 43 | 58.90 |
| **Total** | 22 | 100 | 45 | 100 | 4 | 100 | 1 | 100 | 1 | 100 | 73 | 100 |
| **STUDY AREA** | Doba | | Pukur | | Dighi | | Beel | | Jola | | Total | |
| **Quantile Class** | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage | Number | Percentage |
| 1800-1970 | 34 | 24.82 | 32 | 24.24 | 3 | 42.86 | 4 | 100.00 | 5 | 71.43 | 78 | 27.18 |
| 1971-1980 | 3 | 2.19 | 6 | 4.55 | 0 | 0.00 | 0 | 0.00 | 1 | 14.29 | 10 | 3.48 |
| 1981-1990 | 25 | 18.25 | 23 | 17.42 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 48 | 16.72 |
| 1990-2002 | 75 | 54.74 | 71 | 53.79 | 4 | 57.14 | 0 | 0.00 | 1 | 14.29 | 151 | 52.61 |
| **Total** | 137 | 100 | 132 | 100 | 7 | 100 | 4 | 100 | 7 | 100 | 287 | 100 |

**Source: Author 2001-4.**

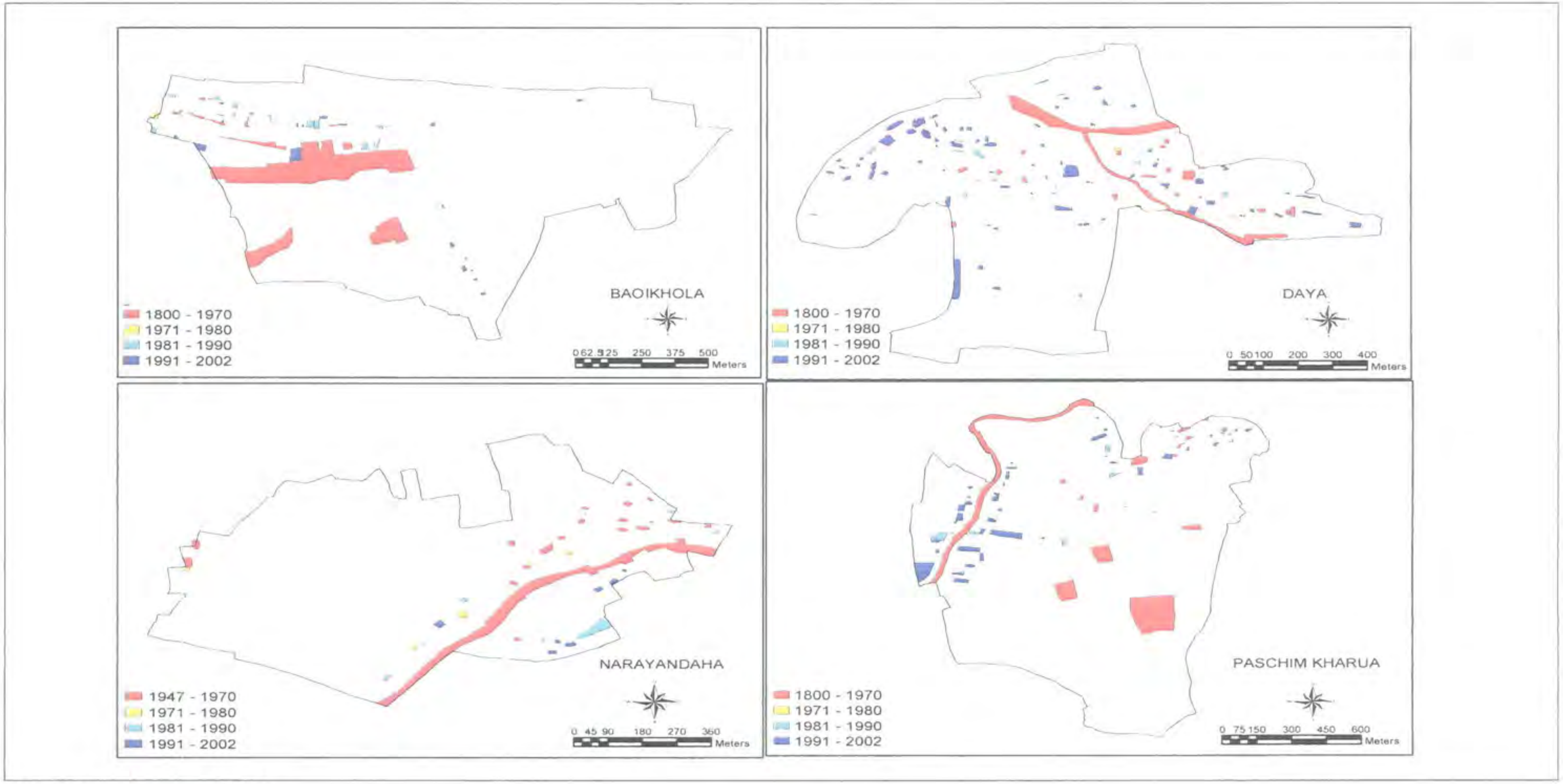
### 4.5.2 Year of creation

From the questionnaire and focus group data I was able to establish the dates at which the various SWB had been created. I double-checked this information against the remote sensing images at appropriate dates. The results are interesting because they show that SWB are continually being created and renewed, right up to the present day. In Figures 4.2 and 4.3 and Table 4.3, for the sake of convenience, the natural features (beels and jolas) are recorded in the category 1800-1970, and this category also includes the older human-made SWB. Note that the acceleration of SWB creation has been quite remarkable since 1990. 151 new ones are visible, mainly pukurs and dobas. This is a landscape in the throes of active creation and modification.




**Source: Author 2001-4**

**Figure 4.2 Graph showing creation year of different SWB.**




**Source : (Author 2004)**

**Figure 4.3 Spatial distribution of different SWB according creation year.**

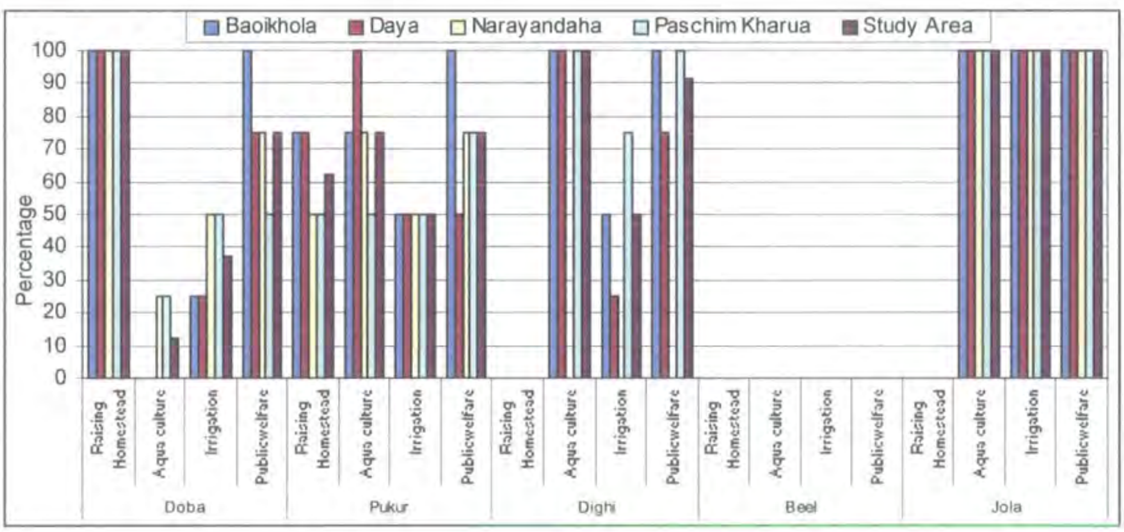
### 4.5.3 Process and Reason of Creation

Family members usually dig their own dobas but for pukurs and dighis it is the custom to for hired labour to be involved. Jolas are the result of the Food for Work aid programme. Beels are natural features. Figure 4.4 and table 4.4 gives a resume of the reasons for creation, which differ between SWB types. Raising a homestead mound is vital in such a flood-prone region and dominates the thinking for dobas and pukurs. Aquaculture is important also for pukurs and dighis, as is irrigation and a variety of household uses for all SWB.

**Table 4.4 The contribution of human effort to the creation of SWB (percentages)**

| SWB | Process | Baoikhola | Daya | Narayandaha | Paschim Kharua | Study Area |
|---|---|---|---|---|---|---|
| Doba | Digging | 100 | 100 | 100 | 100 | 100 |
| | Naturally | 0 | 0 | 0 | 0 | 0 |
| Pukur | Digging | 100 | 98 | 100 | 100 | 99 |
| | Naturally | 0 | 2 | 0 | 0 | 1 |
| Dighi | Digging | 100 | 100 | N/A | 100 | 100 |
| | Naturally | 0 | 0 | N/A | 0 | 0 |
| Beel | Digging | 0 | N/A | N/A | 0 | 0 |
| | Naturally | 100 | N/A | N/A | 100 | 100 |
| Jola | Digging | 100 | 33 | 0 | 0 | 33 |
| | Naturally | 0 | 67 | 100 | 100 | 67 |

**Source: Author's fieldwork (2002).**



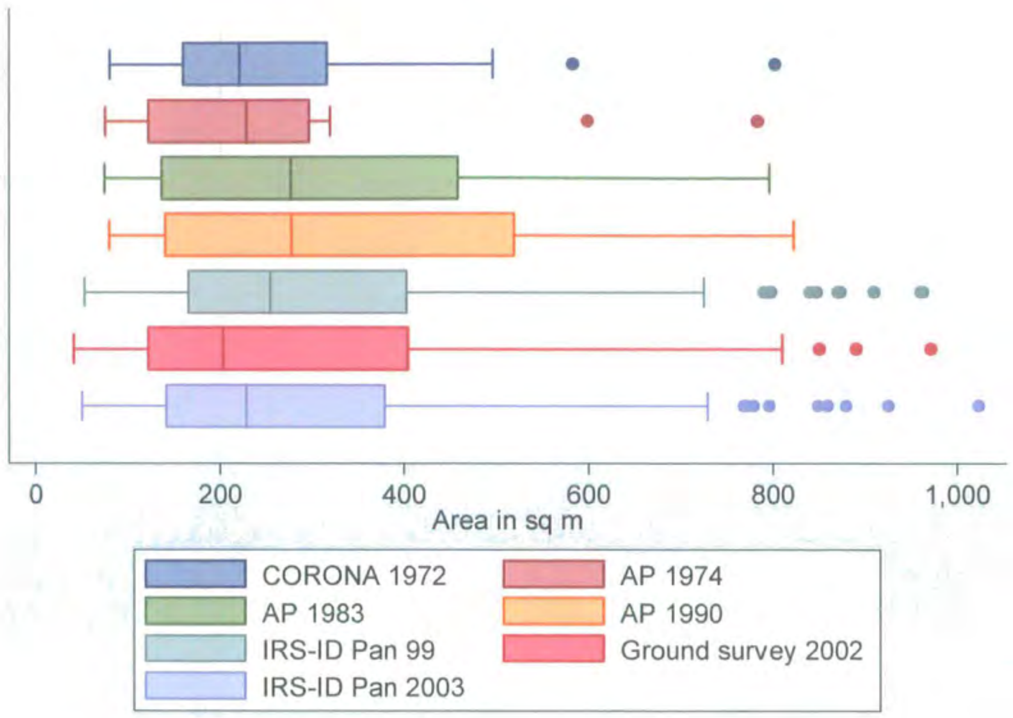

**Source: Author 2001-4**

**Figure 4.4 Graph showing reasons of creation for different SWB.**

### 4.5.4 Monitoring the size of SWB

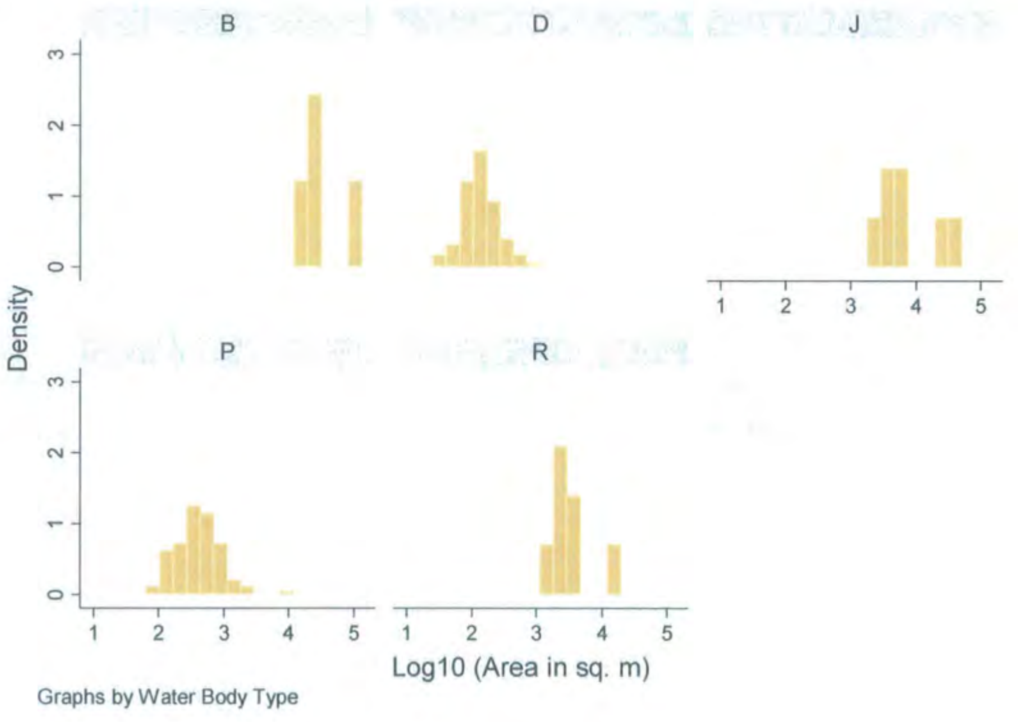
The reader will recall that the names used for SWB in this thesis are local Bengali names (see Glossary), which have an implication of size but also in some cases of function. 'Doba' is the smallest category, equivalent in English to a 'pit' or 'ditch', mainly used for homestead purposes. A little larger are 'pukur' (pond), again used by homesteads but often involving fish culture, and 'dighi' (reservoir). The largest features, both natural, are 'beel' (ox bow lake) and 'jola' (canal). Jolas have often been modified by excavation (Table 4.5) to link with a river and beels are frequently used for fishing and irrigation.

Figures 4.5 and 4.6 give a helpful summary of the results of detecting these SWB in terms of what is visible to various of the sensors employed in this research. Figure 3.9 shows that the median values all fall between 200 and 300 square metres, with upper and lower quartiles ranging from 150-500 square metres. However, note that most of the satellite platforms (Landsat, SPOT, RADAR, ERS-I, SIR-C) are not included because their resolution is not adequate. Figure 3.10 gives the size distribution pattern, in log of square metres, by type of water body (B = beels; D = doba; J = jola; P = pukur; R = reservoir (dighi). There is an overlap in size between dobas and pukurs, and between jolas and dighis.




**Source: Author 2004**

**Figure 4.5 Size distribution of the interpretation of SWBs (up to 1000 sq m).**




**Source: Author 2004**

**Figure 4.6 Size and typewise distribution pattern of SWBs.**

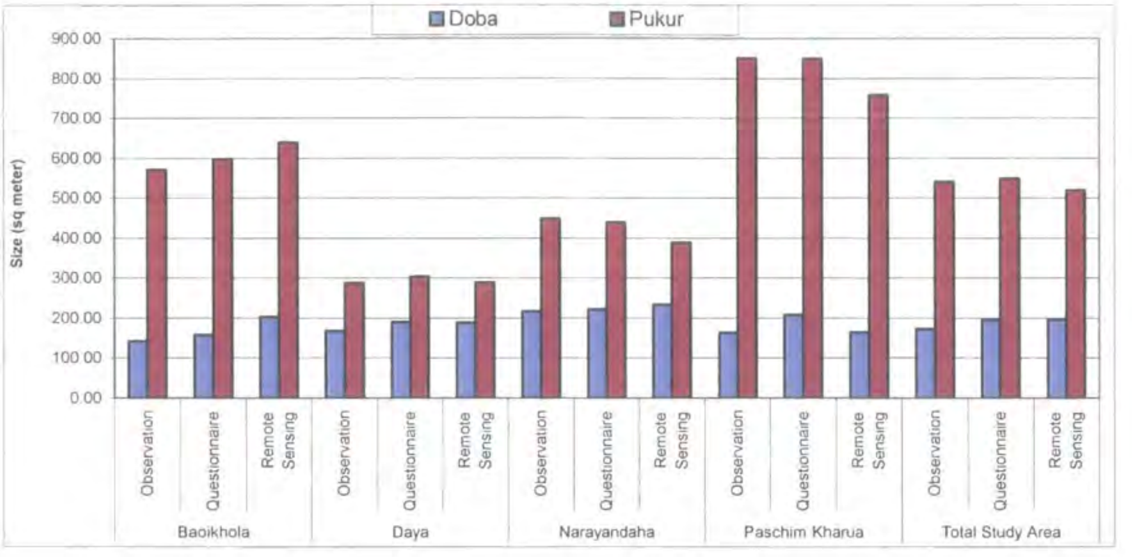
Table 4.5 and Figures 4.7 and 4.8 show data on size for 2002/3 according to three different data collection methods: questionnaire, direct observation by the author and his team, and remote sensing data from the IRS ID (Panchromatic band which has a nominal spatial resolution of 5.8 metres). A fourth method, measurement by GPS coverage, is not included here because the coverage is incomplete due to time constraints and also there were technical problems in processing the data.

**Table 4.5 The Mean sizes of SWB in square metres (2002/3)**

| Mouza | Types | Doba | Pukur | Dighi | Beel | Jola |
|---|---|---|---|---|---|---|
| Baoikhola | Observation | 141.93 | 570.37 | 2736.77 | 35097.77 | 2043.57 |
| | Questionnaire | 157.89 | 597.70 | 2429.00 | 42153.33 | 3481.00 |
| | Remote Sensing | 202.98 | 639.46 | N/A | 41710.59 | 2633.47 |
| Daya | Observation | 168.00 | 287.19 | 1497.26 | N/A | 9233.21 |
| | Questionnaire | 189.89 | 304.18 | 1259.89 | N/A | N/A |
| | Remote Sensing | 188.62 | 289.38 | 1509.14 | N/A | 9344.34 |
| Narayandaha | Observation | 218.09 | 449.88 | N/A | N/A | 26098.84 |
| | Questionnaire | 222.10 | 439.89 | N/A | N/A | 26312.00 |
| | Remote Sensing | 232.70 | 389.23 | N/A | N/A | 26617.00 |
| Paschim Kharua | Observation | 162.86 | 851.09 | 5707.75 | 26717.00 | 26717.00 |
| | Questionnaire | 207.97 | 848.83 | 4924.74 | 35374.25 | 34873.28 |
| | Remote Sensing | 165.28 | 757.13 | 10067.32 | 7548.08 | 35297.74 |
| Total Study Area | Observation | 172.72 | 539.63 | 3313.93 | 30907.38 | 16023.16 |
| | Questionnaire | 194.46 | 547.65 | 2871.21 | 38763.79 | 21555.43 |
| | Remote Sensing | 197.39 | 518.80 | 5788.23 | 24629.33 | 18473.14 |

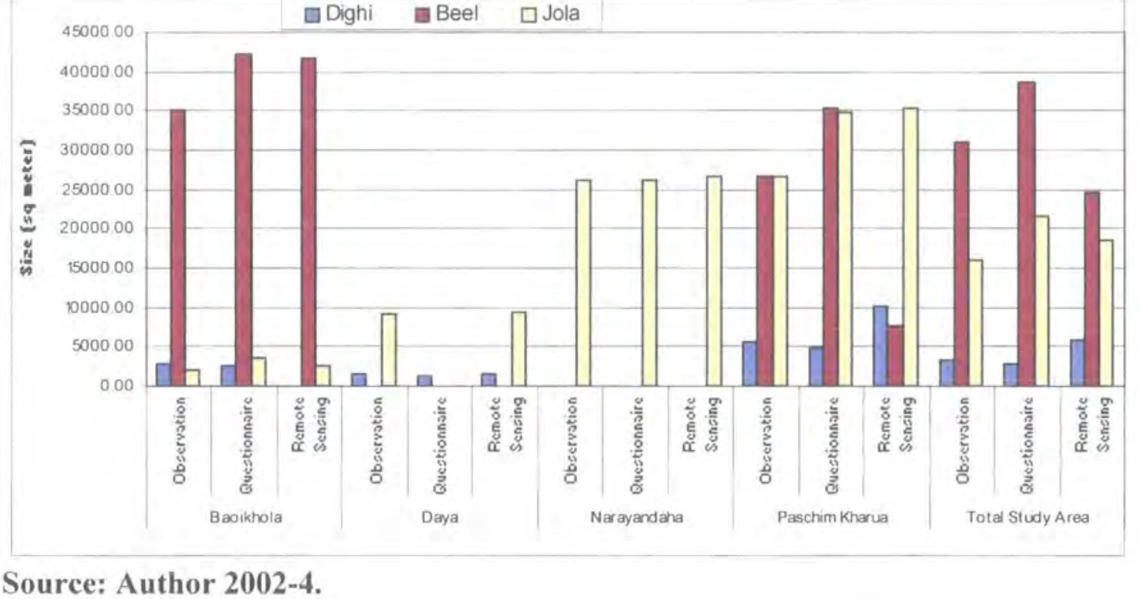
**Source: Author's fieldwork 2002; IRS ID data 2003.**

The first thing to note (Table 4.5) is that there is considerable variation between the different methods of observation. The technologies of the platforms vary and the spatial resolution also varies, so some satellites are understandably more accurate than others. Where we have a low mean, for instance in the case of the survey, this is the result of the research team finding many smaller SWB than are detectable by remote sensing. A high mean may be a function of the technical difficulty of interpreting the image in question but we should not forget that water extent differs according to season, being highest immediately after the monsoon and flood periods. Therefore we may be measuring real variation.




Source: Author 2002-4.

**Figure 4.7 Graph showing detected mean sized Doba and Pukur.**



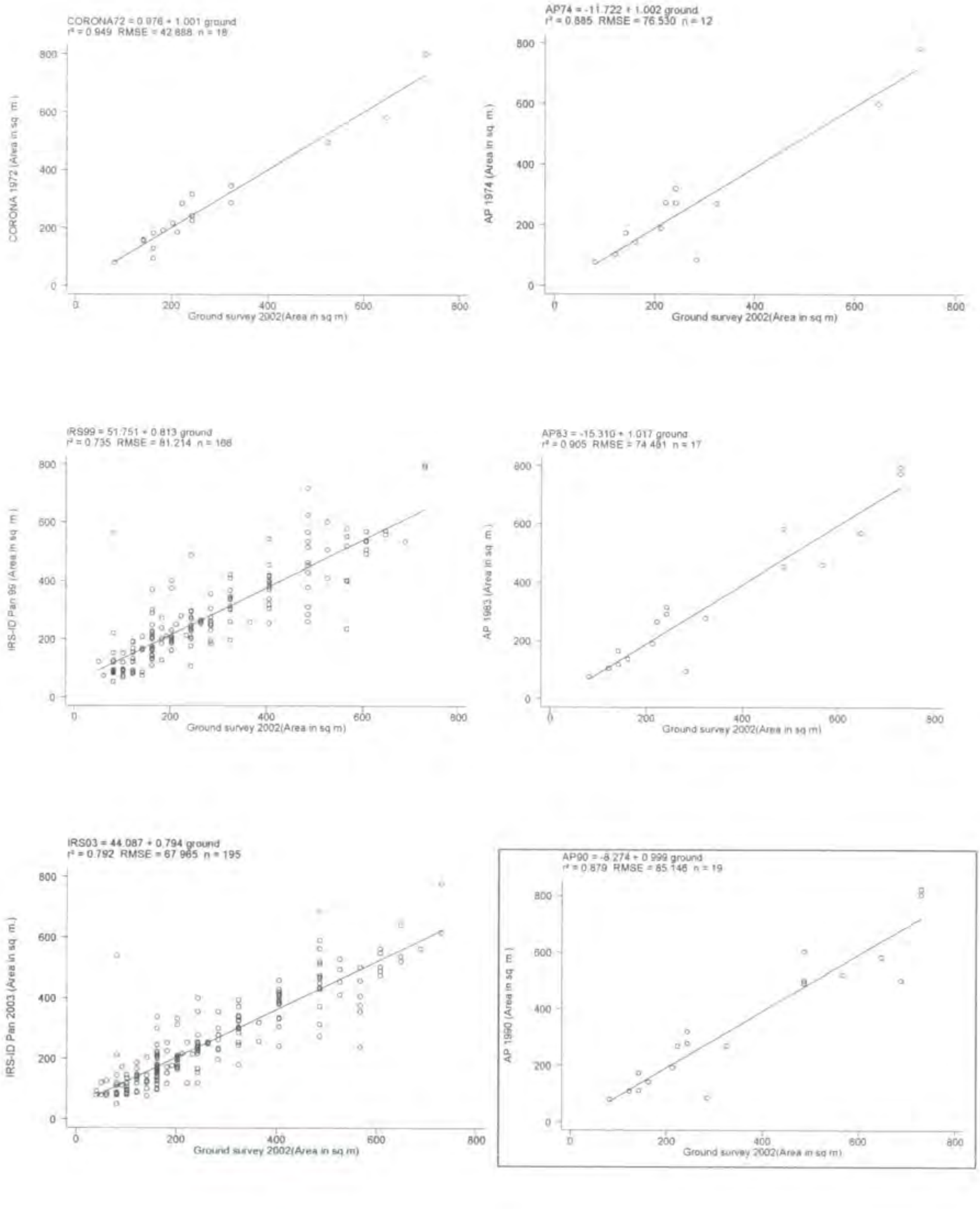

Source: Author 2002-4.

**Figure 4.8 Graph showing detected mean sized Dighi, Beel and Jola.**

Table 4.5 is compiled of observation data (January 2002), questionnaire data (February 2002) and data from the IRS satellite (March 2003), so in theory one would expect there to be minimal difference between the data sets in terms of year and season. In fact the correspondence is quite good. One would expect the research team's observations to be the most accurate; the villagers' perceptions to contain some errors; and the remote sensing to be less precise because of the difficulty of detecting the smaller SWB. The results show this to be so in broad terms. All three figures for dobas and pukurs are within a close band, a pleasing outcome given that these are the smallest SWB. For dighis, beels and jolas the variation is greater. The remote sensing for these larger SWB was technically difficult given that there are edge problems of recognition.

Figure 4.9 shows the relationship between the size of smaller SWB (less than 800 square metres) measured on the ground and that detected by remote sensing, for the following sensors: CORONA 1972; aerial photographs for 1974, 1983 and 1990; and IRS for 1999 and 2003. The satellite sensors are to the left and the aerial photographs are to the right. These are the high resolution sensors shown in chapter 3 to be best equipped to detect SWB. The fit is generally good, with relatively few outliers at the outset (CORONA 1972, aerial photographs 1974) but there were far more SWB in the period of IRS (1999, 2003) and the goodness of fit has, as a result, declined with time. A linear fit between the ground observation and the remotely sensed data show that remote sensing underestimate the size of SWB. Note that each graph has the $R^2$ value which represents the variance explained by a linear fit between the ground survey and the SWB area interpreted. The maximum $R^2$ value is 0.949 for the CORONA image of 1972, and the minimum $R^2$ is 0.735 for IRS of 1999. The root mean square error term (RMSE) expresses the quality of the prediction of area from remote sensing data. In the case of CORONA KH-4B this is 43 sq. m. and for IRS-ID 68-82 sq. m. These results compare favorably with the RMSE observed from air photography 74-86 sq. m, suggesting that high resolution satellite data, if used correctly can be used to assess the area of SWB.

The results show a big increase in the number of SWB seen between 1983 and 1999 and we can be confident that IRS will be able to detect almost all the SWB seen by APs. Figure 4.9 also showing that number of SWBs has increased especially larger size.

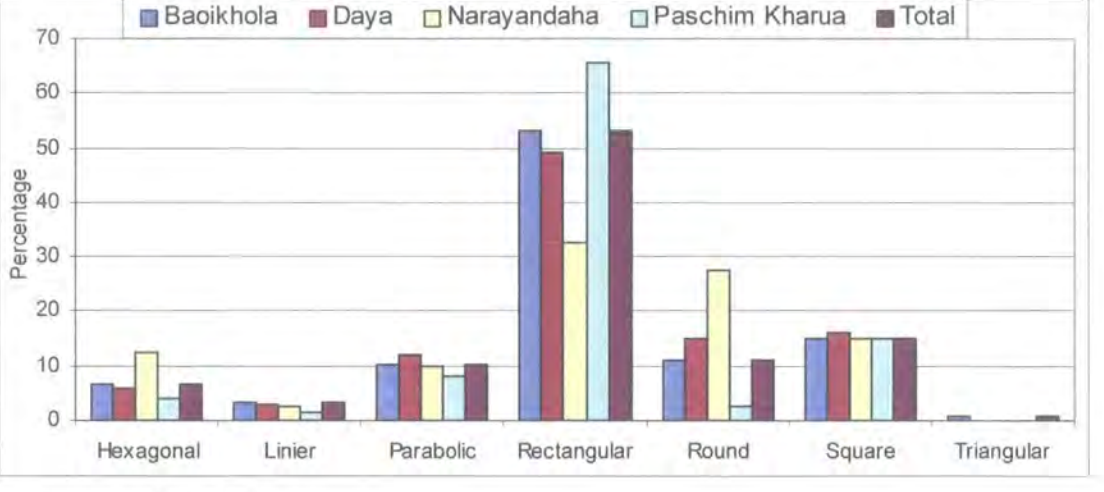



**Source: Author (2004)**

**Figure 4.9 Relationship between ground survey and high resolution sensors.**

### 4.5.5 Shape

Figure 4.10 illustrate the shape characteristics of SWB. Rectangular and square shapes are the most popular because the local custom of payment for excavation is by a calculation of length and breadth, modified by depth. The photographs (Figure 4.11) show that pillars of earth are left to calculate the depth. The overall volume of earth is easier to work out this way in rectangular shapes than round or hexagonal. Irregular banks may indicate original excavation or modification by the owners/users themselves, where payment is unnecessary. Alternatively, natural features, especially in beels and jolas, are incorporated into the system of SWB.




**Source: Author 2001-4**

**Figure 4.10 Graph showing percentage of different shapes of SWB.**

Source: Author 2001-4

**Figure 4.11 Pillars of earth are left to calculate the depth.**

Source: Author 2001-4

**Figure 4.12 Depth measurement with indigenous method.**

### 4.5.6 Depth of water

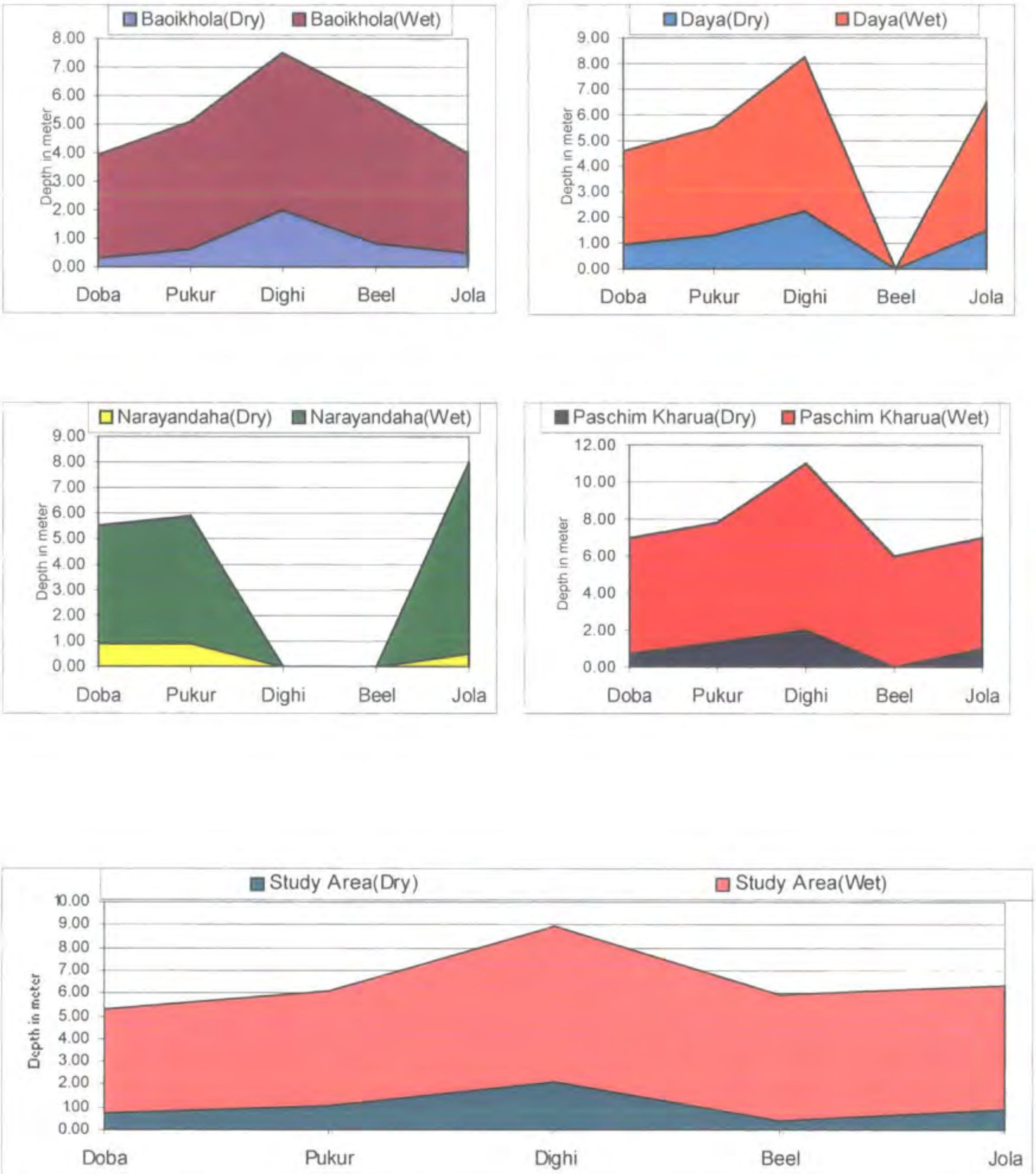
The questionnaire and fieldwork observation yielded information concerning the depth of SWB, something beyond the remote sensing data available to me. Depth is very much a seasonal feature, being affected in turn by the monsoon rains, riverine floods, and then evaporation in the winter. All of the different types of SWB vary in depth, and therefore usefulness. The ratio is 6.29 times more water in dobas in the wet than in the dry season; 4.84 for pukurs; 3.28 for dighis; 2.64 for beels; and 6.25 for jolas. The low ratio for beels shows their reliability as large permanent lakes, whereas dobas, as the smallest features, are the most likely to dry up. Dighis are the deepest, at between 2.08 and 6.83 metres on average, the other SWB having similar depths (see Table 4.6 and Figure 4.13).

**Table 4.6 Depth of SWB's**

| Depth | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean | Baoikhola | | Daya | | Narayandaha | | Paschim Kharua | | Total | |
| Doba | 0.31 | 3.61 | 0.94 | 3.63 | 0.90 | 4.63 | 0.71 | 6.24 | **0.72** | **4.53** |
| Pukur | 0.63 | 4.45 | 1.31 | 4.21 | 0.89 | 4.99 | 1.33 | 6.47 | **1.04** | **5.03** |
| Dighi | 2.00 | 5.50 | 2.25 | 6.00 | N/A | N/A | 2.00 | 9.00 | **2.08** | **6.83** |
| Beel | 0.83 | 5.00 | N/A | N/A | N/A | N/A | 0.00 | 6.00 | **0.42** | **5.50** |
| Jola | 0.50 | 3.50 | 1.50 | 5.00 | 0.50 | 7.50 | 1.00 | 6.00 | **0.88** | **5.50** |

**Source: Author, 2001-4**

The depth of SWB was measured using the traditional local technology of a measuring pole made out of bamboo. Figure 4.12 shows this for a doba in Daya mouza. For beels it was necessary to row out to the middle of the lake in a small boat.



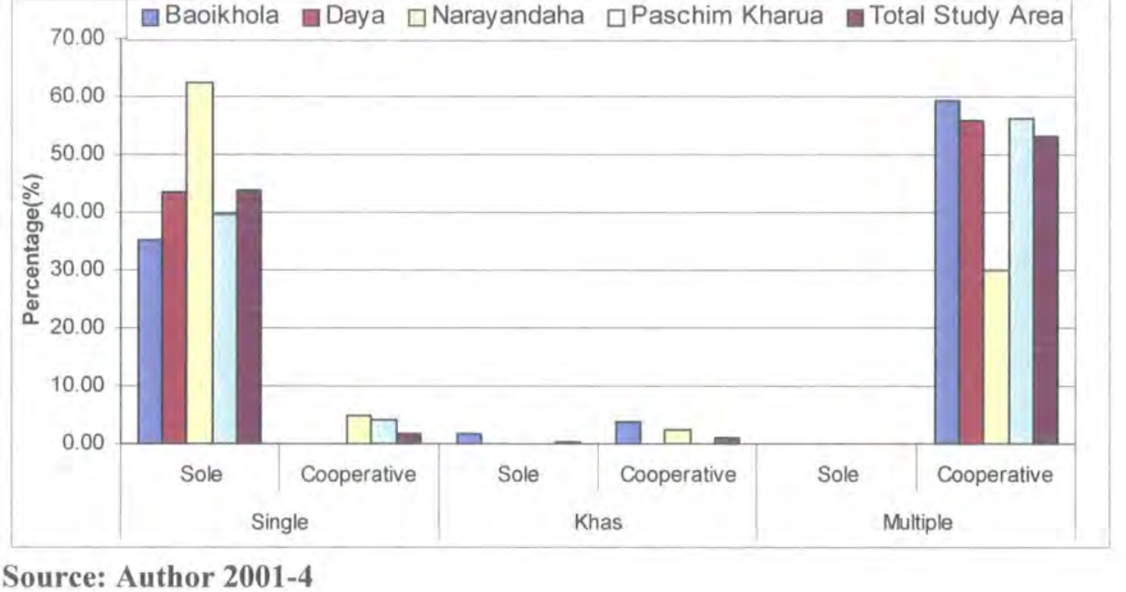

Source: Author 2001-4

**Figure 4.13 Depth in different season.**

### 4.5.7 Ownership and operation

There are three types of ownership of SWB: in the hands of individuals; government owned (khas); and multiple ownership such as several brothers from the same family or groups of households together. Beels and jolas are in khas ownership, but it is important to note that they are often controlled by powerful people, who exploit the resources for their own profit and status. Beels and jolas are leased from the government. Dobas and pukurs are in either single or multiple ownership and dighis, because they are generally dug for public use on leased land, are held multiply.

Operation is usually either by individuals or cooperatively. Individual operation of single-owned SWB is common (125), as is the cooperative use of multiply owned SWB (152). The other categories of operation are less common. Figure 4.14 records these patterns of ownership and operation.

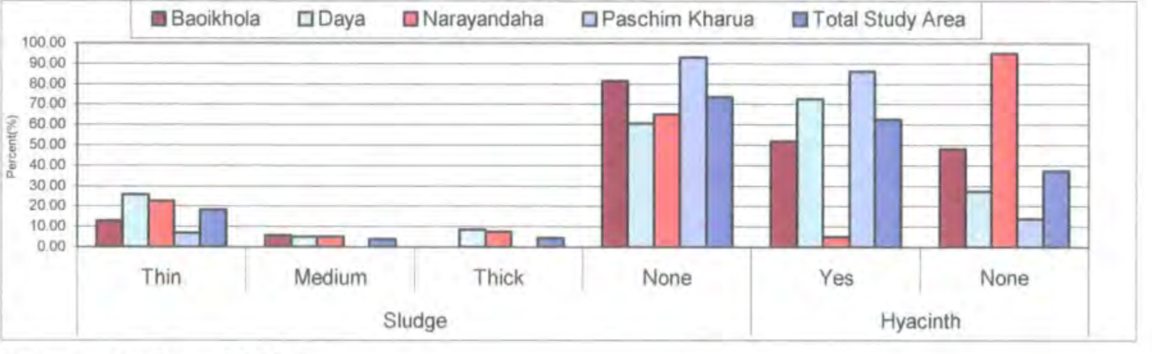



**Source: Author 2001-4**

**Figure 4.14 Ownership and operation.**

### 4.5.8 Sludge and water weeds

SWB rapidly fill up with sediment that is washed in by the rains or deposited during the floods each year. Some become derelict as a result but others may be refreshed by the excavation of sludge. Figures 4.15 have the relevant data. 211 SWB have been maintained, with no sludge present, but there are 24 with either a medium or thick deposit (Figure 4.15). Daya has the biggest problem in this respect, probably because this is a densely populated area where new homesteads are continually being created. Some of the SWB here are present solely as a result of the excavation of soil to create house mounds and the house owners are not concerned when the resulting water body silts up in the next rainy season.




**Source: Author, 2001-4**

**Figure 4.15 Sludge and Hyacinth**

Water hyacinth (Figure 4.15) is a common water weed in Bangladesh. It has several uses. First, it is a cattle feed which, because of its watery composition, encourages maximum milk yield. Second, it is put inside any large container of liquid (including milk vessels) that is transported by cart or truck in order to damp down vibration and spillage. Third, it is regarded as a means of holding a strong current in check during the flood season because it floats on the surface of the water. It is therefore the Bengali equivalent of pouring oil on troubled waters. Figure 4.15 shows 63 percent of SWB as having water hyacinth. Dobas tend not to have any.

### 4.5.9 Uses

Table 4.7 and Figure 4.16 address the important issue of usage. The figure gives a convenient general impression of usage throughout the day and a few comments here will assist the interpretation. First, there are only a few activities (fish farming, hyacinth cultivation, jute retting, and use of privies) that go on all day. Other activities are clustered at certain times, with the early hours from 6am to 9am, midday (12 noon to 3pm) and the early evening (5-7pm) being popular slots for bathing, laundry work, washing crockery, and the collection of water for cooking purposes. In short, the uses of SWB fit with the general daily rhythms of people's lives.

**Table 4.7 Uses of SWB's**

| | 1970 | | 1975 | | 1980 | | 1985 | | 1990 | | 1995 | | 2000 | | 2002 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **T#** | **T%** | **T#** | **T%** | **T#** | **T%** | **T#** | **T%** | **T#** | **T%** | **T#** | **T%** | **T#** | **T%** | **T#** | **T%** |
| Drinking | 25 | **32** | 1 | **1.2** | 1 | **1.1** | 1 | **0.8** | 1 | **0.7** | 1 | **0.5** | 1 | **0.4** | 1 | **0.3** |
| Fish Culture | 65 | **82** | 68 | **83** | 62 | **70** | 98 | **80** | 119 | **84** | 158 | **76** | 200 | **75** | 214 | **75** |
| Aqua Culture | 27 | **34** | 29 | **35** | 30 | **34** | 44 | **36** | 61 | **43** | 90 | **43** | 118 | **44** | 122 | **43** |
| Bathing | 34 | **43** | 34 | **41** | 37 | **42** | 45 | **37** | 73 | **51** | 97 | **47** | 152 | **57** | 167 | **58** |
| Cattle Feeding | 26 | **33** | 22 | **27** | 24 | **27** | 24 | **20** | 28 | **20** | 32 | **15** | 59 | **22** | 48 | **17** |
| Washing Clothes | 28 | **35** | 29 | **35** | 40 | **45** | 49 | **40** | 75 | **53** | 111 | **54** | 172 | **65** | 175 | **61** |
| Cattle bathing | 18 | **23** | 19 | **23** | 20 | **23** | 25 | **20** | 30 | **21** | 44 | **21** | 71 | **27** | 59 | **21** |
| Irrigation | 14 | **18** | 15 | **18** | 17 | **19** | 22 | **18** | 23 | **16** | 36 | **17** | 42 | **16** | 48 | **17** |
| Washing Crockery | 15 | **19** | 16 | **20** | 17 | **19** | 20 | **16** | 42 | **30** | 61 | **29** | 116 | **44** | 118 | **41** |
| Cooking Water | 8 | **10** | 7 | **8.5** | 7 | **8** | 4 | **3.3** | 4 | **2.8** | 4 | **1.9** | 6 | **2.3** | 10 | **3.5** |
| Sewerage | 31 | **39** | 38 | **46** | 39 | **44** | 51 | **41** | 58 | **41** | 106 | **51** | 126 | **47** | 137 | **48** |
| Duck Raising | 62 | **78** | 66 | **80** | 70 | **80** | 89 | **72** | 110 | **77** | 169 | **82** | 219 | **82** | 215 | **75** |
| Dying | 3 | **3.8** | 3 | **3.7** | 3 | **3.4** | 4 | **3.3** | 6 | **4.2** | 16 | **7.7** | 18 | **6.8** | 16 | **5.6** |
| Jute Retting | 19 | **24** | 21 | **26** | 19 | **22** | 27 | **22** | 24 | **17** | 8 | **3.9** | 3 | **1.1** | 3 | **1** |
| Water Sprinkling | 26 | **33** | 18 | **22** | 19 | **22** | 26 | **21** | 28 | **20** | 69 | **33** | 81 | **30** | 89 | **31** |
| **Total Created** | 79 | | 82 | | 88 | | 123 | | 142 | | 207 | | 266 | | 287 | |

**Source: Author 2001-4.**

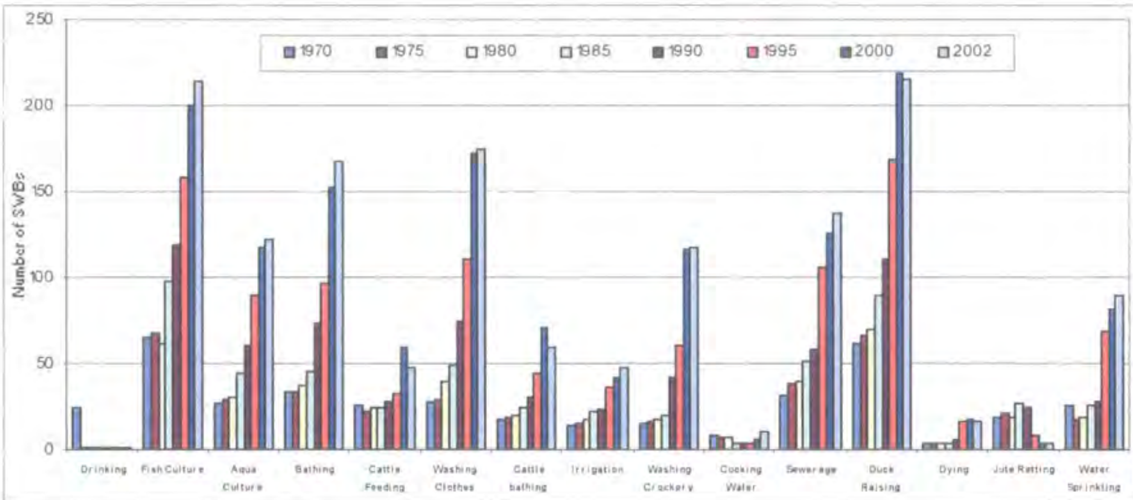
A gender division of SWB use is also notable. Women and girls perform fewer SWB-related activities and are restricted in their time of access to bathing and collecting cooking and drinking water to the midday period. They are busy at other times but there are also cultural issues of modesty here that are constraining.

| Time / Usage | Gender | 6 am | 7 | 8 | 9 | 10 | 11 | 12 | 1 pm | 2 | 3 | 4 | 5 | 6 pm | 7 | 8 | 9 | 10 | 11 | 12 | 1 am | 2 | 3 | 4 | 5 | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drinking | M | | ← | — | — | — | — | — | — | — | — | — | → | | | | | | | | | | | | | |
| | F | | | | | ← | — | — | → | | | | | | | | | | | | | | | | | |
| Fish Culture | M&F | ← | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | → | |
| Aqua Culture | M | ← | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | → | |
| Bathing | M | ← | — | → | | | | ← | — | → | | | ← | → | | | | | | | | | | | | |
| | F | | | | | | | ← | — | → | | | | | | | | | | | | | | | | |
| Cattle Feeding | M | | | ← | → | | | ← | — | → | | | ← | → | | | | | | | | | | | | |
| Washing Cloth | | | ← | — | → | | | ← | — | → | | | ← | → | | | | | | | | | | | | |
| Cattle Bathing | M (Cow) | | | | | | ← | — | — | — | — | — | — | → | | | | | | | | | | | | |
| | M (Buffalo) | | | | | | | | | | | | ← | → | | | | | | | | | | | | |
| | M (Others) | | | | | | | ← | — | → | | | | | | | | | | | | | | | | |
| Irrigation | M | | ← | — | — | — | — | — | — | — | — | — | — | → | | | | | | | | | | | | |
| Washing Crockery | F | ← | — | — | → | | | | ← | → | | | | | | | | | | | | | | | | |
| Cooking Water | M | | | | | | | | | | | | ← | → | | | | | | | | | | | | |
| | F | | ← | → | | | | | ← | → | | | | | | | | | | | | | | | | |
| Sewerage | M&F | ← | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | → | |
| Duck Raising | M&F | | ← | — | — | — | — | — | — | — | — | — | — | → | | | | | | | | | | | | |
| Dying | M | | ← | — | — | — | — | — | — | — | — | — | — | — | → | | | | | | | | | | | |
| Jute Retting | M | ← | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | → | |
| Water Sprinkling | F | | ← | → | | | | | | | | | ← | → | | | | | | | | | | | | |

**Source: Author, 2001-4**

**Figure 4.16 Uses of SWB.**

Table 4.7 and Figure 4.17 as based on the changing importance of the various uses of SWB through time. First, there has been a remarkable switch from their use for drinking water to tubewells instead. This came in the mid 1970s as a result of a government-sponsored programme to improve the quality and availability of water. Since then groundwater has remained the main source of drinking water but it is worth noting that the recent scare with regard to arsenic poisoning from contaminated aquifers may change people's perceptions of risk and a return to the consumption of surface water, this time in some filtered or chemically treated for, cannot be ruled out.




**Source: Author, 2001-4**

**Figure 4.17 Uses of SWB.**

Second, the proportion of SWB used for fish culture and duck raising has remained high over the last thirty years. Clearly SWB have an important economic function, providing secondary income or at least providing a protein supplement for local households. Since the number of SWB has multiplied, the number of household engaged in this kind of enterprise has increased significantly.

Third, irrigation has remained static at about 16-18 per cent of the SWB, and 20-33 per cent for the sprinkling the plants in the homestead garden. Jolas and beels are especially valuable as resources for the irrigation of the fields, particularly as the water table is now low in the winter season and there are problems in pumping sufficient to the surface. As more and more tubewells are installed the water table falls further each year and there is no respite likely from river water because the Indian government extracts so much water upstream of the border that river levels are very low in the winter.

Fourth, cattle are fed on the water hyacinth growing in the SWB and drink there. They are also washed there, raising issues of hygiene that are compounded by the alarmingly high and increasing proportion that are receptacles of human sewage, mainly dobas.

Fifth, domestic functions such as the washing of clothes and crockery have increased as a use of SWB, principally dobas and pukurs.

Industrial uses of SWB include dying and jute retting. The dying is restricted to a few dobas and pukurs in Daya mouza, but the jute retting has virtually disappeared as jute is no longer the major cash export crop that it used to be.

Figures 4.16 and 4.17 show the reader a wide variety of the uses of SWB in the study area. In addition there are video clips available for viewing in Appendix 4.

## 4.6 Conclusion

The purpose of this chapter was to present the methodologies and results of monitoring change. I started with the technical aspects of remote sensing, discussing the pros and cons of the available techniques for change detection. My study is unusual in the Bangladeshi context in that I have collected and analyzed a large number of images over an extended period of time. I therefore have a good grasp of the technical problems and possibilities of this kind of study for the conditions that are found in my country.

From the outset, I was determined to mix my remote sensing methods with those of social science. This chapter outlines the methodologies employs combined methodologies of remote sensing and qualitative approaches to fieldwork that are rarely used in remote sensing studies. My overall feeling is that this ground truthing was a great success and that I have a fuller and better integrated understanding of how the images relate to the real world of the villagers in my study area than would have been possible if I had adopted a purely scientific methodology.

In addition to the technical aspects of change detection, the questionnaires, focus groups and key informants interviews revealed a great deal about changing land use and use of SWB in the last thirty years in the four study mouzas. It is my opinion that the future monitoring of SWB and plans for their management would be heightened in their efficiency and power if they were to adopt techniques that replicate mine to a certain extent, or at least show an epistemological flexibility that crosses and recrosses the boundaries of science and social science. This chapter provides a good foundation, through its discussion of techniques and change monitoring, for the next chapter, Chapter 5, which will shift the emphasis to the consideration of the socio-economic aspects of SWB, and Chapter 6, which will address issues of future management.

# CHAPTER 5: THE SOCIO-ECONOMIC CONDITIONS

## 5.1 Introduction

Understanding the socio-economic context of the study area specially associated with the SWB is very important for the development of a management system. A management system consists of scientific and cultural approaches: a combination of which will facilitate sustainable development. This chapter will discuss the different socioeconomic contexts which are directly associated with the SWB. The different sources and methods that were employed for collecting data will also be covered, and the analysis and results presented. The second part of the chapter discusses the different components of an informal management system present for SWB in my study region. Integrating the remote sensing and GIS data with socio-economic data has given a useful opportunity for effective management planning of these SWB (see Chapter 6).

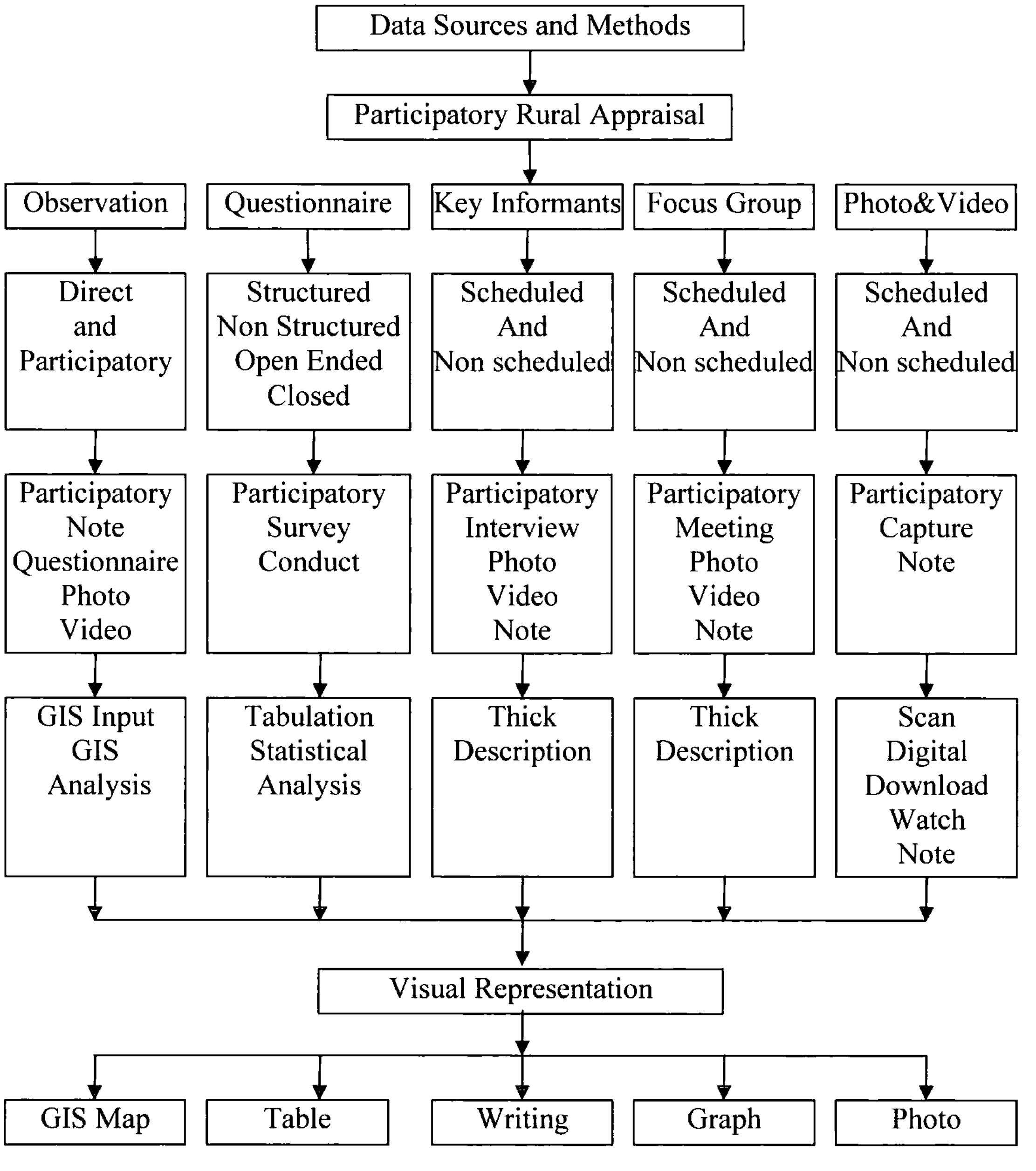
## 5.2 Objectives

The objectives of this chapter are,

1. To understand the different socio economic contexts.
2. To record the different uses of the SWB.
3. To understand people's perceptions of SWB.
4. To discuss the sustainable management of SWB for development planning.

### 5.3 Data Sources and Methods

The different sources of data used and methods applied in this chapter are summarised in figure 5.1 as a flow chart.




**Source: Author (2004).**

**Figure 5.1 Data sources and methods.**

### 5.3.1 Direct and Participatory Observation

The main aims of using these sources and methods were to acquire both data for the different types of SWB and contextual information. By making a field visit to each SWB in the four mouzas, I created the opportunity for direct observation. All of my research assistants and I had the chance for direct and participatory observation. We had detailed discussions with the local people that enriched our understanding of the SWB and their surrounding circumstances. Participant observation combines participation in the lives of the people of study area with the maintenance of a professional distance that allows adequate observation and recording of data.

Participant observation is of considerable appeal in socio-cultural research. Long-term residence helped us to internalize the basic beliefs, fears, hopes and expectations of the people of the study area. The simple behaviours of their quotidian uses of the SWB taught us how people act in time and space, how they determine what is precious or mundane. Participant observation also helped us in clarifying and triangulating results and provided a baseline meaning and a way to review the study area to explore the context of information and results.

### 5.3.2 Questionnaire Survey

Interacting with and talking to people who are the object of the study can take many forms, but perhaps the most common way in which geographers have obtained information from individuals has been via questionnaire surveys (Robinson, 1998). Questionnaire surveys provide both quantitative and qualitative data. The use of questionnaires in geographical research was popularised when the analysis of people's geographical perceptions became a major part of behavioural geography in the early 1970s (Bickman and Rog, 1998; Denzin and Lincoln, 1994; Limb and Dwyer, 2001; Maxwell, 1996; Rubin and Rubin, 1995). Subsequently they were used across a broad spectrum of human geography research as a key means of obtaining information from target groups within the population of the study area (Robinson 1998). One advantage of this method is that it can produce data that can be analysed by standard procedures, especially through exploratory and descriptive statistics using computer GIS software.

An in-depth questionnaire survey was conducted during the field work. The main aim of the questionnaire survey was to collect socio-economic information from the study area which was directly associated with the SWB. The questionnaire survey was designed to extract a broad picture of the participant's world, to map the cultural terrain (Fetterman, 1998). Specific questions search into established categories of meaning or activity. Whereas the overall questionnaire survey shapes and informs a global understanding, specific questions refine and expand that understanding. Structural and attribute questions, subcategories of specific questions were the most appropriate approach for this level of research inquiry (see appendix-A: Questionnaire Survey for socio-economic information). In the questionnaire survey both open-ended and closed ended questions were used to gather the information about socio-economic characteristics associated with the SWB.

### 5.3.3 Key Informants Interviews

I interviewed several key informants who, at different levels of resource management in the study area, were especially associated with the SWB's development planning. These key informants provided detailed historical data and knowledge about the contemporary situation, and as well they expressed their own views also (May, 1993).

This approach required the careful identification of a select group of formal and informal leaders, influential leaders or experts. It provided for structured contact with these informants, usually through direct interviews or a focus group format (http://www.uwex.edu/ces/pdande/progdev/pdf/keyinform.pdf). It was desirable to ensure that the key informants represented each demographic characteristic and each value orientation and had knowledge between them of all of the key groups in the study area (http://www.uwex.edu/ces/pdande/progdev/pdf/keyinform.pdf). There are formal and informal leaders in our community that helped to provide background on environmental issues. These leaders were able to give information on the existing structures and contacts in the community, give their perspective on community perceptions and needs, and provide direction for sustainable management (http://pabcerf.psu.edu/Key_interview_form.pdf).

This interview method is useful in all phases of development activities - identification, planning, implementation, and evaluation. It is very useful; when quantitative data collected through other methods including remote sensing and GIS, need to be interpreted. Key informant interviews can provide the how and the why of what happened. There are different steps for conducting key informant interviews. They start with the formulation of research questions that relate to specific concerns of the research and these should be limited in number; then there is preparation of a short interview guide. Key informant interviews usually don't use rigid questionnaires, which reduce free discussion. However, interviewers must have an idea of what questions they are going to be asked. The guide should list the major topics and issues covered under each research query. It helps to explore in depth the views and thinking of the interviewees.

Careful selection of the key informants and their numbers is vital. They must be representative, especially of gender. Key informants should be selected for their specialized knowledge and unique perspectives on the study area and the concerned research (http://www.childrensvaccine.org/files/USAID_Key_InformInt.pdf). It is best to include all of the major stakeholders so that divergent interests and perceptions can be captured.

Conducting the interview is also sensitive. I began with an explanation of the purpose of the interview, the intended uses of the information and assurances of confidentiality. Then factual questions gave me direct entrance to the issue. Questions requiring opinions and judgments followed. In general, I began with the present and moved to questions about the past or the future of the SWB. I found it helpful if I could be a sympathetic listener and avoid giving the impression of having strong views of my own on the subject under discussion. Neutrality was essential because some informants, trying to be polite, might have said what they thought I wanted to hear.

Adequate note taking was very important. I engaged a research assistant for taking a transcript of the interviews to be written up and also captured everything on video tape (see Appendix 4). After each interview I prepared a summary sheet. Finally the transcript was manually coded and interpreted in order to present the results.

### 5.3.4 Focus Group Meetings

Focus groups are another method of gathering information. A focus group involves a group discussion of a topic that is the "focus" of the conversation (Stewart and Shamdasani, 1998). The most common purpose of a focus group interview is to stimulate an in-depth exploration of the topic of the research. Several focus groups meetings were conducted among the stakeholders of the SWB in the study area.

The use of focus groups provides a number of advantages relative to other methods of research. One of the great advantages I found is that it can collect data from a group of people much more quickly and at less cost than if each individual was interviewed separately. They can also be assembled on much shorter notice. Focus group meetings also gave me the opportunity of interacting directly with respondents, which gave me the opportunity for clarification and the probing of responses as well as following up questions for understanding the in-depth circumstances. They also helped me to collect raw data on the respondent's own language and words.

Focus group meetings were held separately with women and gave me the opportunity of collecting their views on different uses and management of the SWB. I could then add deeper levels of understanding of the socio-economic circumstances in which SWB are found. I also transcribed what I captured on videotape (see Appendix 4) and this gave me the flexibility of watching and observing several times the vital views on SWB for management planning purposes.

### 5.3.5 Videotape Recorders and Camera Photography

Videotape recordings are extremely useful in micro social studies. Researchers usually have a fraction of a second to reflect on a gesture or a person's posture or gait (Fetterman, 1998). Videotape provides the observer with the ability to stop time. I videoed each SWB and associated socio-economic conditions and watched the recordings over and over again. Each time I have found new layers of meaning and understanding. The recorded videotapes focused on certain types of behaviour or phenomena. Thus I now have a good understanding of a specific cultural mechanism and its real role in a particular environment.

Camera photography has also played special role in my research. Photographs documented each SWB, and the people, places, events and settings over time. I agree with Collier (1967) who explained that: "Photography is a legitimate abstracting process in observation. It is one of the first steps in evidence refinement that turns raw circumstances into data are manageable in research analysis. Photographs are precise records of material reality. They are also documents that can be filed and cross-filed, as can verbal statements. Photographic evidence can be endlessly duplicated, enlarged or reduced in visual dimension, and fitted into many schemes or diagrams, and by scientific reading into many statistical designs" (Collier, 1967; Fetterman, 1998).

### 5.4 Analysis, Results and Discussions (Direct and Participant Observation)

Mainly Geographical Information Systems (Arc/View 3.2/3.3 and Arc GIS 8.3) and basic statistics have been used for analyzing and to visualize and represent the data collected through direct and participatory observations. This method is used to collect different types of data directly note taking which has been incorporated in different part of this research. Basically in this section the plot-based data collected through participatory questionnaire (see appendix-1) were inserted under Arc View 3.2/3.3 GIS environment as attribute data associated with the spatial data on all four mouzas.

The data are represented as a large scale plot-based map, the plot being the lowest regional units in the mouza. A mouza is consists of many plots. Four mouzas are consists of 1587 plots for Baoikhola, 1181 plots for daya, 566 plots for Narayandaha and 1374 for Paschim Kharua. All plots were directly and participantly observed and noted. All the data were also inserted in the GIS environment as attributes attached to individual plots. Here only few of those phenomena like land use, local land types, agriculture and population per plot will be discussed.

a) Land use pattern including SWB (Baoikhola, pukur #5)

c) Homestead garden and the SWB (Narayandaha, dhoba #7)

**Source: Author (2001-2).**

**Figure 5.2 Direct and Participatory Observations during field work.**

### 5.4.1 Land use

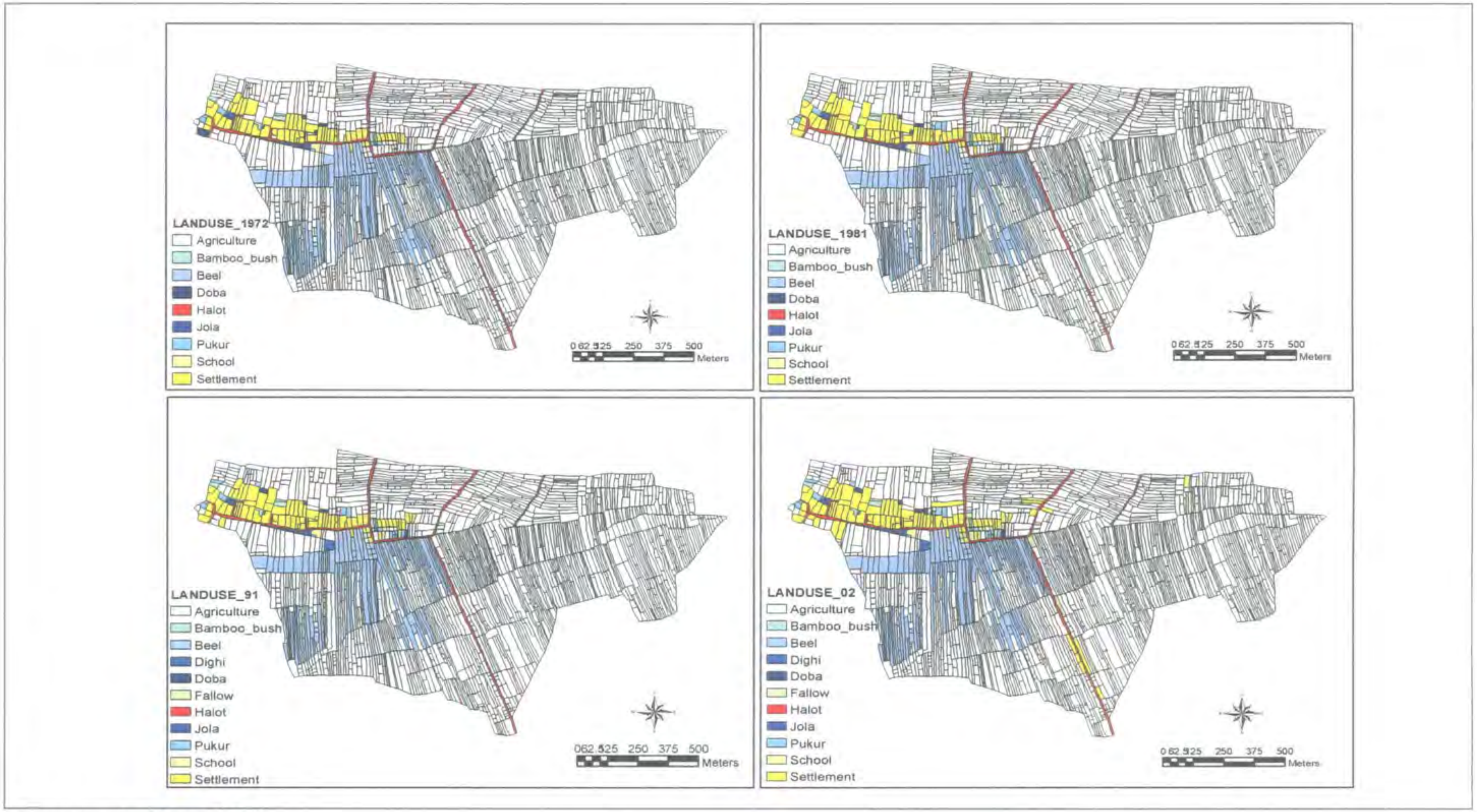
#### 5.4.1.1 Baoikhola

The memories of the participants were very helpful in reconstructing the land use patterns of all four mouzas. For Baoikhola, there was confirmation that over the thirty year period the dominant land use has remained agriculture, with 85.82 per cent of total plots under cultivation in 1972 (Table 5.1), falling only marginally to 82.48 per cent in 2002, the year of my direct observation during fieldwork. It is worth noting that settlement has spread to a total of 89 plots, as against 61 thirty years ago. This has been largely the result of the consolidation of the main village, with some expansion to the south and east of its peripheral road, but there has also appeared a new daughter hamlet in the south of the mouza along a road that was upgraded in the 1990s. Interestingly, each of the new house compounds there was provided with a new pukur, even though people in the mouza have ready access to a large beel in the south west (Figure 5.3). In terms of the SWB, the numbers have increased, notably pukurs, from 8 in 1972 to 19.

**Table 5.1 Plotbase landuse (Baokhola mouza).**

| Landuse | 1972(#) | 1972(%) | 1981(#) | 1981(%) | 1991(#) | 1991(%) | 2002(#) | 2002(%) |
|---|---|---|---|---|---|---|---|---|
| Agriculture | 1362 | 85.82 | 1352 | 85.19 | 1332 | 83.93 | 1309 | 82.48 |
| Bamboo Bush | 8 | 0.50 | 8 | 0.50 | 8 | 0.50 | 5 | 0.32 |
| Beel | 119 | 7.50 | 119 | 7.50 | 118 | 7.44 | 118 | 7.44 |
| Commercial | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Dighi | 0 | 0.00 | 0 | 0.00 | 1 | 0.06 | 1 | 0.06 |
| Doba | 4 | 0.25 | 4 | 0.25 | 4 | 0.25 | 6 | 0.38 |
| Eidgah | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Fallow | 0 | 0.00 | 0 | 0.00 | 5 | 0.32 | 15 | 0.95 |
| Graveyard | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Halot | 9 | 0.57 | 9 | 0.57 | 9 | 0.57 | 9 | 0.57 |
| Jola | 15 | 0.95 | 15 | 0.95 | 15 | 0.95 | 15 | 0.95 |
| Madrasa | 0 | 0 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Mosque | 0 | 0 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Pukur | 8 | 0.5041 | 11 | 0.69 | 18 | 1.13 | 19 | 1.20 |
| Road | 0 | 0 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| School | 1 | 0.06301 | 1 | 0.06 | 1 | 0.06 | 1 | 0.06 |
| Settlement | 61 | 3.84373 | 68 | 4.28 | 76 | 4.79 | 89 | 5.61 |
| Stable | 0 | 0 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |

**Source: Author (2004).**




**Source : (Author 2004)**

**Figure 5.3 Plot based land use map 1972-2002 (Baoikhola Mouza)**

### 5.4.1.2 Daya

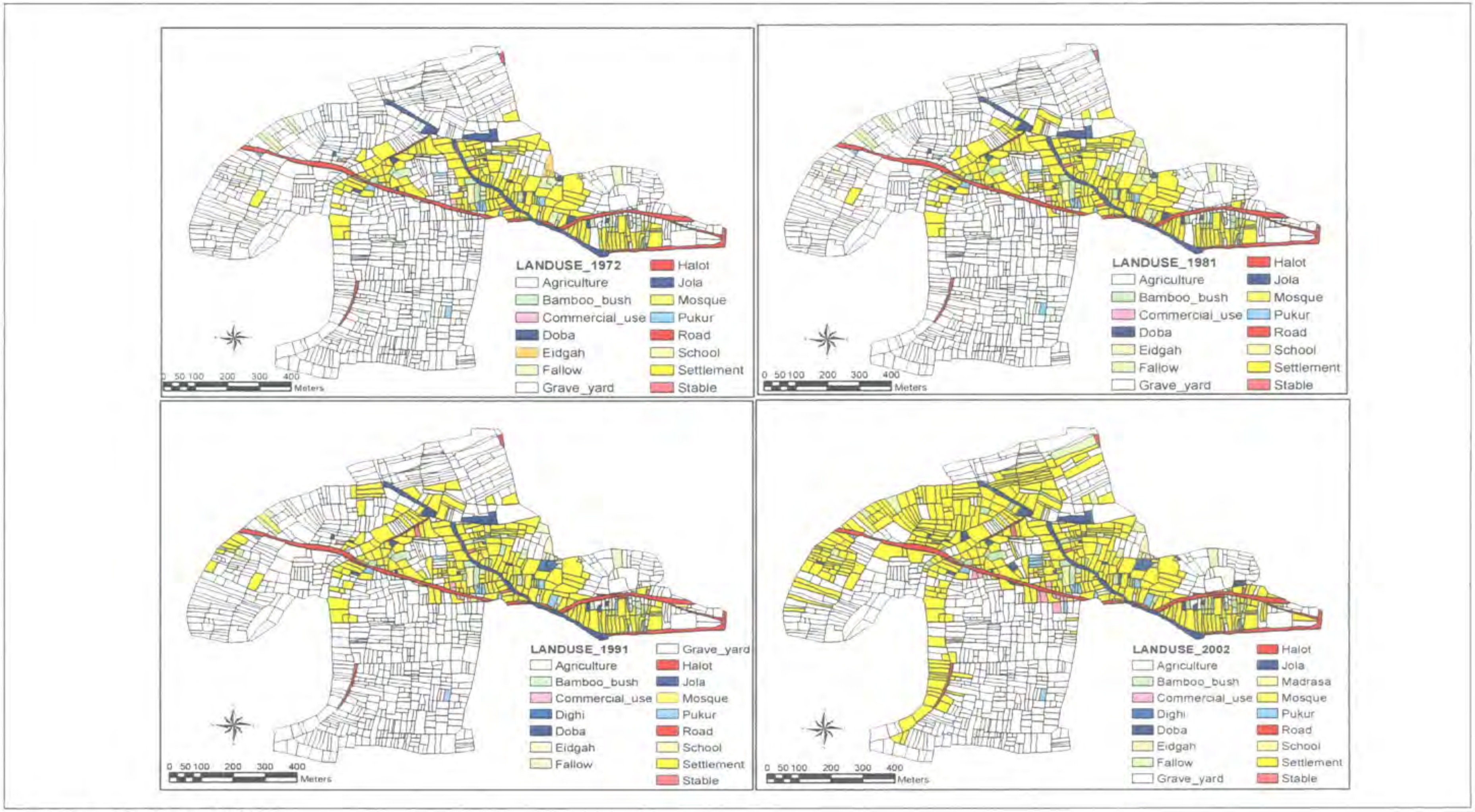
Daya is the mouza that most notably demonstrates the impact of population growth in this part of Bangladesh. There has been a remarkable increase in the number of built up plots from 163 in 1972 to 395 on my visit in 2002 (Table 5.2). Figure 5.4 shows this very clearly with the yellow shading spreading to the north west of the road (made pucca in 1985) and in a ribbon along the south west boundary. Factors involved here include the drying up of a branch the River Hurasagar, the remnant of which is now shown as a jola on the map. This is a highly dynamic flood plain but the lack of recent inundations has encouraged people to construct new houses. Another factor is the proximity of this mouza to the main thana town, and settlement is gradually spreading outwards from this central place. Services have multiplied, such as mosques, madrasas, and there has been a six-fold increase in commercial land use.

As a counterpoint to the growth of settlement, agriculture has declined from 888 to 599 plots. The SWB have, as expected, increased in total, with the number of pukurs rising from 13 to 18, and dobas from 14 to 23. Most of this growth has happened in the last ten years, as has the growth in the built up area.

**Table 5.2 Plotbase landuse (Daya mouza).**

| Landuse | 1972(#) | 1972(%) | 1981(#) | 1981(%) | 1991(#) | 1991(%) | 2002(#) | 2002(%) |
|---|---|---|---|---|---|---|---|---|
| Agriculture | 888 | 75.13 | 855 | 72.34 | 806 | 68.19 | 599 | 50.68 |
| Bamboo Bush | 37 | 3.13 | 40 | 3.38 | 40 | 3.38 | 44 | 3.72 |
| Beel | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Commercial | 2 | 0.17 | 3 | 0.25 | 6 | 0.51 | 12 | 1.02 |
| Dighi | 0 | 0.00 | 0 | 0.00 | 2 | 0.17 | 2 | 0.17 |
| Doba | 14 | 1.18 | 14 | 1.18 | 12 | 1.02 | 23 | 1.95 |
| Eidgah | 4 | 0.34 | 4 | 0.34 | 4 | 0.34 | 4 | 0.34 |
| Fallow | 38 | 3.21 | 37 | 3.13 | 36 | 3.05 | 47 | 3.98 |
| Graveyard | 2 | 0.17 | 2 | 0.17 | 2 | 0.17 | 3 | 0.25 |
| Halot | 2 | 0.17 | 2 | 0.17 | 2 | 0.17 | 2 | 0.17 |
| Jola | 6 | 0.51 | 6 | 0.51 | 6 | 0.51 | 6 | 0.51 |
| Madrasa | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 1 | 0.08 |
| Mosque | 1 | 0.08 | 2 | 0.17 | 4 | 0.34 | 4 | 0.34 |
| Pukur | 13 | 1.10 | 13 | 1.10 | 14 | 1.18 | 18 | 1.52 |
| Road | 9 | 0.76 | 10 | 0.85 | 18 | 1.52 | 18 | 1.52 |
| School | 1 | 0.08 | 1 | 0.08 | 1 | 0.08 | 1 | 0.08 |
| Settlement | 163 | 13.79 | 190 | 16.07 | 225 | 19.04 | 395 | 33.42 |
| Stable | 2 | 0.17 | 3 | 0.25 | 4 | 0.34 | 3 | 0.25 |
| Total | 1182 | 100 | 1182 | 100.00 | 1182 | 100 | 1182 | 100.00 |

**Source: Author (2004).**




**Source : (Author 2004)**

**Figure 5.4 Plotbased land use map 1972-2002 (Daya Mouza)**

### 5.4.1.3 Narayandaha

This is the smallest of the four mouzas. In stark contrast to Daya, very little has changed here of the thirty year period (Figure 5.5). Built up plots have increased from 53 to 73, mainly along the banks of the jola, and there has been a reduction in agriculture from 465 to 444. On the evidence presented in Table 5.3, one might think that the situation of SWB is unchanged but the data here is plot-based. Chapter 4 demonstrates the greater precision that can be gained by using remote sensing and fieldwork and Table 4.4 shows that the number sub-plot SWB have increased significantly, particularly ponds and dobas.

**Table 5.3 Plotbase landuse (Narayandaha mouza).**

| Landuse | 1972(#) | 1972(%) | 1981(#) | 1981(%) | 1991(#) | 1991(%) | 2002(#) | 2002(%) |
|---|---|---|---|---|---|---|---|---|
| Agriculture | 465 | 82.30 | 453 | 80.18 | 447 | 79.12 | 444 | 78.58 |
| Bamboo Bush | 3 | 0.53 | 3 | 0.53 | 3 | 0.53 | 3 | 0.53 |
| Beel | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Commercial | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Dighi | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Doba | 2 | 0.35 | 2 | 0.35 | 2 | 0.35 | 2 | 0.35 |
| Eidgah | 1 | 0.18 | 1 | 0.18 | 1 | 0.18 | 1 | 0.18 |
| Fallow | 5 | 0.88 | 5 | 0.88 | 5 | 0.88 | 6 | 1.06 |
| Graveyard | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Halot | 1 | 0.18 | 1 | 0.18 | 1 | 0.18 | 1 | 0.18 |
| Jola | 20 | 3.54 | 20 | 3.54 | 20 | 3.54 | 20 | 3.54 |
| Madrasa | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Mosque | 2 | 0.35 | 2 | 0.35 | 2 | 0.35 | 2 | 0.35 |
| Pukur | 6 | 1.06 | 6 | 1.06 | 6 | 1.06 | 6 | 1.06 |
| Road | 6 | 1.06 | 6 | 1.06 | 6 | 1.06 | 6 | 1.06 |
| School | 1 | 0.18 | 1 | 0.18 | 1 | 0.18 | 1 | 0.18 |
| Settlement | 53 | 9.38 | 65 | 11.50 | 71 | 12.57 | 73 | 12.92 |
| Stable | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Total | 565 | 100 | 565 | 100.00 | 565 | 100 | 565 | 100.00 |

**Source: Author (2004).**


**Source : (Author 2004)**

**Figure 5.5 Plot based land use map 1972-2002 (Narayandaha Mouza)**

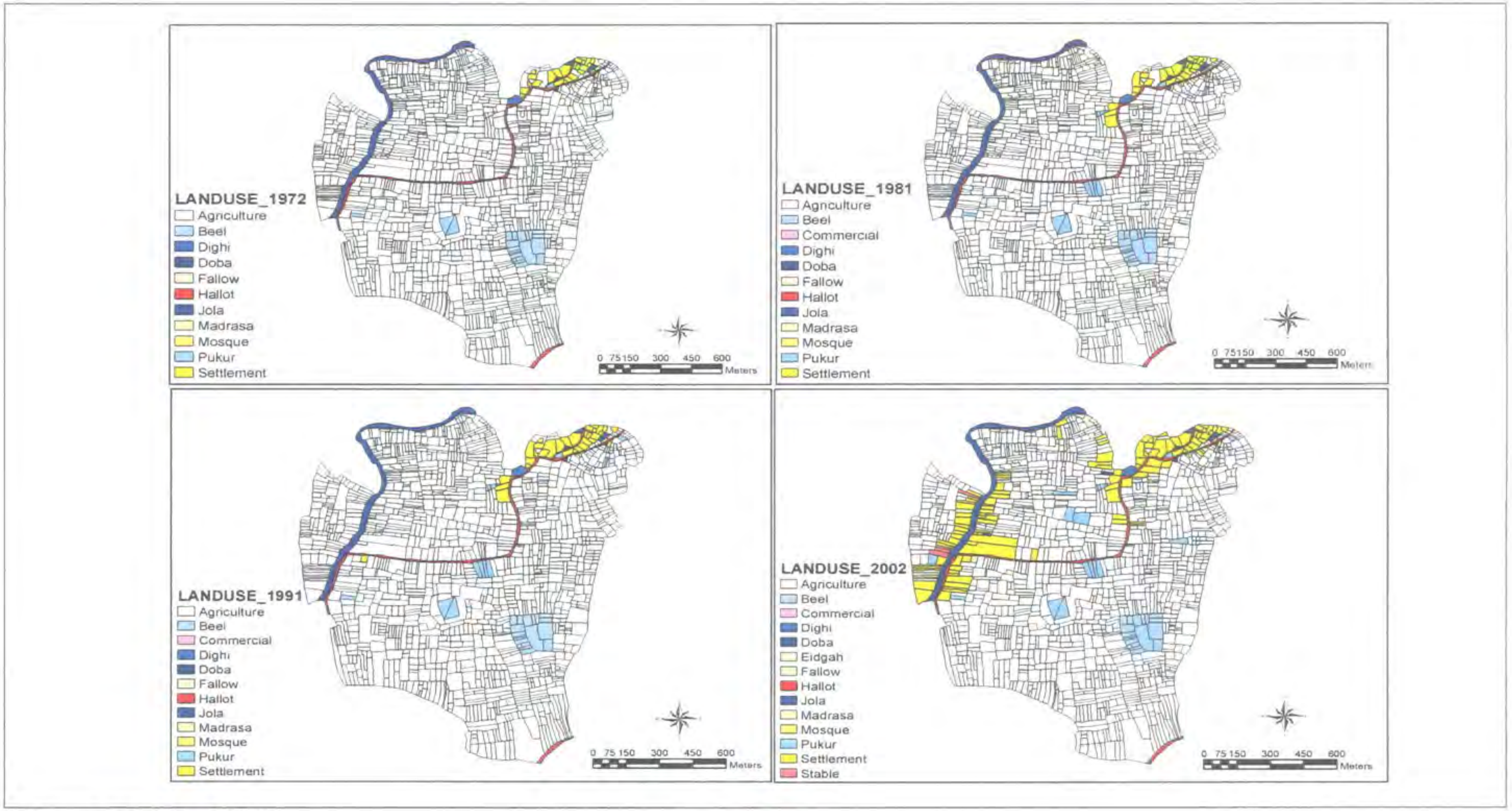
### 5.4.1.4 Paschim Kharua

The plots devoted to house compounds in Paschim Kharua mouza have increased five-fold from 23 in 1972 to 101 in 2002 (Table 5.4), with a new settlement being established on the banks of the jola in the last few years (Figure 5.6). In parallel, SWB have increased in number, notably pukurs from 4 to 18. This is a specialist dairy farming development, each household having an interest in milk production. Agriculture has reduced from 95.27 per cent of plots in 1972 to 87.33 in 2002 but this is not necessarily a reflection of the intensity of land use. In all four mouzas there has been an increase in fallow land. This is to provide dry lots for the dairy farmers to feed their cattle and increase soil fertility.

**Table 5.4 Plotbase landuse (Paschim Kharua mouza).**

| Landuse | 1972(#) | 1972(%) | 1981(#) | 1981(%) | 1991(#) | 1991(%) | 2002(#) | 2002(%) |
|---|---|---|---|---|---|---|---|---|
| Agriculture | 1308 | 95.27 | 1293 | 94.17 | 1289 | 93.88 | 1199 | 87.33 |
| Bamboo Bush | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Beel | 19 | 1.38 | 19 | 1.38 | 19 | 1.38 | 19 | 1.38 |
| Commercial | 0 | 0.00 | 2 | 0.15 | 2 | 0.15 | 2 | 0.15 |
| Dighi | 1 | 0.07 | 1 | 0.07 | 1 | 0.07 | 1 | 0.07 |
| Doba | 6 | 0.44 | 6 | 0.44 | 6 | 0.44 | 9 | 0.66 |
| Eidgah | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 1 | 0.07 |
| Fallow | 4 | 0.29 | 4 | 0.29 | 4 | 0.29 | 11 | 0.80 |
| Graveyard | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Halot | 5 | 0.36 | 5 | 0.36 | 5 | 0.36 | 5 | 0.36 |
| Jola | 1 | 0.07 | 1 | 0.07 | 1 | 0.07 | 1 | 0.07 |
| Madrasa | 1 | 0.07 | 1 | 0.07 | 1 | 0.07 | 1 | 0.07 |
| Mosque | 1 | 0.07 | 1 | 0.07 | 1 | 0.07 | 1 | 0.07 |
| Pukur | 4 | 0.29 | 11 | 0.80 | 13 | 0.95 | 18 | 1.31 |
| Road | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| School | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Settlement | 23 | 1.68 | 29 | 2.11 | 31 | 2.26 | 101 | 7.36 |
| Stable | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 4 | 0.29 |
| Total | 1373 | 100 | 1373 | 100.00 | 1373 | 100 | 1373 | 100.00 |

**Source: Author (2004).**

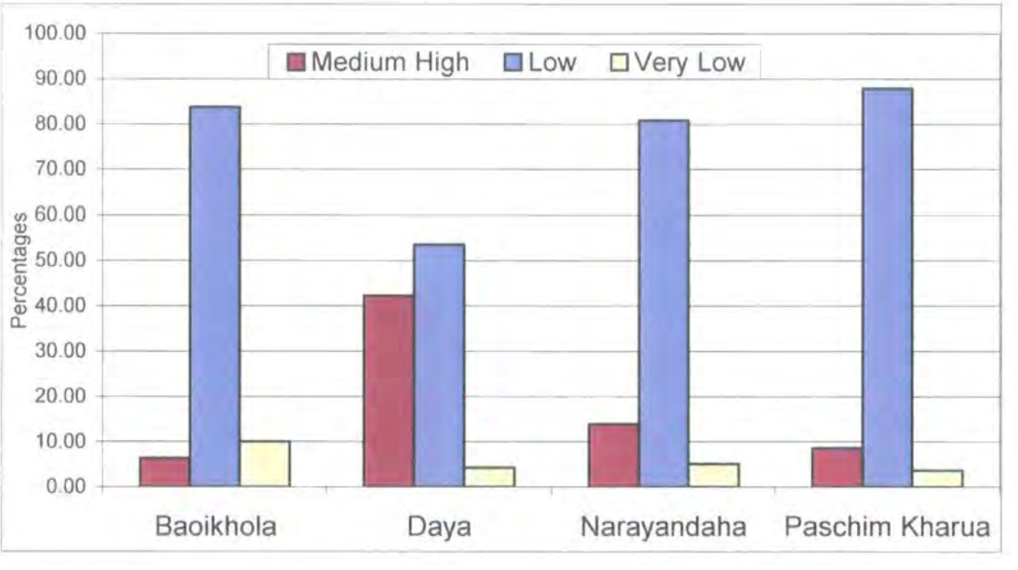



**Source : (Author 2004)**

**Figure 5.6 Plot based land use map 1972-2002 (Paschim Kharua Mouza)**

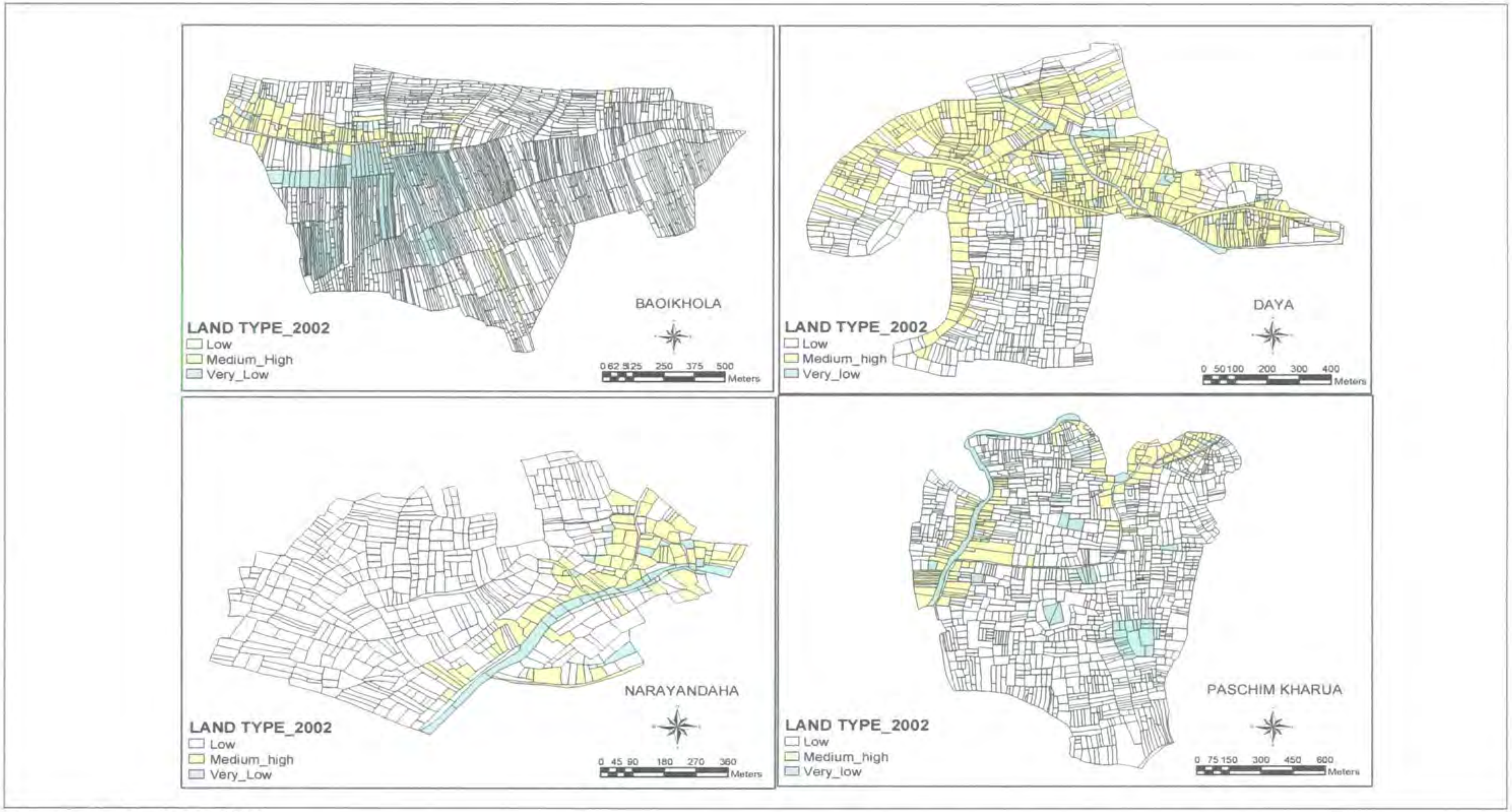
### 5.4.2 Land type

Figures 5.7 and 5.8 record the proportion of land type in each of the four mouzas. In the Bangladesh context this is crucial because it shows the relative proportion of land that is subject to regular inundation. The 'very low' category is standing water, such as jolas, beels and some other SWB. Note the large beel in Baoikhola and the jolas in the other three mouzas. The 'medium high' land is least susceptible to flooding and the predominance of this land type in Daya helps to explain the expansion of settlement here over the last few decades.




**Source: Author (2004).**

**Figure 5.7 Plot based landtypes 2002.**




**Source : (Author 2004)**

**Figure 5.8 Plot based landtypes map 2002**

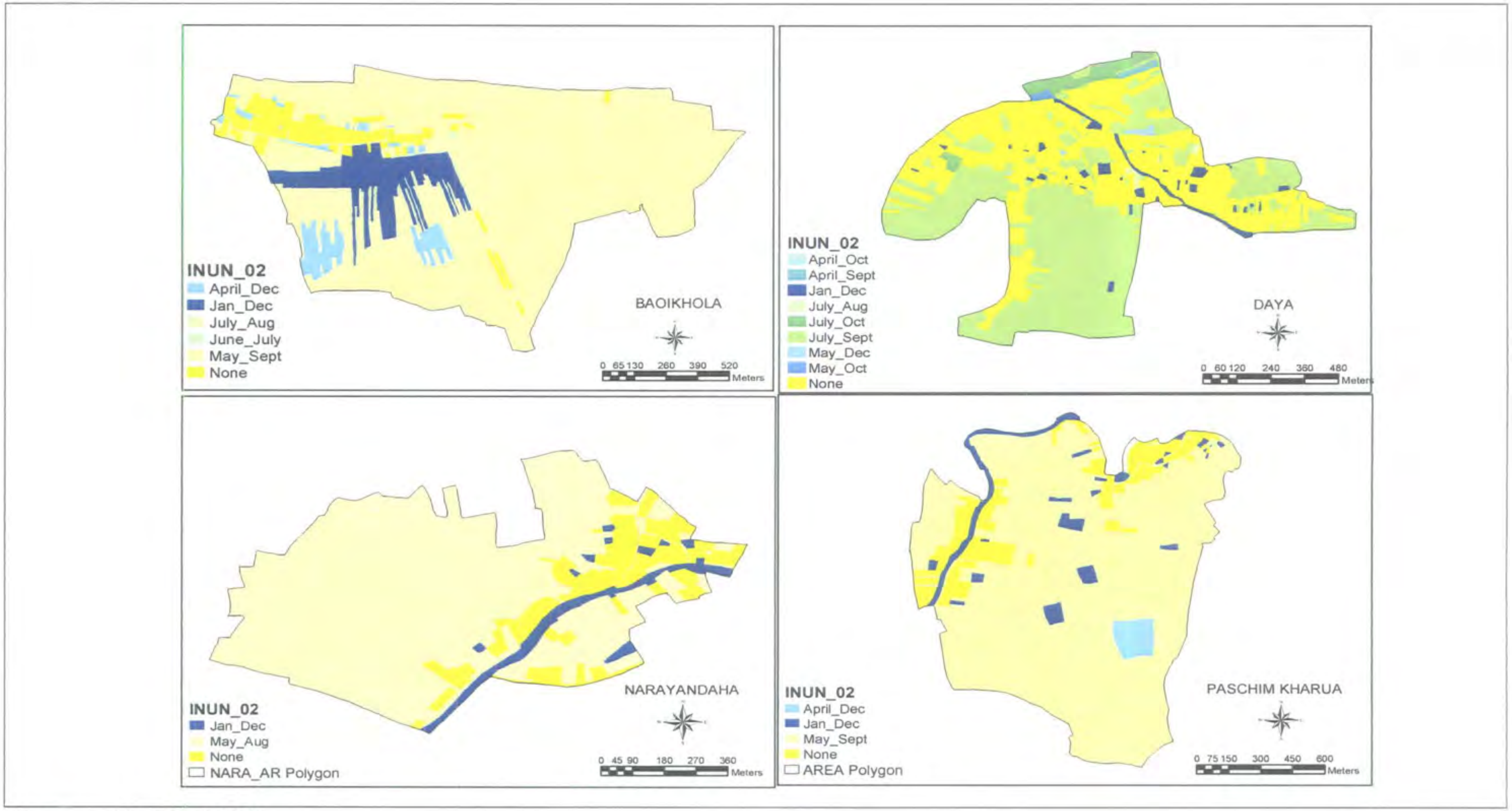
### 5.4.3 Inundation

Following on from 'land type', Figure 5.9 is an intriguing and highly significant map of the extent of seasonal inundation in each of the four mouzas. We should note that the lives of local people are affected in two ways: (a) the monsoon floods, which affect all four mouzas to a certain extent, are disruptive of people's lives because for a period they are cut off from their fields and from the outside world. Daya suffers least from this as can be seen from the yellow shading on the map; (b) there are relatively few water bodies, small or large, that retain water throughout the year, and this constrains the access or ordinary people to water for some domestic purposes. The dark blue shading shows that Baoikhola is the most fortunate, in having a large permanent beel, while the other three mouzas have jolas, and these are important in guiding the settlement pattern. Daya, Narayandaha and Paschim Kharua each have a number of permanent SWB, whereas Baoikhola is deficient in this respect. Table 5.5 shows the numbers and percentages of inundation of SWB for each mouza.

**Table 5.5 Plot based Inundation 2002.**

| Mouza Name → | Baoikhola | | Daya | | Narayandaha | | Paschim Kharua | |
|---|---|---|---|---|---|---|---|---|
| Inundation ↓ | 2002(#) | 2002(%) | 2002(#) | 2002(%) | 2002(#) | 2002(%) | 2002(#) | 2002(%) |
| April_Dec | 76 | 4.79 | 0 | 0.00 | 0 | 0.00 | 19 | 1.38 |
| April_Oct | 0 | 0.00 | 2 | 0.17 | 0 | 0.00 | 0 | 0.00 |
| April_Sept | 0 | 0.00 | 1 | 0.08 | 0 | 0.00 | 0 | 0.00 |
| Jan_Dec | 82 | 5.17 | 45 | 3.81 | 30 | 5.31 | 31 | 2.26 |
| July_Aug | 9 | 0.57 | 3 | 0.25 | 0 | 0.00 | 0 | 0.00 |
| July_Oct | 0 | 0.00 | 23 | 1.95 | 0 | 0.00 | 0 | 0.00 |
| July_Sept | 0 | 0.00 | 605 | 51.18 | 0 | 0.00 | 0 | 0.00 |
| June_July | 1 | 0.06 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| May_Aug | 0 | 0.00 | 0 | 0.00 | 454 | 80.35 | 0 | 0.00 |
| May_Dec | 0 | 0.00 | 3 | 0.25 | 0 | 0.00 | 0 | 0.00 |
| May_Oct | 0 | 0.00 | 3 | 0.25 | 0 | 0.00 | 0 | 0.00 |
| May_Sept | 1319 | 83.11 | 0 | 0.00 | 0 | 0.00 | 1206 | 87.84 |
| None | 100 | 6.30 | 497 | 42.05 | 81 | 14.34 | 117 | 8.52 |
| Total | 1587 | 100 | 1182 | 100 | 565 | 100 | 1373 | 100 |

**Source: Author (2004).**




**Source : (Author 2004)**

**Figure 5.9 Plot based Inundation map 2002**

### 5.4.4 Agriculture

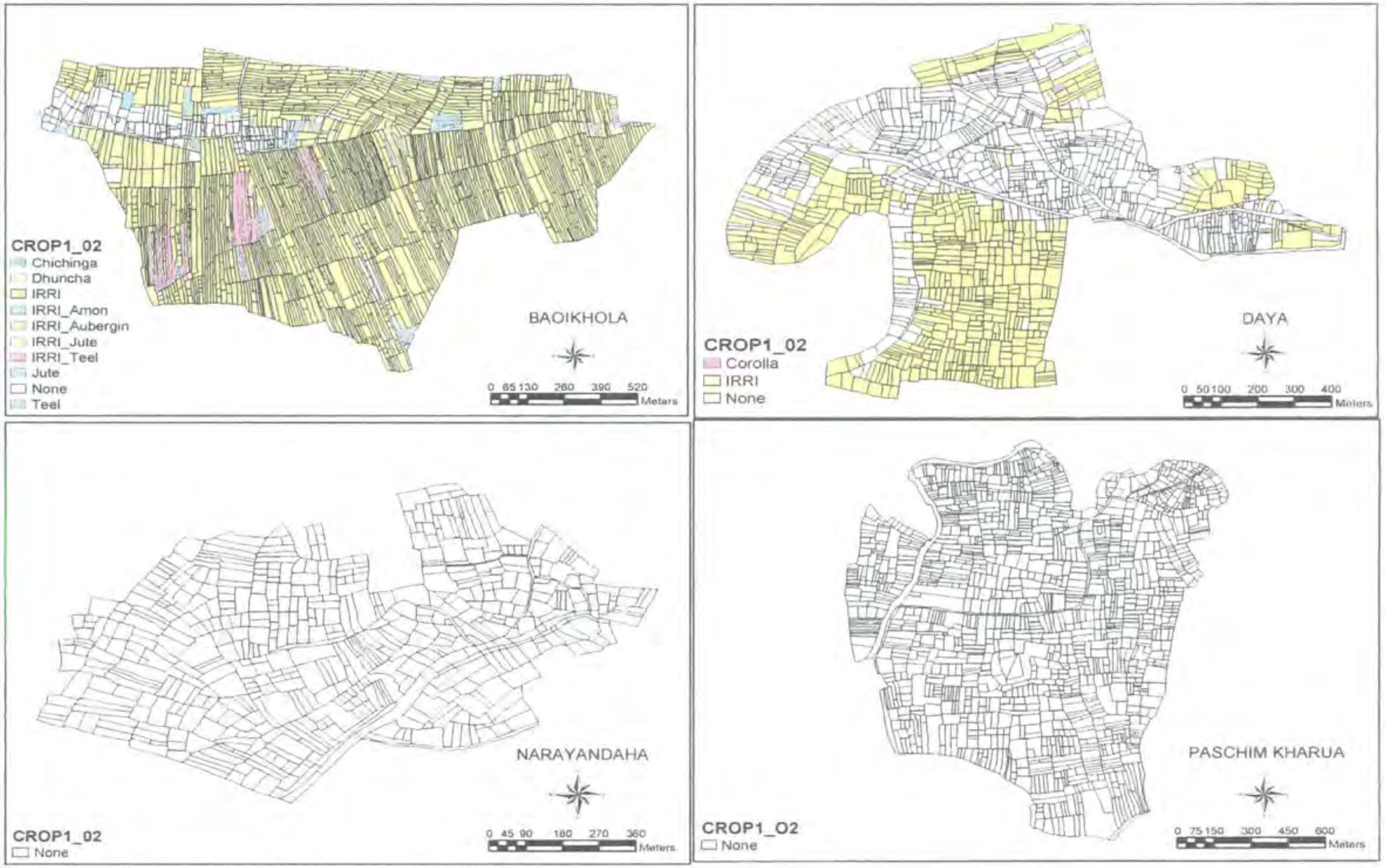
### 5.4.4.1 Kharif-I (Crop-1)

The kharif season (phase I April to July; phase II August to November) is the main cropping season for farmers in Baoikhola and Daya mouzas. They predominantly grow high yielding varieties of rice that were originally developed by the International Rice Research Institute in the Philippines (Table 5.6, Figure 5.10). Improved varieties of this 'green revolution' rice has been remarkably successful in Bangladesh, where they have supplanted the lower yielding local varieties. There are inherent dangers in this process, as has been flagged up in the literature, because non-indigenous varieties are less well adapted to local conditions. In addition to rice, there is a small amount of land in jute and teel (sesame) in Baokhola.

**Table 5.6 Plotbase Kharif-I (Crop-1).**

| Mouza Name → | Baoikhola | | Daya | | Narayandaha | | Paschim Kharua | |
|---|---|---|---|---|---|---|---|---|
| Kharif-I ↓ | 2002(#) | 2002(%) | 2002(#) | 2002(%) | 2002(#) | 2002(%) | 2002(#) | 2002(%) |
| Chichinga | 5 | 0.32 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Corolla | 0 | 0.00 | 1 | 0.08 | 0 | 0.00 | 0 | 0.00 |
| Dhuncha | 4 | 0.25 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| IRRI | 1334 | 84.06 | 513 | 43.40 | 0 | 0.00 | 0 | 0.00 |
| IRRI_Amon | 1 | 0.06 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| IRRI_Aubergin | 1 | 0.06 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| IRRI_Jute | 8 | 0.50 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| IRRI_Teel | 32 | 2.02 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Jute | 24 | 1.51 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| None | 150 | 9.45 | 668 | 56.51 | 565 | 100.00 | 1373 | 100.00 |

**Source: Author (2004).**




**Source : (Author 2004)**

**Figure 5.10 Plot based Agricultural Production 2002 (Kharif-I [Crop-1])**

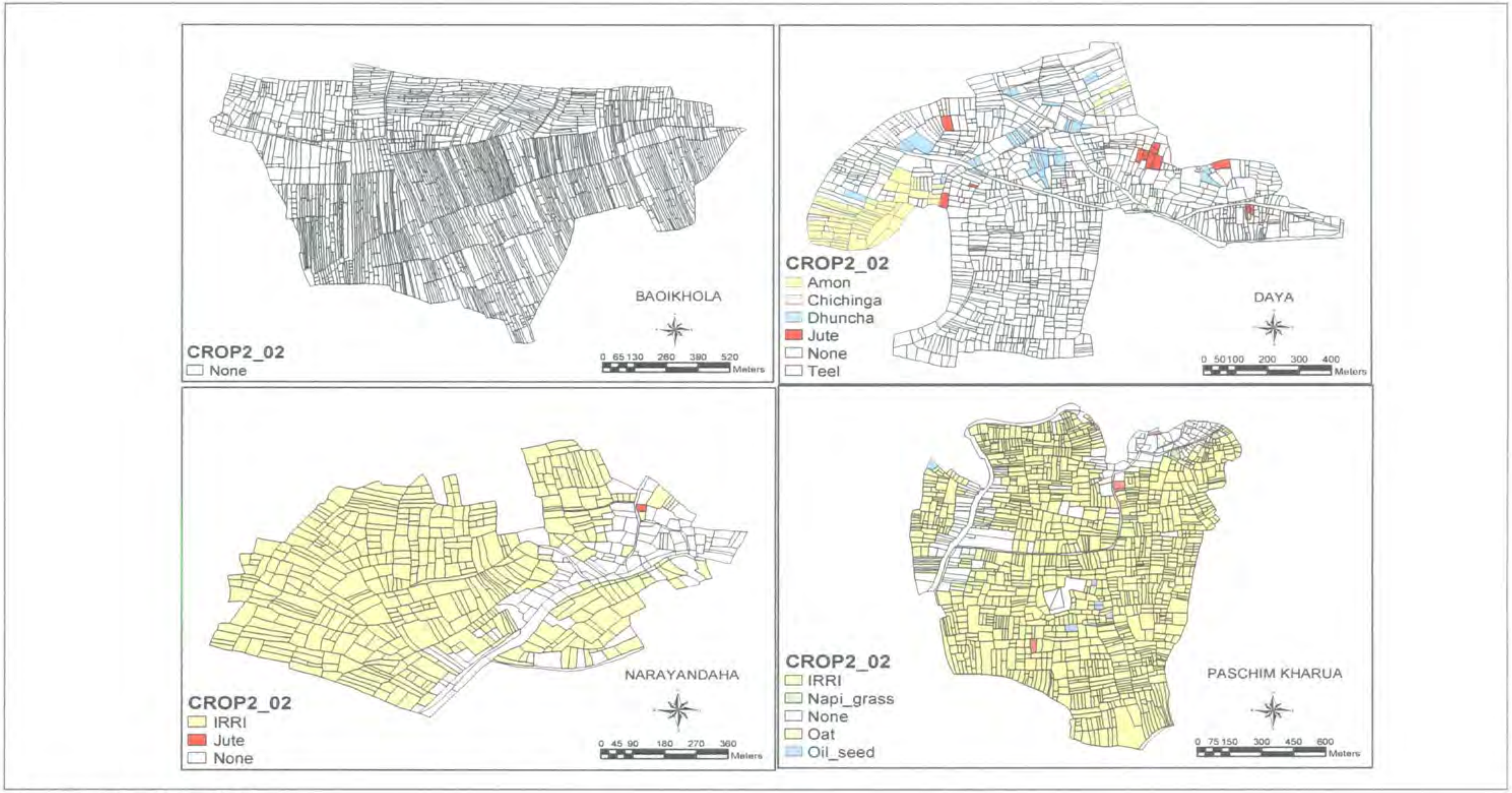
### 5.4.4.2 Kharif-II (Crop-2)

The 'low' land in Narayandhaya and Paschim Kharua is planted to Kharif II crops (Table 5.7, Figure 5.11). Again IRRI rice predominates. At this point I should point out that the data for Kharif I and II were based on the memories of farmers elicited during the fieldwork. The direct observation of myself and my field assistants was only possible from November onwards.

**Table 5.7 Plotbase Kharif-II (Crop 2).**

| Mouza Name → | Baoikhola | | Daya | | Narayandaha | | Paschim Kharua | |
|---|---|---|---|---|---|---|---|---|
| Kharif-II ↓ | 2002(#) | 2002(%) | 2002(#) | 2002(%) | 2002(#) | 2002(%) | 2002(#) | 2002(%) |
| Amon | 0 | 0.00 | 56 | 4.74 | 0 | 0.00 | 0 | 0.00 |
| Chichinga | 0 | 0.00 | 1 | 0.08 | 0 | 0.00 | 0 | 0.00 |
| Dhuncha | 0 | 0.00 | 45 | 3.81 | 0 | 0.00 | 0 | 0.00 |
| IRRI | 0 | 0.00 | 0 | 0.00 | 439 | 77.70 | 1178 | 85.80 |
| Jute | 0 | 0.00 | 15 | 1.27 | 1 | 0.18 | 0 | 0.00 |
| Napi grass | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 4 | 0.29 |
| None | 1587 | 100.00 | 1064 | 90.02 | 125 | 22.12 | 177 | 12.89 |
| Oat | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 7 | 0.51 |
| Oil Seed | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 7 | 0.51 |
| Teel | 0 | 0.00 | 1 | 0.08 | 0 | 0.00 | 0 | 0.00 |

**Source: Author (2004).**




**Source : (Author 2004)**

**Figure 5.11 Plot based Agricultural Production 2002 (Kharif-II [Crop-2])**

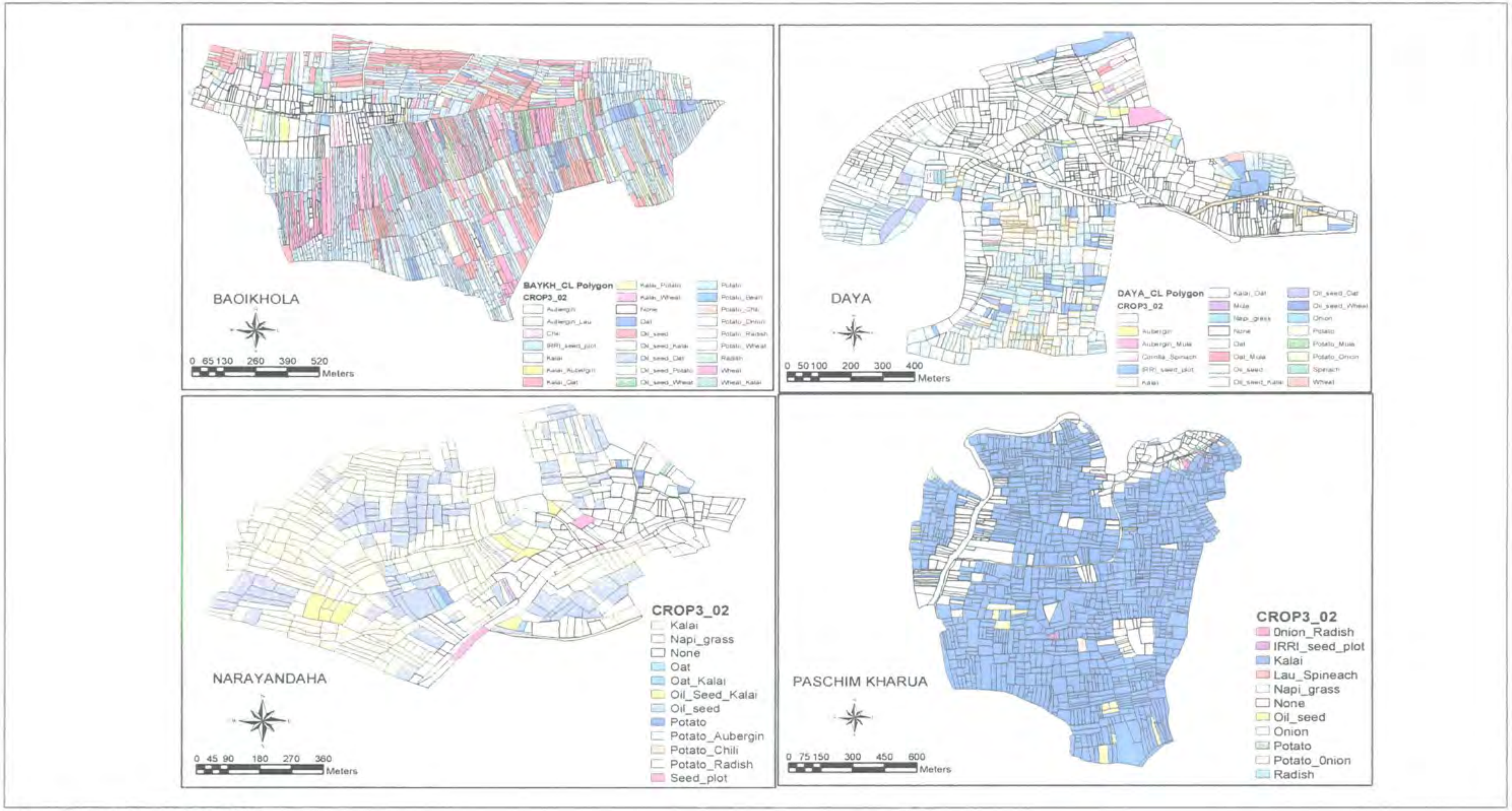
### 5.4.4.3 Rabi

The winter rabi season, December to March, is the dry period when farmers are not having to cope with floods. Traditionally, a wide variety of crops are grown using irrigation from SWB, rivers and tubewells. Table 5.8 and Figure 5.12 show the astonishing variety of crops grown, this time in all four mouzas. Baoikhola has the greatest variety, mainly in various combinations of cattle feed (kalai) with other crops. Farmers in this region combine two or three crops, sown and harvested at different times, in order to maximise the use of their land. Paschim Kharua, with its specialism in dairying, is almost entirely given over to kalai in the rabi season. This is an important feature of the agricultural economy. The other crops deserving attention are oil seeds, especially in Narayandaha, and a small amount of wheat in Baoikhola.

Table 5.8 Plotbase Rabi (Crop 3).

| Mouza Name → | Baoikhola | | Daya | | Narayandaha | | Paschim Kharua | |
|---|---|---|---|---|---|---|---|---|
| Rabi ↓ | 2002(#) | 2002(%) | 2002(#) | 2002(%) | 2002(#) | 2002(%) | 2002(#) | 2002(%) |
| Aubergin | 5 | 0.32 | 4 | 0.34 | 0 | 0.00 | 0 | 0.00 |
| Aubergin_Lau | 2 | 0.13 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Aubergin_Radish | 0 | 0.00 | 1 | 0.08 | 0 | 0.00 | 0 | 0.00 |
| Chili | 1 | 0.06 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Corolla_Spinach | 0 | 0.00 | 2 | 0.17 | 0 | 0.00 | 0 | 0.00 |
| IRRI_seed plot | 41 | 2.58 | 53 | 4.48 | 4 | 0.71 | 6 | 0.44 |
| Kalai | 790 | 49.78 | 116 | 9.81 | 296 | 52.39 | 1155 | 84.12 |
| Kalai_Aubergin | 1 | 0.06 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Kalai_Oat | 9 | 0.57 | 11 | 0.93 | 0 | 0.00 | 0 | 0.00 |
| Kalai_Potato | 8 | 0.50 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Kalai_Wheat | 39 | 2.46 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Lau_Spinach | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 1 | 0.07 |
| Napi Grass | 0 | 0.00 | 3 | 0.25 | 5 | 0.88 | 3 | 0.22 |
| None | 209 | 13.17 | 682 | 57.70 | 130 | 23.01 | 178 | 12.96 |
| Oat | 49 | 3.09 | 75 | 6.35 | 3 | 0.53 | 0 | 0.00 |
| Oat_Kalai | 0 | 0.00 | 0 | 0.00 | 1 | 0.18 | 0 | 0.00 |
| Oat_radish | 0 | 0.00 | 2 | 0.17 | 0 | 0.00 | 0 | 0.00 |
| Oil seed | 226 | 14.24 | 181 | 15.31 | 109 | 19.29 | 14 | 1.02 |
| Oil seed_Kalai | 56 | 3.53 | 5 | 0.42 | 9 | 1.59 | 0 | 0.00 |
| Oil seed_Oat | 2 | 0.13 | 5 | 0.42 | 0 | 0.00 | 0 | 0.00 |
| Oil seed_Potato | 2 | 0.13 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Oil seed_Wheat | 20 | 1.26 | 2 | 0.17 | 0 | 0.00 | 0 | 0.00 |
| Onion | 0 | 0.00 | 2 | 0.17 | 0 | 0.00 | 4 | 0.29 |
| Onion_Radish | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 1 | 0.07 |
| Potato | 9 | 0.57 | 26 | 2.20 | 5 | 0.88 | 8 | 0.58 |
| Potato_Aubergin | 0 | 0.00 | 0 | 0.00 | 1 | 0.18 | 0 | 0.00 |
| Potato_Bean | 1 | 0.06 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Potato_Chilli | 4 | 0.25 | 0 | 0.00 | 1 | 0.18 | 0 | 0.00 |
| Potato_Onion | 6 | 0.38 | 1 | 0.08 | 0 | 0.00 | 2 | 0.15 |
| Potato_Radish | 2 | 0.13 | 3 | 0.25 | 1 | 0.18 | 0 | 0.00 |
| Potato_Wheat | 1 | 0.06 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Radish | 1 | 0.06 | 2 | 0.17 | 0 | 0.00 | 1 | 0.07 |
| Spinach | 0 | 0.00 | 4 | 0.34 | 0 | 0.00 | 0 | 0.00 |
| Wheat | 101 | 6.36 | 2 | 0.17 | 0 | 0.00 | 0 | 0.00 |
| Wheat_kalai | 2 | 0.13 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Total | 1587 | 100 | 1182 | 100.00 | 565 | 100 | 1373 | 100 |

**Source: Author (2004).**




**Source : (Author 2004)**

**Figure 5.12 Plot based Agricultural Production 2002 (Rabi [Crop-3])**

### 5.4.5 Population

Because agriculture is the main activity in this thana, village populations dominate the local demography. These villages tend to be nucleated and are often linear, the main structural feature being ribbon development along a road or a jola. There are relatively few isolated farmsteads because most of the medium-high land, that is the least indundated area, is occupied.

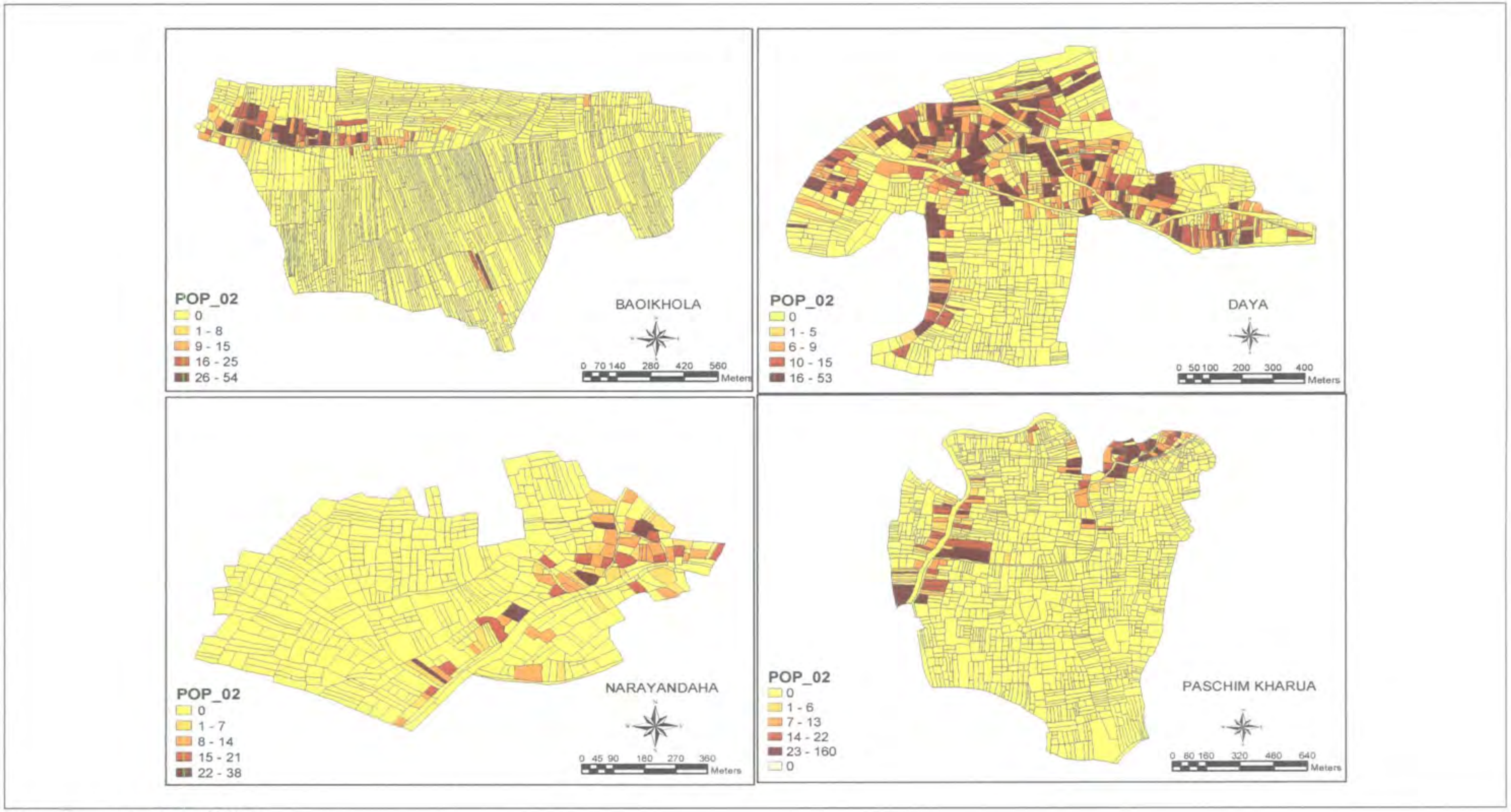
In my fieldwork I have visited each plot and counted the population in detail. This represents the most reliable data for these four mouzas and there are significant discrepancies with the population census, even though this was compiled as recently as 2000.

Table 5.9 and Figure 5.13 show the density of population in each mouza in terms of people per plot. Note that the class boundaries are different for each. There is no pattern immediately obvious from these maps in the way that one might expect a functional association with a central point of accessibility or a public service such as a mosque. On the ground, however, it is clear that there is some correlation between population density and the pattern of SWB. Whether this is cause or effect is debatable.

**Table 5.9 Plotbase population.**

| Population/plot↓ | Baoikhola | Daya | Narayandaha | Paschim Kharua |
|---|---|---|---|---|
| Min | 1 | 1 | 3 | 3 |
| Max | 54 | 53 | 38 | 160 |
| Mean | 17 | 11 | 11 | 17 |
| Standard Dev. | 12 | 9 | 7 | 18 |
| Total Population | 1496 | 4392 | 750 | 1703 |
| Total Plots | 86 | 388 | 66 | 101 |

**Source: Author (2004).**




**Source : (Author 2004)**

**Figure 5.13 Plot based Population map 2002.**

### 5.4.6 Housing

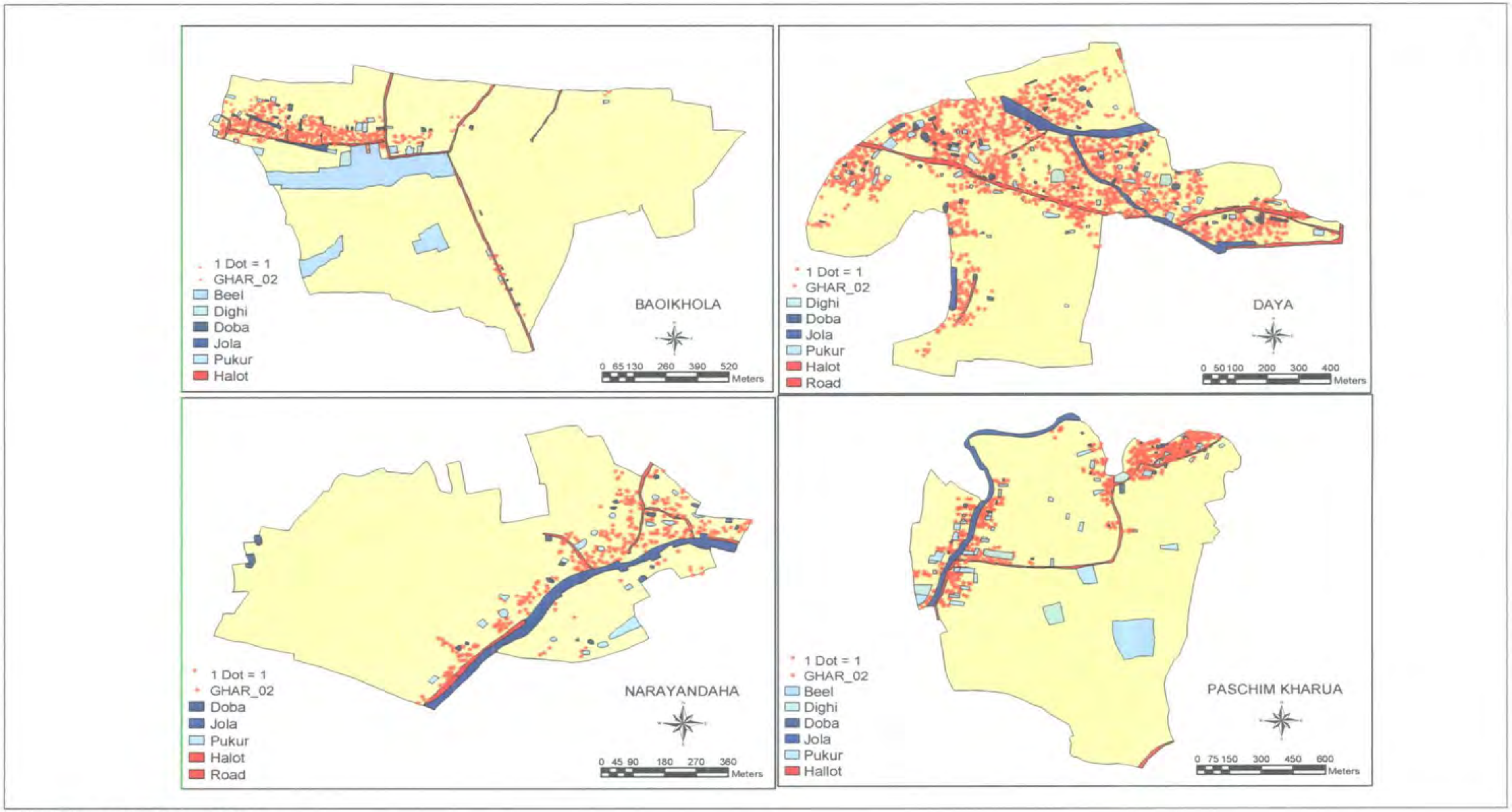
Table 5.10 and Figure 5.14 are based on data for every ghar in the four mouzas. A ghor is a house and is not necessarily the same as a household. In the complex situation of rural Bangladesh, it may be that the people of several buildings in a compound eat together from one stove. These people are often relatives from the same extended family.

The map shows that Paschim Kharua is especially densely built-up, in two small portions of the mouza, along the road and beside the jola. Daya retains some open space between the ghors, retaining some of the open texture of village patterns in this part of Bengal. In both Narayandaha and Baoikhola linearity is noticeable and we should perhaps mention that in the former mouza a large Hindu population started leaving after the Liberation War in 1971 and this exodus was concluded in the 1990s with many moving to the Paurashava of beyond. They have been replaced by another minority group, Shia muslims, mainting this mouza's ghetto status. The population of Narayandaha is the only one to remain stable at 750, as against 761 in 1991.

**Table 5.10 Plotbase numbers of house.**

| Ghars/plot↓ | Baoikhola | Daya | Narayandaha | Paschim Kharua |
|---|---|---|---|---|
| Total Plots | 90 | 417 | 69 | 108 |
| Min | 1 | 1 | 1 | 1 |
| Max | 29 | 22 | 14 | 56 |
| Mean | 8 | 4 | 5 | 6 |
| Standard Dev. | 6 | 3 | 3 | 7 |
| Total Ghars | 678 | 1775 | 357 | 698 |
| Pucca | 2 | 2 | 1 | 5 |
| Tin Roof | 605 | 1697 | 341 | 600 |
| Others | 71 | 76 | 15 | 93 |

**Source: Author (2004).**




**Source : (Author 2004)**

**Figure 5.14 Plot based houses 2002**

### 5.5 Analysis, Results and Discussions (Questionnaire Survey)

#### 5.5.1 Population Characteristics

Population characteristics are important for any resource management planning. Increasing pressure of population and demand for water leads to the creation of more SWB. The uses of the SWB change according to the number, structure and characteristics of the surrounding population. Moreover, overall management and development planning for SWB will be a function of demand and perception. It will therefore be helpful to have a brief discussion on the population characteristics of the study area, based on data collected during field work using in-depth questionnaire surveys.

**Table 5.11 Population distribution by sex (percentage).**

| Sex | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Male | 54.74 | 56.88 | 54.70 | 55.09 | 55.36 |
| Female | 45.26 | 43.12 | 45.30 | 44.91 | 44.64 |

**Source: Author (2001-2).**

The sample represents the study area population distribution by sex and mouzas. It is similar to the national average, although confidence in the latter is undermined by criticisms that have been levelled at the population census (Rashid 2003). Table 5.11 shows that the four mouzas have almost similar figures. Daya has the highest male population whereas Narayandaha has the highest female population. The average percentages of those mouzas are 55.36 for males and 44.64 for females. Although the literature indicates that one might expect a male bias in the demographic structure, the imbalance here is so marked that one suspects an undercounting of females. It may be that male interlocutors have failed to report some female members of their families, but checking is impossible because one of the difficulties in working as a male in rural Bangladesh is that talking to women is unacceptable.

#### 5.5.1.1 Family Size

Out of 450 (Baoikhola:100, Daya: 150, Narayandaha: 100 and Paschim Kharua 100) questionnaire surveys, the modal category of family consist of 4-5 members followed by 6-7 members. In Baoikhola mouza the mode is 6-7 members, and, according to Table 5.12, there were no families in Narayandaha of 10 or more members.

**Table 5.12 Family size in percentages.**

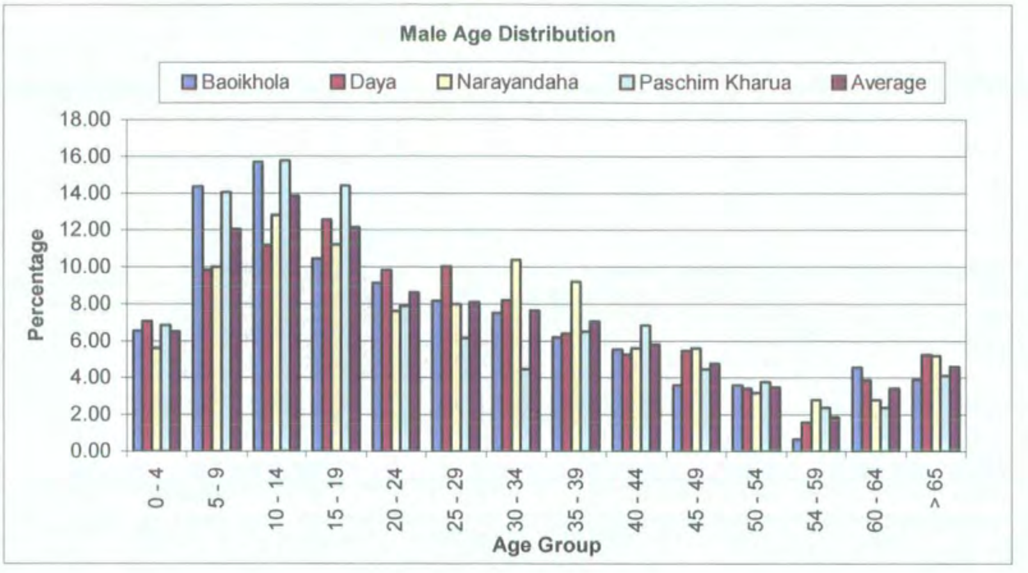
| Family Size | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| 2 - 3 | 11.00 | 18.67 | 21.00 | 7.00 | 14.42 |
| 4 - 5 | 37.00 | 44.00 | 58.00 | 53.00 | 48.00 |
| 6 - 7 | 43.00 | 28.00 | 18.00 | 35.00 | 31.00 |
| 8 - 9 | 7.00 | 7.33 | 3.00 | 3.00 | 5.08 |
| > 10 | 2.00 | 2.00 | 0.00 | 2.00 | 1.50 |

**Source: Author (2001-2).**

#### 5.5.1.2 Age-sex Distribution

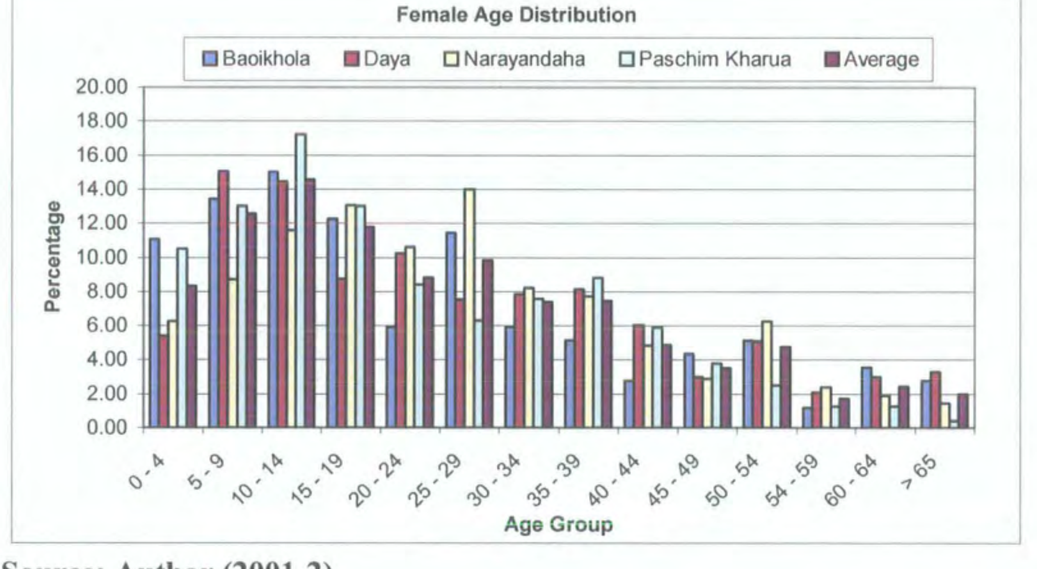
The age-sex distribution is one of the vital components of the population characteristics. For instance the location of the SWB is affected. If a household had more female and old members then the SWB will be close to the house and preferably in the homestead garden, while younger males would not hesitate to use distant or other SWB. The following is a brief discussion of the questionnaire.

The age-sex distribution of total population is shown in figures 5.15 and 5.16. Note the peak numbers in the age group 10-14 followed by 5-9 and 15-19, for both and male and female. A total of approximately 50 percent of the population falls in the active age groups of 20-24, 25-29, 30-34, 34-39 and 40-44. Low numbers at age 0-4 are an encouraging demonstration of a fall in the birth rate, which has fortunately been accompanied by a fall in the infant mortality rate.




**Source: Author (2001-2).**

**Figure 5.15 Distribution of Population according to age groups (percentage).**

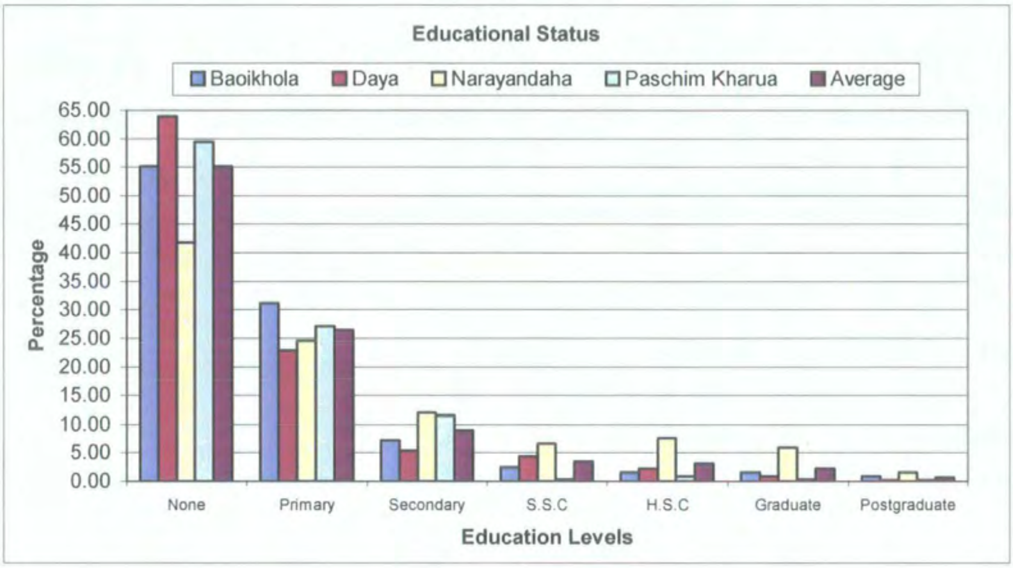



**Source: Author (2001-2)**

**Figure 5.16 Female Age Distribution in percentage.**

### 5.5.1.3 Education

Educational status is important for understanding the people's demands and capabilities. Unfortunately more then 55 percent of the population are illiterate. The highest literacy rate is found in Narayandaha mouza and the lowest in the Daya. On average, 26.40 percent had education up to primary level, followed by 9 percent up to Secondary. The remaining 10 per cent have education levels from secondary to postgraduate (see Figure 5.17).




**Source: Author (2001-2).**

**Figure 5.17 Educational level in Percentage.**

### 5.5.1.4 Occupation

Very high proportions are unemployed (31.37 percent), followed by housewives (21.20 percent) and those in education (19.48 percent). Most of the population are therefore not engaged in any economic activity or generating income. Among the income earners, most are farmers (12.5 percent) and agriculture is the main livelihood locally (Table 5.13). Others among the non income earning community seasonally help on their family members with the agricultural activity. There is a lot scope of for generating income from SWB, especially those that are lying derelict beside houses and were only excavated in order to raise a mound for the homestead. The most significant potential livelihood is fish farming if the SWB are managed properly through an appropriate system.

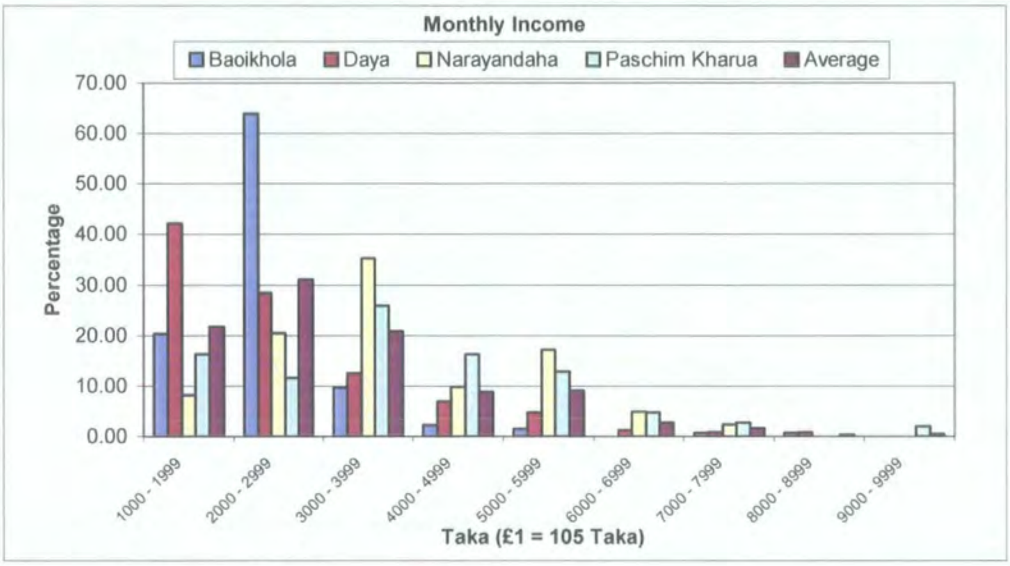
**Table 5.13 Different Occupations in percentages.**

| Occupasion | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Bus Driver | 0.00 | 1.17 | 0.00 | 0.76 | 0.48 |
| Business | 1.84 | 3.39 | 5.33 | 1.71 | 3.07 |
| Carpenter | 0.18 | 0.00 | 0.00 | 0.00 | 0.05 |
| Doctor | 0.00 | 0.13 | 0.00 | 0.00 | 0.03 |
| Farmer | 10.48 | 5.74 | 13.11 | 22.48 | 12.95 |
| Handloom | 12.68 | 15.51 | 1.33 | 0.76 | 7.57 |
| Housewife | 21.69 | 19.82 | 23.11 | 20.19 | 21.20 |
| Labour | 0.55 | 0.52 | 0.22 | 0.19 | 0.37 |
| None | 24.08 | 35.59 | 28.67 | 37.14 | 31.37 |
| Rickshaw Puller | 0.18 | 0.00 | 0.44 | 0.38 | 0.25 |
| Service | 2.39 | 1.83 | 2.89 | 1.33 | 2.11 |
| Shop Keeper | 0.37 | 0.26 | 0.44 | 0.00 | 0.27 |
| Student | 25.55 | 15.78 | 21.56 | 15.05 | 19.48 |
| Tailor | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Teacher | 0.00 | 0.26 | 2.89 | 0.00 | 0.79 |

**Source: Author (2001-2).**

### 5.5.1.5 Income

The highest percentage (31.10) of the population falls into the monthly 2000-2999 taka (£20-29) income category (Figure 5.18). The majority (93 per cent)) of people earn monthly 1000-5999 taka (£10-59). According to local livelihoods, these incomes differ in the various parts of the thana. But overall the four mouzas' average income is very similar to whole the thana and to Bangladesh overall apart from some cities.




**Source: Author (2001-2).**

**Figure 5.18 Monthly Income level.**

#### 5.5.1.6 Social Status

The survey reveals no significant variations in social status. The highest proportion of the population falls into the medium category (57 per cent on average). Daya has more people living in poverty. These categories have been derived from the overall household situation and also depend on the respondents' own self-definition. The categories are not precise and are reported in the spirit of rapid rural appraisal, as indicative (Table 5.14).

There are no matbars, sardars or leaders in these mouzas apart from 2 percent in Paschim Kharua. This is not a good sign as, without leadership, the mouzas are in a fragile condition, especially for representing their needs to the local government and to encourage the development of their own area. Civil society in this region it seems is weakly developed.

**Table 5.14 Percentages of social status.**

| Types | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Rich | 4 | 3 | 1 | 4 | 3 |
| Medium | 68 | 45 | 54 | 63 | 57 |
| Poor | 28 | 51 | 45 | 33 | 39 |
| Matbar | 0 | 0 | 0 | 1 | 0 |
| Sardar | 0 | 0 | 0 | 0 | 0 |
| Leader | 0 | 0 | 0 | 2 | 1 |

**Source: Author (2001-2).**

### 5.5.2 Housing Characteristics

Housing characteristics indices are valuable in understanding the socio-economic condition of a certain area. Some housing characteristics were therefore incorporated into the questionnaire survey in order to understand the reality and context so vital for management planning. The following is a presentation of the results and a brief discussion.

#### 5.5.2.1 Type of Housing

All four mouzas are situated in a very remote rural location. It is a poor area like other parts of the thana and lacks proper management planning of the different components of its resources for development. There are no traces of any Pucca building except for a few primary school buildings and government offices. Most of the houses are constructed of galvanised tin sheets, and the remainder from bamboo, jute sticks and other materials (Table 5.15).

**Table 5.15 Type of House Construction (percentages).**

| Types | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Pucca | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tin | 72.00 | 76.00 | 75.00 | 85.00 | 77.00 |
| Other | 28.00 | 24.00 | 25.00 | 15.00 | 23.00 |

**Source: Author (2001-2).**

### 5.5.2.2 Roof Materials

The roofs of all of the houses are made of tin. This indicates that it is a moderately low income area (Table 5.16). People use tin for water proofing otherwise they would employ cheaper materials like sone (a thatch of long grass).

**Table 5.16 Type of Roof Materials (percentages)**

| Roof Material | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Pucca | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tin | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Other | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Source: Author (2001-2).**

### 5.5.2.3 Wall Materials

There were no houses with pucca walls made of bricks and cement. The majority of walls are constructed with tin sheets. According to the survey, 22.75 percent on average are constructed using jute and bamboo sticks in these four mouzas of Shahjadpur thana (Table 5.17).

**Table 5.17 Type of Wall Materials in percentages.**

| Wall Material | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Pucca | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tin | 72.00 | 76.00 | 75.00 | 86.00 | 77.25 |
| Jute-Bamboo stick | 28.00 | 24.00 | 25.00 | 14.00 | 22.75 |

**Source: Author (2001-2).**

### 5.5.3 Utilities

The availability of utility services is important in judging the socio-economic situation of a region or area. On average, among the four mouzas, 34.92 percent of households are connected to electricity (Table 5.18), although none of the households of Baoikhola mouza has a connection. None of the households in the study area has gas, telephone, and sewerage or mains water supply. This last point is an important consideration because it means a greater incentive to construct, maintain and use SWB.

**Table 5.18 Availability of different utilities in percentages.**

| Utility | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Electricity | 0.00 | 46.67 | 48.00 | 45.00 | 34.92 |
| Gas | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Telephone | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Sewerage | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Water Supply | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Source: Author (2001-2).**

### 5.5.4 Source of Fuel

There is a surprising variety of domestic fuels in the region, depending largely upon the resources to hand. Paschim Kharua is the only mouza where households rely upon dung from animals. Other mouzas also use leaves or wood. All the households of the Baoikhola and Narayandaha and a large portion (74 per cent) of Daya depend on leaves vegetation as well as animal dung (see Table 5.19).

**Table 5.19 Percentages of fuel source.**

| Types | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Dung | 99 | 100 | 98 | 99 | 99 |
| Wood | 97 | 13 | 99 | 6 | 54 |
| Leaves | 100 | 74 | 100 | 9 | 71 |
| Jute stick | 0 | 2 | 0 | 0 | 1 |
| Gas | 0 | 0 | 0 | 0 | 0 |

**Source: Author (2001-2).**

### 5.5.5 Land Utilization

Information on the different types of land utilization by households has been gathered through the questionnaire survey. Table 5.20 shows that almost all (99.58 per cent) of the households have a homestead garden. 44.08 percent also have cultivated land. Significantly, households own small water bodies: 33.25 per cent have a Doba and 26.25 per cent a Pond because these are considered to be essential necessities of daily life.

The mean homestead area per house hold is 0.7 acres (Rashid, 1991) for Bangladesh as whole. A range of vegetables and fruits are grown in homestead gardens. These are part of the regular diet whereas field crops consist in the main of grain for home consumption and sale. In terms of diversity and quality, homestead gardens play an important role, which is normally ignored in agricultural studies (Ghosh, 2002). According to Bloem et al., traditional homestead gardens in Bangladesh provide valuable vitamin-rich fruits and vegetables, which are scarce in other dietary sources (Bloem et al., 1996). They provide not only vitamins, but are the source of other essential nutritional elements. So consideration needs to be given to the homestead gardens under household land utilization.

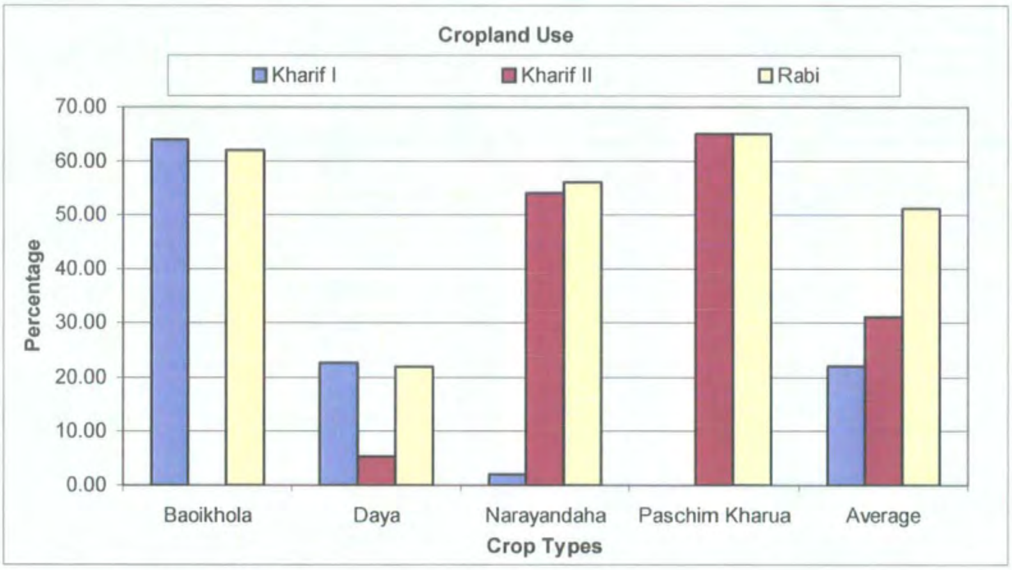
**Table 5.20 Different Land Utilization in each household (percentages).**

| Land Utilization | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Doba | 39.00 | 46.00 | 27.00 | 21.00 | 33.25 |
| Pond | 12.00 | 22.00 | 30.00 | 41.00 | 26.25 |
| Dighi | 0.00 | 2.00 | 0.00 | 5.00 | 1.75 |
| Jola | 6.00 | 7.33 | 31.00 | 0.00 | 11.08 |
| Beel | 1.00 | 0.00 | 0.00 | 0.00 | 0.25 |
| Cultivated | 34.00 | 21.33 | 57.00 | 64.00 | 44.08 |
| Homestead | 100.00 | 99.33 | 100.00 | 99.00 | 99.58 |

**Source: Author (2001-2).**

### 5.5.6 Cropland Use

Agricultural cropland use plays vital role in understanding livelihoods and socioeconomic conditions. Most of the employed population of the area are farmers. Most of the agricultural land produces two crops per annum and some three. According to the crop calendar the whole year is divided into three crop seasons named Kharif-I, Kharif-II and Rabi. On average most of the crop land is used for Rabi crops in the winter. In Baoikhola mouza 64 percent of the agricultural land is used for the Kharif-I crop (Figure 5.19).




**Source: Author (2001-2).**

**Figure 5.19 Different Cropland Uses (percentages).**

### 5.5.7 Homestead Plants

Bangladeshi homestead gardens follow a traditional production system where people cultivate plants for multipurpose use. They are a customary source of food, timber, firewood, fodder, fibre and medicines (Ghosh, 2002). Most of the literature on homestead gardens in Bangladesh (Hocking et al., 1996; Hocking and Islam, 1994; Millat-E-Mostafa, 2000) combines floral composition, structure, management and economic aspects, but pays little consideration to socio-economic and cultural issues, particularly any association with the SWB.

Most rural Bangladesh households either own or share homestead gardens. Their homestead garden signifies the status of farm families: the wealthier the family, the larger the homestead as a production unit (Ghosh, 2002). The product of homestead gardens remains largely unseen because it is not marketed or at least only sold irregularly on a small scale (Chambers, 1997; Hocking et al., 1996; Hoogerbrugge and Fresco, 1993; Rocheleau and Raintree, 1986). These crops are destined mainly for the family's own consumption. The homestead garden is often treated as a secondary source of food and income, while field crops are the major source (Ghosh, 2002).

Millate-e-Mustafa (2000) records 120 perennial species from 200 home gardens and about 85 species having more than one use. He does not include any annual plants or herbs. In his study, he found that some species (e. g. mango, coconut, etc.) have more than seven uses. Women nurture these gardens and they can choose what they plant according to their family's needs. These consist mainly of fruits and vegetables, spices, construction and craft materials, medicine, live fence, etc. purposes. Women not only cultivate crops, but also are also responsible for domestication of several wild plants (Rocheleau et al., 1985; Sillitoe, 1993).

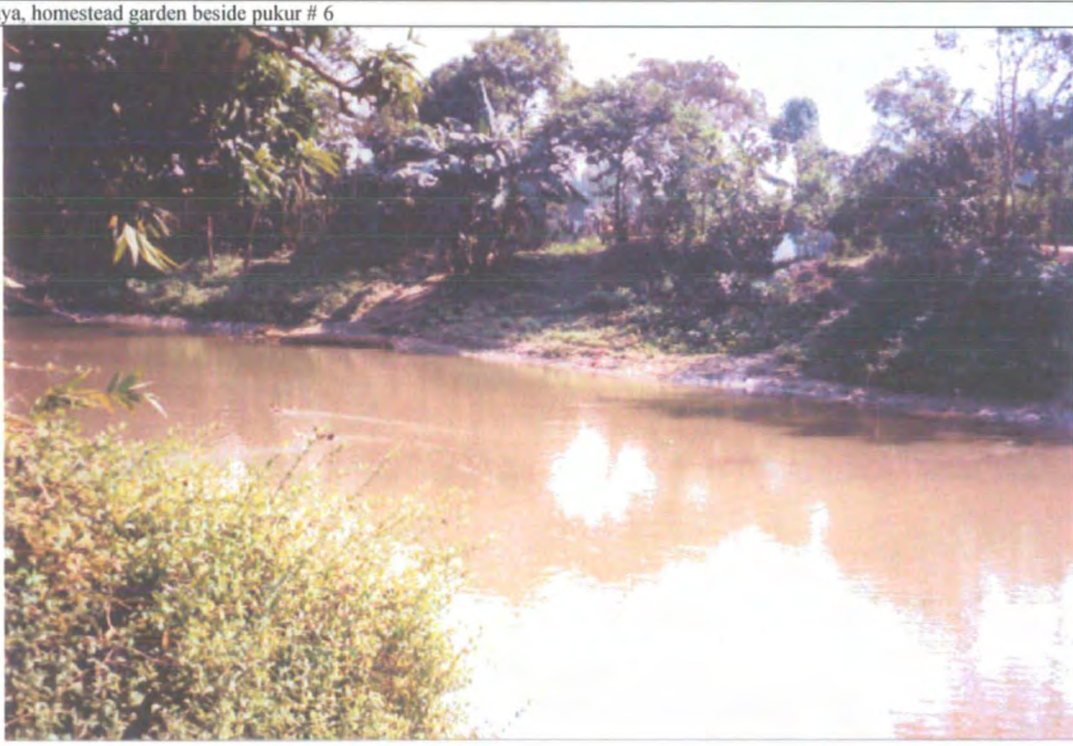
Table 5.21 Percentages of households for homestead Plants.

| Items | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Mango | 48 | 79 | 70 | 61 | 64 |
| Jackfruit | 25 | 24 | 53 | 19 | 30 |
| Coconut | 9 | 29 | 34 | 43 | 29 |
| Guava | 21 | 37 | 11 | 14 | 21 |
| Papaya | 33 | 15 | 23 | 7 | 19 |
| Banana | 14 | 17 | 33 | 5 | 17 |
| Beans | 36 | 9 | 23 | 1 | 17 |
| Laau | 44 | 5 | 14 | 4 | 17 |
| Bamboo | 25 | 11 | 28 | 2 | 17 |
| Borai | 12 | 17 | 22 | 8 | 15 |
| Koroi | 16 | 8 | 0 | 5 | 7 |
| Jam | 10 | 7 | 2 | 8 | 7 |
| Kadom | 0 | 19 | 2 | 1 | 5 |
| Meheguni | 3 | 4 | 6 | 8 | 5 |
| Neem | 10 | 3 | 1 | 3 | 4 |
| Pulm | 0 | 3 | 2 | 11 | 4 |
| Auberjine | 7 | 1 | 5 | 1 | 4 |
| Bel | 6 | 1 | 3 | 1 | 3 |
| Dembul | 10 | 1 | 0 | 0 | 3 |
| Eukaliptus | 2 | 2 | 1 | 5 | 3 |
| Tatul | 6 | 1 | 0 | 3 | 2 |
| Kamranga | 7 | 1 | 0 | 0 | 2 |
| Olive | 2 | 1 | 4 | 1 | 2 |
| Shisu | 2 | 0 | 0 | 4 | 2 |
| Dates | 0 | 1 | 4 | 1 | 1 |
| Dalim | 1 | 0 | 1 | 2 | 1 |
| Shimul | 2 | 0 | 2 | 0 | 1 |
| Supari | 0 | 3 | 0 | 0 | 1 |
| Jaga | 1 | 1 | 0 | 1 | 1 |
| Ata | 1 | 1 | 0 | 0 | 1 |
| Sajna | 2 | 0 | 0 | 0 | 1 |
| Shisu | 2 | 0 | 0 | 0 | 1 |
| Lemon | 0 | 1 | 0 | 1 | 0 |
| Gub | 1 | 0 | 0 | 0 | 0 |
| Lichie | 1 | 0 | 0 | 0 | 0 |
| Petuli | 1 | 0 | 0 | 0 | 0 |
| Puishak | 1 | 0 | 0 | 0 | 0 |
| Sora | 1 | 0 | 0 | 0 | 0 |
| Pumpkin | 0 | 1 | 0 | 0 | 0 |
| Chilie | 0 | 0 | 0 | 0 | 0 |

**Source: Author (2001-2).**

In my study area the mango tree is the most common (see Table 5.21). This is the source of fruit as well as of timber at the end. The same is true for the Jackfruit which is found in especially large numbers in Narayandaha mouza. Here it is worth to mentioning that jackfruit is the national fruit of Bangladesh. Both Mango and Jackfruit have different uses apart from their tasty, juicy and aromatic nature. Other fruit trees like coconut, guava and papaya are also prominent. There are also vegetables like beans (including sword, French, soya and velvet) and laau (pumpkins and gourds). These are cultivated mainly for home consumption.

Daya, homestead garden beside pukur # 6



Narayandaha, jhola # 1.

**Source: Author (2001-2).**

**Figure 5.20 Homestead plants beside the SWB.**

### 5.5.8 Plants associated with small water bodies

Plant diversity is substantial and is allied with the SWB. Wealthier families are interested in growing more tree crops for fruits whereas poorer families concentrate on vegetable crops like laau and beans. During lean periods, low-income families depend, particularly, on leafy vegetables and fruits which, in part, compensate nutritionally for their lower consumption of staple foods (BRAC, 1983; Chambers, 1993; Stokoe, 2000; Wallace et al., 1987). So the importance of plants besides the SWB is immense for management planning.

Most of the SWB are surrounded by bushes which can be seen in photography, especially bamboo. These are used for a variety of household purposes. Fruit trees like banana, coconut and mango are also prominent (Table 5.22).

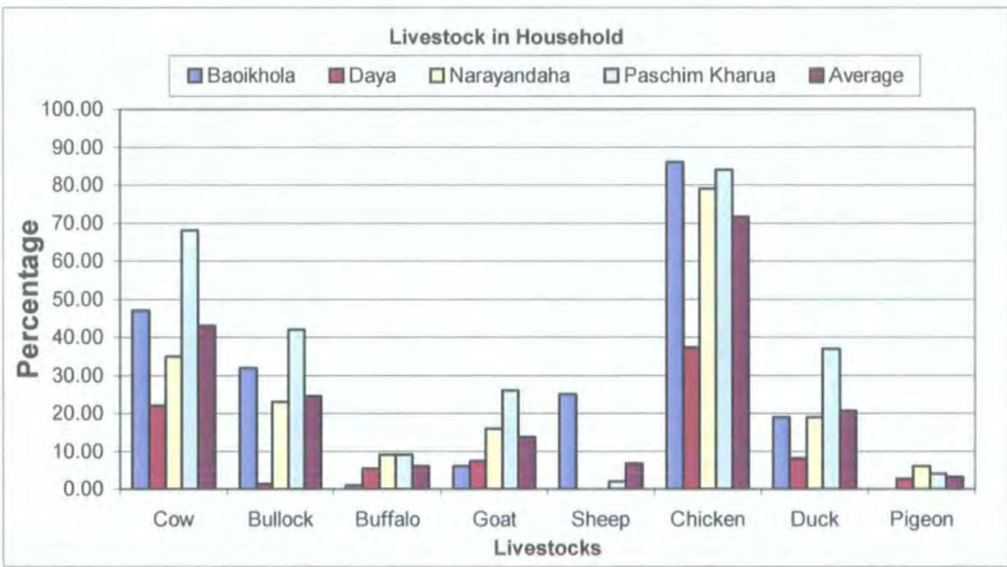
**Table 5.22 Percentages of households for homestead Plants.**

| Items | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Bamboo | 12 | 20 | 31 | 0 | 16 |
| Banana | 0 | 6 | 12 | 0 | 5 |
| Mango | 0 | 7 | 10 | 0 | 4 |
| Coconut | 0 | 6 | 6 | 0 | 3 |
| Bush | 0 | 5 | 7 | 0 | 3 |
| Borai | 1 | 2 | 6 | 0 | 2 |
| Guava | 1 | 1 | 4 | 0 | 1 |
| Papaya | 0 | 2 | 3 | 0 | 1 |
| Tatul | 0 | 1 | 3 | 0 | 1 |
| Kadom | 0 | 3 | 0 | 0 | 1 |
| Koroi | 0 | 1 | 2 | 0 | 1 |
| Shimul | 0 | 1 | 2 | 0 | 1 |
| Laau | 1 | 1 | 0 | 0 | 1 |
| Meheguni | 1 | 1 | 0 | 0 | 1 |
| Dembul | 1 | 0 | 1 | 0 | 1 |
| Pulm | 0 | 1 | 0 | 0 | 0 |
| Auberjine | 1 | 0 | 0 | 0 | 0 |
| Jackfruit | 0 | 0 | 1 | 0 | 0 |
| Bean | 0 | 1 | 0 | 0 | 0 |
| Dates | 0 | 1 | 0 | 0 | 0 |
| Eukaliptus | 0 | 1 | 0 | 0 | 0 |
| Supari | 0 | 1 | 0 | 0 | 0 |

**Source: Author (2001-2).**

### 5.5.9 Livestock

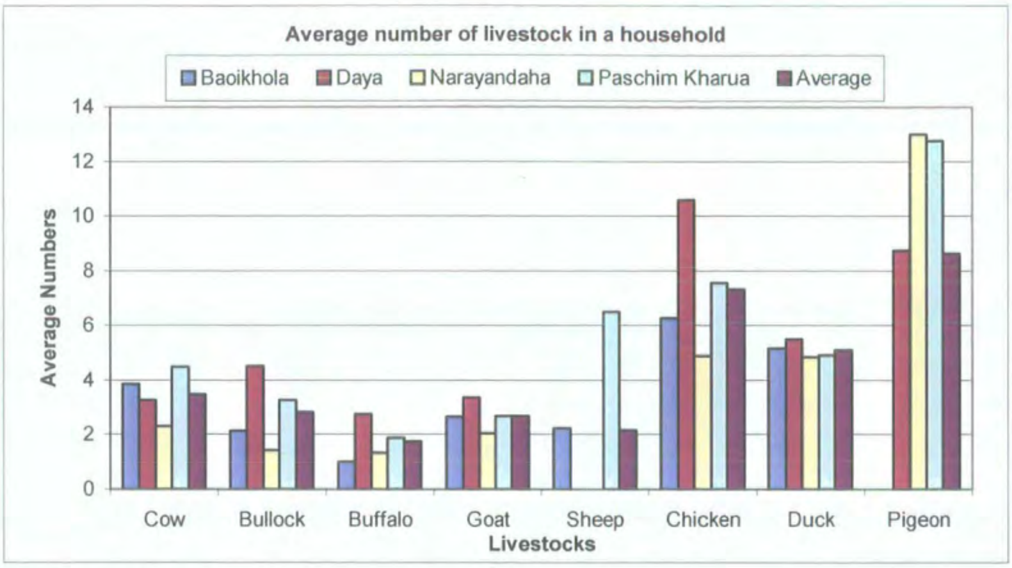
Along with fish, livestock products are important sources of protein in the local diet yet they are often neglected in agricultural geographies of Bangladesh. In this area there is no surprise that chickens are popular, although less so in Daya mouza. Ducks also are significant, especially in Paschim Kharua and, given the local availability of SWB, this is a sector that has further potential. The cow rather then the buffalo is this region's preferred dairy animal. Along with bullocks, they are the main source of meat, with goats and sheep having only a modest presence. The country's largest dairy cooperative, Milk Vita is located nearby in Baghabari mouza.




**Source: Author (2001-2).**

**Figure 5.21 Percentages of different livestock in households.**

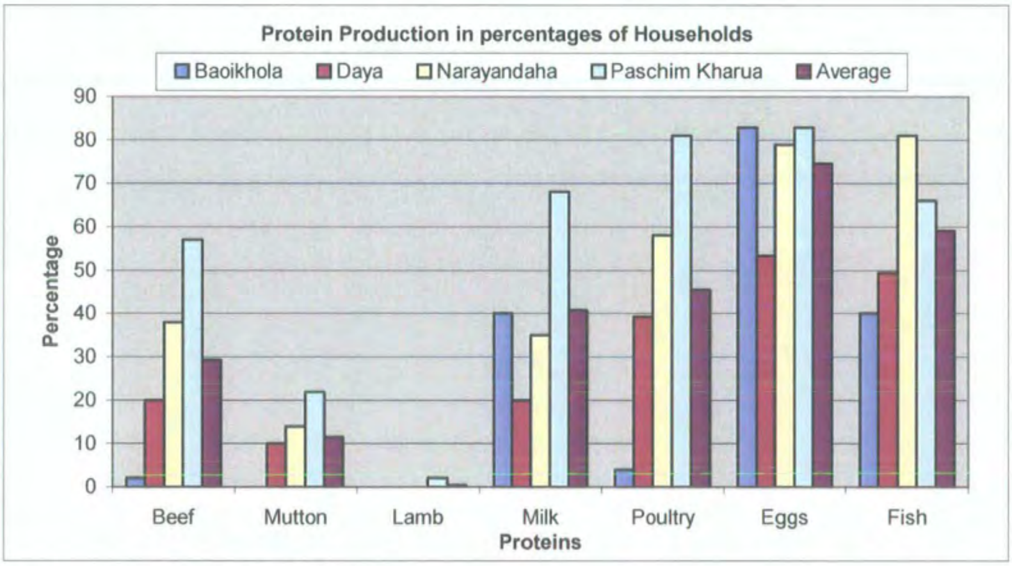
Figure 5.21 gives an interesting snapshot of ownership patterns among these households that have small or large livestock. It seems that pigeons are kept in relatively large numbers, along with chickens. Despite the commercial dairy farming in the thana the average number of cattle for ordinary farms is less than four for cows and bullocks. Sheep are absent in two mouzas (see figure 5.22).




**Source: Author (2001-2).**

**Figure 5.22 Average number of livestock in a household.**

Most protein produced in the study area is for auto-consumption. Eggs are a key source in the diet, along with fish. Being close to a large river, some of the fish are wild but the majority are farmed in SWB. The poultry and pigeons are dual purpose, yielding meat and eggs, although this is less true in Baoikhola, where eggs are the primary product (see Figure 5.23).




**Source: Author (2001-2).**

**Figure 5.23 Protein Production in Percentage of Households.**

### 5.5.10 Fisheries

Understanding the organization of fisheries is important for future development and management planning. There are two types locally: farmed and wild. Usually most of the SWB are naturally recharged from the migration of fingerlings/carps because, in the phase of rising water, the SWB spill over to floodplains and the fish spread by lateral migration. In the receding phase, the water drains from the floodplains as the flooded area diminishes and there is a movement of fish to the river and other SWB.

All of the SWB can be categorised into four aquaculture categories according to the Master Plan Organisation (MPO, 1984). i) Extensive: stocking with carp, no fertilization and feeding. ii) Semi-intensive: stocking with carp, multi-species culture with fertilization but without feeding. iii) Semi-intensive: stocking with carp, multi-species culture with fertilization and low quality feeding. iv) Super intensive: stocking with carp or tilapia, multi-species culture, increased water use and aeration, heavy and regular fertilization and feeding with highly quality feed. Almost all of the SWB in the study area fall into the first two categories. There is a lot of scope for the fisheries through the practice of managed culture.

Of the five reasons suggested by Wood (1994) for a decline of stocks of fish, three are observable locally. The geography of food fish farming sets potential limits to the expansion of the commercial operator category. Marketed food fish are produced for and consumed mainly by the wealthier groups. Disincentives for SWB to be farmed more intensively are the production for use rather than exchange; and co-ownership is often mentioned as a constraint, though there is potentiality for women as co-operators between co-owning joint families.

### 5.5.11 Health and Sanitation

#### 5.5.11.1 Types of Latrine

The household sanitation in the study area is a source of concern. In Daya and Paschim Kharua over 90 percent have access only to kacha latrines, the worst category. Each is a small hut with thatch as walls and the effluent drains to the SWB (Figure 5.24). Some are made with bamboo sheets looking like a small box latrine suspended over the SWB. These are very unhygienic and need proper attention in the management of the SWB. Only in Narayandaha is the situation at all hopeful, although even here only 30 percent have pucca latrines (Table 5.23). Latrines are not only unhygienic for the SWB but also for the environment and the health of the community.

**Table 5.23 Percentage of Latrine types.**

| Type of Latrine | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Kacha | 95 | 93 | 70 | 97 | 89 |
| Half Pucca | 1 | 0 | 0 | 0 | 0 |
| Pucca | 4 | 7 | 30 | 3 | 11 |

**Source: Author (2001-2).**

Daya, latrine, pukur #5.

Narayandaha, latrine, pukur #06.

**Source: Author (2001-2).**

**Figure 5.24 Latrine types.**

#### 5.5.11.2 Sources of Water

SWB are the main sources of household water in Narayandaha and Paschim Kharua (Table 5.24). Although this is a convenient source in the sense of accessibility, it is potentially contaminated and if not boiled this water is implicated in the spread of disease. Tubewells are also widely used and were initially encouraged throughout Bangladesh with a view to providing safer water. However, recent research (Hassan, 2003) has shown that tubewell water drawn from near-surface aquifers often contains arsenic, which is poisonous if consumed long-term. My study area is a risk zone of arsenic contamination. Keeping this in mind, the SWB need to be managed as sources of hygienic water.

**Table 5.24 Percentage of sources of Water.**

| Types | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Small water body | 54 | 73 | 90 | 98 | 79 |
| Tubewell | 97 | 99 | 92 | 100 | 97 |
| Running water | 0 | 0 | 0 | 0 | 0 |

**Source: Author (2001-2).**

These SWB will be the only source of water in future if all the tubewells are found to be arsenic contaminated. Like in the past, people will start using them as sources of drinking water.

### 5.5.11.3 Ill-health

In the survey it is found that the different diseases are prevalent among 47 percent of the population (Table 5.25). The highest incidence is found in Baoikhola and the lowest in Narayandaha. Most are contaminated by diarrhoea, a waterborne disease. It is suspected that this is due to the use of unhygienic water from SWB. Other diseases like scabies and ulcers, influenza, cough are also noted.

**Table 5.25 Percentages of Disease status.**

| Types | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Present | 67 | 43 | 27 | 51 | 47 |
| Absent | 33 | 57 | 73 | 49 | 53 |

**Source: Author (2001-2).**

### 5.5.11.4 Health Status

Health status may be judged from data collected from field, coded into three simple self-identified categories. Good health refers to those people who reported no present or past diseases or major operations and felt well. The medium category represents those who had suffered a long term illness and were now cured or partially cured by an operation or drug treatment. Finally those who are still suffering from disease or other illness are counted in the poor category (see Table 5.26).

**Table 5.26 Percentages of health status.**

| Types | Baoikhola | Daya | Narayandaha | Paschim Kharua | Average |
|---|---|---|---|---|---|
| Good | 4 | 5 | 11 | 9 | 7 |
| Medium | 91 | 75 | 70 | 87 | 81 |
| Poor | 5 | 21 | 18 | 4 | 12 |

**Source: Author (2001-2).**

### 5.6 Analysis, Results and Discussions (Key informants Interview)

The main themes or questions for the participatory key Informants Interviews were:

1. What is the importance of the SWB (Doba/Ditch, Pukur/Pond, Dighi/Reservoir, Beel and Jola/Khal)?

2. How can the people/community benefit from these small water bodies?

3. What are the important uses and the management/development planning needs of these SWB in the socio-economy and agriculture?

4. What are the impacts of dirty and abandoned SWB on environment?

5. What are the steps that should be taken in developing these SWB?

6. What sorts of planning should be taken for the management of these SWB?

A different analytical approach has been taken to the results of the discussions. A combination of hermeneutical, discourse and narrative approach has been applied. The hermeneutical approach is useful for understanding the meaning of human expression and their analysis and interpretation (Baxter and Eyles, 1997; Lee, 1994; Myers, 1994; Ratcliff, 1999; Ricoeur, 1974; Taylor, 1976). According to Myers (1997) this approach primarily deals with the meaning of a transcribed text (Myers, 1997). The hermeneutical approach has been adopted in this part of the research analysis to understand the different interviewees' mode of expression, and the meaning of their reply against the real situation in the study area.

The narrative approach is best used for exploration of ethical, moral and cultural ambiguities (Atkinson, 1998; Bochner, 1997; Cortazzi, 1999; Mishler, 1995; Rybacki and Rybacki, 1991; Sillars, 1991). This approach has been used to understand the key informants' perception of the SWB while analysing and interpreting the transcribed summary and watching the videos. It also helped to understand the key informants' behaviours and motivations.

Discourse analysis is interpretative and deconstructive. This gives awareness of hidden motivations which is useful in understanding socio-economic and cultural phenomena and solving related problems (Hassan, 2003; Ratcliff, 1999). A combination of all three approaches was helpful in understanding and interpreting all the transcribed interviews.

Thana Nirbahi officer (Thana Chief)

Pauroshava Chairman

Union Parishad

**Source: Author (2001-2).**

**Figure 5.25 Key Informants Interview.**

### 5.6.1 Importance of Small Water Bodies

The importance of resources like small water bodies is a big issue in the community. If a resource doesn't have any vital importance then its management is a low priority as either it is in abundance or has no appeal to that community. The first opinion asked of each key informant after having a brief introductory session concerned the importance of the different types SWB in the community.

Almost all of the interviewees expressed an opinion on the importance of these SWB for agriculture and fisheries as Bangladesh's economy is highly dependent on irrigated agriculture. In the past, water from these SWB was the main source of irrigation. Only recently has there been a shift to STW and DTW. The water table is now decreasing and is at danger levels due to this intense use of STW and DTW. Farmers are now concerned about the expanse of establishing STW and DTW especially when longer pipes are needed to reach the aquifers. The relative importance of the SWB has therefore increased. In the dry season, surface water is the only possible source here.

Fisheries is another sector dependent on the SWB. But a lack of proper management has led to the extinction of fish species. This is problematic because fish is one of the main sources of protein consumption in the diet of the study area. Developing and managing SWB sustainably is potentially an important protection strategy against malnutrition.

Apart from agricultural irrigation and fisheries, SWB play a vital role in household uses, from drinking water, to cooking, bathing, washing clothes and utensils like cutlery and crockery, cattle drinking and bathing and, finally, duck raising. The Kachuripanas are used as biological manure and cattle food, and also as packing material to stop milk moving and dropping from the carrier.

Some of the participants raised a very important point about the importance of SWB as recreational focus points. In rural Bangladesh there are no appropriate recreational spots. If proper sitting places were provided, people could sit in the late afternoon on the banks of these SWB.

**5.6.2 Are Small Water Bodies beneficial to the community?**

In response to this question, most of the key informants were highly appreciative of the value of SWB. They also expressed their concerns about a recent trend of conflicts in ownership and access to the SWB, especially for catching fish. They also raised the issue of a proper law and inventory of these SWB. Law enforcers and civil servants reported that the poor people who should have the benefits are deprived due to the lack of a legal framework and the socio-political situation. The benefits are currently being creamed off by the influential groups, especially from the khas SWB.

The majority of key informants think that SWB convey not only economic but also environmental benefits. Some said that the area would be desertified like the nearest northern districts if it were not for the SWB. The multipurpose uses of SWB yield a lot of advantages. The key informants also showed their concern about the derelict and abandoned SWB.

The community has also benefited indirectly, through the planting and maintenance of fruit trees and the fisheries in SWB from the British period when almost all of the buildings such as schools, colleges, religious centres and government and nongovernmental institutions had a SWB attached. This tradition has continued since independence from colonial rule.

### 5.6.3 Impacts on the environment

Most of the respondents said that these SWB are environmentally friendly apart from the derelict and abandoned ones. But, due to the floods every year some become silted and breach their banks. So they need to be re-dug/dredged and the embankments reconstructed.

Clogging with Kachuripana (water-hyacinth) and duck weed can be a problem. These are breeding grounds of mosquitoes and harbour waterborne diseases. So the removal of excessive aquatic vegetation is necessary for a healthier environment.

One pollution problem is that dangerous toxic chemicals are discharged from the dying industry because almost all of local the handloom cottage industries are adjacent to the SWB. Also, pollution comes from the Katcha and semi pucca latrines that are directly connected with these SWB. Sewage is good for fish development in up to a certain stage/limit but in terms of hygiene it is really detrimental for environment and surroundings and encourages the spread of waterborne diseases.

### 5.6.4 Steps for development

Different steps have been identified by the different key informants. Most of them suggested a proper inventory of each SWB and identification of issues. They also expressed concern regarding the khas SWB. They think that only an appropriate law and sincerity on the part of the law enforcing authority can dissolve the Khas SWB's ownership and thus the whole community would benefit. After inventorying all the SWB, categorisation into derelict and useable would help along with a note as to whether re-digging/excavating and rebuilding is needed for the derelict SWB with potentiality.

Where needed creating new SWB is essential. Digging jola/khal is an important step for agricultural irrigation, and locations need to be identified and justified. Late president Ziaur Rahman's Khal khonon/Kata programme was very popular and advantageous. The idea was imported from developed Chinese agriculture. It gave a boost to agricultural production in Bangladesh in the eighties through irrigation. This should again be organized through proper research and planning. All the preparation should be completed before the flood season and SWB need a proper management plan for running properly.

### 5.6.5 Planning and management issues

All the key informants expressed their views on different planning and management issues for the sustainable development of the SWB. They think that a long term proper management system will be appropriate for aspects concerning the stakeholders starting from owners, users, the law enforcing authority, the executive authority, community and technical experts. This needs proper research. A management system should be developed linking all the phenomena regarding SWB. A special consortium department is probably necessary in the government of Bangladesh.

## 5.7 Analysis, Results and Discussions (Focus group Meetings)

The main themes or questions for the participatory focus group meetings were:

1. What are the uses of the SWB now and in the past?
2. How have people benefited from SWB now and in the past and what will be the benefits in future?
3. What types of management planning should there be?
4. What are steps to be taken to encourage economically benefits?
5. What are the impacts of the present SWB on the Environment?

### 5.7.1 Uses of SWB

The SWB were used for various purposes in the early days and these have changed very little. Especially after tubewells were introduced in the late sixties and early seventies, the source of drinking and cooking water changed from the SWB in a few well-off households. Both deep and shallow tubewell also started to be used extensively for irrigation. But the situation has changed recently since the water table gone down and water was shown to be contaminated with iron and possibly arsenic.

Dobas are usually created as a bi-product of raising the homestead mound. Every year dobas are excavated for this purpose before and after the floods to prevent problems of flooding during the rainy season. Virtually all of the SWB are silted up during the monsoon floods. During the monsoon and Banna some of the top soil of the homestead and other lands is washed and deposited in these SWB.

According to the focus group meetings, irrigation and fisheries are the important uses part from the household uses. Water for the drinking, cooking, washing, bathing, duck rising, poultry, water sprinkling in the homestead garden, cattle washing and feeding are the domestic uses of the SWB.

### 5.7.2 Benefits of SWB

Several benefits of the SWB have been mentioned in the focus group meetings. The main emphasis was given to the socio-economic benefits. Domestic benefits were mostly voiced by the women's groups, for instance the issue of drinking water, particularly for those households who do not have direct access to a tube well or in areas, such as Paschim Kharua, where there are few alternative sources to SWB. In addition the women in video clips 19-23 (Appendix 4) emphasised the washing of clothes, the drawing of water for cooking purposes, crockery washing and bathing. They also stressed the need for proper management of SWB. These are the issues that are high on their personal agendas, although less so for the men. Women were also concerned about the relative scarcity of water in the dry season and of hygienic water during the monsoon.

The men mentioned the benefits for agricultural and fishery production. In video clip 17 (Appendix 4) they discussed fish culture in particular and they also expressed a desire for larger SWB to assist with irrigation. It is also interesting to note their comment that water hyacinths on the SWB minimize the effect and pressure of waves and currents during periods of flooding and water logging.

The one point mentioned in common by both men and women was irrigation. They pointed out that SWB are cheaper for this than using tube wells.

### 5.7.3 Environmental Impacts

Several adverse environmental impacts have been pointed out due to the unplanned use, and the absence of proper management and motivation for future development. Apart from the dobas, all other SWB are not re-excavated or dredged regularly resulting in less water retention. In two mouzas some of them dried up during the winter. Then a scarcity of water for domestic uses and irrigation is exposed.

Other problems include, first, an underground water deficiency due to excessive water pumping by STW and DTW. The water now has an excess of iron due to these uses and there is always the arsenic hazard to remember, which has been such a problem in other parts of Bangladesh. Second, the damaged embankments of some jolas result in excessive water with flooding in the monsoon.

Third, the re-excavation of jolas is necessary from time to time. In video clip 18 (Appendix 4), for instance, there is a discussion of the failure of the Gohala Project, with the result that aman rice cannot be cultivated and farmers cannot benefit from two crops during the year. This was due to the silting of a jola and the installation of a sluice gate that is not properly managed, cutting off the connection with the river at the wrong time. A similar problem with the Hura Sagar canal was mentioned in video clip 16. Also the absence of flushing from river water has led to the silting of SWB, reducing the surface water-holding capacity of the region.

Finally, abandoned and derelict SWB have an adverse effect on environment. These are very unhygienic, with an upsurge of mosquito and fly populations and the dumping of lots of unhygienic materials, including sewage (video clip 22). There is also a danger of other water-borne diseases.

### 5.7.4 Steps for the development

The focus group participants commented on a need for the following:

a) A proper and appropriate inventory of all SWB.

b) Re-excavation and dredging where necessary.

c) Cleaning of excessive water-hyacinths, weeds and sledges.

d) Pump and drain out unhygienic water and refill with fresh water.

c) Excavate and dig new SWB according to necessity.

d) Build and rebuild banks and embankments.

e) Inspiration, motivation, encouragement and incentive for fisheries and aquaculture.

f) Technical and economical support.

g) Proper and regular stocking and maturing for fisheries.

h) Proper laws for khas SWB and transparency in leasing and operation.

i) Construction of sluice gates in jolas; and

j) An appropriate management-planning guide for sustainable development.

### 5.7.5 Management plan

Similarly the focus groups made suggestions on longer-term management needs:

a) A plan giving access to water throughout the year;

b) The ability to irrigate more efficiently from SWB;

c) Prioritisation of the provision of jolas and pukurs, either re-excavation of silted up SWB or new sites;

d) A proper legal framework for khas SWB, giving access to everyone;

e) A fisheries extension programme that will provide economic benefits;

f) Financial assistance for a fisheries management programme;

g) Funding for a local programme of SWB maintenance.

Daya (Male)

Narayandaha (Female)

Pashcim Kharua (Joint)

**Source: Author (2001-2).**

**Figure 5.26 Focus Group meetings.**

### 5.8 Analysis, Results and Discussions (Videotapes and Photography)

Photographs are very useful during the analysis and writing up periods. Videotapes and photographs brought rich fieldwork detail that might not otherwise have been remembered. Capturing cultural scenes and episodes on videotapes and photographs gave me the advantage of interpreting events retroactively (historically), producing a valuable second chance to visit the field while my study area is far away. Also both devices captured details that my eyes missed during fieldwork. Although these devices are an extension of the subjective eye, they can be a more objective mode of observation, less dependent on the field worker's biases and expectations (Fetterman, 1998). These two tools were also used in combination with the other methods discussed previously in this chapter. They enhanced the quality of data collection and were useful for data interpretation analysis and finally for discussion.

Extensive video clips are attached in the form of a Compact Disk VCD-ROM (Appendix 4). This will give the reader a flavour of: direct and participatory observation for each SWB; key informants' interviews; focus group meetings; and the ethnographic survey. If this thesis achieves nothing else, it will at least be an early example in geography of the capture and preservation of fieldwork, giving the texture in space and time of the author's interaction with his subjects. It will also record different aspects of the management and planning of SWB for sustainable development.

My work in this area has been very timely. I note a trend in social and cultural geography towards 'visual ethnography' and I am hoping that geographers in Bangladesh will perhaps adopt my approach in order to enrich their fieldwork and bring it closer to the research frontier identifiable in the epistemology of colleagues in the UK and North America.

## 5.9 Conclusion

In concluding this chapter, I want to comment on a number of points. These relate mainly to the methods I used in my research, and the management of SWB.

In choosing research methods for a PhD, difficult choices have to be made about the appropriateness of measurement techniques and their cost-effectiveness (Table 5.27). On the socio-economic side of my work, I decided at an early stage that a mixture of methods would be the best approach. I could have restricted myself to ground-truthing my remote sensing data but this would have been a minimalist solution and would have yielded very little about the real world context in which the SWB are created and used. My instinct was to use a number of ways of collecting data, both quantitative and qualitative, and to build the results into a comprehensive picture of SWB in my four mouzas. Although I did have an advantage in already being familiar with the study area, in reality I soon realised how little I knew about the number and variety of SWB.

**Table 5.27 Research methods**

| Method | Advantages | Disadvantages |
|---|---|---|
| Observation | Immediacy, checkability | Time-consuming |
| Questionnaires | Structured data | Closed questions |
| Key informants | Efficient and cost-effective way of collecting informed insights | Marginalization of views beyond elite |
| Focus groups | Users' views | Domination by certain speakers |
| Photo and video | Allow review of visual images of interviews and of the SWB after completion of fieldwork | Selection of images |

**Source: Author 2004**

After some thought and consultation, I decided to use the following techniques: direct and participant observation; questionnaire surveys; key informant interviews; focus groups; and video and photography. Observation and questionnaires were valuable for background, descriptive data that unfortunately is not available in reliable form from official sources. For example, it was obvious from my collection of demographic data that the government's population census of 2000 is seriously flawed. In retrospect I am pleased that I generated my own dataset, although it was costly in time and effort.

The participant observation taught me that acquiring local knowledge is a slow process but nevertheless extremely important for understanding how SWB fit into the daily lives of rural people. Supporting this, in-depth discussions with selected key informants and focus groups added value in terms of the kind of qualitative insights on people's perceptions that are poorly grasped by questionnaires. For instance they revealed tensions between the various stakeholders that might otherwise have been suppressed. Admittedly an ethnographic epistemology is unusual for a researcher whose skills lie mainly in remote sensing but my first excursion into this methodological territory was inspirational and in future I will want to argue that other researchers follow my example.

Perhaps the most innovative, and certainly the most enjoyable, aspect of the work recorded in this chapter, was my use of video. Because of limits on space, it has not proved possible to give the reader more than a brief flavour of this but a CD-ROM disk is attached as an appendix for further information. In summary, video was highly productive as a recording device, helping me to revisit the field from my computer in Durham and to recall the facial expressions and group dynamics that are absent in most write-ups of fieldwork.

This chapter has shown that SWB are an important and integral part of the daily lives of villagers in my study area. Their management is sophisticated and fruitful in terms of homestead gardens, and small livestock and fisheries, but there are problems with water quality, the disposal of waste products and insect breeding.

It is possible to envisage improvements in long-term management but these are better facilitated by government than imposed top-down. An issue in the study region is the relatively weak development of civil society and a first step might be an exploration by the local state and the various government agencies and NGOs of how people might contribute to a consultation process. Unfortunately this may cause conflict because presently there are elite groups who are benefiting most from the use of SWB and they are bound to resist any attempt to shift the balance towards greater use by poor people. At the very least, a better legal framework is required to protect the interests of vulnerable groups, but the enforcement of rights is probably best achieved by a gradual process of awareness-raising among all groups of the importance of sustainable environmental management and encouragement for the spreading of best practice in the use of SWB.

Overall, this chapter confirms in my mind the importance of participatory remote sensing and the integration of remotely sensed data with the micro-scale socio-economic context. This approach could be used widely across Bangladesh, not only for SWB but also for a broad range of environmental resources and their management.

# CHAPTER 6: CONCLUSION

## 6.1 The water problem in Bangladesh

It is well-known that water is one of the major issues for the development of Bangladesh. Observers in the west may see it as a hazard that is manifested in the form of the risk of riverine and marine flooding resulting from monsoon rainfall or cyclones in the Bay of Bengal, but for the people of Bangladesh water is a more complex and ever-present constraint on development. Yes, there is occasional damage to property and loss of life from floods, the most recent example being in July/August 2004, when two-thirds of the country was under water and the western news media went into overdrive. But it tends to be forgotten that 'normal' floods are welcomed, bringing renewed fertility to the soil. In fact, shortages of water and poor management of existing water resources are perhaps greater problems than the occasional excess.

During the dry season (December-February) the rivers are low and extracting sufficient for irrigation, drinking purposes, and industrial processes, can by no means be taken for granted. Disputes with India concerning her water extraction above the international boundary, demonstrate that water is now so short that it has become a matter of geopolitical significance. The 1997 Bangladesh-India Treaty on Sharing of the Ganges Waters at Farakka has given some hope of better cooperation in future but the sheer scale of demand for water in the rapidly growing population and economy of India remains a source of concern for Bangladesh, the downstream country with less political power.

Among the water management issues not dealt with in this thesis but deserving the attention of researchers are:

1. The lack of protection from untreated industrial effluents and municipal wastewater, runoff pollution from chemical fertilizers and pesticides, and oil and lube spillages in the coastal areas. Poor rural sewerage systems also contribute to a general problem of contamination that has yet to be addressed.
2. Water development and flood control projects have had serious negative impacts on wetlands, fisheries and on the ecosystems of some parts of the country.
3. Fishery resources need further attention. Recently, capture fish production has declined by about 50 per cent and the availability of many species that were very popular locally has been drastically decreased. The modification of aquatic habitats is a major factor, due to thousands of physical structures, dykes, and drainage systems that have been constructed to control floods and reduce the impact of cyclones, and other natural calamities.

There is a substantial literature on water management in Bangladesh. Most is concerned with macro-scale issues, such as management of river resources and planning for the future needs of major conurbations such as Dhaka. There has been less written about water management at the micro-scale and about the SWB that proliferate in the countryside and villages. It has been the aim of this thesis to address this literature gap and to deal with it in a manner that is new. I have employed a combination of technically advanced methods, notably Environmental Remote Sensing and Geographical Information Systems, coupled with the 'softer' but very effective approaches of social science, especially various methods of questioning and participant surveying. It is the central argument of this thesis that such a combined methodology yields a great deal more than is possible from separate and non-integrated work.

An admirable recent trend has been towards the involvement of local people in identifying and prioritizing problems and concerns with regard to sustainable natural resource management (Soussan and Datta, 1998). Personally, I think that this grassroots approach can be enhanced if the everyday resources of these people are fully understood. This helps in the formulation of action plans and in securing commitments for the sharing of responsibility for future sustainable management.

It is disappointing that international donor- and government-sponsored research and development projects have so far given little attention to SWB. To a certain extent this understandable because the infrastructure-engineering bias of development from the 1960s to the present day has tended to emphasize large-scale, technically sophisticated, and financially 'lumpy' investments that are well understood by western experts, politicians and media. It is less acceptable if one considers that the most effective 'development' for poor rural people is attention to the resources that they utilize on a daily basis. Less investment may even be needed to make an impact under these circumstances, something which is often difficult for outsiders to grasp. It so happens that the evidence of this thesis is that people in my study area have been developing and managing their own water resources for decades without any help from outside. With minor adjustments to this indigenous, informal management system, the use of SWB could be greatly improved and the water shortages of Bangladesh during the dry season could be eased. There does need to be some input from local and central government, along the lines of the methodology used in this thesis but the sums of money involved would pale into insignificance by comparison with the huge investment in projects such as the Flood Action Programme. SWB may not be politically high profile or sexy but the optimization of their use could contribute much to the national well-being.

### 6.2 Thesis Summary

This study used visual interpretation and digital classification of remotely sensed imagery to develop the most efficient and cost effective methods for detecting, inventorying and mapping SWB of four mouzas of Shahjadpur Thana, Sirajgonj District of Bangladesh and to make recommendations about these methods for future surveys. The study used the spectral, spatial and multitemporal properties of satellite data to discriminate SWB from the surrounding land surface features with the support of field knowledge.

Chapter 2 discussed the study area, its geographical context and relevant datasets for the whole of Shahjadpur thana. Many datasets had to be converted into digital format and careful planning was required to make them compatible with the associated attribute data. I prepared a list of information used for this study and this has been vital for an understanding of the dynamic nature of SWB and associated socio-physical phenomena. I described the physical and human conditions of the thana. It is a region typical of the floodplains of Bangladesh, with a dynamic environment and a rural population that achieves a meagre existence from the agricultural resources.

My fieldwork was planned with a view to collecting further data beyond official, published statistics and to provide a context within which I could interpret the remotely sensed images effectively. I decided that a time series was desirable and the images collected range over thirty years from 1972 to 2003. The planning of the fieldwork and data acquisition went well. I was able to generate what might reasonably be called a 'vast' database.

In chapter 3, using the best combination of spatial and temporal resolution, it was found that indeed SWB less than 100 sq metres were not reliably detected. It was observed that the panchromatic image of the CORONA and aerial photographs, although they have a very high resolution, lacked the necessary spectral information adequately to detect the SWB like Dobas. The number of SWB in this small size class represented about 50 per cent of the total.

Overall I would conclude that RADAR and Landsat are of little use in detecting individual SWB, mainly due to their spatial resolution, although, having said that, Landsat would be a serviceable means of detection for the larger water bodies such as beels, especially if a rapid inventory was more important than minute accuracy. SPOT is also somewhat limited, although it is redeemable through image fusion with high resolution platforms. I found aerial photography to be useful, along with CORONA, but IRS Pan was the most helpful of all because of its spatial resolution of 5.8 metres.

The chapter described purposes of inventory of SWB with sizes greater than 100 sq. m.. The methods developed in this study are reasonably reliable and cost-efficient when compared to field surveys and other techniques that have been used in the past. The remote sensing techniques are therefore applicable and can be recommended for future inventories or studies. There are several differences when comparing traditional ground-based-survey methods with the remote sensing methods used in this study. The advantage of a ground survey is that virtually all of the SWB are mapped, and all of the characteristics are represented in the survey. The limitation of this method is the logistics and costs required, and that the SWB are not accurately located. There is a substantial cost advantage in using the methods of this study; the cost of ground survey is high whereas remote sensing methods, using multitemporal and multi resolution imagery, is comparatively low. Because the RS methods are about 25 per cent of the costs of ground survey, it is recommended that RS data like CORONA, IKONOS and Quickbird should be used for inventory in larger areas such as the thana level. SWB with an area smaller than 100 sq metres can then be estimated using several sampling techniques in representative areas.

The spatial resolution of the imagery was found to be very important for identifying the SWB. The study showed that the remote sensing methods are not suitable for inventory of SWB with a size of less than 100 sq metres and are not reliable for SWB with a size of less than 144 sq metres (2 decimals). The date and season when the remote sensing data are obtained is important when trying to identify as many SWB as possible while maintaining enough accuracy to make a good estimation of the area covered by the SWB.

The mission of chapter 4 was the monitoring of change. My study is unusual in the Bangladeshi context in that I have collected and analyzed such a large number of images over an extended period of time. I therefore have a better grasp than most of the technical problems and possibilities of this kind of study for the conditions that are found in my country.

The second part of the chapter outlined the methodologies employed, including qualitative approaches to fieldwork that are rarely used in remote sensing studies. My overall feeling is that this ground truthing was a great success and that I have a fuller and better integrated understanding of how the images relate to the real world of the villagers in my study area than would have been possible if I had adopted a purely scientific methodology.

In addition to the technical aspects of change detection, the questionnaires, focus groups and key informant interviews revealed a great deal about changing land use and use of SWB in the last thirty years in the four study mouzas. This chapter provides a good foundation, through its discussion of techniques and change monitoring for the next chapter.

In chapter 5, I argued that the participant approach to research helped me to acquire the local knowledge that is extremely important for understanding how SWB fit into the daily lives of rural people.  Supporting this, in-depth discussions with selected key informants and focus groups added value in terms of the kind of qualitative insights on people's perceptions that are poorly grasped by questionnaires.

Perhaps the most innovative, and certainly the most enjoyable, aspect of the work recorded in this chapter was my use of video. Because of limits on space, it was not proved possible to give the reader more than a brief flavour of this but a CD-ROM is attached as appendix 4 for further information. It is hoped that the reader will have time to review the 31 video clips that are included in this Appendix on the attached cd-rom. In summary, video was highly productive as a recording device, helping me to revisit the field from my computer in Durham and to recall the facial expressions and group dynamics that are absent in most write-ups of fieldwork.

Overall, this research confirms in my mind the importance of participatory remote sensing and the integration of remotely sensed data with the micro-scale socio-economic context.  This approach could be used widely across Bangladesh, not only for SWB but also for a broad range of environmental resources and their management.

### 6.2.1 The Advantage of using Remote Sensing for the Study of SWB

For the formulation of any sustainable development strategy and policy, a clear understanding of the existing development strategies, their problems and viable alternatives that are environmentally sound, is a prerequisite (Rao and Subramanian, 1999). Environmental Remote Sensing plays a crucial role in this endeavour. This is a very promising side of my research that I have used different Environmental remotely sensed Data to explore and compare in spatial mapping and change detection of SWB.

High resolution imagery has a good reputation in both the academic and planning spheres and for my purposes it was helpfully compatible in scale and complementary in characteristics with my base maps. Through a process of integration, non-image maps can be converted to an image-map and vice versa. For instance, mouza maps generally contain plots, while high resolution images (i.e. IKONOS and CORONA) do not have that information. Images contain land use and land cover in the existing situation (own natural boundaries). If we combine the GIS-based plot maps and their associated social attributes with images, then together they become a very powerful tool for decision-makers, local government, planners, developers, lawyers, environmentalists and researchers.

One of the potential criticisms of environmental remote sensing is that it provides almost limitless amounts of data. It is obvious that this information cannot stand on its own. Combining it with other associated data under a stable and compatible Information System (i.e. GIS) adds powerful potential for integrated analysis. The current challenges of new high resolution data, especially the prospect of its 'hyperspectral' capabilities in the near future, and also multi-frequency RADAR offer exciting new possibilities of Environmental Remote Sensing for resource mapping.

### 6.2.2 Integrating RS with GIS, and fieldwork using qualitative techniques

These integrated approach yield insights at the micro-scale that are not available using any other techniques. The integrated GIS-RS and fieldwork approach is the basis of the entire research, to efficiently handling the vast data of different characteristics and map them efficiently. All the data and maps presented in the research were the outcome of GIS analysis. For example, data entry, topology building, map digitisation, image integration, geo-processing, attribute data insertion. The current GIS and RS system can handle both raster and vector data and this was an additional advantage.

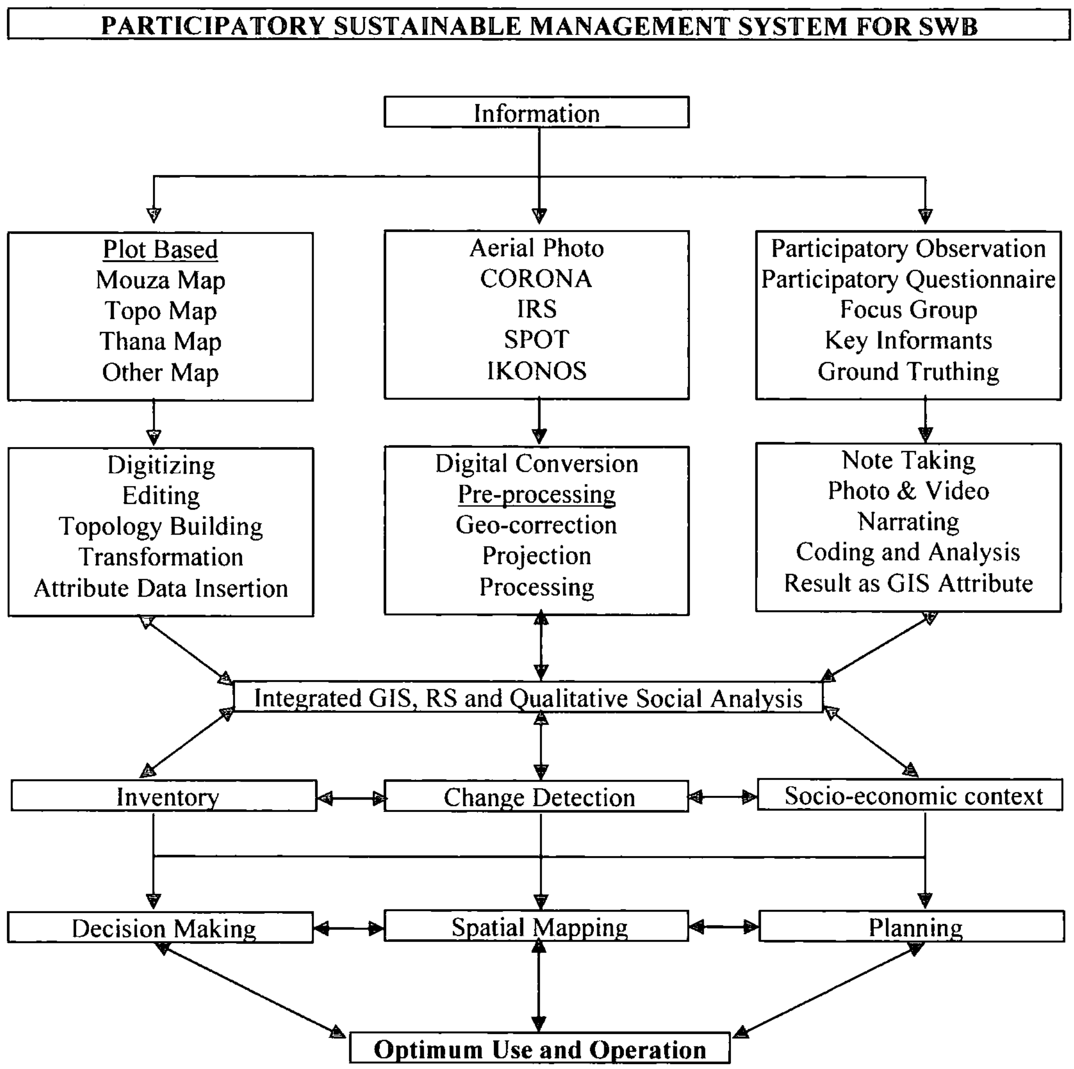
I found that integrating RS with GIS and fieldwork is especially helpful for fieldwork and I anticipate this as an advantage for inventorying and management purposes also. I do, however, anticipate some resistance because both academic work and development practice have hitherto been very much on the basis of specialised disciplines that have some distance between them. Vested interests have grown up over the last decades because status is attached to being an 'expert' in one or other of these specialisms. What I am proposing is different. It suggests either (a) that experts work closely together in teams to achieve integrated results, with the consequent need to see each other's needs and point of view; or, (b) that training is required for individuals to have a range of skills that hitherto would have been considered incompatible. My personal preference is for the latter and in my opinion Geography is the ideal home for such training because it already is the meeting ground of the natural and social sciences.

### 6.2.3 Proposed Participatory versus Existing Management System

Water in all its phases is of prime concern to Bangladeshi rural society. A goal of the participatory sustainable management system proposed here is to use SWB more effectively than at present. This goal can be re-worded as a wish to improve the performance of the existing informal system. To facilitate this goal, a set of up-to-date tools are needed. The most prominent new tool is named a "Participatory Sustainable Management System" for SWBs. This "Participatory Sustainable Management System" can be defined as the systematic observation, inventorying, monitoring, change detection and understanding of the associated socio-economic conditions for using SWB's effectively and sustainably for development purposes.

Systematic and timely information is required for the "Participatory Sustainable management System". The use of integrated GIS, Remote Sensing and a social participatory approach is needed for this purpose. Filling a database with measured and collected data will take up a considerable part of the management budget, but remote sensing and GIS are promising tools to measure a variety of such data in a cost-effective manner.

Central and local authorities can adopt a version of my methodology and proposed participatory sustainable management system for their water management. This may not be strictly relevant for large-scale water management but my attention to SWB is novel and important and I think that others should take an interest also.




**Source: Author 2004.**

**Figure 6.1 Proposed Participatory Sustainable Management System.**

### 6.3 What would be the difference if I started this research again?

If I were to start my PhD research again, I would reorganize my schedule and the amount and types of data juggled. The use of so many different types of satellite and RADAR images took up a lot of my precious time in geo-processing, geo-correcting and conversion to a unique format, so that they could be compatible for comparative analysis and discussion.

I would travel more than once to the field to tally the data and results. Specifically it would have been valuable if I could have tested the proposed management system and improve and develop it further.

I would be more than satisfied if I could use the Quickbird, IKONOS 1-metre resolution panchromatic data with multi-spectral bands and the recent coloured Aerial Photos. I tried my best to acquire them but due to financial and time constraints it was impossible. However, I have used the recent 5-metre IRS, 2-metre CORONA and the less than 2-metre aerial photo data, which in my opinion were adequate.

I have collected a great deal of detailed plot and household base data of four mouzas, but I have used less then 40 per cent of this in the thesis. In fact altogether, only about one-third of my data has been utilized in this write-up. In retrospect I was very enthusiastic in my collection of data but could have planned its use more effectively.

### 6.4 Recommendations and Future Directions

I am satisfied that the approach that I have adopted in this thesis is academically sound and relevant to the practical development of rural Bangladesh. The amount of literature is small on remote sensing that is integrated with social science approaches, perhaps because the range of skills required is unusually broad. Geographers tend to have the breadth of training and the openness of outlook to make such an 'interdisciplinary' leap but, if geographical experience is not available, it should nevertheless be possible to assemble teams of scientists and social scientists to produce an integrated view. The crucial point is to have integration as a goal.

My recommendation to government is that specialist teams are required for the further inventorying of SWB. My thesis shows that this is both possible and desirable. With a little further refinement, for instance the use of Quickbird, IKONOS 1-metre resolution panchromatic data with multi-spectral bands and the recent multispectral Aerial Photos, it is possible to extend my methodology to selected areas in other parts of the country. By so doing we will have a much better grasp of the resources at our disposal and the management methods to make them sustainable. The most obvious team, with the necessary skills, is the GIS section of the Local Government Engineering Department, widely known as the LGED. This team would need to be extended in personnel and capital budget to make this work possible.

I also recommend the formulation of multi-sectoral management plans to optimize the utilization of SWB. Several purposes would be served by these that have been highlighted in my research. Firstly, the arsenic crisis that has hit the groundwater sector could be mitigated by the increased use of surface water in SWB. A selection of ponds in each mouza would suffice for this, located at points convenient for the collection of water. Historically, this was a traditional means of water gathering until the tubewell revolution of the 1970s and 1980s. An important issue here is that hygiene and management would be focused on local people agreeing to the specialized use of SWB for drinking purposes and the exclusion of other functions such as washing, jute retting and so on.

Secondly, my fieldwork has shown that a proportion of SWB are used for sewage. This function requires much more careful thought and management than is currently the case if the spread of water-borne diseases is to be minimized. Local communities are by far the best level at which to make this intervention, but some assistance from local authorities may be helpful in terms of location and basic hygiene measures.

Thirdly, SWB come into their own especially during the dry season. This is the time when water is short for drinking purposes and for irrigation. Increasing the number of SWB in a carefully planned way, it seems to me, would be an important investment for the future development of the country. This is not cost-free, of course, but some kind of monetary or other incentive from government to villagers would encourage them to excavate more, in the right places and of the right kind. A modified version of the present Food for Work Programme might be a vehicle for delivering this. Since the people are already making new SWB without outside intervention, only a change in pace of construction is required.

Fourthly, Local Authority plans based on the common purpose at the community level are required and central government might be advised to support or even require these. They might, for instance, improve their system of leasing khas water bodies because of their hijacking by local vested interests, with the inevitable conflicts that arise.

However, without an improved legal framework to enforce a modern khas framework, local authorities will remain ineffective in this regard.

Future directions of academic research might involve the following. First, we need to continue with the development of the technical aspects of remote sensing and GIS that bear upon the issue of water in Bangladesh. As the reader will have gathered in Chapter 3, I was frustrated by my lack of success in gathering useful data from radar sensors and more research on this needs to be done to see if more useful information can be extracted. Second, both academic and technical work on water quality would be valuable. At present both access to water and very poor water quality are issues for rural Bangladeshis and there is extensive scope for useful research on both. Third, we need to know more about the geomorphological origins of natural SWB and also the time-space variations of water tables.

Fifthly, hydrological research is needed on water flows during the wet season, for instance the influence of jholas/khals on channelling floods away from inhabited and cultivated areas. Late President Ziaur Rahman (1978-81) encouraged the construction of more such canals. There may be no stomach for the recycling of this kind of policy but the physical geography behind it deserves attention if it would provide some relief from the negative aspects of floods.

Sixthly, further research is desirable on the types of qualitative techniques that I have employed in this thesis. It seems to me to be possible, through focus groups and related techniques, that conflict resolution may be possible concerning the disputed use of scarce resources. Such approaches help because they lay bare the essentials of intra-community relationships. I am not naive enough to think that this would work in every situation, however, because conflicts in rural Bangladesh often run deep and can have expressions in outright violence.

Seventhly, work is underway on sustainable fisheries, however much of the research concerns river fish and coastal fish farming. Less work has been done on the potential of SWB and I maintain that a small investment by government or international donors would be exceptionally valuable here because it could support community-based, small-scale fisheries that, if successful, would add further protein to the diet of poor people.

Eighthly, some research is progressing on wetlands in Bangladesh. An interesting future direction might be to include SWB within the definition of the country's wetlands. The larger SWB, mainly beels, have many of the characteristics of wetlands, including, quite apart from the human uses addressed in this thesis, their varied flora and fauna and ecological complexity.

Ninthly, in cost benefit terms, there are advantages in my methods for government, NGO and donor organizations in accuracy, timeliness and transparency. My sampling approach imposed a realistic view of the very complex and highly dynamic Bangladeshi environment. My evaluation of the available technologies will allow interested parties to skip expenditure on images and data sets from the less useful sensors. My detection and monitoring procedure over time has uncovered often rapid change, showing that research must take account of season and human intervention. My involvement of local people in the data collection and what, in effect, has been participatory remote sensing, is a further strength.

Finally, my experience of undertaking research at the mouza level convinces me that more such micro-level work needs to be done. Geographers and other scientists and social scientists in Bangladesh often mirror the structure of the development machine by approaching their work from the top down. I am now certain that bottom up, detailed fieldwork provides insights that will be vital for understanding and managing the development process in the future.

My methods have proved successful and have yielded the following results:

1. Most sensors are inappropriate for the detection and monitoring of SWB. This is because the smallest SWB, which are highly significant in the lives of rural Bangladeshis, are smaller in size than the spatial resolution of Landsat and to a certain extent even SPOT.
2. RADAR is not very helpful either because of difficulties of interpretation.
3. All sensors have problems in dealing with the close association of SWB with buildings and the vegetation of home gardens.
4. Workers in remote sensing are used to ground truthing their images but I assert in this thesis the importance of the use of social science methodologies for understanding the human context of the objects of study. There is no other satisfactory way of grasping the complexity of varied uses associated with SWB. This is also true for the formulation of a management plan, where both physical and human aspects must be integrated.
5. Other wetland research projects and water management plans in Bangladesh can benefit from the experience of this research, especially in the replication of some aspects of the methodology.

## Appendix-1: Plot Level Mouza Landuse Survey Sheet

RS #

**Plot Level Mouza Survey 2001-2**

| Name of Respondent/s | Age | Sex | Occupation | Years in Mouza |
|---|---|---|---|---|
| | | | | |

If Migrants- How many years ago and from where?

Village: Para (New Name/Old name-if any):

Mouza Name: Plot/Daag Number - CS: RS: Sheet number:

| Category | | 1951 | 1961 | 1974 | 1981 | 1991 | 2001-2 | Comment |
|---|---|---|---|---|---|---|---|---|
| Land-type (H, MH, L, VL ) | | | | | | | | |
| Local Topographic Name (Uzarbari, Vita, Palan, Chak, Mythal, Pagar, Doba, etc) | | | | | | | | |
| Duration of Inundation (Months, e.g. July-Sept) | | | | | | | | |
| Number of Ghars | A. Pucca Roof | | | | | | | |
| | B. Tin Roof | | | | | | | |
| | C. Other Roof | | | | | | | |
| Number of People living on the plot | | | | | | | | |
| How long family members have been living on this plot (oldest one) | | | | | | | | |
| Ownership (Own/rented-barga/ govt/ khas/ Commercial etc) | | | | | | | | |
| Are there any small water bodies? i.e. Doba, Pukur, Dighi, Khal & Beel | | | | | | | | |
| What are the uses of small water body? | | | | | | | | |
| Main Profession (in general for the inhabitants (agriculture, fishing, business, handloom, van driver, industry, service etc) | | | | | | | | |
| Social Class of the inhabitants of the plot in general (H, MH, ML, L) | | | | | | | | |
| Land use (current land use must be drawn clearly on the provided map) | | | | | | | | |
| Vegetation/agriculture (Crop 1, Crop 2, Crop 3 and Homestead garden / Forest) | | | | | | | | |
| Any Remarkable Infrastructure/s (e.g. schools, bridge, tube well) | | | | | | | | |
| Utility lines (Electricity, Gas, Sewerage, Internet, etc) | | | | | | | | |

**CODES**

| | | | |
|---|---|---|---|
| H = High Land | 1 = Drinking | 09 = Washing Crockery |
| MH = Medium High Land | 2 = Fish Culture | 10 = Cooking Water |
| ML = Medium Low Land | 3 = Aqua Culture | 11 = Sewerage |
| L = Low Land | 4 = Bathing | 12 = Duck Raising |
| VL = Very Low Land | 5 = Cattle Feeding | 13 = Dying in Cottage Industries |
| | 6 = Washing Cloth | 14 = Jute Retting |
| Crop 1 = Prak Kharif-I | 7 = Cattle Bathing | 15 = Sprinkling in homestead Garden |
| Crop 2 = Kharif-II | 8 = Irrigation | |
| Crop 3 = Rabi | | |

Is there any problem occurred during data collection? If yes, please specify in detail and how to solve it:

| Information Collected By:<br>Name:<br>Date: | Information Verified By:<br>Name:<br>Date: |
|---|---|

Appendix-2: Small Water Body Survey Sheet

## Survey Based On Small Water Bodies 2002 (Shahjadpur Thana)

| Name of Respondent | Age | Sex | Occupation | Mouza |
|---|---|---|---|---|
| | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Types | Doba | | Pukur | | Dighi | | Jola | | Beel | | Others |

| |
|---|
| Name of small water body: |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| R.S | | | | | | | | | | |

| | |
|---|---|
| Area Incl Bank (Decimal) | Area Excl Bank (Decimal) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Shape | Triangular | Rectangular | Parabolic | Hexagonal | Linier | Round | Square | etc |

| | | | |
|---|---|---|---|
| Depth in metre (Dry Season) | | Depth in metre (Wet Season) | |

| | | | | |
|---|---|---|---|---|
| Water retention (month) | From | | To | |

| | | | |
|---|---|---|---|
| Seasonal | | Perennial | |

| | | | |
|---|---|---|---|
| Highest water depth (M) | | Month | |
| Lowest water depth (M) | | Month | |

| | | | | | |
|---|---|---|---|---|---|
| Submerged in flood water | Yes | | No | | How long (months) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Year of creation | | How was it created | Naturally | By digging | Both | Others |

| | | | | | | |
|---|---|---|---|---|---|---|
| Why was it created ? | Raising Homestead | | Community uses | | Aquaculture | |
| | Household uses | | Public welfare | | Others | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Size changed | | Year | | Shape changed | | Year | | Depth changed |

**Why and how shape, size and depth changed: ...........................................................**

| | | |
|---|---|---|
| Owners Name | | |
| | | |
| | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Ownership | Single | | Leased | | Khas (Govt) | |
| | Multiple | | Institutional | | Others (Specify) | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Operator | Sole owner | | Single leased | | Share producer | |
| | Co owner | | Joint leased | | Others (specify) | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Any offensive odour | Yes | | No | | Character of odour | Ammonia | | Sulphur | |

| | | | |
|---|---|---|---|
| Water colour | | Appearance | |

| | | | | | |
|---|---|---|---|---|---|
| Sludge | Present | | Absent | | Sludge thickness |
| Sludge distribution | | | | | |

| | | |
|---|---|---|
| Algae | | |
| Aquatic | | |

| | | | |
|---|---|---|---|
| Chemical | | | Months |
| Pesticide | | | |
| Disease treatments | | | |

| Major uses | 1960 | 1965 | 1970 | 1975 | 1980 | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|---|---|---|---|---|
| Drinking | | | | | | | | | |
| Fish culture | | | | | | | | | |
| Aquaculture | | | | | | | | | |
| Bathing | | | | | | | | | |
| Cattle feeding | | | | | | | | | |
| Washing cloth | | | | | | | | | |
| Cattle Bathing | | | | | | | | | |
| Irrigation | | | | | | | | | |
| Washing Crockery | | | | | | | | | |
| Cooking Water | | | | | | | | | |
| Sewerage | | | | | | | | | |
| Duck Raising | | | | | | | | | |
| Dying in Cottage | | | | | | | | | |
| Jute Retting | | | | | | | | | |
| Water Sprinkling | | | | | | | | | |

**How is this small water bodies managed?**

**How often is it cleaned and in what process?**

**How often does its bank have to be rebuilt?**

| | | | | |
|---|---|---|---|---|
| Is there any village conflict | Yes | | No | |

| Nature of conflict | With Whom | Resolved or Not | What problem do these conflicts create in the uses and management of small water bodies |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

**What are your opinions regarding the strategies for developing planning for better uses and management of these small water bodies?**

## Fish Culture

| Present Species | Amount | Diseases | Cropping Pattern | Past Species | Amount | Diseases | Cropping Pattern |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

| Fertilizers/Feed | Amount (kg) | Source (Own) | Source (Purchased) | Price (Tk./kg) |
|---|---|---|---|---|
| Urea | | | | |
| TSP | | | | |
| MP | | | | |
| Cattle Dung | | | | |
| Rice Bran | | | | |
| Mustard Oil Cake | | | | |
| Others (Specify) | | | | |

| Activity | Family Labour | | | | Hired Labour | | | |
|---|---|---|---|---|---|---|---|---|
| | M/Rate | Wage | F/Rate | Wage | M/Rate | Wage | F/Rate | Wage |
| Fertilization | | | | | | | | |
| Feeding | | | | | | | | |
| Maintenance | | | | | | | | |
| Harvesting | | | | | | | | |
| Marketing | | | | | | | | |
| Others | | | | | | | | |

| Amount | Table Fish | Fingerlings | Wild Fish | Total |
|---|---|---|---|---|
| Harvest (kg) | | | | |
| On-farm Consumption | | | | |
| Given away | | | | |
| In-kind Payment | | | | |
| Sold Price (Tk/kg) | | | | |
| Average Size (cm) | | | | |
| Average Size (gm) | | | | |

| Capital outlay | |
|---|---|
| 1) Rent (in-case of lease) | |
| 2) Preparation | |
| 3) Nets/Gear | |
| 4) Equipments(Basket etc) | |
| 5) Others(Specify) | |

| Fingerlings | |
|---|---|
| 1) Date of stoking | |
| 2) No of fingerlings stocked | |
| 3) Date stoking | |
| 4) Source of supply | |
| 5) Unit price | |
| 6) Total price | |

**Multipurpose Uses of Small Water Bodies Shahjadpur Thana, Mouza: Plot:**

| Time<br>Usage | Gender | 6 am | 7 | 8 | 9 | 10 | 11 | 12 | 1 pm | 2 | 3 | 4 | 5 | 6 am | 7 | 8 | 9 | 10 | 11 | 12 | 1 am | 2 | 3 | 4 | 5 | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drinking | M | | | | | | | | | | | | | | | | | | | | | | | | | |
| | F | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fish Culture | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Aqua Culture | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bathing | M | | | | | | | | | | | | | | | | | | | | | | | | | |
| | F | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cattle Feeding | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Washing Clothes | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cattle Bathing | Cow | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Buffalo | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Irrigation | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Washing Crockery | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cooking Water | M | | | | | | | | | | | | | | | | | | | | | | | | | |
| | F | | | | | | | | | | | | | | | | | | | | | | | | | |
| Sewerage | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Duck Raising | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dying | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Jute Retting | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Water Sprinkling | | | | | | | | | | | | | | | | | | | | | | | | | | |

## Appendix 3: Household Survey Sheet

# House Hold Based Survey On Shahjadpur Thana 2002

| Name of Respondent | Age | Sex | Occupation | Mouza | RS |
|---|---|---|---|---|---|
| | | | | | |

**Family Information:**

| Members Name | Relation with Head | Age | Sex | Education | Principal Occupation | Subsidiary Occupation | Monthly Income |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

**Land Utilization in (Dec) per plot (Also specify and mark the plot on the map)**

| Description of land | Own | Taken | Given | Lease | Lease out | Total |
|---|---|---|---|---|---|---|
| Doba area | | | | | | |
| Pond area | | | | | | |
| Dighi area | | | | | | |
| Jola area | | | | | | |
| Beel area | | | | | | |
| Cultivated area | | | | | | |
| Homestead | | | | | | |
| Others | | | | | | |

**Land Utilization (plot wise)**

| Plot Number | Land Area(Dec) | Water Bodies | Cropping Pattern | Soil Type | Water Holding | Water Remains | Water Depth |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

**Type of House Construction**

| Roof | Pucca | | Tin | | Other | | Wall | Pucca | | Tin | | Others(Specify) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| **Utility Line** | Electricity | | Gas | | Telephone | | Sewerage | | Water supply | |
|---|---|---|---|---|---|---|---|---|---|---|

**Cropland use, Yield, Cost and value of Production:**

| Season | Varieties | | Cultivated | | Production | Yield | | Current |
|---|---|---|---|---|---|---|---|---|
| | Present | Present | Present | Present | Cost | Present | Present | Price |
| Kharif I | | | | | | | | |
| Kharif II | | | | | | | | |
| Rabi | | | | | | | | |

**Animal**

| Animal name | Cow | Bullock | Buffalo | Goat | Chicken | Duck | Pigeon | Others |
|---|---|---|---|---|---|---|---|---|
| No | | | | | | | | |

**Animal Protein**

| Item | Production | Process |
|---|---|---|
| Beef & cattle (Kg) | | |
| Mutton & goat (Kg) | | |
| Poultry (Kg) | | |
| Milk (Kg) | | |
| Eggs (#) | | |
| Fish (Kg) | | |
| Others (Kg) | | |

**Fishery**

| Cropping Pattern | Area | Season | Species | Culture Practised | Species Cultivated | Production |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |

**Plant**

| Name | Homestead | Field | Dobaside | Pondside | Dighiside | Beelside | Fallow | Others |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

**Other sources of income**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Business | | Trade | | Service | | Labour | | Agriculture | | Others(specify) | |

**Personal properties**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cycle | | TV(BW/Colour) | | VCR/VCP | | Satellite | | Furniture | | Ornaments | |

**Major Expenditure**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Agriculture | | Food | | Medicine | | Cloths | | Festival | | Repair | |

**Intake of Daily Food and items:**

| | Morning | Mid Day | Afternoon | Evening | Others |
|---|---|---|---|---|---|
| Items | | | | | |
| Expenses | | | | | |
| Frequency | Fish culture | Meat | Chicken | Egg | Milk |
| Per day | | | | | |

**Information on implements:**

| Implements | Possession | Do you lend | Do you borrow | Terms | Rent | Problems |
|---|---|---|---|---|---|---|
| Plough | | | | | | |
| Yoke Ladder | | | | | | |
| Spade | | | | | | |
| Don | | | | | | |
| Swing basket | | | | | | |
| Power tiller | | | | | | |
| DTW | | | | | | |
| STW | | | | | | |
| Low lift pump | | | | | | |
| Spray machine | | | | | | |
| Fishing net | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Others | | | | | | |

**Health and Sanitation:**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Type of Latrine | | Sources of water | | State of Health | | Diseases | |

**Source of Fuel:**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Dung | | Wood | | Leaves | | Gas | | Other(specify) | |

**Social Status:**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rich | | Medium | | Poor | | Matbar | | Sardar | | Leader | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Handloom** | Production | | Price | | Process | |

**Comments:** On different uses of SWB and their management planning for development.

**Appendix 4: Video Clips on attached Compact Disk**

Videoclip 01: Multipurpose uses of Small Water Bodies.

Videoclip 02: Excavation process.

Videoclip 03: Doba Digging.

Videoclip 04: Pond observation in Baoikhola Mouza.

Videoclip 05: Pond in Daya Mouza.

Videoclip 06: Dighi in Daya Mouza.

Videoclip 07: Dighi in Paschim Kharua Mouza.

Videoclip 08: Beel in Baoikhola Mouza.

Videoclip 09: Jola in Paschim Kharua Mouza.

Videoclip 10: Indigenous Irrigation from SWB.

Videoclip 11: Conflict due to the excavation of SWB in agricultural field.

Videoclip 12: Participatory Landuse and SWB survey in Baoikhola with Mouza Map.

Videoclip 13: Participatory Landuse and SWB survey in Daya with Mouza Map.

Videoclip 14: Participatory Landuse and SWB survey in Narandaha with Mouza Map.

Videoclip 15: Ice breaking meetings with local people in Tea stall.

Videoclip 16: Focus Group meeting in Daya Mouza.

Videoclip 17: Focus Group meeting in Naryandaha Mouza.

Videoclip 18. Focus Group meeting in Paschim Kharua Mouza.

Videoclip 19: Focus Group meeting with women in Baoikhola.

Videoclip 20: Focus Group meeting with women in Daya Mouza.

Videoclip 21: Focus Group meeting with women in Narayandaha.

Videoclip 22: Focus Group meeting with women in Narayandaha.

Videoclip 23: Focus Group meeting with women in Paschim Kharua.

Videoclip 24: Key informant interview with a farmer in Baoikhola.

Videoclip 25: Key informant interview with Thana Agriculture and Local Govt Development Project Officer.

Videoclip 26: Key informant interview with Thana Fisheries, Social Welfare and Project Development Officer.

Videoclip 27: Key informant interview with Thana Nirbahee (Chief) Officer.

Videoclip 28: Key informant interview with Paurashava Chairman.

Videoclip 29: Key informant interview with local Govt. Union Parishad Members.

Videoclip 30: Key informant interview with Local Member of Parliament.

Videoclip 31: Livelihood in rural Shajadpur: Women in weaving cottage industry.

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