Small water bodies in Bangladesh

K. M. Shariful Huda[a], Peter J. Atkins[b*], Daniel N. M. Donoghue[b], Nicholas J. Cox[b]

[a] *Department of Geography and Environment, Jahangirnagar University, Savar, Dhaka, Bangladesh*

[b] *Department of Geography, Durham University, Durham DH1 3LE, UK*

* Corresponding author. Tel +44 191 334 1865, Fax +44 191 334 1801

E-mail addresses: kmshuda007@yahoo.com; p.j.atkins@durham.ac.uk; danny.donoghue@durham.ac.uk; n.j.cox@durham.ac.uk

ABSTRACT

Excavations are easy in the soft, unconsolidated sediments of Bangladesh and are widespread for the creation of raised, flood-free homestead platforms. Small water bodies form in the resulting hollows and are used for fisheries, livestock management, irrigation, bathing and washing clothes. Despite their importance to everyday life, there is no up-to-date inventory or monitoring. The paper uses remote sensing, GIS and a number of qualitative data collection techniques to reconstruct the pattern of the small water bodies in Shahjadpur thana. It concludes that there has been an expansion in their numbers but no systematic planning of their use.

Keywords: Bangladesh; small water bodies; fish farming; remote sensing; GIS; mixed methods

Small Water Bodies in Bangladesh

Introduction

What image does water conjure up for you in the context of Bangladesh? Most people would probably say floods and social dislocation, some might refer to the extraordinarily dynamic hydro-geomorphological systems, and a few would no doubt raise the issue of the future havoc that may be wrought in low-lying coastal areas by rising sea-levels. Far less prominent in the popular consciousness of the global North is any thought of water shortages in Bangladesh or her need to manage scarce water resources; yet consideration of these issues is crucial to the long-term success of the government's National Water Management Plan (approved in March 2004). Even the waters of the Ganges are no longer guaranteed to be a limitless source of raw material for irrigation and industrial processes. India's inauguration in 1975 of the Farakka Barrage only 18 km upstream of the border has substantially reduced dry season flow, causing a level of hardship that the Bangladesh-India Treaty on Sharing of the Ganges Waters signed in 1996 has failed to mitigate (Brichieri-Colombi and Bradnock 2003). As a result, water has become an issue of geopolitical importance between these riparian neighbours.

Water quality is another practical and policy issue in Bangladesh. Water-borne diseases are a common source of morbidity and a substantial portion of the high rate of infant mortality is thought to be water-related (WHO 2000). The use of oral rehydration therapy has been a help with the latter problem but the need for clean water supplies of better bacteriological quality has been acknowledged for three decades or more. In 1972 the United Nations Children's Fund decided to invest in drilling for cleaner groundwater and their initiative has since been taken up privately by millions of families around the country (Smith *et al.* 2000). There are now 12 million or more tubewells in Bangladesh tapping aquifers in the Quaternary sediments composing the delta. This groundwater source represents about 80 per cent of drinking water nationwide (Ahmed 2002).

Since the water now available is of a better bacteriological quality than ever before, one might be forgiven for thinking that the problem is solved. However, in 1995 it was announced that this new, underground source is extensively contaminated with a life-threatening toxin – arsenic. Extensive screening of tubewells has shown that 27 per cent are poisoned and unsafe for drinking purposes at the government's declared threshold of 0.05 mg of arsenic per litre (BGS and DPHE 2001; Atkins *et al*. 2007). As a result, a debate has begun about a possible reversion to the use of surface waters if these can be managed in such a way as to minimize the bacteriological load. Some commentators are sceptical and instead prefer measures that include the chemical removal of arsenic from groundwater, but others insist that properly sealed dug wells are suitable (Smith *et al.* 2003). Another option might be the use of the many ponds, lakes and other surface water bodies that are abundant in Bangladesh (Kränzlin 2000). It is these water bodies that concern us here.

One of the problems in the debate about supplies from water bodies in rural areas has been a lack of information. We actually know very little, especially for small water bodies (SWBs), about the traditional patterns of usage and management that were in place before the 1970s or 1980s, and their potential for the future. Our fieldwork was therefore in essence a detailed exploration of SWBs in a typical region, Shahjadpur thana, in the floodplain of the River Jamuna (Brahmaputra) (Figure 1). Within that we selected four mouzas, the lowest administrative unit, and looked at all their 287 SWBs (Huda 2004; Huda and Atkins 2005). In addition to fieldwork in all of the local villages, the research had a laboratory-based element that involved the analysis of maps, aerial photographs and satellite images. This paper will describe the methods used and the results achieved. First, after a brief introduction to Shahjadpur thana, we describe the range of SWBs found in the study area and their use by local people. Next, we look at their change through time, employing a number of source materials. The objective here is to understand the place of SWBs in the shifting patterns of water use in rural Bangladesh. Finally, we reflect upon the mixed methods used in this research and their potential for replication in other parts of the country, and possibly further afield. Although it is not possible for the present paper to pursue this point in depth, it is possible that SWBs could play an increasingly important role in the sustainable use of natural resources in Bangladesh and that a combination of remote sensing and qualitative survey techniques could add a great deal to resource management through understanding popular perceptions and uses of surface water bodies.

< Figure 1 here >

Shahjadpur thana

Shahjadpur thana, in Sirajganj district, is located on the western bank of the Jamuna just north of its confluence with the Padma (Ganges). This is a poor, rural area, densely populated at 1,296 people per sq. km in 1991 and reliant upon agriculture. The average literacy rate is 31 per cent for males, but a meagre 18 per cent for females (BBS 1996). Only 13 per cent of households have an electricity connection and other physical infrastructure is weakly developed. For instance, Narayandaha, one of our study mouzas, although less than a kilometre from the centre of Shahjadpur town, has no direct road access. This may be explained by its ghetto status, first as a home for Hindus, and more recently for the minority Shia muslim community. Daya mouza is equally close to the *paurashava* (municipality) but has, in contrast, benefited from its growth, more than doubling in population from 163 in 1972 to 395 in 2002. Paschim Kharua mouza has also expanded rapidly, as a dairy farming area serving a cooperative factory, Milk Vita, and our fourth mouza, Baoikhola, specializes in high yielding varieties of rice, cultivated in the early kharif (April-July) and rabi (dry) seasons using irrigation from its large beel. Baoikhola is the only one of our study areas to have none of the modern conveniences of electricity, gas, land line telephones, sewers or piped water.

Roughly 70 per cent of the thana is cultivated and the remainder is made up of homesteads, roads, and permanent water bodies like rivers, khals/jola 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 reaches a peak with over-bank river discharge in July and August.

People in the region have long since abandoned the use of SWBs for drinking water. Instead this comes almost wholly from tubewells, with SWBs now being used for irrigation and fisheries, along with household uses such as water for cooking, bathing, and the washing of clothes and utensils. In addition, they are important in the raising of livestock, and for the common *kachuripana* or water-hyacinth (*Eichhornia crassipes*) that grows profusely and is used as a green manure, cattle fodder, and a packing material (for instance to stop spillages from full milk vessels on their way to market). SWBs are also associated with a wide diversity of useful plants through the use of their water in the irrigation of house gardens. Wealthier families grow tree fruit and the poor concentrate on vegetable crops like bottle gourd and beans, which during lean periods supplement their staple foods (Stokoe 2000; Wallace *et al.* 1987). The SWB use of greatest concern is as cess pools. In 2002 in Daya and Paschim Kharua, for instance, over 90 per cent of households used *kacha* latrines, small huts with thatched walls from which the effluent drained directly to a SWB. Our survey showed that there were some people bathing in and eating fish from these polluted water bodies.

Most of our key informants suggested the need of a proper inventory of all the SWBs for the identification of issues. They also expressed concern regarding the *khas* SWBs, which are state-owned but often leased to influential people or just occupied illegally. There is a customary expectation that the poor will benefit from khas resources, which are thought of as common property, but the enforcement of both traditional and legal rights is weak. Our focus groups and participant observation raised different points on SWB management for women and men. Domestic benefits were articulated strongly 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 SWBs. In addition, they emphasised the washing of clothes, the drawing of water for cooking purposes, crockery washing and bathing. Women were also concerned about the relative scarcity of water in the dry season and of hygienic water during the monsoon. In contrast, the men mentioned the economic benefits of SWB use for agricultural and fishery production. The one point mentioned in common by both men and women was irrigation.

The use of SWBs for fish farming has fluctuated over the last 30 years but remains high at 75 per cent. Usually there is natural recharge during the annual floods due to the migration of fingerlings. According to the Master Plan Organization (MPO 1984), SWBs can be categorized according to the intensity of their fishery management: (i) extensive: stocked with carp, no fertilization and feeding; (ii) semi-intensive: carp, multi-species culture with fertilization but without feeding; (iii) semi-intensive: carp, multi-species culture with fertilization and low quality feeding; (iv) super-intensive: stocked with carp or tilapia, multi-species culture, increased water use and aeration, heavy and regular fertilization and use of high quality feed. Almost all of the SWBs in the study area fall into the first two categories. Of the five reasons suggested by Wood (1994) for a decline of stocks of fish, three are observable locally. First, there are few commercial operators, with dominance by small, domestic operations. Second, marketed fish are consumed mainly by wealthier groups and the economy is generally one of use rather than exchange. Third, co-ownership of SWBs is often mentioned as a constraint, although there is a clear potential for cooperation between co-owning joint families.

Types of small water bodies

Several types of SWBs may be recognised in this part of Bangladesh (Figure 2). First, there is the human-made pit or ditch known as a 'doba' or 'pagar', which is approximately 25-400 sq. m in extent, like the vernal pools mapped in a similar exercise to ours by Lathrop *et al.* 2005. Dobas retain water only in the wet season and then dry out. Most are located close to homesteads, as is the larger 'pukur', which at 150-1,000 sq. m is a perennial water source and is often used for fish farming. Both dobas and pukurs are the result of the need to excavate earth to build house mounds up high enough to avoid floods. Most houses on the flood plains of Bangladesh are elevated in this way and there are therefore millions of excavated ponds. Second, a 'dighi' is a small tank or reservoir, of over 750 sq. m, and a 'jola' or 'khal' is a linear watercourse made for transport or irrigation purposes and to provide means for excess water to drain away during floods. Both of these are artificial but our third and final SWB, the 'beel', 'baor' or 'haor', is natural. A beel is a saucer-shaped depression, often an ox-bow lake, found in association with a river that has altered its course, a common phenomenon in the ever-changing geomorphology of lowland Bangladesh. This may be the result of river meandering due to siltation, or the aggressive riverbank erosion that is often found along this portion of the Jamuna. Beels vary in size from 1,000 sq. m to several square kilometres and they are valuable resources for local people wanting water for irrigation or for aquaculture.

< Figure 2 here >

In 1982 the Bangladesh Bureau of Statistics, through the Non-Crops Statistics Section of its Agricultural Statistics Wing, estimated a total of 1.86 million SWBs, mostly managed ponds, through a field survey conducted in 420 thanas (sub-districts) out of 493 (BBS, 1984). At the same time another survey was undertaken by the Space Research and Remote Sensing Organization, using satellite imagery and aerial photographs, at the request of the Bangladesh Fisheries Department (SPARRSO 1984). This classified water bodies suitable for fish production as either 'small' or 'large'. The SWBs included ponds and tanks with surface areas of less than 25 ha. Colour infrared aerial photographs taken in 1983 and 1984 were used to identify and locate 122,000 ponds in 40 selected thanas, covering an area of 13,900 ha. The total number of ponds in Bangladesh was then estimated by extrapolation to be 1.3 million, covering an area nationally of 164,000 ha. The survey showed the pond density to be 2 to 35 ponds per sq. km, with an average water area of 0.13-2.9 per cent.

The Second Phase Agricultural Census Project (1985-90) carried out a survey of SWBs in 1989 to obtain a comparison with the earlier surveys, and had the objective for the first time of establishing comprehensive statistics on inland fisheries resources. The result was published in 1994, the estimated total number of ponds this time being 1.95 million (BBS 1994). SWBs were also the focus of research 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). These studies found similar numbers in their areas as had the BBS, and they pioneered a classification using the terms ‘cultured’, ‘culturable’ and ‘derelict’ ponds, finding 15 per cent in the last category.

Although these studies are of interest for their estimates, it was not an objective of our study to provide similar scaled-up calculations of SWBs at the national level. In our view this would not have been helpful without comparative studies of a sample of the various hydrological landscape regions of Bangladesh.

Detecting the changing numbers of small water bodies in Shahjadpur thana

Our study was partly historically-oriented, using a number of sources to estimate the changing number and use of SWBs. We were particularly interested in the scope for combining remote sensing with field techniques in order to maximize our knowledge of the historical geography of SWBs over the thirty years since their change in use away from drinking water. Our expectation was that this shifting use pattern might have reduced people’s enthusiasm for excavating silt and renewing the dobas, pukurs and dighis after the annual floods, and therefore that the number might have diminished.

We used multi-spectral and panchromatic satellite data with the highest available resolution and were fortunate to be able to access all of the available imagery for the study area and use it to evaluate change over the period 1972 to 2003. Previous studies (Vonders and Clevers 1999) had identified the need for high spatial resolution sensors in SWB detection and Table I shows that we were able to fulfil this requirement from the earliest date. Such rich and detailed sources are unusual for work on Bangladesh but it was nevertheless important for us to prove an added value in interpretation. It is arguable that consistency and analytical depth might have been gained from the use of just one source, Landsat for instance, through time or that further triangulation might have been possible from the use of several different sensors at key cross-sectional moments, but limited resources and access meant that we were pleased with the data available to us.

Our earliest source (1972) was declassified data from the American spy satellite code-named CORONA. These came as filmstrips and were processed using a photogrammetric optical scanner at 7.5 micron resolution, giving a very high quality of image that is equivalent to a two metre ground resolution. Since we were fortunate also to have access to black and white aerial photography for this period, our early baseline in the early 1970s was solid. This was supplemented by optical satellite images of a good radiometric and geometric quality from the well-known French satellite, SPOT, the American Landsat, and the Indian Remote Sensing (IRS) platforms. Because these images were captured at a series of dates from 1972 to 2003, we were able to engage in land-use change detection. Because optical sensors are restricted by cloud cover, a major problem for Bangladesh in the monsoon season, we also experimented with RADAR, which has the additional advantage of collecting data day and night and, at microwave frequencies, of penetrating the vegetation canopy. The European Resource Satellite (ERS), Shuttle Imaging Radar (SIR-C), and X SAR (also Shuttle-based) were evaluated, although for technical reasons the results were disappointing. Other studies have shown that the consistent tone and smooth texture of small inland water bodies are often well delineated by higher resolution RADAR sensors. We think that there may be potential here for future work with SWBs in Bangladesh.

Before outlining our methodology, it is worth noting that, to the best of our knowledge, no-one has previously performed a comparative assessment of the visibility of different types of water bodies on images of different spatial and spectral resolution.

< Table I here >

First, a visual analysis was performed using manual on-screen digitizing methods for identification and mapping, and the images were digitally classified, using various methods, to identify the water bodies in the area. The classified images were then verified using GIS data derived from mouza maps, which enabled the identification of land use features, plot boundaries, and the location and identification of individual SWBs. Each plot thought to have an SWB present was then visited during the fieldwork to measure the spatial extent of that particular feature and to get an idea of the surrounding land use. All of the SWBs were checked by a participatory fieldwork technique that involved showing the relevant CORONA image and aerial photographs to local people who, once they had orientated themselves with known landmarks, were very helpful in providing commentaries on past changes and present uses. Finally, GPS data were used to ground truth the remotely sensed data, which were then geocorrected and registered to a base map using GIS software, and matched to the image using image analysis software (Figure 3). Rather than describe the full technical detail in this paper, we will instead focus on the results from analyzing the best available images and from the ground survey.

< Figure 3 here >

The first field survey (winter 2001/2) of the four mouzas found 287 SWBs (Table II; Figure 4). The largest was measured at 34,812.8 sq. m using a hand-held GPS and, at the lowest end, the minimum doba size is about 40 sq. m. 20 SWBs were reported as dry during the field survey. The distribution pattern for the different class sizes follows more or less the pattern as observed for the whole study area; in other words, there is no spatial concentration of large or small water bodies.

<Table II here>

< Figure 4 here >

An important technical issue for the inventory of SWBs is the smallest size threshold at which they can confidently be identified by remote sensing (Lathrop *et al.* 2005). This is important for future use of that technique wherever fieldwork is not feasible; we therefore employed imagery with the best resolution in order to provide meaningful results. One problem with the preliminary assessment of the images was occasional confusion in the separate identification of vegetation in the house compounds and the water of a SWB. It is common, for instance, for people to have mango, jackfruit, coconut, guava, papaya, banana and other fruit trees or bamboo stands that overhang the water's edge. Second, haze also significantly influences the spectral properties of the image and affects the classification results. Third, the months from December to March are normally the middle stage of irrigated paddy cultivation and low and medium-high lands are covered with paddy. These irrigated paddy fields add big clusters of scattered water pixels to the croplands and, again, cause uncertainties of classification.

Table III summarises the results of the remote sensing interpretation in terms of the smallest SWB that was detected, in square metres.[1] The reader will immediately notice the inconsistency of the results. This is due to the different resolutions of the various sensors and their ability to distinguish SWBs from surrounding noise. The smallest SWBs were detected by the IRS-ID for 1999 and 2003, although we must remember that SWBs 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. The other sensors detected larger SWBs such as beels and jolas but were less successful with dighis, dobas and pukurs. The resolution of SPOT images has now improved (5 m 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.

< Table III here >

Table III excludes synthetic aperture RADAR imagery: ERS-I 1993 and NASA SIR-C 1994. We found that these low resolution sensors cannot identify all of the types reliably. However, they may in future be helpful for understanding changes, especially the larger water bodies above 1000 sq. m., and it is worth remembering that RADAR data can be acquired during the day or night and through cloud.

Figure 5 uses a series of miniature histograms to depict the size range of each type of SWB. These sizes were determined by ground survey using a hand-held GPS and they are presented here on the horizontal axis in square metres on a logarithmic scale. The vertical bars represent the number of SWBs in each size category but we will not delve further into that in the present paper, other than to point out the concentration (dobas and pukurs) at the lower end of the size range. The small triangular symbols under each histogram show the median size for each SWB type and provide a means of visualising the observation data in Table IV.

< Figure 5 here >

< Table IV here >

The integration of GIS, remote sensing and fieldwork was the basis of our research. Our experience shows that the most successful visual interpretation requires familiarity with feature types on the ground and we were particularly fortunate to be able to draw upon our detailed prior knowledge of the field area. This is by no means always possible for researchers. Table IV is a summary of the results, showing a comparison between estimates of the average size of SWBs derived from remote sensing platforms, and those gathered through two ground-based methodologies. First, we used questionnaires, focus groups and interviews with key informants to reconstruct the changing number and size of SWBs through time. To aid their deliberations, informants were shown copies of satellite images to orientate themselves. We were surprised at how visually literate people were and, generally speaking, they had no difficulty in identifying landmarks and in describing the SWBs under discussion. The older respondents in particular remember the details of past SWB excavation, extension and extinction as clearly as they do the construction of their houses. This is because these water resources play a key part in their daily lives and are important features in the local landscape. Second, we walked the villages and fields, using a GPS to measure the location and dimensions of present-day water features, and recording a range of characteristics such as depth. The table shows inconsistent variation between the three approaches but, comfortingly, the high resolution remote sensing estimates were generally close to those from the most accurate method, observation. Because SWBs are, by definition, at the limit of present remote detection technologies, it has been highly instructive to test the images currently available.

About two-thirds of our SWBs have a surface area of less than 800 sq. m. We found that remote sensing methods are not suitable for the inventory of SWBs with a size of less than 200 sq. m and are not capable of detecting more than a portion of SWBs with a size of less than 80 sq. m. SWB signatures have a tendency for confusion 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 (November) most SWBs are full of water and some are dry. We found more SWBs to be dry on a revisit in February/March 2002.

Figure 6 summarises our results for the number of different types of SWBs through time. As far as we are aware, this resource chronology is a first for Bangladesh. Contrary to our expectations, the number of SWBs has increased rapidly over that period, mainly as a result of house building, and our best guess is that this will continue.
< Figure 6 here >

Since the completion of the field work and image analyses for this study, a new era of very high resolution, commercially available satellite images has begun. The IKONOS and Quickbird satellites have been launched and are transmitting high-quality imagery with 1 m and 61 cm panchromatic resolution and 4 m and 2.4 m multispectral resolution respectively. Using merging techniques with such very high-resolution imagery should in future provide an even better means to identify most of the SWBs in Bangladesh.

Conclusion

We have described a research programme based on the novel combination of technical remote sensing and GIS with qualitative human geography fieldwork methods such as focus groups and interviews with key informants. Although not covered here, we also used participant observation and video methods to enhance our understanding of SWB use and management. From the point of view of the planners and policy-makers, we assert that it is possible to relate present government water policies to a dynamic of water resource management over three decades and to make some predictions for the future. As we saw in Table V, it was possible to reconstruct the history of SWBs in four rather different mouzas, showing a surprising increase in dobas and pukurs. Many of these new SWBs are under-used, for instance for fisheries, or misused. Better provision of sanitary facilities would remove the need to use SWBs as cess pools and reduce the contamination that is threatening those who wish to use them for fish farming, bathing or other domestic purposes. The restoration of the strict usage codes that were in place until the 1970s might even allow the allocation of some to drinking water, a necessary step in view of the extensive problem of arsenic in groundwater. But the microbial loading of such surface waters that may have been acceptable in the 1970s is certainly not acceptable at present, and so water treatment measures will still be needed, which raises the issue of expense.

Note

1 We have kept the technical aspect of image interpretation to a minimum in this short paper but it is worth noting at this point that the ability to identify water bodies is often enhanced or inhibited by image tonal variations.

CAPTIONS

Table I. Remote sensing data.

Table II. Data collected through participant observation, questionnaires and ground truthing.

Table III. The smallest water body detected in each mouza (sq. m).

Table IV. Results of the mixed methods: mean size of water bodies (sq. m).

Fig. 1. The study area in Shahjadpur Thana.

Fig. 2. Composite of photographs showing small water bodies of different sizes.

Fig. 3. SWBs identified in Paschim Kharua mouza.

Fig. 4. Small water bodies in the four sample mouzas.

Fig. 5. Median size and distribution different types of SWBs in the four sample mouzas.

Fig. 6. The changing numbers of small water bodies in the four mouzas.
Source: Remote sensing imagery, key informant interviews and focus groups.

Table I

Platform	Sensor	Year	Mode	Media	Resolution/Scale
CORONA	KH-4B	1972	Panchromatic	Film	2 m
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 m
SIR-C	SAR	1994	X-Band	Digital	30 m
X SAR	SAR	1994	C-Band	Digital	25 m
Landsat 5	TM	1997	Band 2-4	Digital	30 m
Landsat 5	TM	1998	Band 2-4	Digital	30 m
IRS	ID	1999	Panchromatic	Digital	6 m
IRS	ID	2003	Panchromatic	Digital	6 m
IRS	LISS	2003	XS	Digital	23 m

Table II

	Baoikhola	Daya	Narayandaha	Paschim Kharua	Total
Plots	1587	1181	566	1374	4708
Doba	28	67	20	22	137
Pukur	20	48	19	44	131
Dighi	1	2	0	5	8
Jola	2	3	1	1	7
Beel	3	0	0	1	4
Total	54	120	40	73	287

Note: Plots are the lowest level of revenue collection, the boundaries of which are marked on a mouza map.

Table III

Platform	Year	Sensor	Resolution (m)	Baoikhola	Daya	Narayandaha	Paschim Kharua
CORONA	1972	Panchromatic	2.0	79.6	93.9	83.2	129.4
Aerial photo	1974	AP	1.5	75.3	n/a	n/a	n/a
Aerial photo	1983	AP	1.5	74.4	n/a	n/a	n/a
SPOT, HRV	1989	Panchromatic	16.0	n/a	n/a	n/a	n/a
Aerial photo	1990	AP	1.5	78.8	n/a	n/a	n/a
Landsat TM	1997	Multispectral	30.0	n/a	n/a	n/a	n/a
Landsat TM	1998	Multispectral	30.0	n/a	n/a	n/a	n/a
IRS-ID	1999	Panchromatic	5.8	85.9	73.6	86.4	86.1
IRS-ID	2003	Panchromatic	5.8	84.7	78.7	85.2	87.4
IRS-LISSIII	2003	Multispectral	23.0	800.3	812.7	865.2	834.0

Table IV

Mouza	Method	Doba	Pukur	Dighi	Beel	Jola
Baoikhola	Observation	141.9	570.4	2736.8	35,097.8	2043.6
	Questionnaire	157.9	597.7	2429.0	42,153.3	3481.0
	Remote sensing	203.0	639.5	n/a	41,710.6	2633.5
Daya	Observation	168.0	287.2	1497.3	n/a	9233.2
	Questionnaire	189.9	304.2	1259.9	n/a	n/a
	Remote sensing	188.6	289.4	1509.1	n/a	9344.3
Narayandaha	Observation	218.1	449.9	n/a	n/a	26,098.8
	Questionnaire	222.1	439.9	n/a	n/a	26,312.0
	Remote sensing	232.7	389.2	n/a	n/a	26,617.0
Paschim Kharua	Observation	162.9	851.1	5707.8	26,717.0	26,717.0
	Questionnaire	208.0	848.8	4924.7	35,374.3	34,873.3
	Remote sensing	165.3	757.1	10,067.3	7548.1	35,297.7
Total Study Area	Observation	172.7	539.6	3313.9	30,907.4	16,023.2
	Questionnaire	194.5	547.7	2871.2	38,763.8	21,555.4
	Remote sensing	197.4	518.8	5788.2	24,629.3	18,473.1

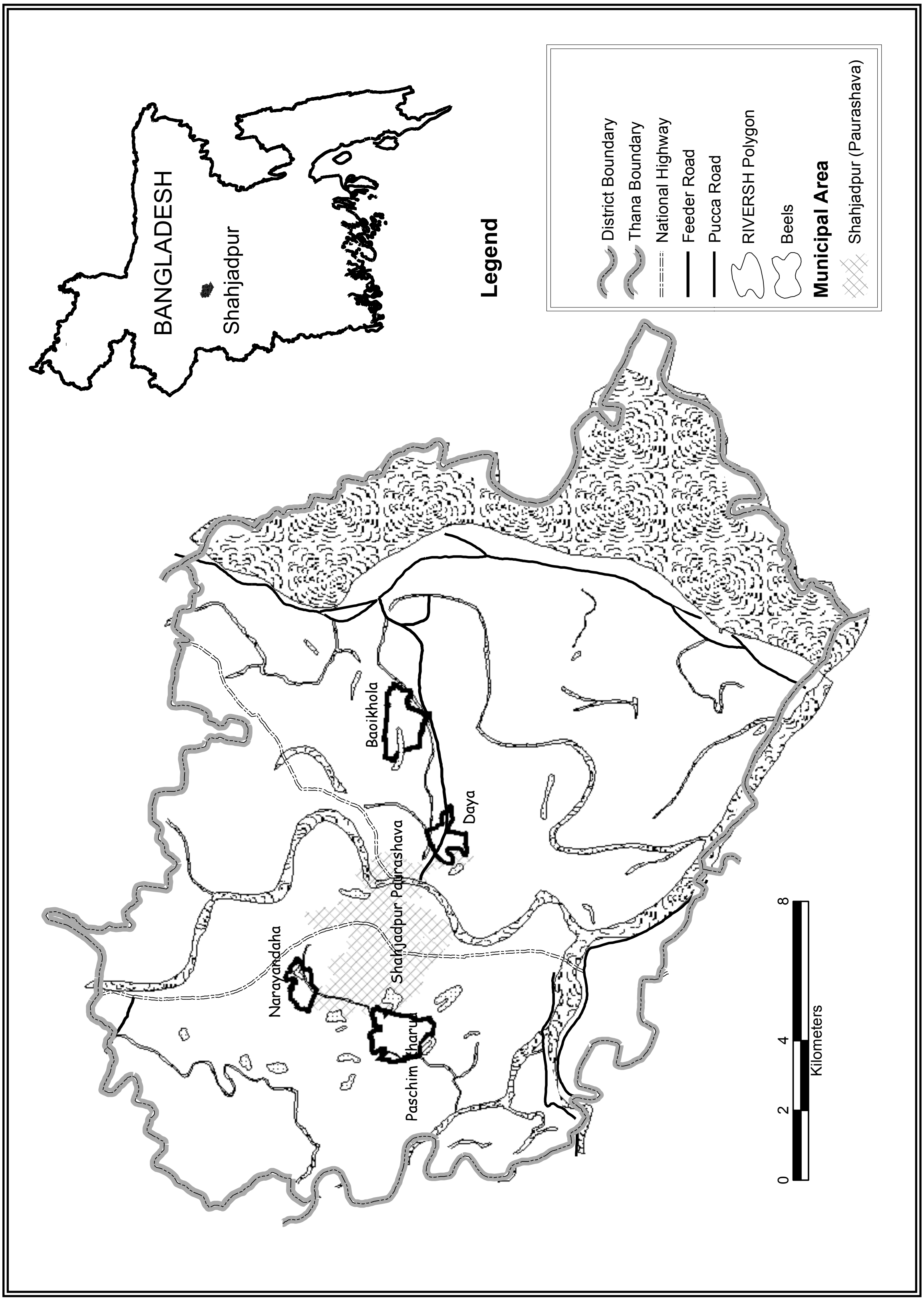
BANGLADESH
Shahjadpur
Legend
District Boundary
Thana Boundary
National Highway
Feeder Road
Pucca Road
RIVERSH Polygon
Beels
Municipal Area
Shahjadpur (Paurashava)
Baoikhola
Daya
Shahjadpur Paurashava
Narayandaha
Paschim Gharu
0
2
4
8
Kilometers

Fig. 1.

(a) Beel, Baoikhola

(b) Jola, Paschim Kharua

(c) Dighi, Baoikhola

(d) Pukur, Baoikhola

(e) Doba, Paschim Kharua

Fig. 2.

Fig. 3. **(New version attached as Figure 3 New.jpg)**

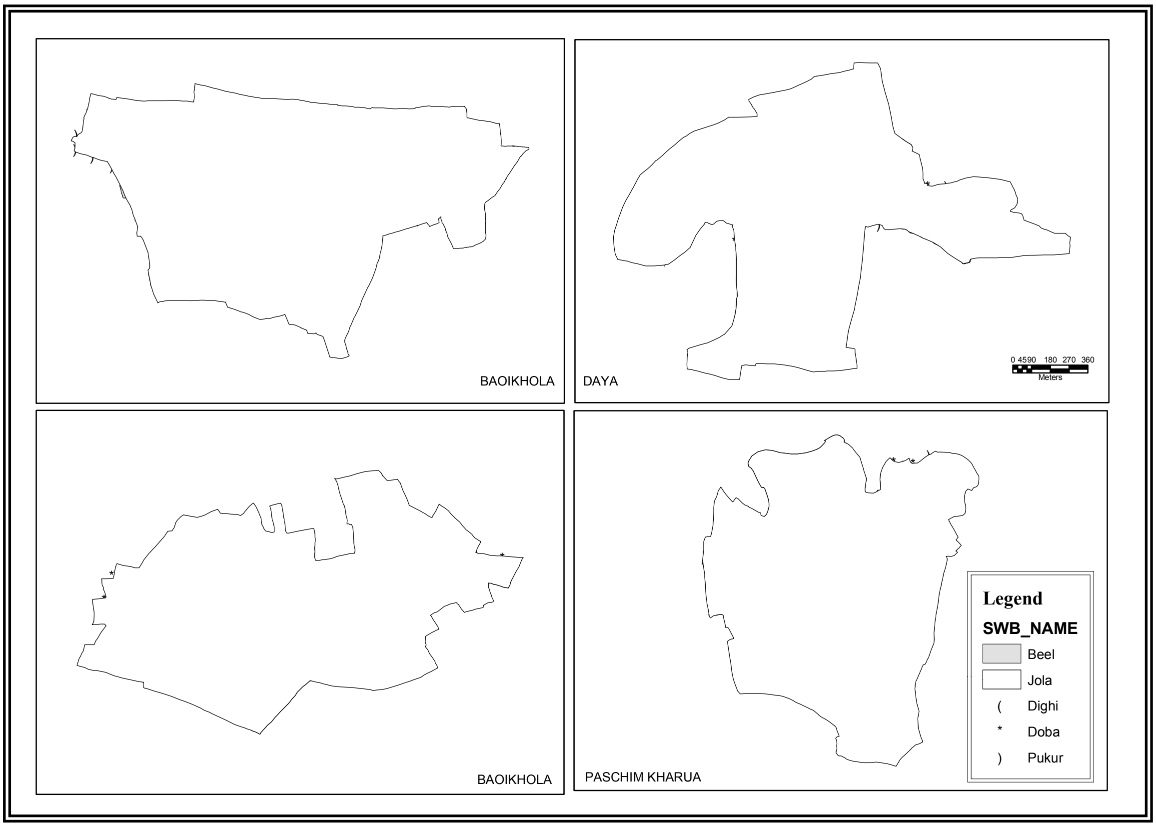
BAOIKHOLA
DAYA
0 45 90 180 270 360
Meters
BAOIKHOLA
PASCHIM KHARUA
Legend
SWB_NAME
Beel
Jola
(Dighi
* Doba
) Pukur

Fig. 4.

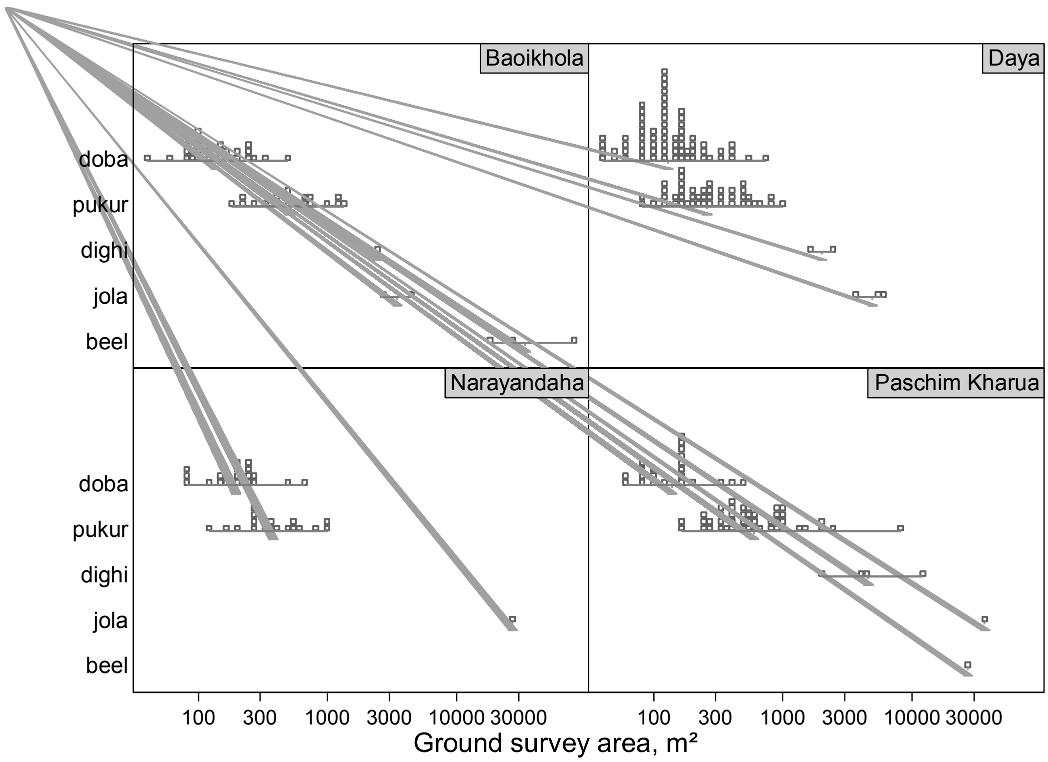
Baoikhola
Daya
Narayandaha
Paschim Kharua
doba
pukur
dighi
jola
beel
doba
pukur
dighi
jola
beel
100
300
1000
3000
10000
30000
100
300
1000
3000
10000
30000
Ground survey area, m²

Fig. 5.

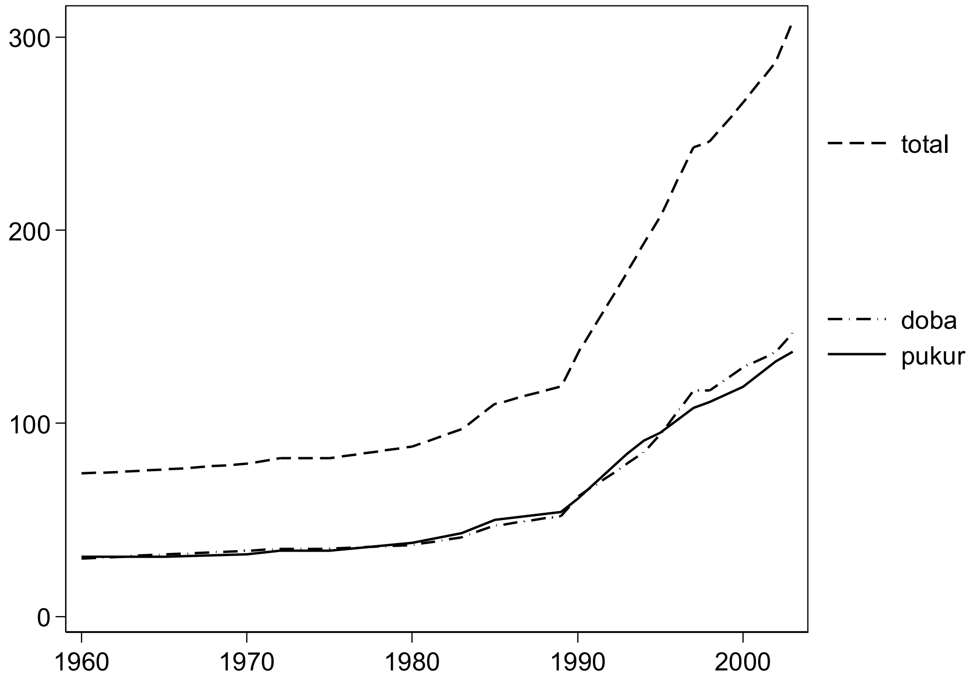

Fig. 6.

References

Ahmed M F 2002 *Alternative water supply options for arsenic affected areas of Bangladesh, International Workshop on Arsenic Mitigation in Bangladesh, Dhaka, 14-16 January, 2002* ITN Bangladesh, Centre for Water Supply and Waste Management, Dhaka

Atkins P J Hassan M M and Dunn C E 2007 Poisons, pragmatic governance and deliberative democracy: The arsenic crisis in Bangladesh *Geoforum* 38 155-70

B B S 1984 *The survey of ponds – 1982* Bangladesh Bureau of Statistics, Dhaka

B B S 1996 *Bangladesh population census 1991, Community Series, Zila: Sirajgonj* Bangladesh Bureau of Statistics, Dhaka

Brichieri-Colombi S and Bradnock R W 2003 Geopolitics, water and development in South Asia: cooperative development in the Ganges-Brahmaputra delta *Geographical Journal* 169, 43-64

British Geological Survey and Department of Public Health Engineering 2001 *Arsenic contamination of groundwater in Bangladesh Volume 2: final report* in **Kinniburgh D G and Smedley P L** eds BGS Technical Report WC/00/19 British Geological Survey, Keyworth

Compartmentalization Pilot Project 1996 Extension programme: activities and achievements during 1994-96 *Technical Note 96114* CPP, Dhaka

Huda K M S 2004 Detection monitoring and management of small water bodies: a case study of Shahjadpur Thana, Sirajgonj District, Bangladesh Unpublished PhD thesis, Durham University

Huda K M S and Atkins P J 2005 The creation and uses of small water bodies in Bangladesh: case study of Shahjadpur thana *Indian Journal of Landscape Systems and Ecological Studies* 28 2 1-7

Kränzlin I 2000 Pond management in rural Bangladesh: system changes, problems and prospects, and implications for sustainable development *Basler Beiträge zur Geographie* 46

Lathrop R G Montesano P Tesauro J and Zarate B 2005 Statewide mapping and assessment of vernal pools: a New Jersey case study *Journal of Environmental Management* 76 230-38

Master Plan Organization 1984 *Second interim report: Vol. VII – fisheries* MPP, Ministry of Irrigation, Water Development and Flood Control, Dhaka

Smith A H Lingas E O and Rahman M 2000 Contamination of drinking-water by arsenic in Bangladesh: a public health emergency *Bulletin of the World Health Organization 78* 1093-1103

Smith M M Hore T Chakraborty P Chakraborty D K Savarimuthu X and Smith A H 2003 A dugwell programme to provide arsenic-safe water in West Bengal, India: preliminary results *Journal of Environmental Science and Health, Part A: Toxic/Hazardous Substances and Environmental Engineering* 38 289-99

Space Research and Remote Sensing Organization 1984 *Survey on water bodies using satellite image and aerial photos* SPARRSO, Dhaka

Stokoe J 2000 Wild vegetables: a valuable natural resource for the rural poor in **Sillitoe P** ed *Indigenous knowledge development in Bangladesh* Intermediate Technology Publishing, London 79-89

Vonders O W and Clevers J G P W 1999 *Multisensor RS land capabilities land. Report 1: applications of optical remote sensing satellite sensors* USP Report 98-25 Netherlands Remote Sensing Board, Delft

Wallace B J Ahsan R M Hussain S H and Ahsan E 1987 *The invisible resource: women and work in rural Bangladesh* Westview, Boulder, CO

Wood G D 1994 *Bangladesh: whose ideas, whose interest?* Intermediate Technology Publishing, London

World Health Organization 2000 *Towards an assessment of the socio-economic impact of arsenic poisoning in Bangladesh* WHO, Geneva