ASSESSMENT OF THE POTENTIAL FOR ARSENIC ACCUMULATION IN RICE FIELD SOILS IN BANGLADESH AND ITS IMPLICATION ON RICE YIELD

by

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DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

August ,2012

Md Saiful Islam

Dedicated
To
My Father

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ABSTRACT

Widespread use of arsenic (As) contaminated water for irrigation to produce dry season crop (mainly boro rice) poses threats to sustainable agriculture and to human health in Bangladesh. Presence of As in irrigation water leads to elevated levels of As in soil, with significant spatial and temporal variation. Monsoon flooding removes significant fraction of As added to soil through irrigation each year. Reported soil-As data from non-flooded areas show much higher retention of As added through irrigation water. So areas without pronounced monsoon flooding are at greater risk of soil-As accumulation than seasonally flooded paddy fields. This study makes an assessment of the potential of arsenic accumulation through irrigation in soil where extensive boro rice cultivation is carried out; the potential of arsenic accumulation has been presented in the form of a "Arsenic Hazard Map". The Arsenic hazard map has been prepared considering the hypothesis on As deposition/ mobilization in paddy soils, using data on arsenic distribution in groundwater, boro cultivation/ irrigation intensity, and flood inundation depth. This risk level of arsenic accumulation in soils has been divided into seven categories: (a) Very high-risk area, (b) High-risk area, (c) Moderate-risk area, (d) Moderate to low-risk area, (e) Low-risk area, and (f) Very low-risk area. According to the Arsenic Hazard Map, areas to the south-west and some areas in the north-east are at risk of higher accumulation of arsenic, because of higher concentration of arsenic in irrigation water, higher intensity of boro cultivation, and higher land elevation.

"Query analysis" of the hazard map reveals that 282,267 ha of highland used for boro cultivation in 22 upazilas of the south-western region of Bangladesh are at "very high risk" of arsenic accumulation, because of higher arsenic in STW irrigation water and low flood inundation depth; and 382,001 ha of highland in 35 upazilas are at "high-risk" status, where flood inundation depth is low , but arsenic concentration in STW irrigation water is also relatively low. Areas in the northern parts of Bangladesh are at "low to no risk" because of lower concentration of arsenic in irrigation water, despite higher intensity of boro cultivation. Some areas in the south-central region of Bangladesh are at "moderate to low risk" of arsenic accumulation because of higher elevation of these areas (which results in lower flooding intensity). Soil-As data from primary (i.e., field sampling and analysis) and secondary sources qualitatively validate the Arsenic Hazard Map prepared in this study. Soil-As map prepared form collected primary and secondary data shows that in most of the south western region, soil-As level exceed 30 mg/kg.

An assessment of the impact of arsenic accumulation in soil on rice yields in selected high-risk areas has been made utilizing available data/ information correlating arsenic in irrigation water and agricultural soil, and soil arsenic and crop yield. It appears that significant rice yield reductions could result in the future due to accumulation of arsenic in irrigated soil. Estimated yield reductions in nine high-risk upazilas varied for about 9 percent to 24 percent for the year 2020, and 12 percent to 53 percent for the year 2050. Possible yield reduction due to elevated soil arsenic appears to be a potential threat to food security and agricultural sustainability in Bangladesh, where rice is the main crop and staple food, and boro rice accounts for over 50 percent of total rice productions.

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CHAPTER ONE
INTRODUCTION

1.1 Background

Arsenic (As) in groundwater is a major health concern in Asia and the risks associated with use of As-contaminated shallow tube wells (STWs) for drinking-water are well known. At present, twelve countries in the Asian region have reported high As levels in parts of their groundwater resources. Bangladesh has the highest percentage of contaminated STWs (20 percent) and an estimated 30 million people are dependent on those wells for domestic purposes. A major concern related to large-scale use of groundwater for irrigation is As entering the food chain, affecting food safety. This poses a potential dietary risk to human health in addition to the risk from drinking contaminated groundwater. Less well known but potentially more serious is the risk of As to crop production.

Bangladesh relies heavily on groundwater resources, often containing high concentrations of arsenic, for the irrigation of dry season rice. Whilst irrigation enables Bangladesh to maintain food self sufficiency at present, arsenic accumulation in paddy soils may jeopardize rice production in the long term. Rice production in Bangladesh has more than doubled over the last 3 decades (MoA, 2007), mainly due to the increasing cultivation of dry season rice (*boro*). In contrast to the traditional wet season varieties, *boro* rice requires intense irrigation (Field, 1995). Groundwater from shallow tube wells, often high in As, is predominantly used for irrigation, causing an estimated yearly input of 1360 tons of As to arable soils in Bangladesh (Ali et al., 2003a).

Accumulation of As in paddy soils may adversely affect rice yields due to As phytotoxicity and rice quality due to increasing As levels in grains and straw. Both effects have been observed in greenhouse studies with As-spiked soils (Abedin et al., 2002; Xu et al., 2008). Increased As levels in soils (Alam et al., 2000; Meharg and Rahman., 2003; Norra et al., 2005; Van Geen et al., 2006) and rice grains (Duxbury el al. 2003; Hossain et al., 2008) have repeatedly been demonstrated in field studies conducted in As-affected areas, and a recent study has shown alarming evidence of As-related yield reduction under field conditions in Bangladesh (Panaullah et al.,

2009). Irrigation with As rich groundwater leads to laterally heterogeneous As input to soil (Hossain *et al., 2008.)*, affecting the top few centimeters most strongly (Dittmar *et al., 2007).* Topsoil As concentrations seasonally increase during irrigation and decrease during monsoon flooding, indicating that flooding significantly attenuates As accumulation (Ali et al., 2003a; Saha and Ali, 2007).

A study has shown that arsenic is reductively mobilized into soil pore water and released into overlying floodwater throughout the period of monsoon flooding (Roberts et al., 2010). The study estimated that between 53 and 250 mg m^{-2} As were seasonally released into floodwater, corresponding to 13-63% of the arsenic annually added via irrigation for the study area in Sreenagar, Munshiganj. A large portion of this arsenic is likely to be exported through the river system to the Bay of Bengal. Areas without pronounced monsoon flooding may be at greater risk of soil As accumulation than seasonally flooded fields. Continuous build up of As in the soil from As-contaminated irrigation water may reduce crop yield in the long term.

1.2 Objectives of the Present Research

The overall objective of this study is to assess the potential of arsenic accumulation through irrigation on cultivable lands where extensive boro rice cultivation is carried out and to assess the possible effects of this arsenic accumulation on yield of rice.
Specific objectives of this study include:

1) Development of "arsenic hazard maps", i.e., maps showing areas with high risk of arsenic accumulation due to irrigation for boro rice cultivation
2) Validation of the "arsenic hazard maps" through comparison of arsenic concentration in boro rice fields in selected areas with the arsenic hazard map
3) Estimation of possible accumulation of arsenic in boro fields in selected high risk areas
4) Assessment of the impacts of arsenic accumulation on rice yields in selected high-risk areas.

1.3 Scope and Methodology

In this study, arsenic hazard map was developed based on data on on the distribution (thana-wise) of irrigation wells used for boro cultivation(BADC, 2008-2009); arsenic

concentration database of the whole country developed by DPHE/BGS (2000), and flood inundation depth and land type database developed by CEGIS.

The arsenic level in irrigation water and top soil layers were measured for six paddy fields located in six different areas of Bangladesh during the 2011 dry season. Due to time and resource constrains extensive soil sampling could not be performed. Areas with high As in groundwater in high land areas (and thus at potential higher risk of As accumulation); and areas with high As in groundwater in low-lying (flood-prone) areas (and thus at relatively lower risk of As accumulation) were selected for soil sampling. Additional soil-arsenic data were collected from different studies for validation of the developed maps.

Detailed methodologies for each item of works have been described in the respective Chapters of the thesis, and hence are not elaborated here.

1.4 Organization of the Thesis

This thesis consists of five chapters. Apart from this chapter, the remainder of the thesis has been divided into four chapters.

Chapter 2 provides an overview of the arsenic contamination of groundwater, groundwater irrigation in boro rice cultivation in Bangladesh, arsenic in irrigated rice field soils of Bangladesh, and impact of arsenic on rice yield.

The third chapter presents the As hazard maps, developed by combining data on irrigation wells, arsenic concentration in groundwater, and flood inundation depth. This chapter also provides an assessment of the current level of As accumulation in rice field soils, and validation of the developed As hazard maps through comparison with field data.

Chapter 4 provides an assessment of the possible long-term accumulation of arsenic in rice field soils and its potential impact on rice yield for selected areas of Bangladesh; where As rich groundwater is used for cultivation.

Finally Chapter 5 presents the major conclusions from this study and the recommendations for future research works.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Elevated level of groundwater arsenic (As) in Bangladesh has caused a major calamity by exposing a large population to health risks and affecting livelihood and sustainable development of the country. Among the arsenic-affected countries, Bangladesh has the highest percentage of contaminated STWs (20%) and an estimated 30 million people are dependent on those wells for domestic purposes (FAO, 2006). Several scientific studies have reported potential risks from As in irrigation water because of land degradation affecting agro-ecosystem. The most well-known concern is As entering the food chain, affecting food safety. This poses a potential dietary risk to human health in addition to the risk from drinking contaminated groundwater. Another major risk is the potential impact of arsenic in irrigation water on crop yield. Continuous build up of As in soil from As-contaminated irrigation water may reduce crop yields, thus affecting the nutritional status and incomes of rural farming communities. The risks of land degradation are likely to increase with the accumulation of As in the soil (FAO, 2006).

Rice production in Bangladesh has more than doubled over the past three decades, mainly owing to the increasing cultivation of dry-season rice (boro), which requires intense irrigation, primarily from groundwater sources. Accumulation of As in paddy soils may adversely affect rice yields, owing to As phytotoxicity, and rice quality, owing to increasing As levels in grains and straw. Both effects have been observed in greenhouse studies; a recent study by Panaullah et al. (2009) has shown alarming evidence of As-related yield reduction under field conditions in Bangladesh. The knowledge about the distribution of arsenic in groundwater in shallow aquifer, the status of arsenic in soil is important in the study of arsenic in food security of Bangladesh. This Chapter provides an overview of the presence of arsenic in groundwater, use of groundwater in irrigation, the dynamics of arsenic concentration in irrigated paddy field soil and the hypothesis of on Arsenic accumulation in irrigated Soils. This research primarily focuses on the “hypothesis of arsenic accumulation” in irrigated soil, proposed in a recent study (Roberts et al., 2010).

2.2 Arsenic Contamination of Groundwater in Bangladesh

Arsenic contamination of groundwater in Bangladesh is the biggest calamity in the world in terms of the affected population. About 30 million people in Bangladesh poses major health risks due to the presence of significant concentrations of As in groundwater and its affect on the crop production (Chowdhury et al., 2001). Arsenic in groundwater is also alarming problem in Bangladesh, India and several other countries of Southeast Asia (Bhattacharya et al., 2007). The source of As in groundwater of Bangladesh is geogenic and it is not occurred for anthropogenic activities (Ahmed et al., 2004). The discovery of As contamination started from the Indian state of West Bengal bordering Bangladesh, especially along the flood-plains of the Ganges-Bhagirathi Rivers (Khan, 2003). That time the most vulnerable to As contamination were identified in the border of western districts, particularly the south-western region of Bangladesh.

The background fact of this incidence is that both state bordering sites have same depositional history and geological history which is commonly known as the Ganges delta. Moreover, the aquifer of the both contamination region are hydrological connected. This issue of As contamination of groundwater emerged one of the biggest environmental health calamities of more than 100 million people at risk on Ganges delta region of Bangladesh and India (Bhattacharya et al., 2009). The river system transports the sediments, such as sand, silt and clay, from the Himalayan mountain range in the north and from the Indo-Burman Hills in the east. The mountains are weathered by wind, rain, ice and grinding (McArthur, 2006). Arsenic from the weathered minerals sorbs to the Fe (III) oxyhydroxides. This material is deposit and accumulated in the delta. Year after year new material deposits and older sediments are buried (McArthur, 2006).

The surface geology of Bangladesh is dominated by alluvial sediments from the Quaternary period (Bivén and Häller, 2007). Quaternary period are divided into two major epochs (Holocene and Pleistocene) which is extended from two million years ago to present year. Pleistocene aquifers were created two millions years to ten thousand years ago. On the other hand, Holocene aquifers created from ten thousand years until present time. The As-enrichments are mainly restricted to the Holocene

alluvium (Figure 1). These alluviums cover about 70% of the uppermost aquifers in Bangladesh (DPHE and BGS, 2001, Ahmed et al., 2004). DPHE and BGS (2001) divided the Holocene aquifer system in the BDP into shallow (<150 m) and deep (>150 m) aquifers. The shallow aquifer is further subdivided into the upper (0-50 m) and the lower (50-150 m) shallow aquifers. The shallow aquifers in many regions contain water with As concentrations >50 μg/L. The environment in these aquifers is reducing and the sediments are generally grey or black in colour. The colour is due to high contents of organic matter, biotite and other dark coloured ferromagnesian and opaque minerals (McArthur et al. 2004). Tube wells with water containing As <10 μg/L have been found to be located in oxidised sediments, that are brown or red in colour and are normally in the lower shallow and in the deep.

British Geological Survey (BGS) conducted a study in 1998 under BGS-DPHE project Phase I, funded by DFID. They collected 2022 water samples from the 41 As-affected districts of Bangladesh. Among them 35% of these water samples were found to have As concentration above 50 μg/L in the laboratory analysis (Table 2.1). National Institute of Preventive and Social Medicine (NIPSOM) and the School of Environmental Studies (SOES) from Jadavpur University in Calcutta conducted a study in Rajarampur village of Nawabganj district in 1996 and this study observed 29% of the 294 tube-wells tested had arsenic concentrations greater than 50 μg/L (Ahmad et al., 1997). Further, SOES and Dhaka Community Hospital (DCH) jointly conducted a study from August 1995 to February, 2000 and during this period; they tested 22003 tube-well water samples which was collected from 64 districts in Bangladesh. They reported that out of 64 districts in Bangladesh, As in groundwater is above 10 μg/L in 54 districts and above 50 μg/L in 47 districts. According to Dainichi Consultant (2000), As contamination of groundwater in Bangladesh is approximately 85% of the total area of Bangladesh and about 75 million people are live in risk. The statistics data of As calamity in Bangladesh are presented in Table 2.2.

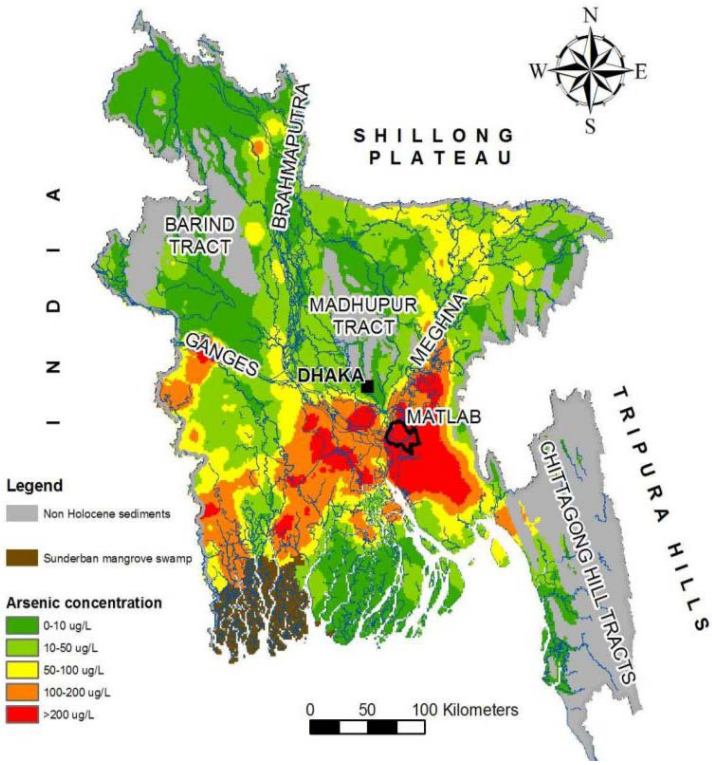

Figure 2.1: Map of Bangladesh with the three large rivers Ganges, Brahmaputra and Meghna. The map shows geomorphology and arsenic concentration in groundwater (Ahmed, 2009)

Table 2.1: Percentage of Groundwater Surveyed in 1998 by British Geological Survey with Arsenic Levels above 50 µg/L

District	Percentage of Groundwater wells Surveyed	District	Percentage of Groundwater wells Surveyed
Bagerhat	66	Madaripur	93
Barisal	63	Magura	38
Brahmanbaria	38	Manikganj	15
Chandpur	96	Meherpur	60
Chittagong	20	Moulvibazar	12
Chuadanga	44	Munshigang	83
Comilla	65	Narail	43
Cox‘s Bazar	3	Narayanganj	24
Dhaka	37	Nawabganj	4
Faridpur	66	Noakhali	75
Feni	39	Pabna	17
Gopalganj	94	Pirojpur	24
Jhalakati	14	Rajbari	24
Jhenaidah	26	Rajshahi	6
Khulna	32	Satkhira	73
Kushtia	28	Shariatpur	80
Lakshmipur	68	Syllhet	19

Table 2.2: Statistics of Arsenic Calamity in Bangladesh

Total Number of Districts in Bangladesh	64
Total Area of Bangladesh	148,393 km2
Total Population of Bangladesh	125 million (142.3 million, 2011 census)
WHO Arsenic Drinking Water Standard	10 µg/L
Bangladesh Arsenic Drinking Water Standard	50 µg/L
Number of Districts Surveyed for Arsenic Contamination	64
Number of Districts Having Arsenic above 50 µg/L in Groundwater	59
Area of Affected 59 Districts	126,134 km2
Populationat Risk	75 million
Potentially Exposed Population	24 million
Number of Patients Suffering from Arsenicosis	8500
Total Number of Tube-wells in Bangladesh	4 million
Total Number of Affected Tube-wells	1.12 million

Source**:** www.dainichi-consul.co.jp/english/arsen.htm

Phase II of the BGS-DPHE project continued from Phase I. The remainder of Bangladesh, excluding the three Chittagong Hill Tract districts, was surveyed and the detailed studies in the three Special Study Areas located in Chapai Nawabganj, Faridpur and Lakshmipur continued. According to the final report, water samples from 3534 tubewells from 61 out of 64 districts and from 433 out of the 496 upazilas were analyzed. Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) carried out a very detailed screening of tubewells and survey of arsenicosis patients in 270 arsenic-affected upazilas of the country in 2005. In this study, every household of these arsenic-affected upazilas was surveyed and all tubewells were tested using field test kits. A total of 4,946,933 tubewells were screened for arsenic and over 66 million people surveyed for arsenicosis (BAMWSP, 2005).

Water from 27% of the 'shallow' tubewells, that is wells less than 150 m deep, exceeded the Bangladesh standard for arsenic in drinking water (50 µg/L) and 46% exceeded the WHO guideline value of 10 µg/L (DPHE and BGS, 2001). Figures for 'deep' wells (greater than 150 m deep) were 1% and 5%, respectively. Since it is believed that there are a total of some 6–11 million tubewells in Bangladesh, mostly exploiting the depth range 10–50 m, some 1.5–2.5 million wells are estimated to be contaminated with arsenic according to the Bangladesh standard. 35 million people

are believed to be exposed to an arsenic concentration in drinking water exceeding 50 µg/ L and 57 million people exposed to a concentration exceeding 10µg/L (DPHE and BGS, 2001). There is a distinct regional pattern of arsenic contamination with the greatest contamination in the south and south-east of the country and the least contamination in the north-west and in the uplifted areas of north-central Bangladesh. However, there are occasional arsenic 'hot spots' in the generally low-arsenic regions of northern Bangladesh. In arsenic-contaminated areas, the large degree of well-to-well variation within a village means that it is difficult to predict whether a given well will be contaminated from tests carried out on neighboring wells.

2.3 Groundwater Irrigation in Bangladesh

In Bangladesh there has been widespread use of both shallow and deep tube wells for irrigation of agricultural lands, particularly during the dry period (November to March). Since high yielding varieties of rice are very susceptible to drought, these need very frequent irrigation. During dry season the availability of surface water is very low. So groundwater is extensively used as a source of irrigation. Table 2.3 shows the increase of groundwater irrigation.

Table 2.3: Area irrigated by surface and groundwater in Bangladesh
(Data Source: BADC, 2009)

	Irrigated Area (ha)					
Source of Water	**Year 2000**	**Year 2001**	**Year 2002**	**Year 2003**	**Year 2004**	**Year 2008**
Ground Water	2670802	2874354	2900215	3012058	3031948	5126851

Due to the increase of population, the surface water sources like ponds, lakes, and beels are being filled for various purposes like building construction, road construction, and extension of agriculture land. At the same time collection and distribution of groundwater from shallow aquifer have become easy and less costly. Hence, as a source of irrigation water, use of surface water has decreased and that of groundwater has increased.

In the dry season, irrigation in Bangladesh is heavily dependent on groundwater. This water is mainly abstracted by shallow tube-well (STW), deep tube-well (DTW),

artesian well, dug well, and non-mechanized pumps. Among them STW with motor pumps are very popular irrigation equipment. Mainly shallow tube-wells having a discharge capacity of about 14 l/s are used in irrigation. Special emphasis was given on the use of STW in irrigation in view of the availability of water at shallow depth, comparatively lower unit cost and relatively easy drilling, operation and maintenance technology. All the shallow tube-wells including deep set shallow tube-well (DSSTW) and very deep set shallow tube-well (VDSSTW) abstract water from shallow aquifer, which is contaminated with arsenic in many areas of the country.

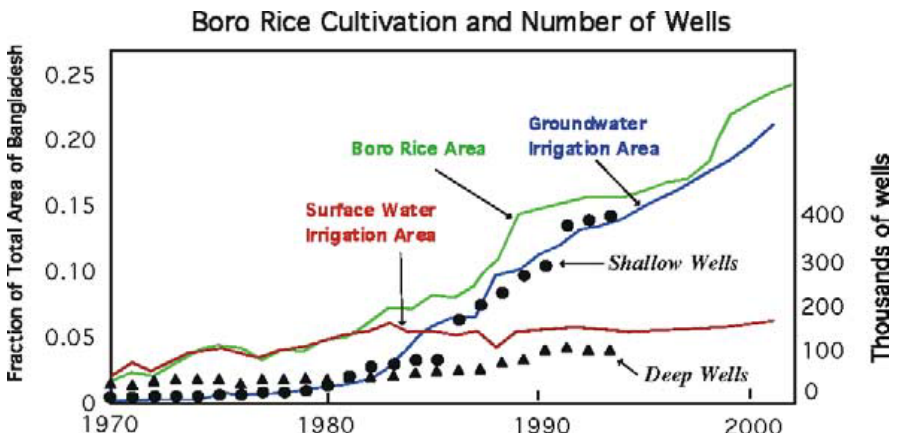

Figure 2.2: Cultivation of high yielding Boro rice has greatly expanded over the last several decades to cover approximately 20% of Bangladesh, or approximately 45% of the cultivatable area. Most Boro is irrigated by groundwater so extraction has also risen. (Source: Harvey et al., 2005)

According to BADC (2009), in boro season of 2008-09, a total of 1374548 shallow tubewells, 32174 deep tubewells, 146792 low lift and floating pumps, and 64235 other equipments were used for irrigation all over Bangladesh. Table 2.4 shows the number of STW used countrywide from 2000 to 2008. It shows that contribution of STW is increasing day by day and the number of STW has increased by 84 % during the eight-year period. The contribution of surface and groundwater sources to total irrigated area has changed considerably over time. During each irrigation season, an estimated 27209 Mm^3 of water (considering average discharge of 10 1/s and 1200 hours of irrigation per season) is extracted through shallow tube wells (Masud, 2003). This quantity is an order of magnitude higher than the amount of groundwater extracted for domestic purpose throughout the year. Table 2.5 shows the year wise

areas irrigated for different types of crop production which indicates the major portion of irrigation is used for rice production and irrigation in boro rice fields is above 68% of total irrigation in 2008-2009.

Table 2.4: Irrigation equipment and irrigated area in different years
(Data Source: BADC,2009)

Season	Equipment/ Area	Type of irrigation		
		DTW	STW	LLP&FP
Year 2000	No. of Equipment	23536	707574	58058
	Irrigated Area(ha)	529640	2122511	581801
	% of area	14.89	59.68	16.35
Year 2001	No. of Equipment	23182	865213	71309
	Irrigated Area(ha)	538264	2295067	603787
	% of area	14.29	60.94	16.24
Year 2002	No. of Equipment	23001	893359	77007
	Irrigated Area(ha)	530291	2355033	628748
	% of area	13.77	61.17	16.33
Year 2003	No. of Equipment	23434	924023	79872
	Irrigated Area(ha)	587937	2409407	664018
	% of area	14.63	59.96	16.53
Year 2004	No. of Equipment	24718	925152	77784
	Irrigated Area(ha)	589482	2429127	630668
	% of area	14.58	60.07	15.80
Year 2005	No. of Equipment	28280	1182520	119130
	Irrigated Area(ha)	700660	3120610	80310
	% of area	14.72	65.56	16.87
Year 2006	No. of Equipment	29170	1202720	107290
	Irrigated Area(ha)	725260	3196120	810020
	% of area	14.85	65.45	16.6
Year 2007	No. of Equipment	31300	1304970	138630
	Irrigated Area(ha)	785680	3197180	903870
	% of area	15.56	63.31	17.89
Year 2008	No. of Equipment	32174	1374548	146792
	Irrigated Area(ha)	790115	3245143	957035
	% of area	15.41	63.30	18.67

Table 2.5: Area Irrigated Under Different Crops

(Area in acre)

Crop	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10
Rice : Aus	211000	-	-	-	-	-	-
Aman	805000	838000	1162000	1368000	1349000	1549000	1417000
Boro	8938000	9049000	9560000	10050000	10472000	11025000	10964000
Total Rice	9954000	98870000	-	11418000		12574000	12381000
Wheat	944000	900000	855000	773000	754000	806000	823000
Other cereals	60000	-	-	-	-	-	-
Pulses	7000	-	-	-	-	-	-
Oilseeds	81000	-	-	-	-	-	-
Potato	446000	492000	587000	649000	789000	911000	825
Vegetables	330000	376000	584000	584000	611000	713000	612000
Sugarcane	72000	82000	95000	106000	112000	138000	123000
Cotton	21000	17000	11000	16000	14000	32000	13000
Others	279000	687000	988000	123000	1044000	1012000	929000
Grand Total	12194000	12441000	13842000	14569000	15145000	16186000	15706000

(Source: BBS, 2008)

Table 2.6: Area Irrigated by Methods

	Area (in acres) for Different year						
Method	**2003-04**	**2004-05**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**
Power pumps	1940000	1982000	2191000	2371000	2560000	2696000	2702000
Tube wells	9177000	9252000	10583000	11161000	11623000	12129000	12619000
Canals	359000	-	-	-	-	-	-
Traditional sources	718000	1207000	1068000	1037000	963000	871000	875000
Total	12194000	12441000	13842000	1456900	15145000	16186000	15706000

(Source: BBS, 2008)

2.4 Arsenic in Irrigated Rice Field Soils

Several studies have been conducted to investigate the fate of arsenic in irrigated soils. A survey of paddy soils throughout Bangladesh has showed that arsenic levels were elevated in zones where arsenic in groundwater used for irrigation was high, and where these tube-wells have been in operation for the longest period of time (Meharg et al., 2003). Soil arsenic levels reached 46 μg/g dry weights in the most affected zone, compared to levels below 10 μg/g in areas with low levels of arsenic in the groundwater (Meharg et al., 2003). Arsenic levels in rice grain from an area of

Bangladesh with low levels of arsenic in groundwater and in paddy soils showed that levels were typical of other regions of the world.

In Bangladesh, As levels in un-irrigated floodplain soils is around 10 mg/kg (Abedin et al., 2002) and similar to or lower in the topsoil than in the subsoil (Saha and Ali, 2007). In irrigated areas, Duxbury and Zavala (2005) reported topsoil As levels of 10 mg/kg at 48% of 456 STW sites studied, and Huq et al. (2006) reported that 21% of samples from a 24-upazila study had levels of 20 mg/kg, with the highest level of 81 mg/kg. Recent studies (Ali et al., 2003b, Huq et al., 2006 Saha and Ali, 2007) show that virtually all the As added with irrigation water to agricultural soils remains in the top 10–15 cm of soils, implying that little is lost to the atmosphere by volatilization, leaching to deeper soil layers and removal by crops. However, Dittmar et al. (2007) reported similar topsoil As contents at the start of two successive irrigation seasons, and suggested that As added during the first irrigation season had been leached by floodwater during the following monsoon season. In a much earlier field trial on flooded rice soils in the USA contaminated with arsenical pesticides applied to previous cotton crops, Reed and Sturgis (1936) reported substantial loss of soil As between the start and end of the rice-growing period and suggested that this loss might be due to reduction of As to gaseous arsine. Table 2.7 shows how As might accumulate in soil over time at different concentrations in irrigation water, assuming an annual water application of 1000 mm. A soil irrigated with 1000 mm of water containing 100 ppb As receives 1 kg/ha As per annum. The limited evidence at present suggests that the safe limit of soil As for rice lies somewhere in the range 25–50 mg/kg (Saha and Ali, 2007; Duxbury and Panaullah, 2007). In Table 2.7, boxes showing 25–50 and 50 mg/kg have been shaded to show when, in principle these soil concentrations might be reached. Actual soil loading rates will vary with the amount of irrigation water applied, As concentrations in the water and losses due to volatilization, leaching and crop removal. Because of the short period since As contamination of soils by groundwater irrigation was recognized, little information is available at present on As accumulation and removal rates.

Table 2.7: Potential effect of arsenic in irrigation water on soils with time

Years of irrigation	Arsenic in irrigation water (ppb)				
	50	**100**	**250**	**500**	1000
	Arsenic added to soil (mg/kg)				
1	0.28	0.56	1.4	2.8	5.6
5	1.4	2.8	7	14	28
10	2.4	5.6	14	28	56
20	5.6	11	28	56	110
30	8.4	17	42	84	170
50	14	28	70	140	280

(Source: Brammer and Ravenscroft, 2009)

Hossain (2005) reported that topsoil arsenic concentrations in some rice fields of Faridpur, which had been irrigated for about 20 years, ranged from 61 mg/kg in the field nearest the well-head to 11 mg/kg in a field near the far side of the command area. In some rice fields of Munshiganj , which had been irrigated for 15 years with an assumed annual water application of 1000 mm, Dittmar et al. (2007) reported that topsoil As concentrations varied considerably within fields. In one field studied in detail, As concentrations decreased gradually from 23.0 mg/kg near the field inlet to 11.3 mg/kg at the far corner of the field. With continuing irrigation, these differences within command areas and within fields are likely to increase with time, and should be taken into account in soil and crop sampling.

2.5 Impact of Arsenic on Rice Yield

Some greenhouse studies (Abedin et al., 2002) have found increasing concentration of As significantly decreased rice plant (BR11) height, grain yield, the number of filled grains, grain weight and root biomass. A recent field study/trial (Panaullah et al., 2009) for the first time showed that increasing soil As levels resulted in significant decrease in rice yield, raising serious concern about phytotoxicity of As. The impact of As contaminated irrigation water on soil-As content and rice productivity was studied over two winter-season rice crops in the command area of a single tubewell in Faridpur district of Bangladesh (Panaullah et al., 2009). After 16–17 years of use of the tubewell, a spatially variable build up of As and other chemical constituents of the water (Fe, Mn and P) was observed over the command area, with soil-As levels ranging from about 10 to 70 mg kg−1. A simple mass balance calculation using the current water As level of 0.13 mg As L^{-1} suggested that 96% of the added arsenic was retained in the soil. When BRRI dhan 29 rice was grown in two successive years

across this soil-As gradient, yield declined progressively from 7–9 to 2–3 t ha−1 with increasing soil-As concentration. The average yield loss over the 8 ha command area was estimated to be 16%. Rice-straw As content increased with increasing soil-As concentration; however, the toxicity of As to rice resulted in reduced grain-As concentrations in one of the 2 years. The likelihood of As-induced yield reductions and As accumulation in straw and grain has implications to agricultural sustainability, food quality and food security in As-affected regions throughout South and Southeast Asia.

The presence of arsenic in irrigation water results in significant increase of arsenic concentration in the irrigated soils; particularly up to about 150 mm layer (Ali et al., 2003b). Ali et al (2003b) also concluded that, arsenic concentration in soil decreased with depth. Arsenic concentrations in soils are significantly higher at the end of irrigation season, compared to concentration at the beginning of the season. In a study Dittmar et al. (2010) investigated the As contents of rice straw and grain over three consecutive harvest seasons (2005-2007) in a paddy field in Munshiganj, Bangladesh, which exhibits a documented gradient in soil As caused by annual irrigation with As-rich groundwater since the early 1990s. The field data revealed that straw and grain As concentrations were elevated in the field and highest near the irrigation water inlet, where As concentrations in both soil and irrigation water were highest. Pot experiment with soils and rice seeds from the field site indicates that both soil As accumulated in previous years and As freshly introduced with irrigation water influence As uptake during rice growth. At similar soil As contents, plants grown in pots exhibited similar grain and straw As contents as plants grown in the field. This suggested that the results from pot experiments performed at higher soil As levels can be used to assess the effect of continuing soil As accumulation on As content and yield of rice.

2.6 Hypothesis on Arsenic Accumulation in Irrigated Soils

According to the study by Roberts et al (2007), total As input to a rice field is independent of the length of the irrigation channel between well and field inlet, but within each field, As input to soil decreased strongly with increasing distance from the inlet (Fig 2.3). The pattern of As distribution and the extent of lateral

heterogeneity that can be expected at other locations depend both on the composition of the local irrigation water and on the type of irrigation system used, including the size of the area under irrigation by a single well.

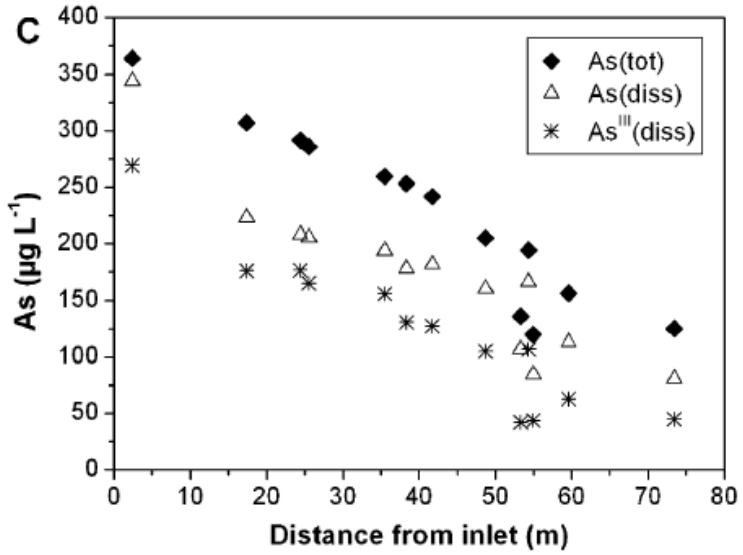

Figure 2.3: Irrigation water on a rice field shortly (0-2 h) after a 2.75-h irrigation period in February 2006. Total and dissolved (0.2 µm filtered) Fe (mg/L) (A), P (mg/L) (B), and As (tot) (µg/L) concentrations, as well as dissolved AsIII (µg/L) concentrations (C) are shown. (Roberts et al , 2007)

The study by Roberts et al. (2010) identifies As release into floodwater, followed by lateral removal to rivers, as a major pathway attenuating As accumulation in paddy soils. In areas with monsoon flooding, topsoil As concentrations seasonally increase during irrigation and decrease over the monsoon season, suggesting attenuation of soil arsenic accumulation by flooding. Roberts et al. (2010) obtained a first quantitative estimate of As release from paddy soil into overlying floodwater and assessed lateral removal of As with receding floodwater. The study measured As and other major elements and chemical parameters in floodwater and soil pore-water in paddy fields near Sreenagar (Munshiganj) and in a channel connecting the fields to the local river. Floodwater was sampled at four locations in rice fields during the 2006 and 2007 monsoon seasons. Distinct concentration gradients indicating limited vertical mixing were measured on various days in both years (Fig 2.4).

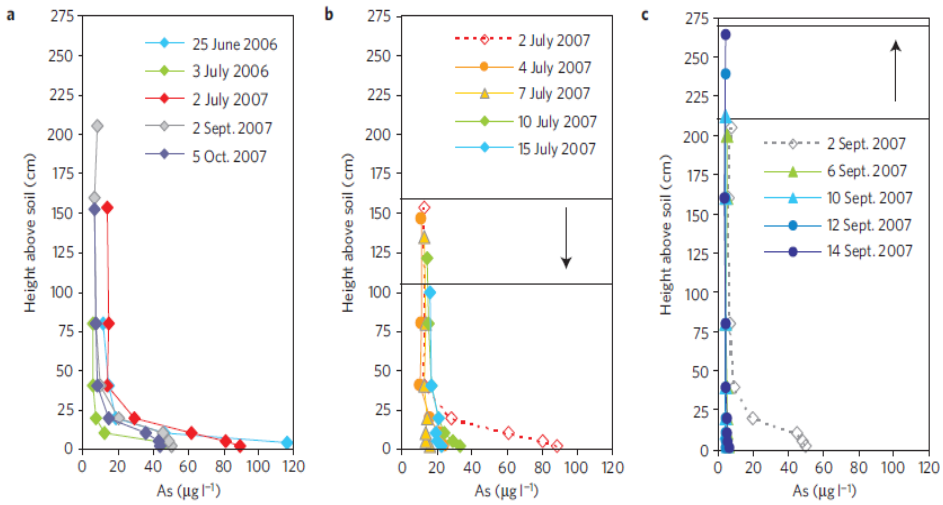

Figure 2.4: Arsenic profiles in floodwater on the rice field (Source: Roberts et al., 2010)

Floodwater As concentrations were highest close to the soil surface (40-120 µg/l) and decreased sharply towards shallower water depths, indicating As release from soil. Arsenic gradients were observed both in the initial and final stages of flooding, implying that As mobilization occurred throughout the entire flooded period (Fig. 2.4a). The floodwater As profiles were fitted and integrated over this depth and from the difference between the two time points, an estimate of As release from the soil was obtained, assuming negligible lateral flow in the bottom floodwater and negligible mixing with the bulk floodwater. For the two periods 30 June-2 July and 5-7 October 2007, the study obtained As releases of 5.68 and 5:71 mgm^{-2}, respectively. Spatial scaling of the resulting fluxes (obtained at 3m distance from the inlet) yielded average fluxes of 1.80 and 1:76 mgm^{-2} As d^{-1} for both periods. By excluding vertical mixing with the bulk floodwater during the two-day periods, the study potentially overestimated the time of build-up of the final As profile measured. As the soil As concentrations were above average at the inlet-near location sampled (Dittmar, et al., 2007), lateral flow would probably have had a diluting effect, partially masking As release. Both assumptions underlying this estimate therefore contributed to a potential underestimation of As flux.

Other pathways, such as volatilization and transport to deeper layers may also have a role, but remain to be identified and quantified (Roberts et al., 2010). The field site is likely to be representative of most areas in Munshiganj district, 57% of which is

flooded more deeply than 0.9m during typical monsoon seasons, and of other districts with similar conditions. About 21% of the total area of Bangladesh is annually affected by monsoon floodwaters exceeding 0.9 m depth. Roberts et al (2010) concluded that with As pools increasing in paddy soils, annual input and release in seasonally flooded fields may approach a steady state over the next decades, but trends are difficult to predict and depend on local conditions. Although As volatilization or downward As leaching may lead to some As release from As-affected areas without pronounced monsoon flooding, it is clear from the study (Roberts et al., 2010) that these areas are at greater risk of soil As accumulation than seasonally flooded fields. Continued accumulation of As in paddy soils as a consequence of irrigation with As-rich water will result in increasing As uptake by rice (Dittmar et al., 2010).

The following conclusions may be drawn based on the literature review:

- Presence of As in irrigation water leads to elevated levels of As in soil, with significant spatial and temporal variation.
- Monsoon flooding could remove significant fraction of As added to soil through irrigation each year.
- Reported Soil-As data from some non-flooded areas show much higher retention of As added through irrigation water.
- Areas without pronounced monsoon flooding may be at greater risk of soil As accumulation than seasonally flooded fields.

2.7 Summary

Irrigation with As-rich groundwater poses threats to sustainable agriculture and to human health in Bangladesh. The extent and urgency of this threat urgently need to be assessed in affected areas so that appropriate countermeasures can be introduced. Continued irrigation with As-rich groundwater causing As build-up in rice fields is a potential threat to agricultural production in the long term. It appears that the arsenic-contaminated high land areas of Bangladesh without pronounced flooding are the most vulnerable in terms of boro rice production.

Widespread use of As-contaminated irrigation water could ultimately affect food security, food safety and degradation of the environment through:

a) Reduction of agricultural productivity due to As toxicity to rice
b) Unacceptable quality (i.e., with high arsenic content) of agricultural products.
c) Enhanced exposure of humans to As through agricultural products containing elevated levels of As, especially rice.

So detail study is required to identify areas which are at potential risk of high arsenic accumulation in agricultural soils. Agro-ecological characteristics of such areas should be carefully monitored and immediate counter-measures should be devised and implemented in order to reduce arsenic accumulation in agricultural soils in these potential high-risk areas. The present study focuses on identification of such high-risk areas and assessment of potential impact of soil arsenic accumulation on rice yield in such areas.

CHAPTER THREE
DEVELOPMENT OF ARSENIC HAZARD MAP USING GIS

3.1 Introduction

At present GIS has become an emerging management tool for various environmental agencies to provide spatial and temporal information on different environmental issues. The powerful GIS software tools in problem oriented systems provide direct and easy access to large volumes of data. It supports their interactive analysis and helps to display and interpret results in a format directly understandable and useful for decision-making processes. GIS provides a valuable tool for information analysis, automated mapping and data integration. Mark et al. (1996) gives a useful definition that encompasses its functionality. It is defined as a computerized system for the storage, retrieval, manipulation, analysis and display of geographically referenced data, which include physical, biological, cultural, demographic or economic information and provide valuable tools in the natural resources, social, medical and engineering sciences, as well as in business and planning. GIS provide powerful tool for effective decision support in natural resources management. A GIS can automate existing as well as provide enhanced capability to analyze geographic information for decision-making purposes.

The present study focuses on development of "arsenic hazard maps", based on analysis of huge data sets on arsenic concentration in groundwater, boro cultivation area, and land type based on flood inundation depths.GIS has been found to be the most appropriate and effective tool for the present research, which involves analysis of large data sets and presentation of the analysis in the form of maps. . In the present study, various information/ data were stored in the GIS in the form of geographic data sets or layers. The digitized thana (upazila) census blocks map provided the geographical framework in the present study. ArcGIS 10.0 was used for analyzing data and producing As hazard maps. Geographically referenced arsenic data were collected from DPHE-BGS and from some selected irrigation wells in different locations for the selected thana (upazila) census block. The Arsenic Hazard maps were prepared combining all the required data in ArcGIS 9.3 interface. This Chapter presents the methodology and logic followed for the analysis of data and preparation

of maps. The maps are presented and the subsequently the maps have been validated by comparing with field data.

3.2 Methodology

The overall methodology of consists of the following steps:

a. Data collection
   i) As concentration data in groundwater for whole Bangladesh
   ii) Areas under boro cultivation in Bangladesh
   iii) Land type data based on flood depth
b. Data Processing
c. Development of arsenic hazard maps using GIS
d. Analysis of the maps
e. Selection of sampling sites of boro rice fields
f. Field visits to selected sites for soil and water sampling
g. Laboratory analysis of soil and water samples
h. Cross validation of arsenic hazard maps by comparing the maps with field data on arsenic concentration in irrigated agricultural lands.

The following data have been used for the development of arsenic hazard maps:

i) Agricultural land use data
ii) Distribution of arsenic concentration in groundwater
iii) Inundation land type data of Bangladesh
iv) Administrative map of Bangladesh
v) STW Irrigation data

All the data were collected from the different organizations, which include the Center for Environment and Geographic Information Services (CEGIS), Bangladesh Agricultural Development Corporation (BADC), Soil Research and Development Institute (SRDI). Arsenic database of groundwater prepared in the DPHE-BGS has been used for the distribution of arsenic concentration in groundwater. The software ArcGIS has been used used for arsenic hazard map preparation. The flow diagram of the methodology followed in this study is shown in Fig 3.1

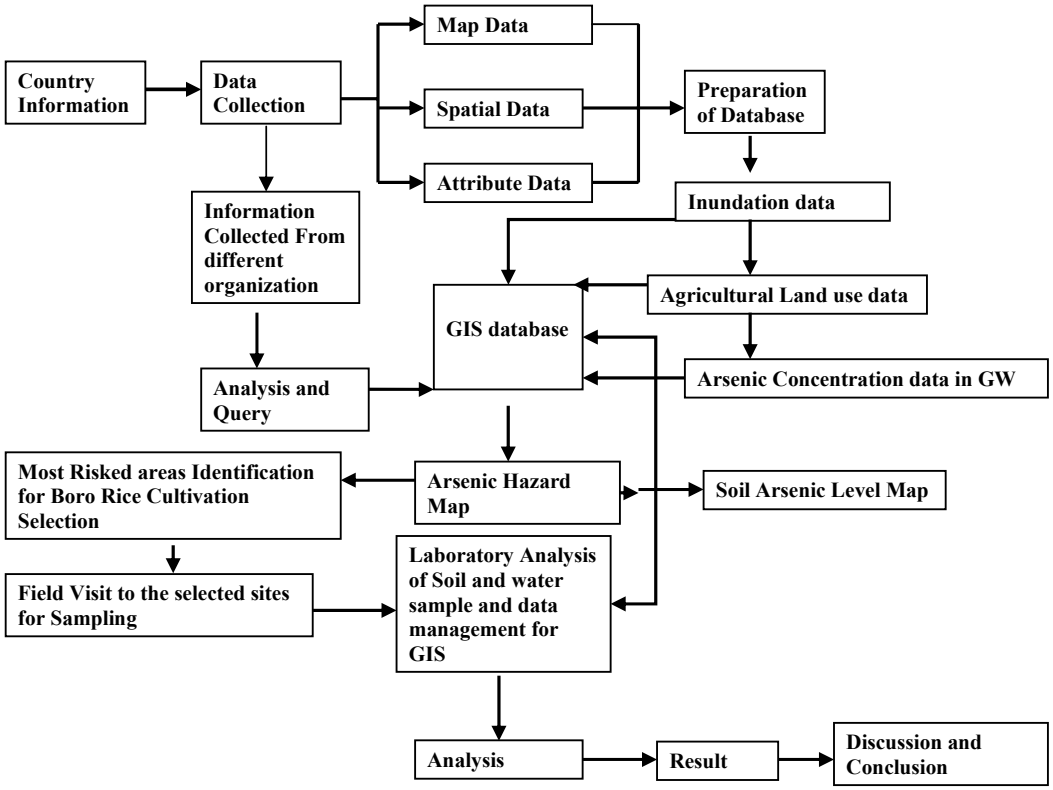

Figure 3.1: Flow diagram of the methodology followed in this study

3.2.1 Distribution of As in Groundwater

In this study, to prepare the As hazard map arsenic concentration database developed by BGS and DPHE (2000) has been used. The distribution of sampling sites from the BGS and DPHE National Hydro-chemical Survey and the arsenic concentrations are shown in Figure 3.2. Arsenic concentrations ranged from less than 0.25 µg/L to more than 1600 µg/L. The map shows clear differences in arsenic concentrations in different parts of Bangladesh, with the greatest number of high-arsenic wells in the south and south-east of the country. However, superimposed on this regional pattern, there is considerable well-to-well variability over the scale of a few kilometers.

The high-arsenic region in the south and east of Bangladesh is clear from this map. The BGS and DPHE survey showed that 25% of all the tube- wells sampled contain in excess of 50 µg/L arsenic, the Bangladesh drinking-water standard. In addition, 9% of the tubewells exceeded 200 µg/L and 0.1% exceeded 1000 µg/L. Few shallow

groundwater samples from the south of the country were 'arsenic-free' (i.e. contained less than 3 µg/L). On the other hand, 24% of water samples had arsenic concentration below the instrumental detection limit for arsenic, normally 0.25 or 0.5 µg/L.

The minimum arsenic concentration is likely to be in the ng/L range. Concentrations of less than 1µg/L are common in northern Bangladesh. They are also typical of the deep aquifer (including water from the city of Dhaka) and the water derived from aquifers in the older sediments of the Madhupur and Barind tracts. The median arsenic concentration found in all of the tubewells sampled was 4 µg/L and the maximum concentration found was 1670 µg/L. The mean concentration was about 55 µg/ L. This value depends to some extent on the concentration of arsenic assumed in the large number of wells containing less than the detection limit. The concentration of arsenic in these less-than-detection limit samples was assumed for statistical purposes to be half the detection limit. There were important differences between 'shallow' wells and 'deep' wells (defined here as greater than or equal to 150 m depth), as well as between samples from recent (Holocene) alluvium and older (Plio-Pleistocene) alluvium. Of the wells sampled in the DPHE/BGS National Hydrochemical Survey, 9% were 'deep'. Most of these deep wells were either from the southern coastal belt or from the Sylhet area. There are very few deep wells in the rest of the country. Of the shallow tubewells, 27% contained in excess of 50 µg /L and 46% in excess of the WHO guideline value for arsenic (10 µg/ L). Only 3 out of the 327 (1%) deep well samples exceeded 50 µg/L. Eight of the 61 sampled districts had no samples exceeding the Bangladesh standard for arsenic (50 µg/ L), and all districts except Thakurgaon had at least one well exceeding the WHO guideline value for arsenic (BGS-DPH, 2001).

The worst-affected districts were (percentage of sampled wells with greater than 50 µg/L in parentheses): Chandpur (90%), Munshiganj (83%), Gopalganj (79%), Madaripur (69%), Noakhali (69%), Satkhira (67%), Comilla (65%), Faridpur (65%), Shariatpur (65%), Meherpur (60%), Bagerhat (60%) and Lakshmipur (56%). Percentages are the percentage of all wells sampled. The least-affected districts were: Thakurgaon, Barguna, Jaipurhat, Lalmonirhat, Natore, Nilphamari, Panchagarh, Patuakhali (all 0%), Rangpur (1%), Dinajpur (2%), Naogaon (2%), Gazipur (2%), Cox's Bazar (2%), Bhola (4%), Nawabganj (4%), Jhalakati (6%), Rajshahi (6%),

Gaibandha (7%), Tangail (9%) and Kurigram (9%). Again, percentages are the percentage of all wells sampled. The district-wise average arsenic concentration varies from 1 µg/L in Thakurgaon to 366 µg/L in Chandpur. This reflects a very large difference in the average arsenic dose likely to be taken in from drinking water by the people of these two districts (BGS-DPH, 2001).

There is a great deal of short-range variation in the arsenic concentration from well to well, which makes predicting the concentration of arsenic in groundwater from un-sampled wells in arsenic-contaminated areas difficult even when the concentrations in adjacent wells are known. Even in areas of generally low arsenic concentrations, there are occasionally 'hot spots' where a cluster of wells with unusually high concentrations of arsenic are found. Such hot spots are most noticeable in northern Bangladesh. The Chapai Nawabganj hot spot in north western Bangladesh was estimated in the DPHE/BGS national survey to be about 5 km by 3 km in extent.

Arsenic data available in the DPHE/BGS National Hydrochemical Survey for the thanas were in union/ mouza level. For each thana there was significant variation in union level arsenic concentration. Since the As data is point data and land type data is parcel data, it was difficult to correlate the point data with parcel data. Superimposing point data on the parcel data was not very useful for the preparation of arsenic hazard map. So for the development of As hazard map a new Arsenic code was defined considering the arsenic concentration, as shown in the Table 3.1.

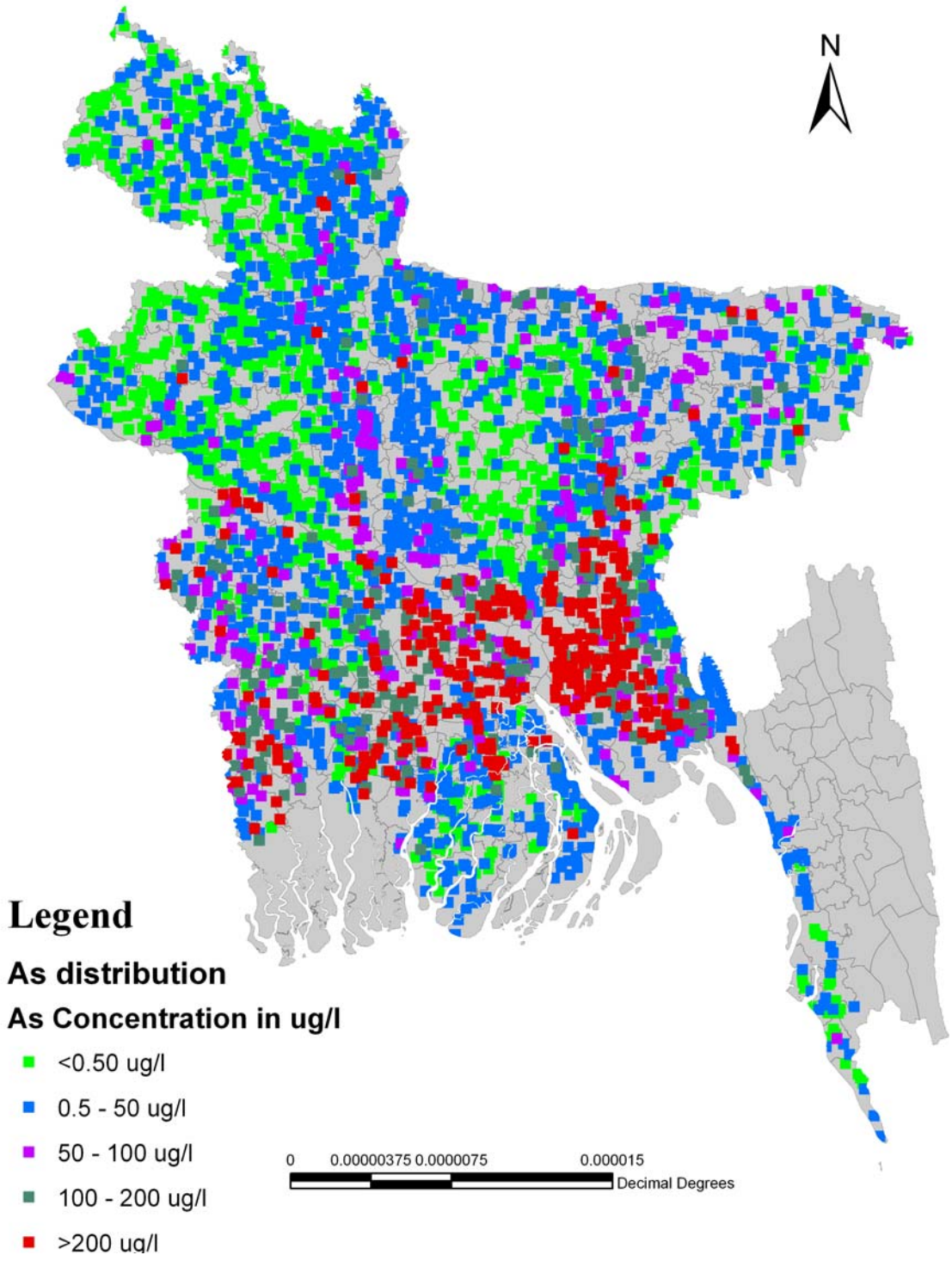

Figure 3.2: Map showing the concentration of arsenic in ground water based on BGS/DPH National Hydrochemical survey. (Data Source BGS-DPH, 2001)

Table 3.1: Arsenic code definition of water for Bangladesh

Arsenic Code	GW Arsenic Level
AS 0	0.5 µg/L to <50 µg/L
AS 1	0.50 µg/L to <100 µg/L
AS 2	0.50 µg/L to < 200 µg/L
AS 3	0.50 µg/L to <300 µg/L
AS 4	0.50 µg/L to above 300 µg/L

Using the query builder option in ArcMap-ArcIfo, analysis was made to find all the unions of all thana that have threshold arsenic level value as mentioned in the code definition (Table 3.1). Thus, all unions of Bangladesh were classified according to the Arsenic Code used in this study. The Arsenic Code was assigned to each thana using the editor toolbar in Arcinfo.

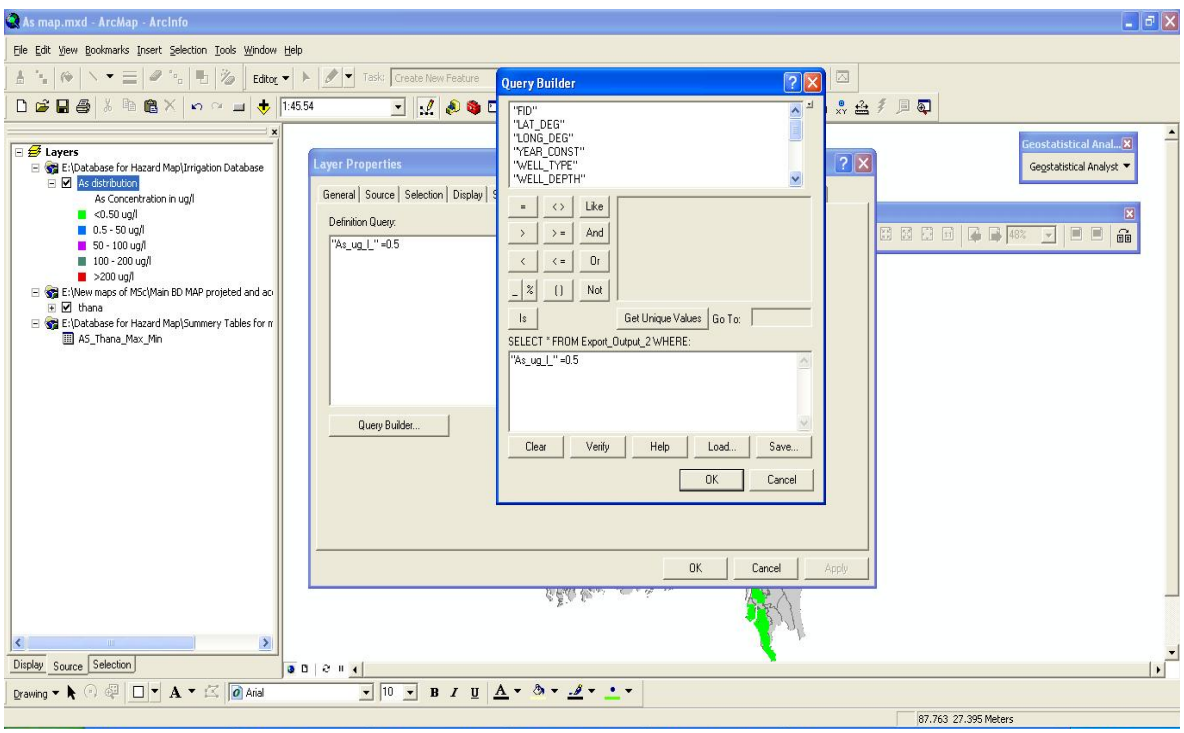

Figure 3.3: Formation of database according to the Arsenic Code definition in Arcinfo

Finally a new map of ground water arsenic distribution for whole Bangladesh was constructed incorporating the As definition code to the previous geo-database.

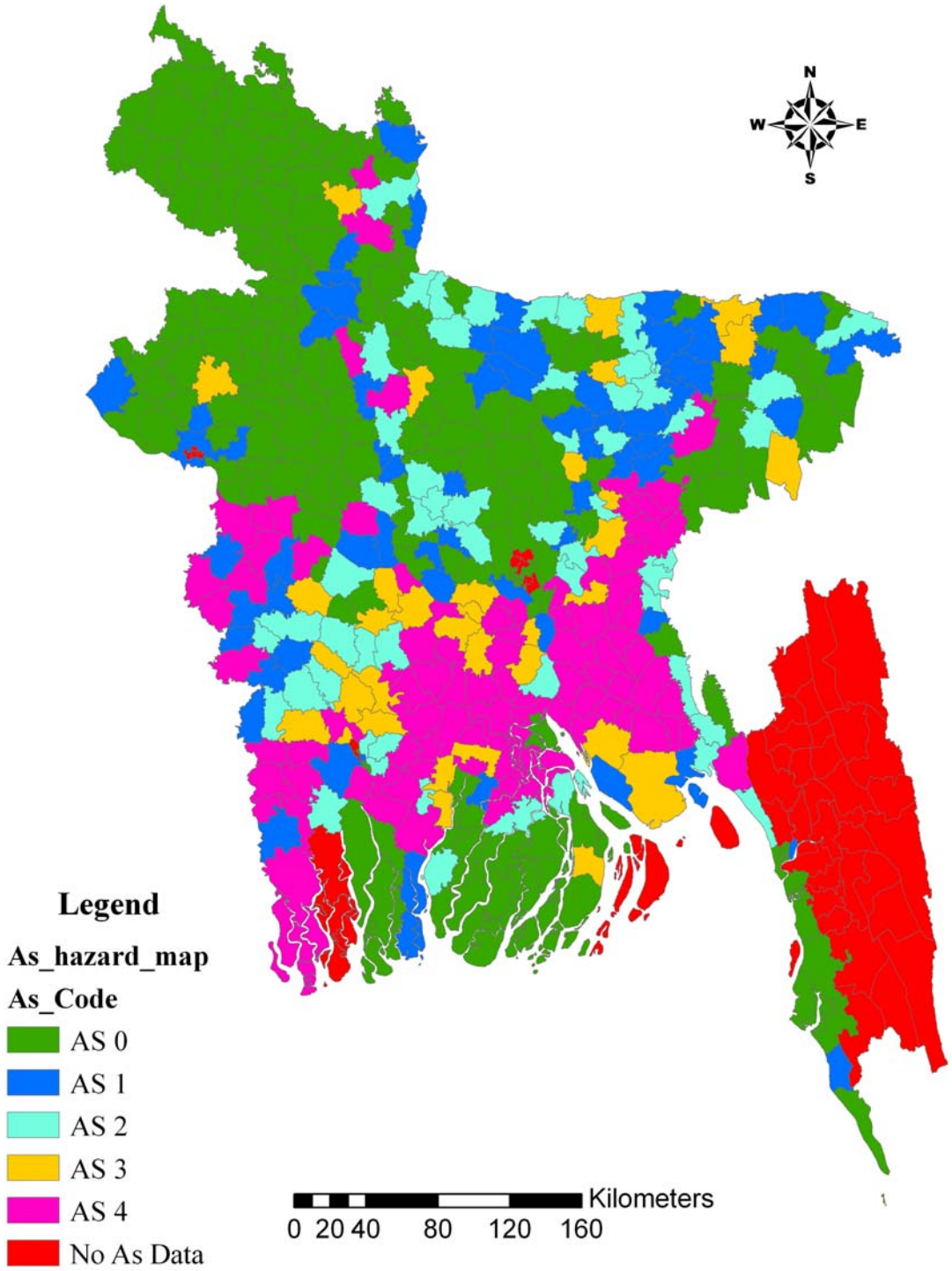

Figure 3.4: New map of Groundwater arsenic distribution

3.2.2 Areas under Boro Cultivation in Bangladesh

During the time of independence, Aman was the major food crop, which was the dominant source of total rice production. Structure of rice production in Bangladesh has remarkably changed over time. With the development of rice cultivars for Boro season and expansion of irrigation system, both area and production of Boro rice increased over time. Since 1999-00, Boro contributes more than half of the total rice production in Bangladesh (CPD, 2009). Average area under Boro rice in 2007-08 was 4.31 million hectare (ha), which produced about 15.56 million metric tonnes (MT) of rice. Currently Boro occupies about 41 per cent of total rice area and contributes 56 per cent of total rice production in Bangladesh (BBS, 2008).On the other hand, Aman rice occupies 50 per cent of total rice area and contributes 38 per cent of total production. Aus rice contributes about 9 per cent of total rice area and 6 per cent of rice production. An analysis of area and production of Boro rice during 1980-81 to 2007-08 revealed that both area and production of Boro rice has increased (Figure 3.5). Area under Boro rice has increased from 11.6 lakh ha in 1980-81 to 46 lakh ha in 2007-08 (BBS, 2008), which has led to increased extraction of ground water from shallow aquifer.

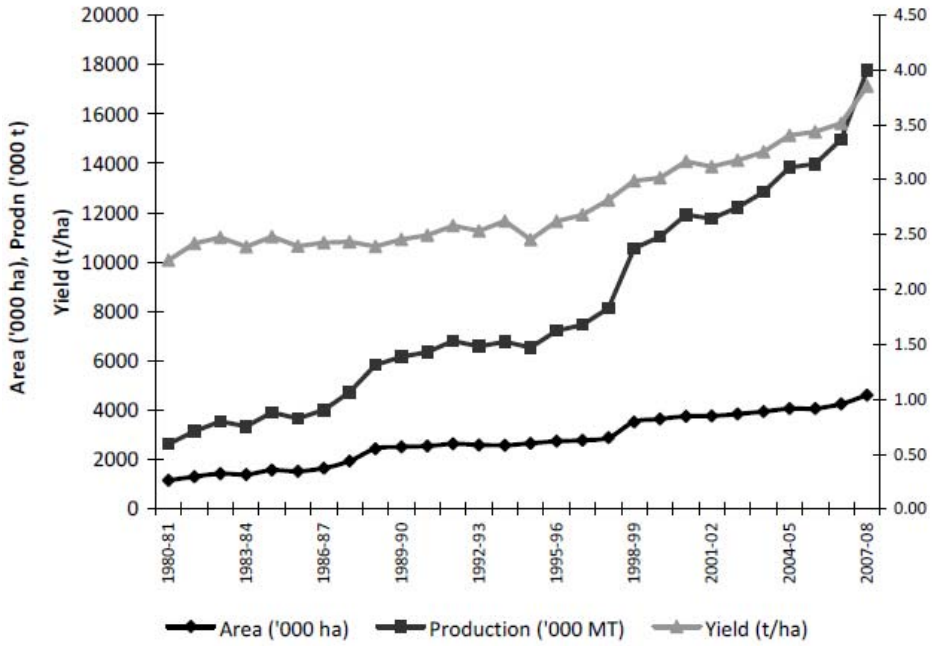

Figure 3.5: Trends in Area, Production and Yield of Boro Rice: 1980-81 to 2007-08

(Source: BBS, 2008)

Rabi season is generally treated as irrigation dependent season. Irrigation is very much essential for cultivation of major crops in the Rabi season, especially for boro rice and wheat cultivation. Besides, some parts of the country grow other crops like potato, oil, pulses, vegetables, etc., which require much less irrigation water compared to boro and wheat. Groundwater is the major source of water in Bangladesh for irrigation of crops both in Rabi (October to April) and Kharif (May to September) seasons. Approximately 95 percent of all groundwater extracted is used for irrigation, mainly for Boro rice production. Most of the irrigation equipments are used during the Rabi season. Survey of irrigation equipment is done during this season by Bangladesh Agricultural Development Corporation (BADC). So for the assessment of the Boro Cultivation area minor irrigation survey data of BADC for the year 2008-2009 has been used in this study. Since shallow aquifer contains more arsenic, the shallow irrigation well data was analyzed to identify the irrigated boro areas in 2008-2009. According to the survey report of BADC (2008-2009), 13,74,548 nos. of STW were in operation for irrigation and 32,45,143 hectares area were irrigated, which is 63.30 percent of total irrigated area. Division wise irrigation by STWs is shown in Table 3.2.

Table 3.2: Division Wise Irrigation by STW in 2008-2009(Data Source: BADC, 2009)

Name of the division	No. of STW	Irrigated area (ha)	% of total area
Dhaka	360313	826681	25.47
Rajshahi	644477	1552107	47.83
Chittagong	58194	175317	5.40
Khulna	304480	649531	20.02
Barisal	31	240	0.01
Sylhet	7053	41267	1.27
Total	**1374548**	**3245143**	**100**

STW Irrigation data tables from the BADC (2008-2009) report were scanned and doc files ware converted to excel format, finally the data was joined with the previous geo-database. Finally, STW Irrigation map was prepared in Arcmap.

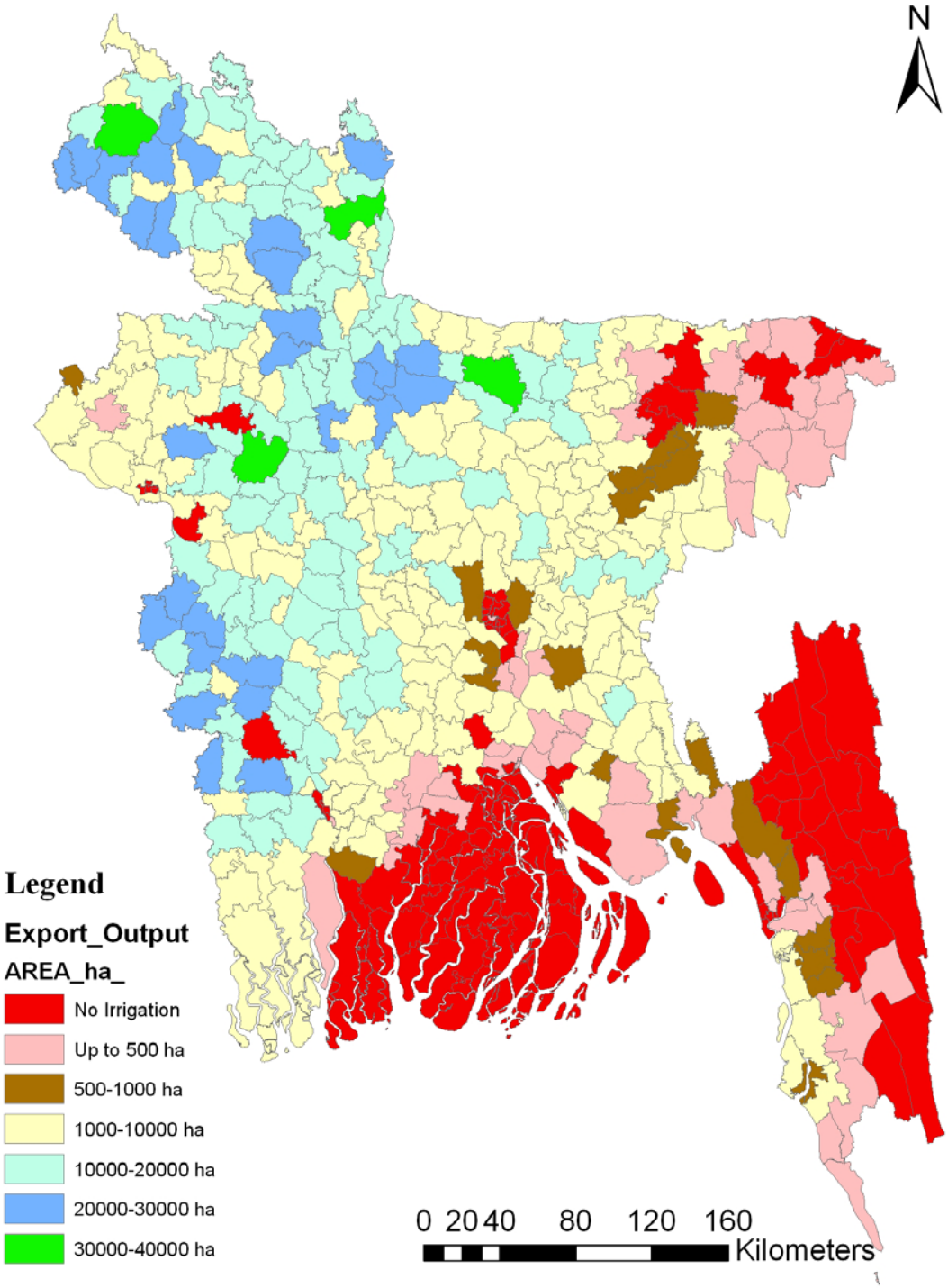

Figure 3.6: Thana-wise irrigation status for the year 2008-09.

3.2.3 Classification of Land Type based on Flood Depth

Agro ecological zone land areas are classified on the basis of hydrology, physiography, soil types, tidal activity, cropping patterns, and seasons. In fact, an agro ecological zone indicates an area characterized by homogeneous agricultural and ecological characteristics. This homogeneity is more prominent in the sub region and unit levels. The agro ecological zones of Bangladesh have been identified on the basis of four elements such as physiography, soils and land levels in relation to flooding and agro climatology. Bangladesh has been tentatively divided into 30 agro ecological zones (see Table 3.3). These 30 zones have been sub-divided into 88 agro ecological sub-regions, which have been further sub-divided into 535 agro ecological units.

Table 3.3: Agro ecological Zones of Bangladesh

ID	Zones/Regions	Sub Regions
1	Old Himalayan Piedmont Plain	a) North-central; b) Northern; c) Southern
2	Active Tista Floodplain	Active Tista Floodplain
3	Tista Meander Floodplain	a) Central; b) Eastern; c) Lower Atrai Floodplain; d) Lower Little Jamuna Floodplain; e) North-eastern and Southern North-western; f) Upper Little Jamuna and Middle Atrai Floodplain
4	Karatoya-Bangali Floodplain	a) Northern and Central; b) South-western
5	Lower Atrai Basin	Lower Atrai Basin
6	Lower Punarbhaba Floodplain	Lower Punarbhaba Floodplain
7	Active Brahmaputra-Jamuna Floodplain	Active Brahmaputra-Jamuna Floodplain
8	Young Brahmaputra and Jamuna Floodplain	a) High Jamuna Floodplain; b) Upper Brahmaputra Floodplain; c) Upper Brahmaputra-Jamuna Floodplain
9	Old Brahmaputra Floodplain	a) Bansi Valley; b) High; c) Low; d) Medium High; e) Medium Low
10	Active Ganges Floodplain	Active Ganges Floodplain
11	High Ganges River Floodplain	a) Central and Southern; b) Ganges-Mahananda Floodplain; c) Northern
12	Lower Ganges River Floodplain	a) Central; b) Eastern
13	Ganges Tidal Floodplain	a) Khulna Sundarbans; b) Nonsaline, calcareous; c) Nonsaline, calcareous and non-calcareous; d) Nonsaline, noncalcareous e) Saline, Acid Sulphate Soils; f) Saline, calcareous and noncalcareous; g) Saline, noncalcareous
14	Gopalganj-Khulna Beels	Beel centres

ID	Zones/Regions	Sub Regions
15	Arial Beel	Arial Beel
16	Middle Meghna River Floodplain	Middle Meghna River Floodplain
17	Lower Meghna River Floodplain	a) Calcareous, flood protected; b) Calcareous, unembanked; c) Noncalcareous, flood protected; d) Noncalcareous, unembanked
18	Young Meghna Estuarine Floodplain	a) Nonsaline: Central Bhola; b) Nonsaline: Meghna Estuary Charland; c) Nonsaline: North Bhola; d) Saline: Central Bhola; e) Saline: Noakhali, Hatiya and Meghna Estuary; f) Saline: Sandwip and South Bhola
19	Old Meghna Estuarine Floodplain	a) Dhaka-Narayanganj-Demra Project Area; b) High: Old Meghna Estuarine Floodplain; c) Low: Daudkandi-Habiganj; d) Low: Dhaka-Shariatpur-Barisal; e) Low: Eastern Kishoreganj; f) Low: Gopalganj Beels margins g) Low: Habiganj-North Brahmanbaria; h) Low: Titas Floodplain; i) Medium Low; j) Very poorly drained: Laksham-Begumganj
20	Eastern Surma-Kushiyara Floodplain	Eastern Surma-Kushiyara Floodplain
21	Sylhet Basin	a) Central and Southern; b) Northern; c) Western
22	Northern and Eastern Piedmont Plain	a) Northern and Eastern Basins; b) Northern and Eastern Plains and Basins; c) North-western Plains and Basins; d) South Sylhet Piedmont Plains
23	Chittagong Coastal Plain	a) Beach Ridges, Mangrove Swamp and Mud Clay; b) Mangrove Tidal Floodplain; c) Piedmont Plains and River Floodplains; d) Young Tidal Floodplain
24	St. Martin's Coral Island	St. Martin's Coral Island
25	Level Barind Tract	a) Highland and Medium Highland; b) Medium Lowland and Lowland
26	High Barind Tract	High Barind Tract
27	North-eastern Barind Tract	a) Mainly poorly drained; b) Mainly well drained; c) Mixed well drained and poorly drained
28	Madhupur Tract	a) Mainly poorly drained level terrace; b) Mainly well drained dissected terrace
29	Northern and Eastern Hills	a) Low hills and Piedmont Plains; b) Mainly high hill ranges; c) Mainly low hills
30	Akhaura Terrace	Akhaura Terrace

Physiography forms the primary element in defining and delineating the agro-ecological regions in Bangladesh. Soils form the second element in defining and differentiating agro-ecological zones as soil conditions determine important properties for plant growth, moisture supply, root aeration and nutrient supply. The third factor is land level in relation to flooding. The land area of the country may be divided broadly into three categories i.e., floodplain (80%), Pleistocene terrace (8 %), and tertiary hills (12 %) based on its geological formation (NAPA, 2005). The floodplain comprises of a succession of ridges (abandoned levees) and depressions (back

swamps or old channels). Differences in the elevation between adjoining ridge tops and depressions range from less than 1 meter on tidal floodplains, 1 meter to 3 meters on the main rivers and estuarine floodplains, and up to 5 to 6 meters in the Sylhet Basin in the north-east. Only in the extreme northwest do land elevations exceed 30 meters above mean sea level. The tertiary hill soil occupies the Chittagong hills in the south-east, and the low hills and hillocks of Sylhet in the north-east. The two major uplifted blocks (Pleistocene terrace) are known as Madhupur (in the central Bangladesh) and Barind tracts in the north-west. The land type of the country has been classified according to depth of inundation with seasonality into four types of land level such as highland (land which is above normal flood-level), medium highland (land which normally is flooded up to about 90 cm deep during the flood season), medium lowland (land which normally is flooded up to between 90 cm and 180 cm deep during the flood season), lowland (land which normally is flooded up to between 180 cm and 300 cm deep during the flood season), very lowland (land which normally is flooded deeper than 300 cm during the flood season). An additional class, bottomland, is recognized for depression sites in any land level class which remains wet throughout the year. The depth limits between the depth of flooding classes are not rigid. Flood levels in an area may vary by as much as a meter or more between different years. They may also reach their peak levels for only a few days at a time during a particular year. These classes actually indicate the level of flooding which farmers expect when they decide which CROPs to grow in the kharif season on different kinds of land, based on their long experience of cultivation on particular sites. Land area with different flood depths as well as seasonality is given in Table 3.4.

Table 3.4: Inundation Code

Land type	Maximum depth of flooding	Seasonally flooded	Permanently flooded
Highland (F0)	0-0.3m	16%	0%
Medium Highland (F1)	0.3-0.9m	44%	1%
Medium Lowland (F2)	0.9-1.8m	23%	1%
Lowland (F3)	1.8-3.0m	11%	3%
Very lowland (F4)	>3.0m	1%	1%
Total		95%	6%

Floodplains located in the north-western, central, south-central and north-eastern regions are subject to regular flooding at different frequency and intensity while the coastal plain is subject to cyclones and storm surges, salinity intrusion and coastal inundation. Pleistocene terrace land is characterized by moisture stress while flash flood is common in the hilly areas and the piedmont plains in the northeast and northwestern parts of the country. The Agro-ecological Zones (AEZ) database has used for this study for arsenic hazrd map preparation. Figure 3.7 shows the inundation map prepared from this database.

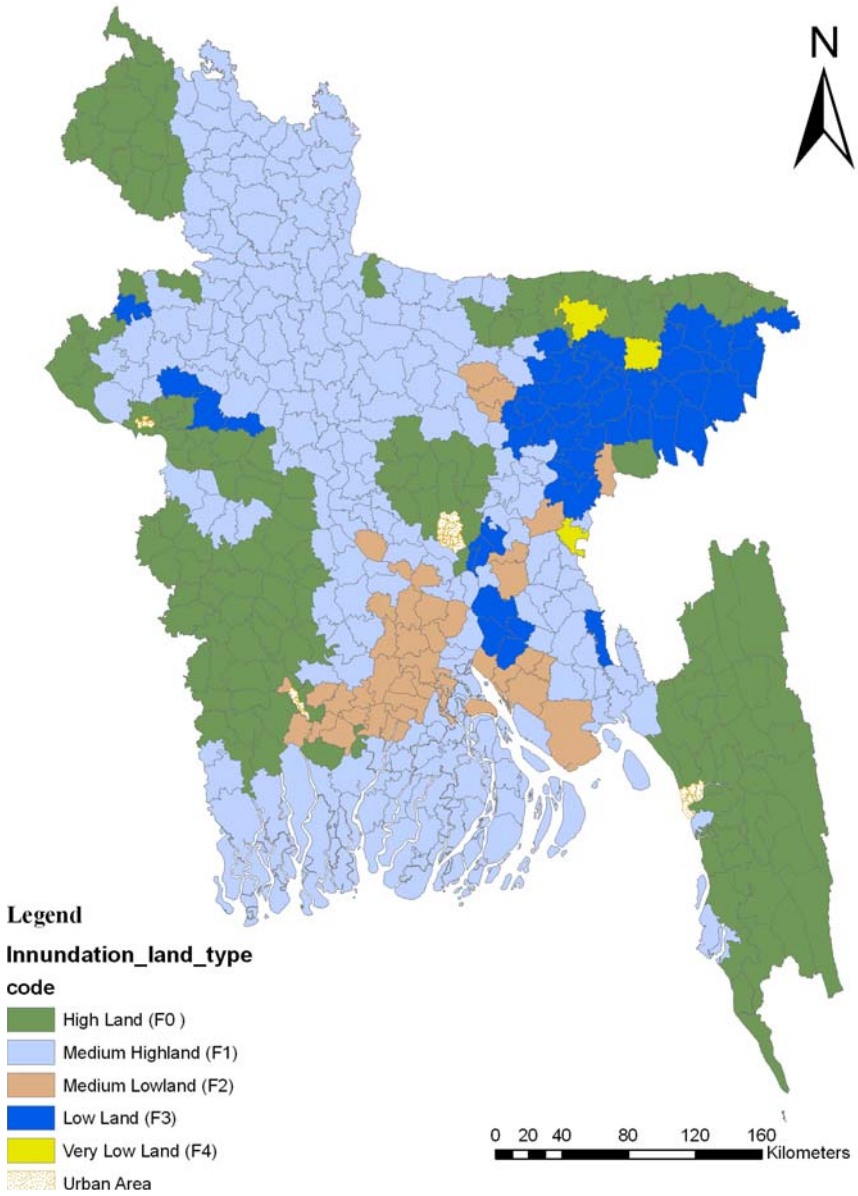

Figure 3.7: The Flood Regime Land Type Map of Bangladesh

3.2.4 Criteria for Arsenic Hazard Map

It is apparent from literature review that increased Boro cultivation in Bangladesh has resulted in increased exposure of agricultural soil to As loading though irrigation pathway. As explained in Chapter 2, Roberts et al. (2010) identified As release into floodwater, followed by lateral removal to rivers, as a major pathway attenuating As accumulation in paddy soils. In areas with monsoon flooding, topsoil As concentrations seasonally increased during irrigation and decreased over the monsoon season, suggesting attenuation of soil arsenic accumulation by flooding. Thus, the high land areas in arsenic-affected regions which experience low or no monsoon flooding are at higher risk of arsenic accumulation in agricultural soil. Therefore, following criteria have been set in preparing As hazard Map.

1) High lands in areas with high arsenic level in groundwater, and subjected to STW irrigation are considered to be at high risk of arsenic accumulation in agricultural soil.
2) Any land type having arsenic level in groundwater below drinking water guideline value is at "Low to No risk" of arsenic accumulation from agriculture.
3) Low lands in areas with high arsenic level in groundwater, and subjected to STW irrigation are considered relatively low risk of arsenic accumulation in agricultural soil

Based on the above criteria, "risk levels" for arsenic accumulation in agricultural for different land types and groundwater arsenic level have been defined. Table 3.5 shows the "risk level" used in the arsenic hazard map.

Table 3.5: Criteria for Arsenic Hazard Map for Irrigated Land

Land Type	Inundation Code	Arsenic Code	Risk Level
Highland	F0	As 4 and As 3	Very High-risk area
Highland	F0	As 2 and As 1	High-risk area
Medium Highland	F1	As 4, As 3, As 2 and As 1	Moderate risk area
Medium Lowland	F2	As 4, As 3, As 2 and As 1	Moderate to Low-risk area
Lowland	F3	As 4, As 3, As 2 and As 1	Low-risk area
Very lowland	F4	As2 and As1	Very Low-risk area

3.2.5 Soil Arsenic Concentration in Selected Areas

For validation of Arsenic Hazard Map, soil arsenic concentration data is required. Secondary data on soil arsenic concentration have been collected from literature and primary data have been generated through sampling and analysis of irrigation water agricultural soil from selected field sites.

3.2.5.1 Data Collected from Literature

Meharg and Maziburrahman (2003) reported Arsenic level in the 0-15 cm surface paddy soils varied between 3.1 and 42.5 μg/g (Table 3.8) . Alam and Sattar (2000) found that arsenic levels in surface soils (0-15 cm) ranged from not detectable to 31.8 μg/g. They found that soil arsenic levels were correlated with local well water concentrations, suggesting that the soils had become contaminated through irrigation with arsenic contaminated water. Ullah (1998) reported arsenic level in 0-15 cm surface soil up to 83 μg/g in another survey of Bangladesh soils and suggested that these soils were contaminated through irrigation with arsenic contaminated groundwater. The highest levels of arsenic in the survey reported by Meharg and Maziburrahman (2003) were in districts to the west of the country, particularly the districts of Meherpur, Chuadanga, Kushtia, and Rajbari (Table 3.8, all having one or more soil samples with arsenic level >30 μg/g. Soils in the range of 20-30 μg/g arsenic are scattered throughout the central belt of Bangladesh, mostly associated with

the high zones of groundwater arsenic contamination. The zone of high arsenic in groundwaters basically covers the bottom half of central and western Bangladesh. Huq el al. (2003) divided arsenic contaminated areas into: Gangetic alluvium flood plain, Teesta alluvium flood plain, Meghna Brahmaputra alluvium flood plain and Pleistocene terrace belts (Table 3.6) and reported soil As concentration in 15 districts (Table 3.7)

Table 3.6: Name of the district selected for soil sample collection (Huq et al, 2003)

Gangetic alluvium flood plain	Teesta alluvium flood plain	Meghna Brahmaputra alluvium flood plain	Pleistocene terrace
Jessor	Rangpur	Comilla	Dhaka
Kushtia	Kurigram	Narayanganj	Dinajpur
Meherpur	Pabna	Noakhali	
Chuadanga		Munsiganj	
Fatidpur		Noakhali	
		Bramonbaria	

Table 3.7: Arsenic in water and corresponding As in soils (Huq et al, 2003)

Location	Water As (mg/kg)	Soil Depth cm	Soil As (mg/kg)
Sharsha	0.041	0-15	13.670
Sirajdikhan	0.544	15-30	10.655
Alamdanga	0.021	0-15	16.647
Alamdanga	0.021	15-30	11.820
Alamdanga	0.191	0-15	11.918
Alamdanga	0.058	0-15	10.675
Meherpur	0.163	0-15	33.912
Meherpur	0.016	15-30	28.220
Laksham	0.145	15-30	10.791
Laksham	0.658	15-30	39.107
Laksham	0.729	0-15	18.125
Laksham	0.037	15-30	16.971
Laksham	0.261	0-15	28.009
Laksham	0.261	15-30	42.608
Laksham	0.397	0-15	22.763
Laksham	0.341	15-30	12.529
Chandina	0.38	15-30	19.270
Chandina	0.16	15-30	19.270
Sonargaon	0.682	0-15	38.930
Sonargaon	0.860	0-15	22.866

Location	Water As (mg/kg)	Soil Depth cm	Soil As (mg/kg)
Sonargaon	0.860	15-30	14.829
Sonargaon	0.860	0-15	14.000
Sonargaon	0.860	15-30	13.671
Bancharampur	0.092	0-15	17.147
Bancharampur	0.115	0-15	11.318
Nagarkanda	0.077	0-15	81.248
Nagarkanda	0.064	15-30	26.559

Table 3.8: Arsenic levels in individual paddy fields in Bangladesh, listed by administrative divisions and districts (Meharg and Maziburrahman, 2003)

Division	Soil series	District	As content (µg/g)
Barisal	Bagalkati	Bagalkati	24.5
Barisal	Barisal	Barisal	19.3
Barisal	Barisal	Barisal	26.1
Barisal	Nilkamal	Bhola	16.3
Barisal	Ramgati	Bhola	16.8
Chittagong	Burichang	Chandpur	18.4
Chittagong	Chandina	Chandpur	6.8
Chittagong	Debidwar	Chandpur	7.3
Chittagong	Mirsharai	Chittagong	6.5
Chittagong	Pahartali	Chittagong	7
Chittagong	Rawjan	Chittagong	8.6
Chittagong	Burichang	Comilla	21.6
Chittagong	Chandina	Comilla	9.2
Chittagong	Chandina	Comilla	9.9
Chittagong	Debidwar	Comilla	3.1
Chittagong	Debidwar	Comilla	11
Chittagong	Tippera	Laksham	7.4
Dhaka	Belabo	Gazipur	14.6
Dhaka	Tejgaon	Gazipur	10.9
Dhaka	Ghatail	Jamalpur	16.5
Dhaka	Shilmondi	Jamalpur	16.4
Dhaka	Sonatala	Jamalpur	13.4
Dhaka	Kendua	Kishoregonj	9
Dhaka	Jadurpara	Manikgonj	13.5
Dhaka	Lokdeo	Mymensingh	8.2
Dhaka	Melandaha	Mymensingh	6
Dhaka	Shilmondi	Mymensingh	17.1
Dhaka	Shilmondi	Mymensingh	17.3
Dhaka	Sonatala	Mymensingh	9.8
Dhaka	Sonatala	Mymensingh	12.8
Dhaka	Sonatala	Mymensingh	25.4
Dhaka	Sotiakhali	Mymensingh	15.8
Dhaka	Tarakanda	Mymensingh	9.3
Dhaka	Chandra	Tangail	5.7

Division	Soil series	District	As content (µg/g)
Dhaka	Khilgaon	Tangail	24
Dhaka	Melandaha	Tangail	9.6
Dhaka	Shilmondi	Tangail	19.2
Dhaka	Sonatala	Tangail	12.8
Khulna	Ghior	Chuadanga	29
Khulna	Ishurdi	Chuadanga	33.3
Khulna	Dumuria	Jessore	21
Khulna	Ganges silt	Jessore	23.3
Khulna	Ghior	Kushtia	42.5
Khulna	Ishurdi	Kushtia	34.2
Khulna	Golapur	Meherpur	30.2
Khulna	Golapur	Meherpur	36.6
Khulna	Sara	Meherpur	10.8
Khulna	Sara	Meherpur	15.7
Khulna	Golapur	Rajbari	30.7
Khulna	Sara	Rajbari	23.9
Rajshahi	Gangachhara	Bogra	15.5
Rajshahi	Jamun	Bogra	9.3
Rajshahi	Lauta	Bogra	4.9
Rajshahi	Lauta	Bogra	5.1
Rajshahi	Nijhuri	Bogra	5.3
Rajshahi	Nijhuri	Bogra	6.3
Rajshahi	Baliadangi	Dinajpur	11.7
Rajshahi	Tista silt	Kurigram	9.6
Rajshahi	Bhabanipur	Naogaon	24.3
Rajshahi	Gopalpur	Naogaon	26.7
Rajshahi	Gopalpur	Nawabgonj	20.9
Rajshahi	Sara	Nawabgonj	15.7
Rajshahi	Atwari	Panchagarh	8.1
Rajshahi	Ruhia	Panchagarh	9.6
Rajshahi	Gopalpur	Pbna	14.4
Rajshahi	Amnura	Rajshahi	7.8
Rajshahi	Chandra	Rangpur	6.5
Rajshahi	Gangachhara	Rangpur	11.5
Rajshahi	Polashbari	Rangpur	7.6
Rajshahi	Baliadangi	Thakurgaon	9.1
Rajshahi	Pirgachha	Thakurgaon	12.4

Dittmar et al. (2007) reported 9 -25 mg/kg soil As in a study of Munshiganj district near Sreenagar, 30 km south of Dhaka and 5 km north of the Ganges river. Masud (2003) reported 3.17-19.02 mg/kg soil As in Sonargaon , 0.1-2.75 mg/kg in Dinajpur and 2.13-3.54 in Comilla. Saha and Ali (2007) reported As concentrations in the soil layers of 12 rice fields located in four As affected areas and two unaffected areas in Bangladesh. About 71% of the As that is applied to the rice field with irrigation water accumulates in the top 0 to 75 mm soil layer by the end of the irrigation season. Mean

soil As concentration varies fro 4.15 t0 14.75 mg/kg for As affected area depending upon the sampling period.

Table 3.9: Arsenic content in the top 0-75 mm segment of soil core samples collected from different sampling areas (Saha and Ali, 2007)

Sampling Location	Parameter	1st Sampling, March 2003 (mg/kg)	2nd Sampling, May-June 2003 (mg/kg)	3rd Sampling June-July 2003 (mg/kg)	4th Sampling, November-03-January 04 (mg/kg)
Bogra	Range	0.88-2.54	0.68-3.85	1.90-3.25	0.82-2.36
Field-1	Mean ± SD	1.40 ± 0.62	2.12 ± 0.84	2.37±0.52	1.29 ± 0.55
Bogra	Range	0.69-2.05	0.98-3.84	1.36-3.01	2.04-3.90
Field-2	Mean ± SD	1.49 ± 0.50	2.68 ± 1.09	2.39 ± 0.50	2.90 ± 0.58
Naogaon	Range	1.16-4.58	1.70-4.99	1.18-3.27	1.31-3.07
Field-1	Mean ± SD	2.45 ± 1.02	3.36 ± 1.08	2.61 ± 0.75	2.39 ± 0.71
Naogaon	Range	1.26-3.35	2.17-3.65	0.79-3.03	1.36-3.89
Field-2	Mean ± SD	2.25 ± 0.64	2.80 ± 0.53	2.18 ± 0.63	2.58 ± 0.80
Munshiganj	Range	4.18-12.04	8.65-22.35	5.15-14.18	5.58-11.04
Field-1	Mean ± SD	8.38 ± 2.31	14.75± 3.88	9.96 ± 2.82	6.87 ± 1.86
Munshiganj	Range	4.22-10.36	7.26-24.65	4.26-16.03	4.57-15.36
Field-2	Mean ± SD	7.62 ± 1.70	12.39± 5.42	8.58 ± 3.51	8.22 ± 3.17
Comilla	Range	3.27-7.69	4.26-9.67	4.83-8.62	3.65-9.92
Field-1	Mean ± SD	4.67± 1.41	7.97 ±1.87	6.74 ± 1.39	5.90 ± 2.23
Comilla	Range	3.20-5.68	4.06-8.61	3.03-7.37	1.87-7.00
Field-2	Mean ± SD	4.36 ± 0.89	6.20 ± 1.35	4.85 ± 1.31	4.51 ± 1.56
Faridpur	Range	2.07-7.62	4.68-10.44	3.52-7.66	2.03-6.35
Field-1	Mean ± SD	5.74 ± 1.74	7.22 ± 2.22	6.03 ± 1.44	4.84 ± 1.42
Faridpur	Range	4.23-7.19	4.71-12.33	5.04-11.36	4.76-8.69
Field-2	Mean ± SD	5.66 ± 0.98	9.86 ± 2.45	9.13 ± 2.08	6.51 ± 1.63
Brahmanbaria	Range	4.33-8.59	5.85-17.62	4.98-14.68	4.62-7.42
Field-1	Mean ± SD	6.675 ± 1.34	10.29 ± 3.58	8.96 ± 2.94	5.95 ± 0.81
Brahmanbaria	Range	2.60-6.36	3.41-16.65	2.24-7.35	2.65-5.40
Field-2	Mean ± SD	4.15 ± 1.21	9.22 ± 3.64	4.45 ± 1.55	3.95 ± 0.94

3.2.5.2 Primary Data

In this study, arsenic level in irrigation water and the top layers paddy field soil samples were measured for six boro paddy fields located in two different areas of Bangladesh during the dry season (October to March) of 2011. The arsenic affected areas were: (i) Bhanga, Faridpur (ii) Harirampur, Manikgonj. Bhanag thana was selected since the land type in "Medium Low" land and arsenic code is "As 4" (ground water As varies from103 µg/l to 468 µg/l). Besides, some field data on arsenic concentration in soils of Jessore district were collected through personal communication with Dr. Linda Roberts.

Well water used for irrigation in each of the six sampling areas was collected. At each paddy field, well water sample was collected in two pre-washed 500 ml plastic bottles, after running the well for at least 15 minutes. Water sample in one bottle was acidified with 1 ml concentrated hydrochloric acid, which was later analyzed for dissolved arsenic. Arsenic test result of irrigation water is shown in Table 3.9.

Table 3.10: Arsenic Concentration of irrigation well water samples of selected sites

Location of Well	Disrict	Arsenic Concentration (µg/l)
Bhanga, Field 1	Faridpur	396.7
Bhanga, Field 2	Faridpur	178.0
Bhanga, Field3	Faridpur	158.4
Bhanga, Field 4	Faridpur	147.7
Harirampur, Field 1	Manikgonj	30.6
Samta, Field 1	Jessor	128.9
Samta, Field 2	Jessor	273.2

In order to estimate average arsenic level in the top soil layer of a paddy field irrigated by a particular irrigation well, soil core samples were collected at the point close to irrigation water inlet, middle of the plot and the farthest point of the plot from irrigation water inlet. Soil core samples were collected by inserting into the soil, a 37.5 mm diameter PVC pipe sampler, about 750 mm in height. A 3-pound hammer was used to insert the pipe sampler to a depth of about 500 mm. After withdrawing the sampler along with the soil core, both the ends were sealed with tapes to reduce contact with air and transported to the laboratory.

Before analysis, each soil core sample was divided into four segments; the first segment consisting of the top 75 mm of soil, the second segment consisting of the next 75 mm, the third segment consisting of the next 150 mm, and the fourth segment consisting of the rest of the core. Each segment of soil was analyzed for total (aqua-regia extractable) arsenic. For determination of aqua-regia extractable arsenic, the selected soil sample was taken in an aluminum bowl and kept in an oven at 110 °C for 24 hours. After drying for 24 hours, the sample was ground in a grinder. The grinded soil sample was digested with aqua-regia for extraction of metal ions. For digestion, 2.5 ml concentrated nitric acid and 7.5 ml concentrated hydrochloric acid were added to 5 gm grinded oven dried sample taken in a 500 ml volumetric flask. The sample

was kept overnight in the flask and then it was heated to boiling for two hours. Afterwards distilled water was added up to the 500 ml graduation mark. The contents of the flask were stirred for 5 minutes, then cooled and finally filtered using a filter paper (0.45 micron). The filtrate was stored in a plastic bottle for analysis of arsenic using an AAS attached with a graphite furnace (Shimadzu AA6800). The laboratory analysis result of collected soil sample is shown in the Table 3.10, which indicates higher arsenic concentration in Faridpur and Jessore districts.

Figure 3.8: Collection of soil core sample using PVC pipe at Manikgonj

Table 3.11: Arsenic Concentration of Soil samples of selected sites

Sample ID	Soil Depth	Thana	District	Arsenic Concentration in mg/kg
Sample 2	0-75 mm	Bhanga	Faridpur	42.3
Sample 3	0-75 mm	Bhanga	Faridpur	32.1
Sample 4	0-75 mm	Bhanga	Faridpur	39.2
Sample 6	0-75 mm	Bhanga	Faridpur	18.6
Sample 7	0-75 mm	Bhanga	Faridpur	30.0
Sample 8	0-75 mm	Bhanga	Faridpur	13.7
Sample 10	0-75 mm	Bhanga	Faridpur	25.6
Sample 11	0-75 mm	Bhanga	Faridpur	19.9
Sample 12	0-75 mm	Bhanga	Faridpur	16.8
Sample 14	0-75 mm	Bhanga	Faridpur	20.2

Sample ID	Soil Depth	Thana	District	Arsenic Concentration in mg/kg
Sample 15	0-75 mm	Bhanga	Faridpur	14.1
Sample 16	0-75 mm	Bhanga	Faridpur	12.5
Sample 17	0-75 mm	Bhanga	Faridpur	12.5
Sample 18	0-75 mm	Bhanga	Faridpur	10.2
Sample 19	0-75 mm	Bhanga	Faridpur	11.0
Sample 20	0-75 mm	Harirampur	Manikgonj	13.2
Sample 21	0-75 mm	Harirampur	Manikgonj	9.12
Sample 22	0-75 mm	Harirampur	Manikgonj	9.92
Sample 23	0-75 mm	Harirampur	Manikgonj	7.24
Sample 24	0-100 mm	Samta	Jessor	41.2
Sample 25	0-100 mm	Samta	Jessor	39.4
Sample 26	0-100 mm	Samta	Jessor	31.0
Sample 27	0-100 mm	Samta	Jessor	24.4
Sample 28	0-100 mm	Samta	Jessor	25.1

3.3 Arsenic Hazard Map

The major GIS processes for preparation of arsenic hazard map are as follows:

- Creation of layer from environmental survey data
- Input of attributes for each layer
- Interpolation of arsenic level in soil within the study area using arsenic value in each thana
- Query and analysis between ground water arsenic level, flood inundation depth, boro cultivation area

The process mentioned above was applied in this study using the ArcGIS 9.3, which provides a scalable framework for implementing GIS for a single user or many users on desktops, in servers, over the Web, and in the field. The main application in ArcGIS is ArcMap, which is used for all mapping and editing tasks as well as for map-based query and analysis. A map is the most common view for users to work with geographic information. It is the primary application in any GIS to work with geographic information. ArcMap represents geographic information as a collection of layers and other elements in a map view. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive text, and a symbol legend.

The following steps were followed for the development of arsenic hazard map in Arc Map:

i) Using the digitized thana census blocks map a new arsenic distribution map was created which indentifies As concentration density thought the thanas of Bangladesh. A central geo-database was created using ArcCatalog in personal computer HDD. The geo-database is a collection of geographic datasets of various types used in ArcGIS and managed in either a file folder or a relational database. It is the native data source for ArcGIS and is used for editing and data automation in ArcGIS.

ii) The database of Agricultural land use obtained from BADC irrigation data was processed on ArcMap-ArcInfo interface and joined with the As distribution map.

iii) The next step was assembling the flood regime land type database with the previously constructed geo-database.

iv) Considering the criteria for Arsenic Hazard Map, arsenic accumulation risk symbology was defined for the previously constructed map layer in the central geo-database and new thematic map was created, which is the ultimate As hazard map (Fig 3.9). This map shows high risk zone to low risk zone with respect to arsenic accumulation on top soil due to irrigation during Boro rice cultivation.

v) Finally query and spatial analysis were conducted to identify the risk zones.

Figure 3.9 shows the Arsenic Hazard Map. It shows that risk of arsenic accumulation in agricultural soils depends on arsenic concentration in irrigation (STW) water, land type and agricultural practice (i.e., boro cultivation). Areas in the northern parts of Bangladesh are at “low to no risk” because of lower concentration of arsenic in irrigation water, despite higher intensity of boro cultivation. Areas to the south west and some areas in the north east are at risk of higher accumulation of arsenic, because of higher concentration of arsenic in irrigation water, higher intensity of boro cultivation, and higher land elevation (i.e., lower intensity of flooding, which attenuate arsenic concentration in soil). On the other hand, some areas on the north-east are at “low risk” of arsenic accumulation because of lower elevation (i.e., higher flooding intensity), despite relatively higher arsenic concentration in irrigation water.

Areas in the southern coastal areas are at "low to no risk" lower arsenic concentration in groundwater and because of lower intensity of boro cultivation (because of higher salinity in STW water). Some areas in the south-central region of Bangladesh are at "moderate to low risk" of arsenic accumulation because of higher elevation of these areas (which results in lower flooding intensity).

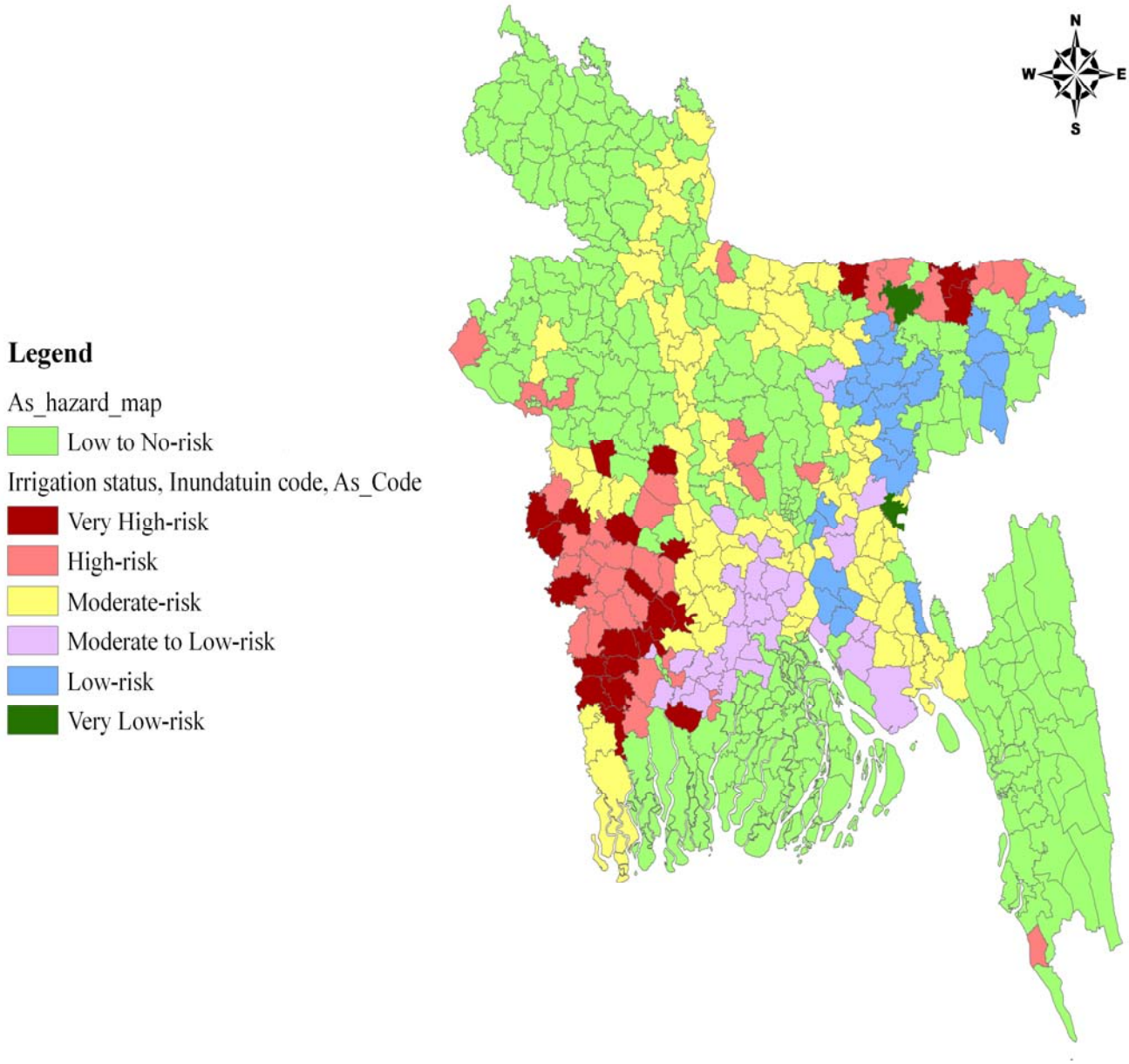

Figure 3.10: Arsenic Hazard Map of Bangladesh due to STW irrigation for Dry season crop production

The analysis of Arsenic- Hazard Map reveals that out of all (mention number of thana) thanas of Bangladesh, 22 are at very high-risk status, 35 are at high-risk status, 98 fall under moderate risk catetory, 39 under moderate to low risk category, 29 under low risk, and 2 under very low risk category. All thanas under different risk category with respect to arsenic accumulation in agricultural soil are shown in the Tables 3.12 through 3.17. Figure 3.10 to 3.14 shows the percentage of different land types that is in various risk status due to irrigation by STW for Boro cultivation.

Table 3.12: Risk summary for different types of land irrigated

Total land (ha)	Total Irrigated (ha)	% Irrigated for Boro	Land Type	Risk Type due to Irrigation
3270764	282267	9	Highland	Very High-risk
3270764	382001	12	Highland	High-risk
4548616	867000	19	Medium Highland	Moderate-risk
1053255	86272	8	Medium Lowland	Moderate to low -risk
778826	68038	9	Lowland	Low-risk
54921	5980	11	Very Lowland	Very Low-risk

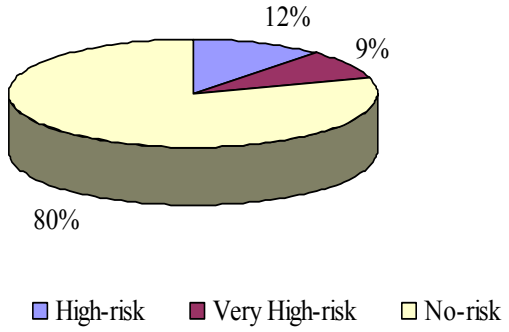

Figure 3.11: Distribution of High Land areas under different risk categories

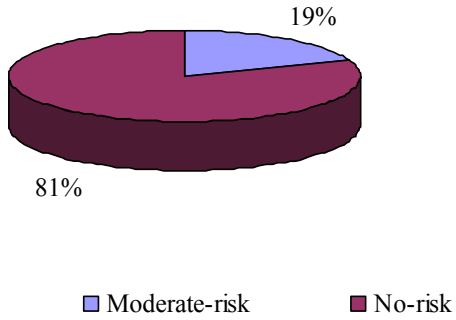

Figure 3.12: Distribution of Medium Land areas under different risk categories

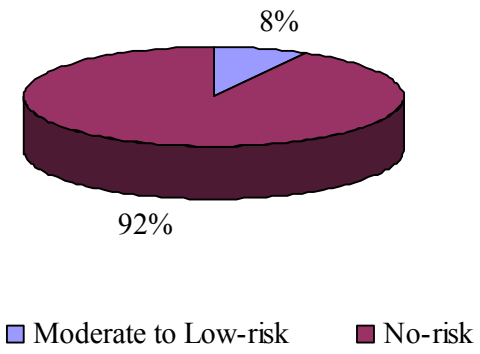

Figure 3.13: Distribution of Medium Low land areas under different risk categories

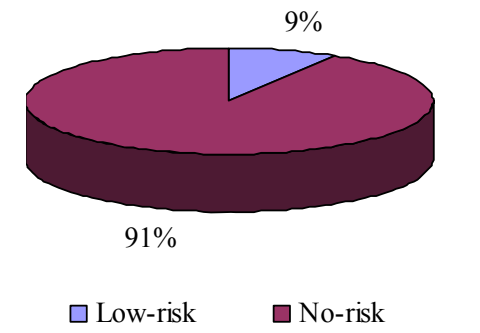

Figure 3.14: Distribution of Low Land areas under different risk categories

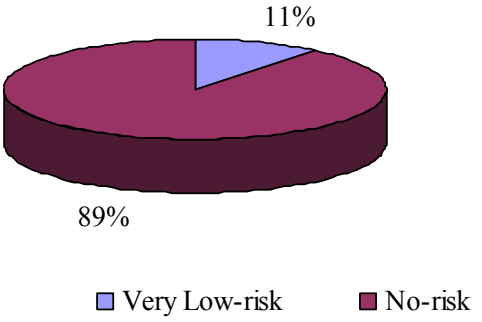

Figure 3.15: Distribution of Very Low Land areas under different risk categories

Table 3.13: Thanas under "Very high-Risk" of arsenic accumulation in agricultural soils

District	Thana	Land Type	Inundation code	Total Highland (sqm)	Irrigated Area (ha)	As Code	% Irrigated of High Land	GW Arsenic (µg/l) Variation in Mouza level	Arsenic Mean	GW Arsenic Std Dev.
Bagerhat	Rampal	Highland	F0	304234036	908	AS 4	3	37-505	257	201
Satkhira	Kalaroa	Highland	F0	230979779	6519	AS 4	28	88-453	198	129
Meherpur	Sadar	Highland	F0	376534021	20190	AS 4	54	43.4-484	190	159
Satkhira	Assasuni	Highland	F0	359641760	9482	AS 4	26	0.5-330	178	122
Satkhira	Tala	Highland	F0	328647281	18850	AS 4	57	15.5-319	159	119
Satkhira	Satkhira Sadar	Highland	F0	396486087	19760	AS 4	50	1.1-501	131	130
Chuadanga	Damurhuda	Highland	F0	303414599	14266	AS 4	47	24-497	130	154
Pabna	Ishurdi	Highland	F0	250517621	5160	AS 4	21	0.5-493	128	194
Jessore	Avoynagar	Highland	F0	242941390	12293	AS 4	51	77-355	122	145
Jessore	Monirampum	Highland	F0	443769172	28135	AS 3	63	40-224	100	75
Narail	Lohagara	Highland	F0	282186066	7620	AS 3	27	0.5-248	98	101
Jessore	Keshabpur	Highland	F0	255354463	16740	AS 4	66	0.5-308	98	110
Chuadanga	Alamdanga	Highland	F0	344968764	29250	AS 4	85	1.2-538	98	162
Jhenaidah	Moheshpur	Highland	F0	388862840	22933	AS 4	59	1.7-557	89	168
Netrakona	Kalmakanda	Highland	F0	384855232	10858	AS 3	28	2.1-262	83	78
Faridpur	Madhukhali	Highland	F0	215263631	4876	AS 3	23	1.1-228	67	82
Narail	Narail Sadar	Highland	F0	378577178	15531	AS 3	41	0.5-203	65	91
Pabna	Santhia	Highland	F0	337314777	11886	AS 4	35	0.5-341	63	112
Sunamganj	Duarabazar	Highland	F0	293579895	1150	AS 3	4	0.5-204	62	80
Sunamganj	Chatak	Highland	F0	433625498	59	AS 3	0.1	8.2-246	60	84
Magura	Shalikha	Highland	F0	229210280	13651	AS 3	60	0.5 - 216	59	77
Jhenaidah	Sailkupa	Highland	F0	371757403	12150	AS 3	33	0.5-281	49	91
	Thana Total			**7152721773**	**282267**					

Table 3.14: Thanas under "High Risk" of arsenic accumulation in agricultural soil

Thana	District	Land Type	Inundation code	High Land Area (sqm)	Area Irrigated (ha)	As Code	% Irrigated	As (µg/l) Variation in Mouza level	As Mean	Std Dev.
Bagharpara	Jessore	Highland	F0	273493905	13737	AS 2	50	0.5-152	38	50
Basail	Tangail	Highland	F0	164814935	8556	AS 1	52	0.5-92.6	25	31
Chowgacha	Jessore	Highland	F0	277461753	12710	AS 1	46	0.5-86.7	45	26
Chuadanga Sadar	Chuadanga	Highland	F0	289788569	22785	AS 1	79	0.5-86.7	45	26
Companyganj	Sylhet	Highland	F0	259761294	314	AS 1	1	8.6-7.3	40	29
Degholia	Khulna	Highland	F0	71968914	1625	AS 2	23	0.5-168	41	62
Dhamri	Dhaka	Highland	F0	301428289	12644	AS 2	42	0.5-107	22	36
Dharmapas	Sunamganj	Highland	F0	495143388	5525	AS 2	11	35.3-145	92	38
Dumuria	Khulna	Highland	F0	448341844	13595	AS 1	30	0.9-65.7	23	24
Gangni	Meherpur	Highland	F0	342987720	27654	AS 1	81	0.5-62.5	31	24
Gowainghat	Sylhet	Highland	F0	477393439	473	AS 1	1	0.5-61.4	21	23
Horinakundu	Jhenaidah	Highland	F0	228680444	10530	AS 1	46	0.5-135	36	50
Jessore Sadar	Jessore	Highland	F0	435461009	27430	AS 2	63	0.5-172	51	64
Jhenidah Sadar	Jhenaidah	Highland	F0	461467942	21458	AS 2	46	0.5-148	38	46
Jhikorgacha	Jessore	Highland	F0	309210477	13880	AS 2	45	0.5-201	92	58
Jiban Nagar	Chuadanga	Highland	F0	202759008	15070	AS 1	74	0.5-98.7	43	36
Kachua	Bagerhat	Highland	F0	125742126	7	AS 2	0	10.1-177	61	60
Kaligonj	Jhenaidah	Highland	F0	313150371	21937	AS 1	70	0.5-90.9	25	33
Kaligonj	Gazipur	Highland	F0	160471827	3912	AS 2	24	0.5-155	18	51

Thana	District	Land Type	Inundation code	High Land Area (sqm)	Area Irrigated (ha)	As Code	% Irrigated	As (µg/l) Variation in Mouza level	As Mean	Std Dev.
Kotchndpur	Jhenaidah	Highland	F0	171453170	6696	AS 2	39	0.5-133	33	47
Mirzapur	Tangail	Highland	F0	361588125	6062	AS 2	17	0.5-131	22	39
Mohammadpur	Magura	Highland	F0	217450006	9625	AS 2	44	0.5-168	30	60
Paba	Rajshahi	Highland	F0	283458741	7393	AS 1	26	0.5-91.8	24	37
Paikgacha	Khulna	Highland	F0	355057094	6105	AS 2	17	3.9-130	66	50
Pangsha	Rajbari	Highland	F0	404470596	16361	AS 2	40	0.5-158	27	48
Puthia	Rajshahi	Highland	F0	196451703	13824	AS 1	70	0.5-63.8	13	20
Rupsha	Khulna	Highland	F0	111879650	2537	AS 2	23	0.5-137	43	48
Sadar	Magura	Highland	F0	399157941	16800	AS 2	42	0.5-106	23	33
Sharsha	Jessore	Highland	F0	337609733	21706	AS 1	64	1.4-57.3	28	21
Shibgonj	Nawabganj	Highland	F0	509091248	5825	AS 1	11	0.5-63.9	20	27
Sreebordi	Sherpur	Highland	F0	256013934	13702	AS 2	54	0.5-168	31	53
Sujanagar	Pabna	Highland	F0	301035214	16232	AS 1	54	0.5-57.8	7	19
Sunamganj Sadar	Sunamganj	Highland	F0	584625985	554	AS 1	1	27.2-60.7	45	12
Taherpur	Sunamganj	Highland	F0	315260007	2037	AS 1	6	0.5-68	25	26
Ukiya	Cox'S Bazar	Highland	F0	254250847	2700	AS 1	11	0.5-70.1	11	24
	Thana Total			10698381249	382001					

Table 3.15: Thanas under "Moderate Risk" of arsenic accumulation in agricultural soil

Thana	District	Land Type	Inundation code	Medium High land Area (sqm)	Irrigated Area (ha)	As Code	% Area Irrigated	As variation in mouza level	GW As Mean	GW As St. Dev.
Shahrasti	Chandpur	Medium Highland	F1	158447103	1220	AS 4	8	2-1090	407	321
Bharamara	Kushtia	Medium Highland	F1	134876365	5092	AS 4	38	6-1660	302	603
Muradnagar	Comilla	Medium Highland	F1	342796311	2997	AS 4	9	70.8-412	288	116
Sirajdikhan	Munshiganj	Medium Highland	F1	166591041	956	AS 4	6	14.3-529	286	189
Gopalganj Sadar	Gopalganj	Medium Highland	F1	372624869	6453	AS 4	17	121-602	275	175
Kachua	Chandpur	Medium Highland	F1	225646117	2750	AS 4	12	30-414	267	140
Nagarkanda	Faridpur	Medium Highland	F1	389069297	13461	AS 4	35	95.6-924	259	260
Banchharampur	Brahamanbaria	Medium Highland	F1	188217029	3800	AS 4	20	41.9-735	256	245
Chandina	Comilla	Medium Highland	F1	202326508	4637	AS 4	23	96.4-407	247	115
Muksudpur	Gopalganj	Medium Highland	F1	308477975	6451	AS 4	21	6-588	231	178
Begumgonj	Noakhali	Medium Highland	F1	411979521	400	AS 4	1	8.6-530	226	157
Louhajang	Munshiganj	Medium Highland	F1	118219205	522	AS 4	4	87.6-347	209	105
Goshairhat	Shariatpur	Medium Highland	F1	143961457	438	AS 4	3	2.7-576	206	195
Laksham	Comilla	Medium Highland	F1	419966315	5890	AS 4	14	1.6-525	198	156
Mirpur	Kushtia	Medium Highland	F1	326831838	18770	AS 4	57	0.5-1030	198	371
Gazaria	Munshiganj	Medium Highland	F1	83152589	320	AS 4	4	47.9-312	197	101
Senbag	Noakhali	Medium Highland	F1	161229094	4830	AS 4	30	6-478	197	161

Thana	District	Land Type	Inundation code	Medium High land Area (sqm)	Irrigated Area (ha)	As Code	% Area Irrigated	As variation in mouza level	GW As Mean	GW As St. Dev.
Tongibari	Munshiganj	Medium Highland	F1	113410974	242	AS 3	2	70.2-292	183	86
Debidwar	Comilla	Medium Highland	F1	237771218	8452	AS 4	36	6.1-452	183	117
Dagonbhuiy	Feni	Medium Highland	F1	142145753	3256	AS 4	23	1.2-420	173	133
C.Vodrason	Faridpur	Medium Highland	F1	118127185	1018	AS 4	9	0.7-427	164	203
Alphadanga	Faridpur	Medium Highland	F1	115993514	10104	AS 4	87	12.3-346	155	140
Debhata	Satkhira	Medium Highland	F1	174380635	7339	AS 4	42	3.5-315	149	108
Sadarpur	Faridpur	Medium Highland	F1	220854591	4517	AS 3	20	6.7-290	133	129
Barura	Comilla	Medium Highland	F1	241400169	10058	AS 4	42	1.8-320	131	114
Nangalkot	Comilla	Medium Highland	F1	237390780	9875	AS 4	42	4.6-668	131	220
Bhairab	Kishoreganj	Medium Highland	F1	98728030	2935	AS 4	30	0.7-505	121	174
Nawabgonj	Dhaka	Medium Highland	F1	245493220	6272	AS 3	26	58.7-262	114	70
Kalia	Narail	Medium Highland	F1	297758300	8293	AS 3	28	0.5-255	111	111
Kashiani	Gopalganj	Medium Highland	F1	283569262	7076	AS 4	25	5.3-380	110	115
Rajbari Sadar	Rajbari	Medium Highland	F1	307002778	11173	AS 3	36	0.5-359	105	121
Mirersharai	Chittagong	Medium Highland	F1	454897781	33	AS 4	0	0.8-344	102	133
Shamnagar	Satkhira	Medium Highland	F1	435228581	12915	AS 4	30	0.5-509	102	189
Daulatpur	Kushtia	Medium Highland	F1	425602118	16796	AS 4	39	0.5-665	101	233
Damudya	Shariatpur	Medium Highland	F1	95322592	414	AS 4	4	0.5-490	98	202
Bajitpur	Kishoreganj	Medium Highland	F1	166461283	3616	AS 4	22	0.5-537	97	166
Bhedarganj	Shariatpur	Medium Highland	F1	249465294	1373	AS 2	6	0.5-200	93	64

Thana	District	Land Type	Inundation code	Medium High land Area (sqm)	Irrigated Area (ha)	As Code	% Area Irrigated	As variation in mouza level	GW As Mean	GW As St. Dev.
Raipura	Narsingdi	Medium Highland	F1	268380903	12431	AS 3	46	1-284	89	97
Dhobarua	Mymensingh	Medium Highland	F1	252002992	4107	AS 2	16	14.8-200	89	63
Shajadpur	Sirajganj	Medium Highland	F1	287855348	14851	AS 2	52	26.8-195	86	62
Rajarhat	Kurigram	Medium Highland	F1	162607091	9376	AS 4	58	1.6-420	85	137
Gabtali	Bogra	Medium Highland	F1	246093559	19404	AS 4	79	0.5-632	81	207
Sonagazi	Feni	Medium Highland	F1	192754145	492	AS 2	3	1.8-166	81	49
Sandargonj	Gaibandha	Medium Highland	F1	371970513	19502	AS 4	52	0.5-708	79	221
Kuliarchar	Kishoreganj	Medium Highland	F1	99114744	4304	AS 3	43	5.4-217	76	76
Boalmari	Faridpur	Medium Highland	F1	272142057	10424	AS 2	38	0.5-181	75	63
Faridpur Sadar	Faridpur	Medium Highland	F1	354615417	15766	AS 3	44	6-245	67	84
Daldowar	Tangail	Medium Highland	F1	162477903	11107	AS 2	68	4.6-153	57	60
Goalanda	Rajbari	Medium Highland	F1	114683427	5295	AS 4	46	1.6-314	56	114
Brahman Para	Comilla	Medium Highland	F1	132084762	4825	AS 2	37	0.5-159	55	69
Kumarkhali	Kushtia	Medium Highland	F1	256987656	11970	AS 4	47	0.5-377	51	132
Bera	Pabna	Medium Highland	F1	214892931	10222	AS 1	48	10-80.7	50	26
Mandha	Naogaon	Medium Highland	F1	415612625	4818	AS 3	12	0.5-244	49	90
Kazipur	Sirajganj	Medium Highland	F1	288098598	8545	AS 4	30	0.5-384	47	114
Durgapur	Netrakona	Medium Highland	F1	280616846	5518	AS 2	20	2-176	46	65
Belabo	Narsingdi	Medium Highland	F1	118369860	5192	AS 2	44	1.3-163	44	63
Dhunot	Bogra	Medium Highland	F1	242242685	23385	AS 1	97	3.1-75.9	43	31

Thana	District	Land Type	Inundation code	Medium High land Area (sqm)	Irrigated Area (ha)	As Code	% Area Irrigated	As variation in mouza level	GW As Mean	GW As St. Dev.
Narsingdi Sadar	Narsingdi	Medium Highland	F1	186602826	4092	AS 2	22	0.5-192	40	61
Feni Sadar	Feni	Medium Highland	F1	210437924	4117	AS 2	20	2-164	39	54
Sirajgonj Sadar	Sirajganj	Medium Highland	F1	264333609	17085	AS 2	65	2.1-118	39	35
Nalitabari	Sherpur	Medium Highland	F1	327127595	7795	AS 2	24	5.3-137	37	39
Sarishabari	Jamalpur	Medium Highland	F1	256726470	20673	AS 3	81	0.5-230	37	79
Kamarkhand	Sirajganj	Medium Highland	F1	94832319	5299	AS 1	56	3.1-92.5	36	34
Nagarpur	Tangail	Medium Highland	F1	240116236	10464	AS 2	44	3.4-149	36	57
Companigonj	Noakhali	Medium Highland	F1	275984383	1220	AS 1	4	1.6-95.6	35	33
Tangail Sadar	Tangail	Medium Highland	F1	291806973	9035	AS 2	31	0.6-144	33	42
Gheor	Manikganj	Medium Highland	F1	142532387	5367	AS 1	38	15.4-89	33	26
Atpara	Netrakona	Medium Highland	F1	188857189	3046	AS 3	16	0.5-216	32	81
Pirgacha	Rangpur	Medium Highland	F1	259154821	14975	AS 3	58	0.5-298	31	85
Bakshigonj	Jamalpur	Medium Highland	F1	194644641	13526	AS 2	69	0.5-113	30	44
Ulipur	Kurigram	Medium Highland	F1	391244368	39602	AS 2	101	0.5-187	29	60
Haluaghat	Mymensingh	Medium Highland	F1	354731478	7842	AS 1	22	0.8-78.8	28	27
Pakundia	Kishoreganj	Medium Highland	F1	167503604	7266	AS 3	43	0.5-273	27	82
Rowmari	Kurigram	Medium Highland	F1	190396056	11495	AS 1	60	2.6-71	27	26
Munshiganj Sadar	Munshiganj	Medium Highland	F1	129223458	105	AS 1	1	2.4-76.1	26	29

Thana	District	Land Type	Inundation code	Medium High land Area (sqm)	Irrigated Area (ha)	As Code	% Area Irrigated	As variation in mouza level	GW As Mean	GW As St. Dev.
Kaligonj	Satkhira	Medium Highland	F1	327694831	7292	AS 1	22	0.7-100	24	32
Shibgonj	Bogra	Medium Highland	F1	312615053	26806	AS 1	86	0.9-91.7	24	37
Belkuchi	Sirajganj	Medium Highland	F1	145180897	5572	AS 1	38	0.6-53.6	22	19
Monohordi	Narsingdi	Medium Highland	F1	194462250	4573	AS 1	24	0.5-68.6	21	26
Keranigonj	Dhaka	Medium Highland	F1	178058159	1456	AS 1	8	0.5-98.5	20	35
Sariakandi	Bogra	Medium Highland	F1	314494586	16778	AS 2	53	0.5-150	20	45
Sadullapur	Gaibandha	Medium Highland	F1	233385674	10854	AS 1	47	0.5-84.1	19	32
Palashbari	Gaibandha	Medium Highland	F1	188761670	11569	AS 1	61	0.5-84	19	24
Akhaura	Brahamanbaria	Medium Highland	F1	90260801	2475	AS 2	27	0.5-110	18	41
Sherpur Sadar	Sherpur	Medium Highland	F1	351409152	25042	AS 2	71	0.5-115	17	33
Fulpur	Mymensingh	Medium Highland	F1	567842567	30001	AS 1	53	0.5-76.5	16	27
Saturia	Manikganj	Medium Highland	F1	135064694	8391	AS 1	62	0.5-62.8	16	19
Kushtia Sadar	Kushtia	Medium Highland	F1	294819277	19922	AS 1	68	0.5-61.6	16	21
Mymensingh Sadar	Mymensingh	Medium Highland	F1	359400189	13088	AS 1	36	0.5-59.4	15	23
Kendua	Netrakona	Medium Highland	F1	304387241	11161	AS 1	37	0.5-79.5	15	29
Gobindagonj	Gaibandha	Medium Highland	F1	458935555	20645	AS 1	45	0.5-54.4	14	18
Gouripur	Mymensingh	Medium Highland	F1	280044461	14072	AS 2	50	0.5-109	13	36
Nageswari	Kurigram	Medium Highland	F1	356637937	24529	AS 1	69	0.5-62.9	12	21
Palash	Narsingdi	Medium Highland	F1	93465292	1501	AS 1	16	0.5-51.9	11	19

Thana	District	Land Type	Inundation code	Medium High land Area (sqm)	Irrigated Area (ha)	As Code	% Area Irrigated	As variation in mouza level	GW As Mean	GW As St. Dev.
Mohonpur	Rajshahi	Medium Highland	F1	159312083	3046	AS 1	19	0.5-58.2	11	20
Burichong	Comilla	Medium Highland	F1	162810809	3659	AS 1	22	1.6-63.2	11	21
Nakla	Sherpur	Medium Highland	F1	172125300	10535	AS 1	61	0.5-54.4	9	18
Muktagacha	Mymensingh	Medium Highland	F1	318590426	4751	AS 1	15	0.5-65.6	9	21
		Thana Total		23715035998	**867000**					

Table 3.16: Thanas under "Moderate to Low Risk" of arsenic accumulation in agricultural soil

Thana	District	Land Type	Inundation code	Medium land Area (sq m)	Area Irrigated	As Code	% Area Irrigated	As variation in mouza level	As mean	As St. Dev.
Agailjhara	Barisal	Medium Lowland	F2	155138065	130.0	AS 4	1	0.5-319	98	120
Bagerhat Sadar	Bagerhat	Medium Lowland	F2	262196991	1925.0	AS 4	7	0.5-535	164	207
Batiaghata	Khulna	Medium Lowland	F2	214664141	3107.0	AS 4	14	0.5-538	78	203
Bhanga	Faridpur	Medium Lowland	F2	213427910	5976.0	AS 4	28	103-468	246	113
Chatkhil	Noakhali	Medium Lowland	F2	136930104	850.0	AS 4	6	10.3-649	251	251
Chitalmari	Bagerhat	Medium Lowland	F2	194669110	1027.0	AS 4	5	96.9-480	236	126
Daudkandi	Comilla	Medium Lowland	F2	353266950	839.0	AS 4	2	72.7-698	274	185
Dohar	Dhaka	Medium Lowland	F2	124857460	2399.0	AS 3	19	11.7-262	118	90
Fakirhat	Bagerhat	Medium Lowland	F2	159041828	4138.0	AS 4	26	0.8-578	235	225

Thana	District	Land Type	Inundation code	Medium land Area (sq m)	Area Irrigated	As Code	% Area Irrigated	As variation in mouza level	As mean	As St. Dev.
Fultala	Khulna	Medium Lowland	F2	56295626	1948.0	AS 3	35	0.5-259	46	93
Haimchar	Chandpur	Medium Lowland	F2	69449670	4.0	AS 4	0	6-529	93	219
Harirampur	Manikganj	Medium Lowland	F2	184382355	5646.0	AS 1	31	1-88.8	52	36
Homna	Comilla	Medium Lowland	F2	157725364	2840.0	AS 3	18	0.9-213	97	76
Hossan Pur	Kishoreganj	Medium Lowland	F2	117780559	2605.0	AS 2	22	0.5-195	28	68
Jazira	Shariatpur	Medium Lowland	F2	197799339	3355.0	AS 4	17	1.9-540	171	209
Kalkini	Madaripur	Medium Lowland	F2	269670769	1211.0	AS 4	4	1-466	162	209
Kotalipara	Gopalganj	Medium Lowland	F2	364613325	459.0	AS 4	1	0.9-521	176	166
Lakshmipur Sadar	Lakshmipur	Medium Lowland	F2	3266566573	10080.0	AS 3	3	6-256	56	82
Madaripur Sadar	Madaripur	Medium Lowland	F2	276881909	4564.0	AS 4	16	0.5-552	294	199
Mollahat	Bagerhat	Medium Lowland	F2	174586652	2205.0	AS 4	13	0.5-317	139	111
Nabinagar	Brahamanbaria	Medium Lowland	F2	335257860	2405.0	AS 4	7	51.5-406	252	159
Najirpur	Pirojpur	Medium Lowland	F2	218704206	45.0	AS 3	0	0.5-270	90	105
Nandail	Mymensingh	Medium Lowland	F2	327002279	7568.0	AS 1	23	0.5-60.8	15	20
Naria	Shariatpur	Medium Lowland	F2	187302984	1342.0	AS 3	7	0.5-298	161	115
NoaKhali Sadar	Noakhali	Medium Lowland	F2	907306754	315.0	AS 3	0	1.8-264	104	98
Palong	Shariatpur	Medium Lowland	F2	173697684	1519.0	AS 4	9	1.3-540	174	178
Rajoir	Madaripur	Medium Lowland	F2	227330308	3838.0	AS 4	17	1.3-627	191	240
Ramganj	Lakshmipur	Medium Lowland	F2	177827603	1495.0	AS 4	8	6-816	421	289

Thana	District	Land Type	Inundation code	Medium land Area (sq m)	Area Irrigated	As Code	% Area Irrigated	As variation in mouza level	As mean	As St. Dev.
Shibchar	Madaripur	Medium Lowland	F2	293862262	6956.0	AS 3	24	4.7-289	97	83
Sreenagar	Munshiganj	Medium Lowland	F2	189932020	1736.0	AS 4	9	104-517	256	162
Terokhada	Khulna	Medium Lowland	F2	182585205	3400.0	AS 2	19	0.5-114	162	52
Tungipara	Gopalganj	Medium Lowland	F2	119802136	280.0	AS 4	2	0.5-315	121	132
Wazipur	Barisal	Medium Lowland	F2	241991570	65.0	AS 3	0	0.5-557	42	83
		Thana Total		**10532547572**	**86272.0**					

Table 3.17: Thanas under "Low Risk" of arsenic accumulation in agricultural soil

Thana	District	Land Type	Inundation code	Low land Area (sq km)	Area Irrigated(ha)	As Code	% Area Irrigated	As variation in mouza level	GW As mean	GW As St. Dev.
A. Hazar	Narayanganj	Lowland	F3	157318616	3025	AS 2	19	0.5-180	56	70
Ajmeriganj	Habiganj	Lowland	F3	173584548	600	AS 2	3	4.9-136	44	47
Austogram	Kishoreganj	Lowland	F3	274626391	896	AS 1	3	0.5-77.5	20	33
Balaganj	Sylhet	Lowland	F3	381556853	16	AS 2	0	10.1-157	55	56
Baniachang	Habiganj	Lowland	F3	506819259	797	AS 4	2	10.1-320	66	99
Beanibazar	Sylhet	Lowland	F3	243536409	33	AS 1	0	0.5-51.9	9	19
Bishwanath	Sylhet	Lowland	F3	210025856	40	AS 1	0	0.5-53	17	19
Brahmanbaria Sadar	Brahamanbaria	Lowland	F3	495647621	13600	AS 4	27	0.5-382	72	119
Chowdagram	Comilla	Lowland	F3	269404455	6150	AS 2	23	0.9-138	53	56
Faridganj	Chandpur	Lowland	F3	240431121	3	AS 4	0	6-644	357	220

Thana	District	Land Type	Inundation code	Low land Area (sq km)	Area Irrigated(ha)	As Code	% Area Irrigated	As variation in mouza level	GW As mean	GW As St. Dev.
Hajiganj	Chandpur	Lowland	F3	192729950	195	AS 4	1	194-586	413	142
Itna	Kishoreganj	Lowland	F3	378281515	2823	AS 1	7	5.4-81.4	34	29
Jokiganj	Sylhet	Lowland	F3	263455703	6	AS 1	0	0.5-83.3	35	34
Kamalganj	Maulvibazar	Lowland	F3	414584031	1041	AS 3	3	0.5-254	39	82
Karimgonj	Kishoreganj	Lowland	F3	199282383	2516	AS 2	13	17.7-176	69	60
Khaliajuri	Netrakona	Lowland	F3	290377857	356	AS 2	1	28.2-1135	82	51
KisorgonjSadar	Kishoreganj	Lowland	F3	189618818	2003	AS 1	11	0.5-172	37	65
M.Bazar Sadar	Maulvibazar	Lowland	F3	349825344	24	AS 2	0	1.1-133	40	42
Madan	Netrakona	Lowland	F3	230177170	5235	AS 2	23	1.6-154	70	53
Matlab(North)	Chandpur	Lowland	F3	332752248	1840	AS 4	6	2.2-644	389	197
Mithamoin	Kishoreganj	Lowland	F3	216386823	952	AS 1	4	0.7-86.6	42	40
Mohongonj	Netrakona	Lowland	F3	240732474	2581	AS 2	11	0.9-145	52	50
Nashirnagar	Brahamanbaria	Lowland	F3	308986779	5827	AS 4	19	0.5-357	61	145
Nikly	Kishoreganj	Lowland	F3	170809931	3812	AS 1	22	11-98.3	54	40
Rajnagar	Maulvibazar	Lowland	F3	338960877	102	AS 1	0	0.5-91	16	32
Chandpur Sadar	Chandpur	Lowland	F3	203968340	458	AS 4	2	1.8-641	421	202
Sarail	Brahamanbaria	Lowland	F3	219209998	7630	AS 4	35	0.5-316	56	127
Sonargaon	Narayanganj	Lowland	F3	152506916	1265	AS 4	8	0.5-324	173	144
Tarail	Kishoreganj	Lowland	F3	142664818	4212	AS 1	30	1.5-52.8	22	17
	Thana Total			**7788263102**	68038					

Table 3.18: Thanas under "Very Low Risk" of arsenic accumulation in agricultural soil

Thana	District	Land Type	Inundation code	Very Low Land Area (sqm)	Area Irrigated(ha)	As Code	% Area Irrigated	As variation in mouza level	As mean	As St. Dev.
Jamalganj	Sunamganj	Very Lowland	F4	337664136	30	AS 1	0	27.5-71.8	53	15
Kashba	Brahamanbaria	Very Lowland	F4	211549950	5950	AS 2	28	0.5-105	18	36
		Thana Total		**549214086**	**5980**					

3.4 Validation of Arsenic Hazard Map

For validation of the prepared As-hazard map, soil arsenic concentration data from secondary and primary source were processed to form Soil-As database. Soil arsenic concentration data is point data which was superimposed on the As-hazard map to assess if the data qualitatively match the hazard map. It should be noted that accumulation of arsenic (contained in irrigation water) in agricultural soil is a long-term process. For example, agricultural (boro) land in areas with "higher risk" of arsenic accumulation would continue to accumulate arsenic at a higher rate (compared to "low risk" areas"); and soils in these areas would exhibit more and more arsenic with passage of time. However, since groundwater irrigation has been continuing throughout Bangladesh for a considerable period of time, the present level of arsenic in agricultural soils is likely to provide indication of long-term arsenic accumulation. In this study, by superimposing the soil arsenic data on arsenic hazard map, effort were made to see if available soil arsenic data provide indication of arsenic accumulation in paddy field soils. Figure 3.15 shows the arsenic hazard map over which the soil arsenic data have been superimposed.

The regional soil arsenic concentration variation can be seen more clearly when point soil arsenic data in Figure 3.15 are smoothed (see Fig 3.16). The smoothing was carried out by a statistical method Disjunctive Kriging. Kriging is a technique that enables estimates of As concentration to be made at point where no observations are available. It can be applied to blocks of land. Disjunctive Kriging assumes the model:

$$f(Z(\mathbf{s})) = \mu_1 + \varepsilon(\mathbf{s}),$$

where μ_1 is an unknown constant and $f(Z(s))$ is an arbitrary function of $Z(s)$. Notice that we can write $f(Z(s)) = I(Z(s) > ct)$, so Indicator Kriging is a special case of Disjunctive Kriging. In Geostatistical Analyst of ArcMap, prediction can be made either the value itself or an indicator with Disjunctive Kriging.

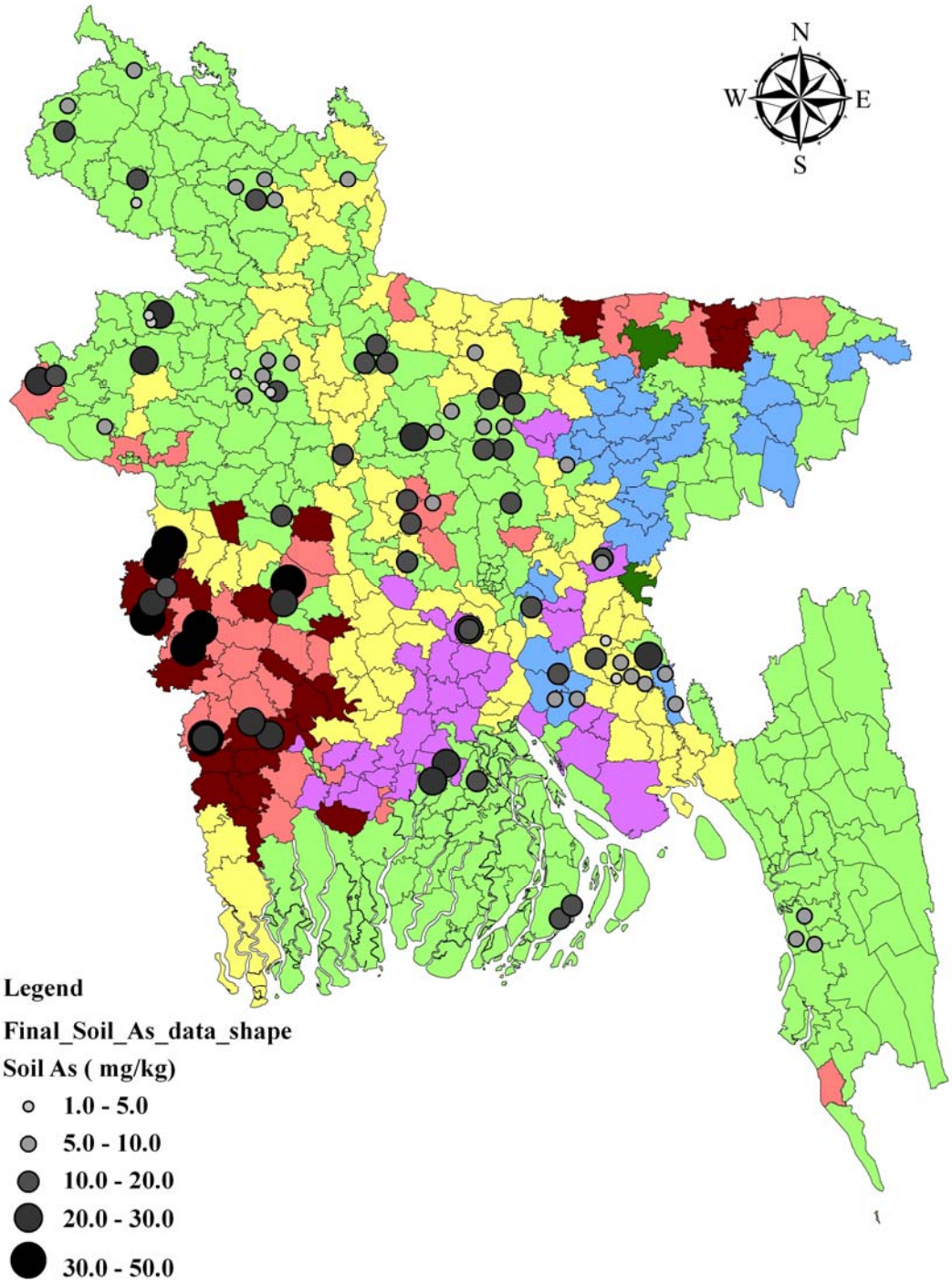

Figure: 3.16: Soil-As data superimposed on As-hazard map

Figures 3.15 and 3.16 show that soil arsenic data matches well with the developed As hazard map. The Arsenic Hazard Map shows that the south western part of Bangladesh is most vulnerable with respect to arsenic accumulation, and available data also confirms higher soil-As in this region. . Similarly, available soil-As data from northern, central and south-eastern region of Bangladesh also match the Arsenic Hazard Map quite well. Table 3.18 shows comparison of selected soil arsenic concentration data with the As-hazard map criteria. It further sthrenthed the phenomena that thanas with high lands (having low flood depth) with higher arsenic in STW irrigation water are more prone to As accumulation.

One the other hand, low lands (with high flood depth) even with higher As in STW irrigation are less prone to As accumulation. So the Arsenic Hazard Map and available soil-As data appear to validate the hypothesis that "areas without pronounced monsoon flooding may be at greater risk of soil As accumulation than seasonally flooded fields".

Table 3.19: Comparison of field soil arsenic concentration data with Arsenic hazard map criteria

District	Thana	Mean Soil As (mg/kg)	Arsenic Map Criteria
Dinajpur	Dinajpur Sadar	1	F0, AS0
Bogra	Bogra Sadar	2.1	F1, AS0
Naogaon	Potnitola	2.6	F1, AS0
Comilla	Barura	5.7	F1, AS4
Brahmanbaria	Nabinagar	6.7	F2 ,AS4
Manikgonj	Harirampur	10	F2, AS1
Narayangonj	Sonagaon	11	F3, AS4
Munshiganj	Shreenagar	20	F2, AS4
Faridpur	Bhanga	21	F2, AS4
Jessore	Sharsa	32	F0, AS1

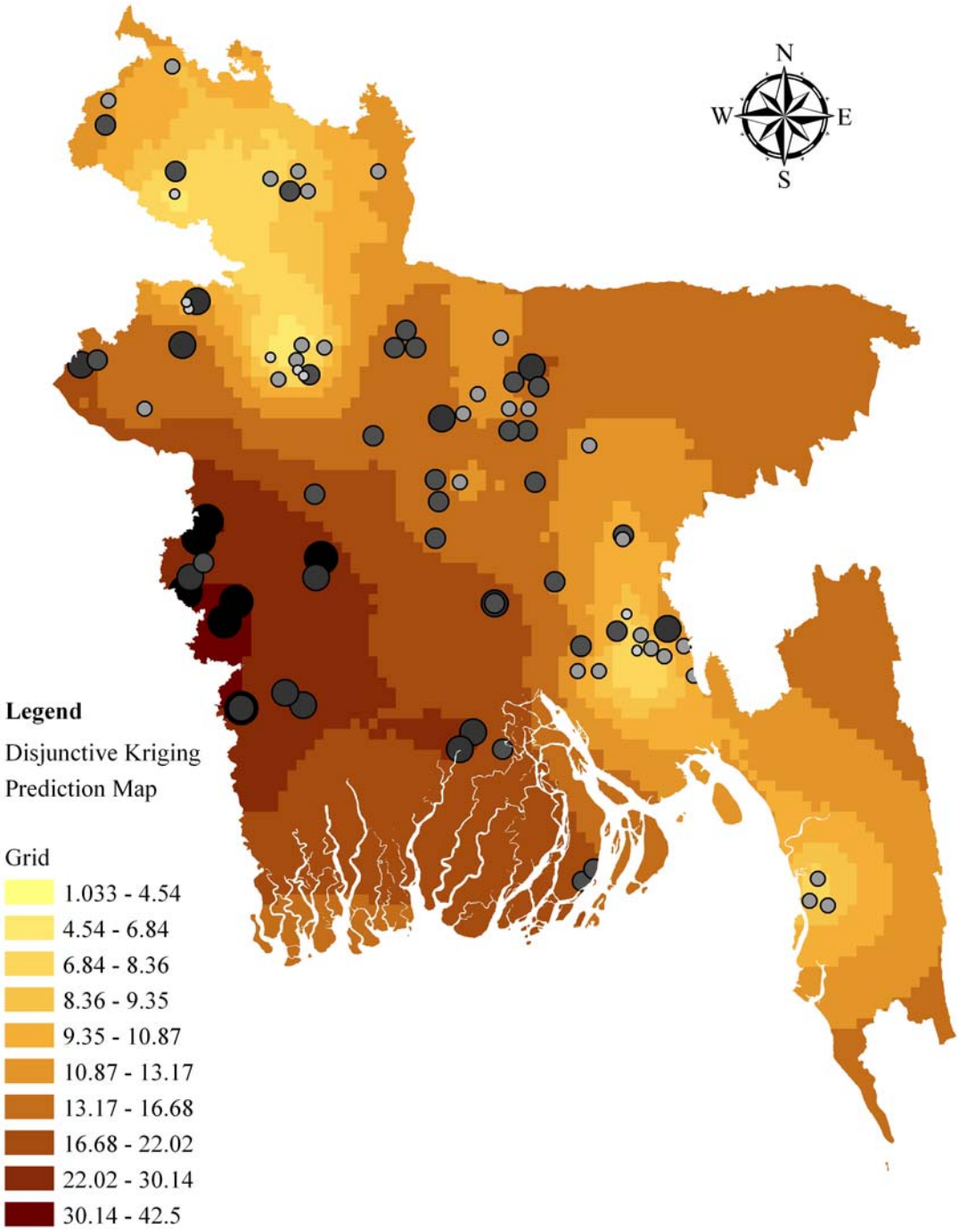

Figure: 3.17: Soil-As data superimposed on smoothed As-hazard map

3.5 Conclusions

As-hazard map indicates significant portion of south western part and some part of northern, central and south-eastern region of Bangladesh are at greater risked status due to higher As deposition in cultivable lands form irrigation pathway and increasing As phototoxity effect.

Soil As probability map prepared form collected primary and secondary data shows most of the south western part exceed soil As level 30 mg/kg and some part of north eastern part exceed 10 mg/kg. However significant amount of rice yield reduction has been observed when soil As level exceeds 10 mg./kg in different study . So Soil-As probability map also indicates the reduction of rice yield in the south western and north eastern part in long run if the irrigation with STW in these regions continues like current frequency.

CHAPTER FOUR
POTENTIAL IMPACT OF ARSENIC ON RICE YIELD

4.1 Introduction

Arsenic (As) in groundwater is a major health concern in Asia and the risks from using shallow tubewells (STWs) for drinking-water are well-known. Bangladesh has the highest percentage of contaminated STWs and an estimated 30 million people are dependent on those wells for domestic purposes (FAO, 2006). However, it has recently become apparent that arsenic-polluted water used for irrigation is adding sufficient arsenic to soils and rice to pose serious threats to sustainable agricultural production in different parts of Bangladesh and to the health and livelihoods of affected people. The Bangladesh agricultural agencies are facing big challenges to understand the potential impacts of arsenic from soil and water on the food chain, including the possibility of increased arsenic in soil, plant uptake of arsenic, reduced crop yields, degradation of food quality, loss of agricultural sustainability, and adverse impacts of arsenic on livestock. It has been estimated that water extraction from the shallow aquifer for irrigation adds 1 million kg of As per year to the arable soil in Bangladesh, mainly in the paddy fields (FAO, 2006). The risks of land degradation are likely to increase with the accumulation of As in the soil. Long-term use of As-contaminated irrigation water could result in As accumulation in the soil. Over time, As accumulation in the soil could reach soil concentrations toxic to crops, thus reducing yields.

Figure 4.1 (FAO, 2006) illustrates potential impact of higher As in irrigation water on As levels in soil, crop and yield. There is no single level of soil As that is toxic to plants. Different plant species tolerate different amounts of As in soils; so do different rice cultivars. Some plants (known as hyper-accumulators) can tolerate very high levels of soil As (Ma et al., 2001). Various symptoms of As toxicity in rice have been reported. These include delayed seedling emergence, reduced plant growth, yellowing and wilting of leaves, brown necrotic spots on older leaves and reduced grain yields (Huq et al., 2006). A disease known as 'straight-head' (because of upright, empty panicles at maturity) or 'parrot beak' (because of misshaped grains) is considered to be an indicator of As toxicity in the USA and Australia (Williams, 2003). Straight-

head disease was reported for the first time in Bangladesh in 2006 (Duxbury and Panaullah, 2007). On soils contaminated by arsenical pesticides in the USA, Yan et al. (2005) found considerable variation in varietal resistance at high soil-As levels, ranging from virtually no yield reduction in one Chinese cultivar to 80–90% reduction in four of ten US cultivars tested.

This chapter presents an assessment of the potential effect of arsenic in irrigation water on rice yield based on secondary data.

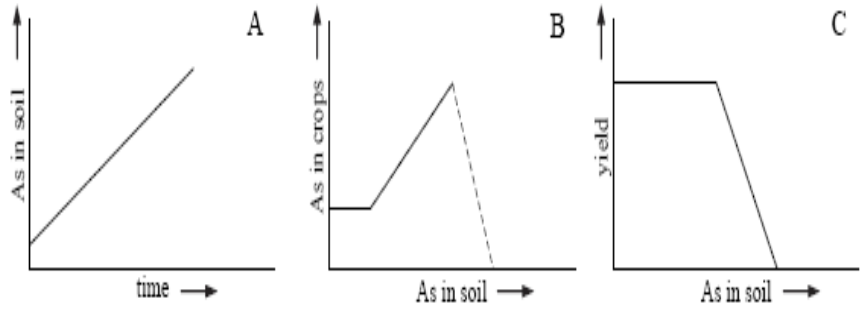

Figure: 4.1: A: input of As via irrigation water can lead to accumulation of As in the soil over time. B: depending on bioavailability, uptake and transport within the plants, higher soil concentrations may be reflected in higher concentrations in crops. The dotted line indicates that at a certain level the plant growth becomes severely inhibited and As concentrations in the plants are then no longer relevant. C: with an increase in soil concentration, yields are expected to stay more or less constant until a threshold level is reached, after which yield will decline (FAO, 2006).

4.2 Methodology

In this study, available literature that links As build-up in soil with As concentration in irrigation water have been carefully reviewed in order to estimate future soil As concentration in different regions of Bangladesh. This was followed by efforts to relate soil As concentration with rice yield, based on available data in the literature. Finally, potential impact of As on rice yield was estimated for selected regions of Bangladesh. .

4.2.1 Estimation of Arsenic Build-up in Soil

Several studies has been conducted to asses the arsenic loading on agricultural soil and the rate of arsenic deposition. Long-term use of As-contaminated water for irrigation results in elevated As concentration in soils and plants (Ullah, 1998; Jahiruddin et al., 2000; Huq et al., 2003; Panaullah et al., 2003; Islam et al., 2004a). Jahiruddin et al (2005) studied levels of As in the irrigation waters, soils, and boro rice (grain and straw) from 100 shallow tubewell (STW) areas of Chapai Nawabganj Sadar Upazila. The effects of As contamination on yield and As accumulation in rice were also investigated by Jahiruddin et al (2005); two sets of pot experiments, one with soil-added As and the other with irrigation-water As, were conducted in the net-house at Bangladesh Agriculture University (BAU), Mymensing. They concluded that STW-water As concentrations ranged from 0.015 to 0.352 µg/ mL, and the soil As contents ranged from 5.8 to 17.7 µg/g over the locations. There was a good correlation between water As and soil As indicating a possibility of As build up in soil with time (see Fig. 4.2).

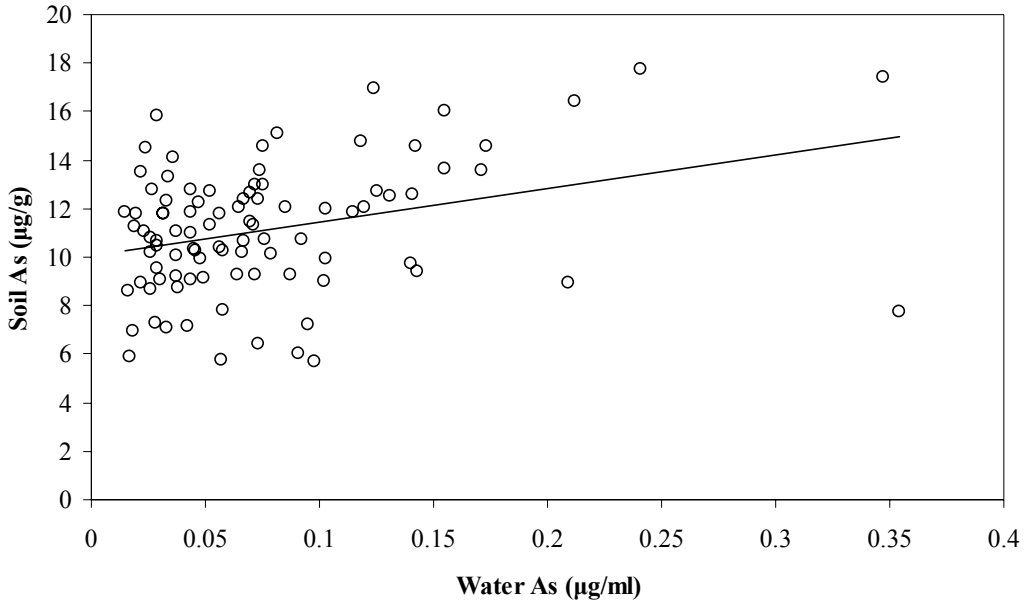

Figure 4.2: Relationship between soil As and water As (n = 100)
(Source Jahiruddin et al., 2005)

Numerous studies have been conducted by Saha and Ali (2007), Dittmar et al (2007), Roberts et al (2007), Roberts et al (2010), Dittmar et al (2010) on the behavior of As accumulation in soil due to irrigation in Munshiganj district. Dittmar et al. (2007)

suggested that 15 years of irrigation have led to an average soil As concentration of about 30 mg kg-1 in the top 25 cm of soil in rice field soils near Sreenagar, Munshiganj. Roberts et al (2010) estimated that between 51 and 250mg m^{-2} of soil arsenic is released into floodwater during the monsoon season in paddy fields near Sreenagar. This corresponds to a loss of 13–62% of the arsenic added to soils through irrigation each year. In Munshiganj, paddy fields subject to an As input of 4.4±0.8 kg ha^{-1} a^{-1} , average As increase in 0-10 cm depth of the soil during irrigation was estimated to be about 71% of the annual input, while about 30% was lost and the average As loss during monsoon accounted for 46% of the annual input (Dittmar et al , 2010).

The Sreenagar, Munshiganj site has flood inundation depth 0.9-1.8m (Land Type Code is F2) and mean arsenic of 256µg/l (Arsenic Level Code is As 4). It means that the area has high As level and is highly flooded, which makes it an ideal site for assessment of As deposition considering the effect of monsoon flooding. Considering all these aspecs, t results from this study site was critically assessed and used to estimate the As accumulation level in agricultural soil for different areas of Bangladesh.

Mass Balance Calculations

From estimating the average As concentration of soil at a particular depth, the following relationship was used:

$$M_{tot} = \sum \left(\left[\overline{As} \right]_d \cdot \overline{\rho}_d \cdot A_{tot} \cdot D_d \right)$$

where M_{tot} is the total As mass in the field, $[As]_d$ describes the mean As concentration in each depth unit d, ρd represents the mean bulk density in depth unit d, A_{tot} is area, and D_d the thickness of each depth unit d.

For irrigation, an opening (inlet) in the field bund is trenched through which the water flows from the channel into the boro rice field. Considering the studies of Saha and Ali (2007), Harvey et al. (2006) and Neumann et al. (2009), the annual amount of irrigation water applied to the boro paddies at the field site of Shreenagar lies between 900 mm a^{-1} (Saha and Ali ,2007) and 1350 mm a^{-1} (Neumann et al. 2009). The amounts published varied in different years and different studies, i.e. ~900 mm a^{-1} (Saha and Ali,2007) and 960 mm a^{-1} (Harvey et al. 2006) in 2004, 1200 mm a^{-1} in 2006 and 1350 mm a^{-1} in 2007 (Neumann et al. 2009). A value of 1000 mm a^{-1} was used for all calculations performed in this study.

From previous chapter it is apparent that the areas without monsoon flooding are prone to higher risk of As accumulation due to boro rice production. So estimation of arsenic build-up in soil was carried out for those Upazilas which have higher arsenic in STW and high land, and for which initial (i.e., present) average level are known. A total of 9 such Upazilas were considered in this study; these are: Gangni (Mehepur); Alamdanga, Damurhuda, and Jiban Nagar (Chuadanga); Kotchandpur (Jhenaidah); Manirampur and Sharsa (Jessore); Pangsha (Rajbari); and Shibganj (Nawabganj).

The following were considered for calculation of As build up by irrigation water:

a) Background (present) average As in soil taken as those reported in different studies for the area being considered, and as those found in soil samples collected and analyzed in this study.
b) Arsenic concentration of irrigation water was taken as the average As concentration of the Upazila
c) Irrigation water depth was taken as 1000 mm over the season
d) As retained by top 10 cm of soil has been considered
e) 70% of arsenic added by irrigation water was assumed to accumulate in the top 10 cm of soil (considering the study by Dittmar et al., 2010); no arsenic loss to floodwater was considered.
f) Soil density was taken as 1.3 gm / cm^3

Considering 1 ha area, arsenic loading (in kg/ha) in irrigated soil and total mass of arsenic added to soil with irrigation water was calculated for each of the selected

Upazilas for the years 2020 and 2050, using the average arsenic concentration in irrigation water.

Considering 70 percent of this applied arsenic is retained in the top 100 mm soil layer, total mass of arsenic in top 100 mm of soil layer was calculated using the mass balance equation above and the initial concentration of arsenic in soil (see Table 4.1) for each of the nine Upazilas. Finally, arsenic concentration in soil (in mg/kg) was estimated for the years 2020 and 2050, for each of the 9 Upazilas. Table 4.1 shows the initial soil arsenic concentration, arsenic loading and estimated soil arsenic concentration in 2020 and 2050 for each of the 9 selected Upazilas.

Table 4.1: Estimation of arsenic build-up in soil in selected Upazilas

District	Upazila	Present[1] Soil Arsenic (mg/kg)	Water Arsenic mean	Arsenic loading (kg/ha)	Arsenic Added (kg/ha) via Irrigation up to 2020	Present Arsenic Mass/ha total	Total Arsenic Mass/ha in 2020	Soil Arsenic (mg/kg) in 2020	Added As (kg/ha) via Irrigation up to 2050	Total Arsenic Mass/ha in 2050	Soil Arsenic (mg/kg) in 2050
Meherpur	Gangni	36.3	31.2	0.31	3.72	47.3	50.97	39.2	10.3	57.5	44.3
Chuadanga	Alamdanga	15.7	97.6	0.98	11.61	20.4	32.02	24.6	32.1	52.5	40.4
Chuadanga	Damurhuda	29.0	129.8	1.30	15.4	37.7	53.14	40.9	42.7	80.4	61.8
Jhenaidah	Kotchandpur	33.3	32.7	0.33	3.89	43.3	47.18	36.3	10.8	54.1	41.6
Chuadanga	Jiban Nagar	34.2	42.8	0.43	5.01	44.5	49.55	38.1	14.1	58.5	45.0
Jessore	Manirampur	21.0	99.8	1.00	11.9	27.3	39.18	30.1	32.8	60.1	46.3
Rajbari	Pangsha	23.9	27.1	0.27	3.22	31.1	34.29	26.4	8.91	40.0	30.8
Nawabganj	Shibganj	20.9	20.1	0.20	2.39	27.2	29.56	22.7	6.60	33.8	26.0
Jessor	Sharsa	32.2	28.4	0.28	1.59	41.9	43.48	33.4	7.55	49.4	38.0

[1] Soil arsenic reported for Gangni, Alamdanga, Damurhuda, Kotchandpur, Jiban Nagar, Manirampur, Pangsha, Shibganj upazila in 2003 and for Sharsa in 2012

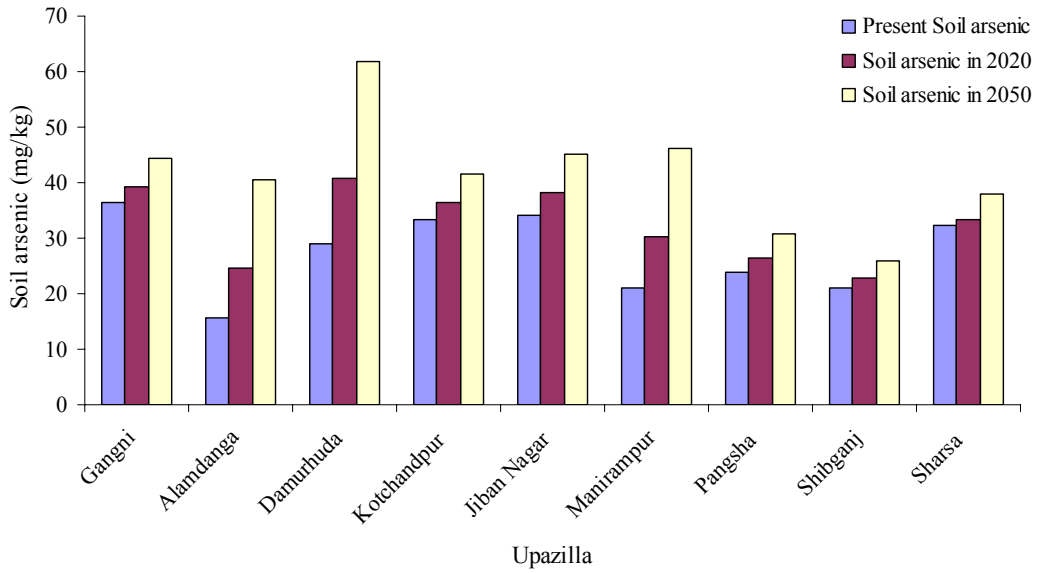

Figure 4.3: Present soil-As and estimated soil-As in the years 2020 and 2050 for the nine selected Upazilas

4.2.2 Estimation of Rice Yield

Duxbury and Panaullah (2007) reported that rice yields in conventional paddy fields in Faridpur decreased from 8.92 to 2.99 t/ha as soil-As levels increased from 26.3 to 57.5 mg/kg. Complementary pot studies showed greater yield reductions at higher soil-As levels than in the field. In both trials, the popular modern rice variety BR29 was used. The results of Duxbury and Panaullah (2007) suggest that the practical limit for paddy cultivation might lie at soil-As levels between 25 and 50 mg/kg. However, differences in varietal tolerance described above need to be kept in view, and so do differences in soil management. Duxbury and Panaullah (2007) also reported results from rice grown on raised beds, in which yields decreased from 8.24 t/ha at a soil As level of 26.3 mg/kg to 5.21 t/ha at 57.5 mg/kg As (i.e., 2.22 t/ha higher than in the flooded field at the highest As concentration).

Jahiruddin et al. (2005) reported yield reduction in rice cultivation in spiked silt loam soil with arsenic. First, a Boro rice cultivar developed by the Bangladesh Rice Research Institute “BRRI dhan 29” and then an Aman cultivar “BRRI dhan 3” was grown. As shown in Fig. 4.4, for Boro rice, the first significant effects occurred at 10 mg/kg soil, causing a grain yield reduction of more than 45 percent. Figure 4.4 also

shows significant yield reduction as soil arsenic level increased; the effect was more pronounced for Boro, compared to the Aman variety. Brammer (2009) , Duxbury and Zavala (2005) also reported irrigation water with high levels of As results in land degradation in terms of crop production (loss of yield) and food safety (food chain contamination).

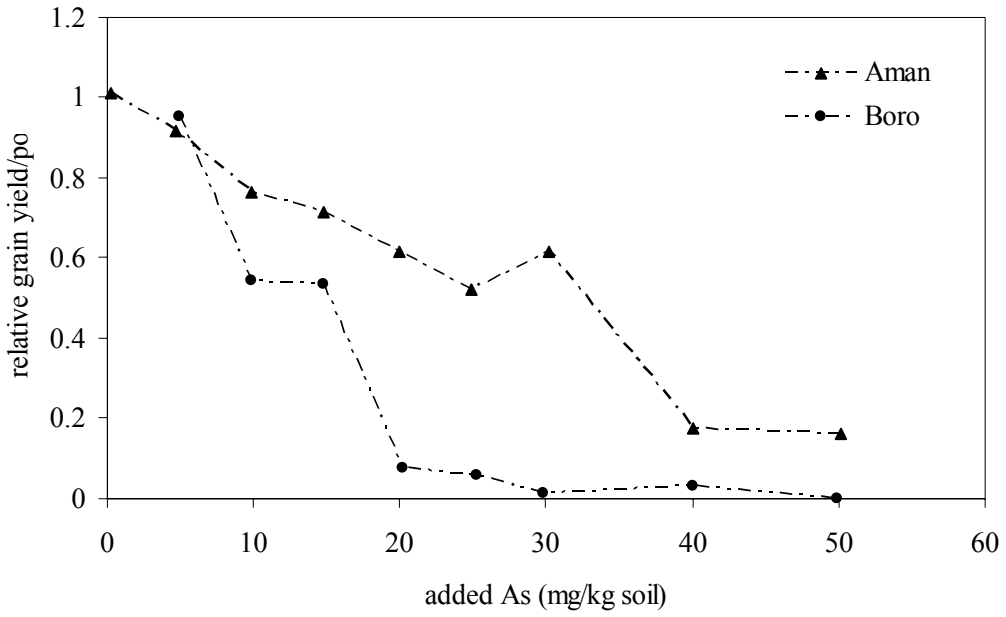

Figure 4.4: The effect of As on grain yield and on As concentrations in grains of Boro and Aman rice cultivars consecutively grown in the same pots
Source: Jahiruddin et al. (2005)

Islam et al. (2004b) carried out a similar experiment with the same soil and rice cultivars as Jahiruddin et al. (2005), with the difference being that As(V) was added via irrigation water during Boro rice cultivation. During the Aman cultivation As-free irrigation water was used, resembling the field situation. With an increase in As concentration in the irrigation water, first an increase in grain yield was observed, both for Boro rice and Aman rice. After that, yields declined (Figure 4.5). Arsenic concentration in grains steadily increased with arsenic levels in irrigation water .

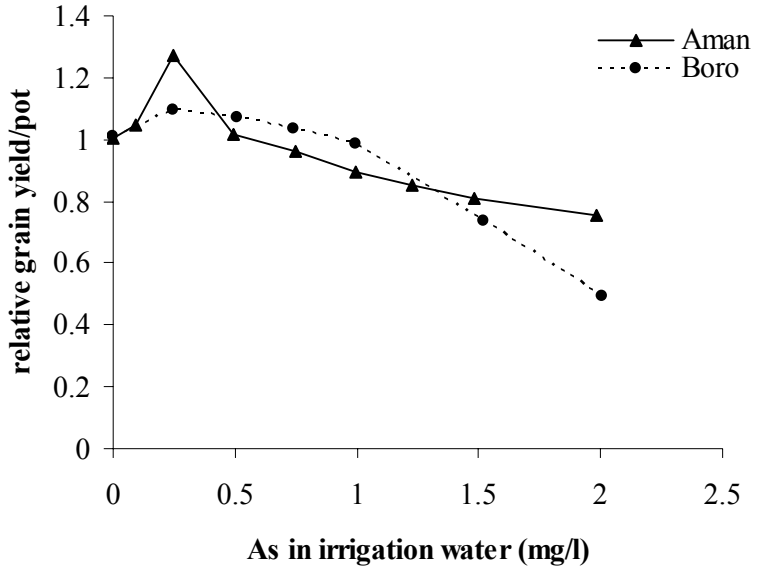

Figure 4.5: Relative grain yield of rice as a function of arsenic concentration in irrigation water [Source: Islam et al. (2004b)]

Panaullah et al (2009) carried out another study on rice yield due to irrigation in a STW command area of about 8 ha in farmer fields located at 23°36.246′ N and 89°45.738′ E (Fig. 1) in the village of Paranpur of the Sadar Upazila in Faridpur, which is a highly arsenic-affected district of the Gangetic Floodplain in central Bangladesh. The soil was a fine-textured (silty clay) (pH 7.5–7.9, organic C 13–18 g kg−1). The predominant cropping pattern at the study site was rain-fed monsoon rice (transplanted Aman) followed by irrigated winter rice (Boro). The arsenic concentration in the water measured at different times from 2005–2007 ranged between 0.10–0.13 mg L^{-1}, but no temporal trend was observed. A single irrigation channel runs laterally in both directions from the STW, and individual fields are irrigated by allowing water to flow from field to field. When BRRI dhan 29 rice was grown in two successive years across this soil-As gradient, yield declined progressively from 7–9 to 2–3 t ha^{-1} with increasing soil-As concentration. The average yield losses over the 8 ha command area was estimated to be 16%. Roughly, rice yield progressively decreased across the soil-As gradient from about 7 to 2 t ha^{-1} in 2006 and from about 9 to 3 t ha^{-1} in 2007 (Fig 4.6)

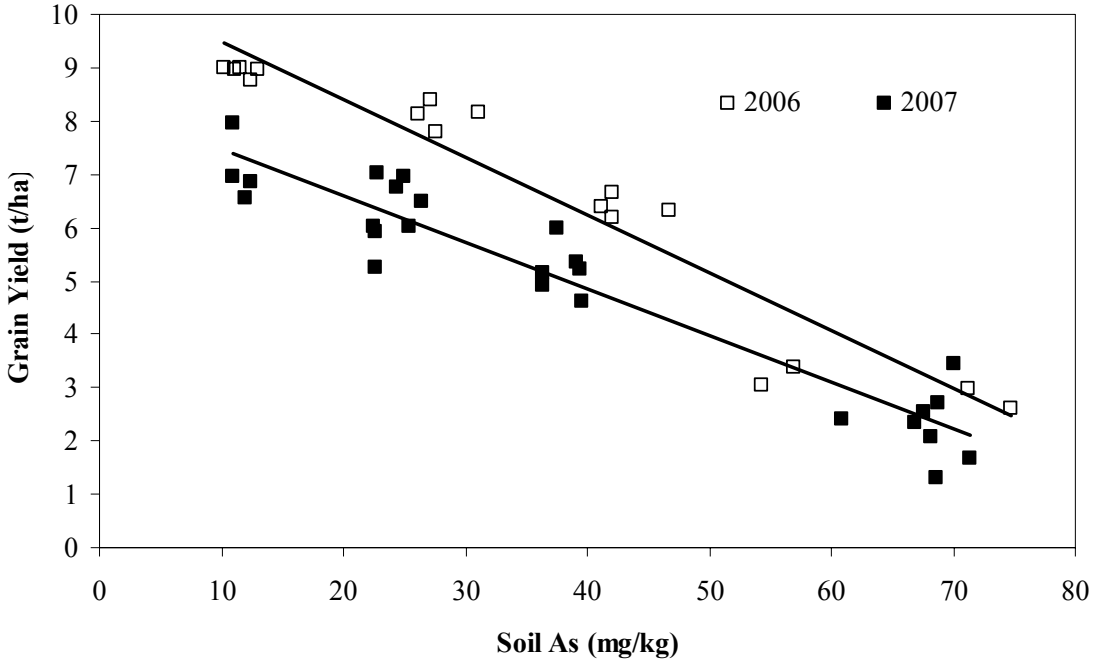

Figure 4.6: Relationship between soil-As and grain yield of BRRI dhan 29 (Source: Panaullah el al., 2009)

In this study, the potential reduction in rice yield due to higher soil arsenic level has been estimated considering the findings of Panaullah el al (2009) since the field site is representative of high arsenic and medium land area. New regression analysis was performed using the data obtained form Panaullah el al (2009). Figure 4.7 presents the regression trend and curve fitting for rice yield reduction due to soil arsenic. Using the best fitted models (linear and cubic models), rice yield was calculated and yield reduction was estimated for the selected Upazilas.

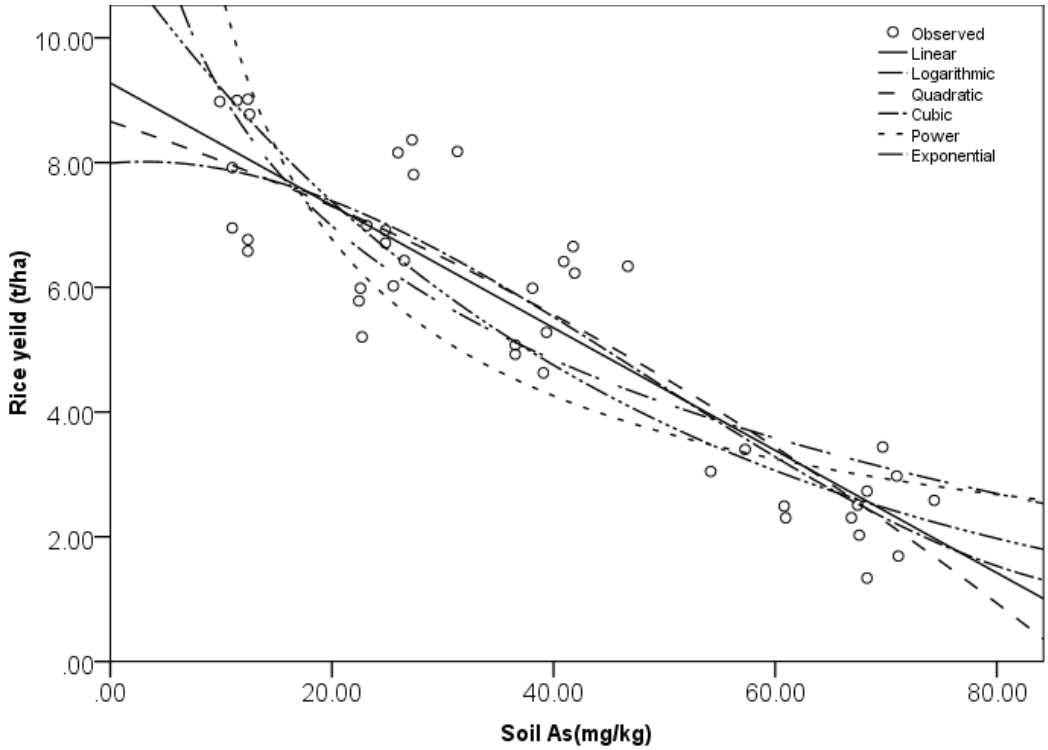

Figure 4.7: Regression analysis and curve fitting of the rice yield data for different soild arsenic levels obtained form Panaullah el al (2009)

Table 4.2: Model summary

Model Type	R	R Square	Adjusted R Square	Std. Error of the Estimate
Linear	0.900	0.809	0.804	1.019
Logarithmic	0.850	0.722	0.715	1.230
Quadratic	0.903	0.815	0.805	1.017
Cubic	0.903	0.816	0.802	1.026
Power	0.816	0.667	0.658	0.303
Exponential	0.895	0.802	0.797	0.234

The independent variable is Soil arsenic.

4.3 Results and Discussion

Table 4.3 and Table 4.4 show the estimated yield reductions of rice using the liner and cubic regressions models, respectively. Figure 4.7 graphically shows rice yield

reductions for the years 2020 and 2050 (using the liner model) for the nine selected Upazilas. The predicted yield reductions are higher for the cubic model. The estimated yield reductions, even for the liner model, are quite significant. For example, estimated yield reductions in the 9 Upazilas varied for about 9 percent to 24 percent for the year 2020, while it varied from about 12 percent to 53 percent for the year 2050; the arsenic concentration in irrigation water for these two cases were about 20 and 130 μg/l, respectively. Therefore, it appears the depending on flood depth, even relatively low arsenic concentration in irrigation water (e.g., 20 μg/l) could lead to significant arsenic accumulation in soil, and subsequent reduction in yield. It should be noted that there are 22 Upazilas in the country where mean arsenic concentration in water varies from 49.4 μg/l to 257 μg/l, and were there is no significant monsoon flooding. These areas are not only very susceptible to quick build up of arsenic in soil (see Arsenic Hazard Map in Chapter 3) and, as shown here, but also faces high risk of yield reductions in the future. Thus, high As areas without monsoon flooding are also at high risk with respect to yield reductions due to high arsenic accumulation in soil.

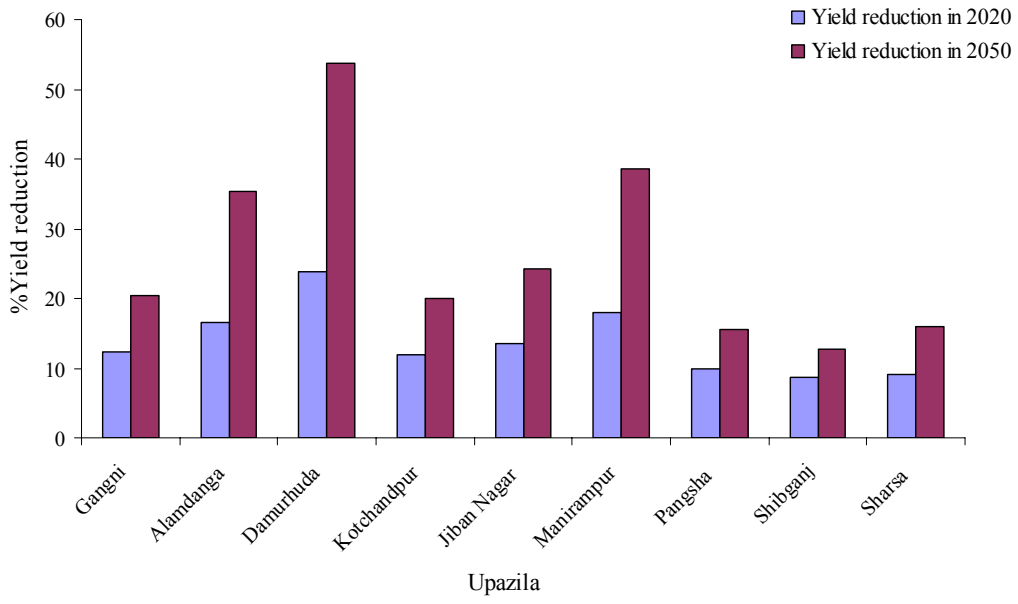

Figure 4.8: Estimated rice yield reductions in 2020 and 2050 for the nine selected Upazilas

Table 4.3: Estimation of rice yield reduction using linear model

District	Upazila	Present[1] Soil As (mg/kg)	Inundation	Arsenic Code	Arsenic loading (kg/ha/year)	Soil Arsenic (mg/kg) in 2020	% Rice yield reduction in 2020	Soil Arsenic (mg/kg) in 2050	% Rice yield reduction in 2050
Meherpur	Gangni	36.4	F0	AS 1	0.312	39.2	12.3	44.3	20.3
Chuadanga	Alamdanga	15.7	F0	AS 4	0.976	24.6	16.6	40.4	35.4
Chuadanga	Damurhuda	29.0	F0	AS 4	1.298	40.9	23.9	61.8	53.7
Jhenaidah	Kotchandpur	33.3	F0	AS 2	0.327	36.3	12.0	41.6	20.0
Chuadanga	Jiban Nagar	34.2	F0	AS 1	0.428	38.1	13.6	45.0	24.2
Jessore	Manirampur	21.0	F0	AS 3	0.998	30.1	17.9	46.3	38.5
Rajbari	Pangsha	23.9	F0	AS 2	0.271	26.4	9.8	30.8	15.6
Nawabganj	Shibganj	20.9	F0	AS 1	0.201	22.7	8.6	26.0	12.7
Jessor	Sharsa	32.2	F0	AS 1	0.284	33.4	9.2	38.0	16.0

[1] Soil arsenic reported for Gangni, Alamdanga, Damurhuda, Kotchandpur, Jiban Nagar, Manirampur, Pangsha,Shibganj upazila in 2003 and for Sharsa in 2012

Table 4.4: Estimation of rice yield reduction using cubic model

District	Upazila	Present[1] Soil As (mg/kg)	Inundation	Arsenic Code	Arsenic loading (kg/ha/year)	Soil Arsenic (mg/kg) in 2020	% Rice yield reduction in 2020	Soil Arsenic (mg/kg) in 2050	% Rice yield reduction in 2050
Meherpur	Gangni	35.4	F0	AS 1	0.312	39.2	16.7	44.3	27.8
Chuadanga	Alamdanga	15.7	F0	AS 4	0.976	24.6	16.8	40.4	39.9
Chuadanga	Damurhuda	29.0	F0	AS 4	1.298	40.9	29.5	61.8	73.8
Jhenaidah	Kotchandpur	33.3	F0	AS 2	0.327	36.3	15.4	41.6	26.7
Chuadanga	Jiban Nagar	34.2	F0	AS 1	0.428	38.1	18.0	45.0	33.0
Jessore	Manirampur	21.0	F0	AS 3	0.998	30.1	18.8	46.3	46.6
Rajbari	Pangsha	23.9	F0	AS 2	0.271	26.4	10.2	30.8	16.7
Nawabganj	Shibganj	20.9	F0	AS 1	0.201	22.7	8.9	26.0	13.1
Jessor	Sharsa	32.2	F0	AS 1	0.284	33.4	11.3	38.0	20.2

[1] Soil arsenic reported for Gangni, Alamdanga, Damurhuda, Kotchandpur, Jiban Nagar, Manirampur, Pangsha, Shibganj upazila in 2003 and for Sharsa in 2012

4.4 Summary

Extensive use of STW for irrigation is increasing the arsenic loading to agricultural soil which ultimately elevating the arsenic level in soil. Estimates made in this study suggest that significant rice yield reductions could result in the future due to accumulation of arsenic irrigated soil. Arsenic affected areas without significant monsoon flooding (i.e., belonging to F0 catetory) are at highest risk of yield reduction. In fact, for such areas, even relatively lower arsenic concentration in irrigation water could lead to quick accumulation of arsenic in soil and thus contribute to yield reductions. There are about 282,267 ha of highland areas in the country which are used for boro cultivation; these areas are most at risk with respected to potential rice yield reduction. This is a potential threat to food security in Bangladesh, where rice is the main crop and staple food, and boro rice accounts for over 50 percent of total rice productions. Urgent measures are therefore needed to come up with ways to reduce exposure of rice fields to elevated levels of arsenic, especially in these areas.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

Arsenic (As) in groundwater is a major health concern in Bangladesh and the risks associated with use of As-contaminated shallow tube wells (STWs) for drinking purpose are well known. A major concern related to large-scale use of groundwater for irrigation is arsenic entering the food chain, affecting food safety. Less well known but potentially more serious is the risk of gradual arsenic accumulation in soil and its resulting impact on crop yield. The overall objective of this study was to assess the potential of arsenic accumulation through irrigation on cultivable lands where extensive boro rice cultivation is carried out and to assess the possible effects of this arsenic accumulation on yield of rice. A major specific objective was to develop "arsenic hazard map", i.e., maps showing areas with high risk of arsenic accumulation due to irrigation for boro rice cultivation, and validation of the map through its comparison with arsenic concentration in boro rice fields in selected areas.

The arsenic hazard map has been developed based on data on the distribution (Upazila-wise) of irrigation wells used for boro cultivation (BADC, 2008-2009); arsenic concentration database of the whole country developed by DPHE/BGS (2000), and flood inundation depth and land type database developed by CEGIS. The map is based on the observation that monsoon flooding could remove significant fraction of As added to soil through irrigation each year; and the hypothesis that arsenic contaminated areas without pronounced monsoon flooding, where large-scale dry season irrigation is carried out using shallow tubewell are at significantly higher risk of arsenic accumulation in soil. The study also has also made an assessment of the impact of arsenic accumulation on rice yields in selected high-risk areas. For this assessment, available data and information correlating arsenic in irrigation water and agricultural soil, and soil arsenic and crop yield have been utilized. This Chapter summarizes the major conclusions from the present study. Recommendations for future studies have also been made.

5.2 Conclusions

Major conclusions from this study may be summarized as follows:

1) The Arsenic Hazard Map prepared in this study indentifies the arsenic affected areas which are at risk of arsenic accumulation in agricultural soil due to boro rice cultivation using STW irrigation. Depending on inundation status (F0 to F4) and average arsenic concentration in irrigation water (As0 to As4), seven levels of risk have been defined, from very high-risk area to very low-risk area.
2) Available primary and secondary data qualitatively validates the Arsenic Hazard Map prepared in this study.
3) According to the Arsenic Hazard Map, areas to the south west and some areas in the north east are at risk of higher accumulation of arsenic, because of higher concentration of arsenic in irrigation water, higher intensity of boro cultivation, and higher land elevation (i.e., lower intensity of flooding
4) A total 282,267 ha of highland used for boro cultivation in 22 Upazilas of the South-West region of Bangladesh are at "very high risk" of arsenic accumulation, because of higher arsenic in STW irrigation water and low flood inundation depth. Another 382,000 ha of highland in 35 Upazilas have been placed under "high-risk" status as flood inundation depth in these areas is very low (0-0.3 m), but arsenic concentration in STW irrigation water is also relatively low.
5) Areas in the northern parts of Bangladesh are at "low to no risk" because of lower concentration of arsenic in irrigation water, despite higher intensity of boro cultivation.
6) Some areas in the south-central region of Bangladesh are at "moderate to low risk" of arsenic accumulation because of higher elevation of these areas (which results in lower flooding intensity).
7) Significant rice yield reductions could result in the future due to accumulation of arsenic in irrigated soil. Estimated yield reductions in 9 high-risk Upazilas varied for about 9 percent to 24 percent for the year 2020, while it varied from about 12 percent to 53 percent for the year 2050.

8) Possible yield reduction due to elevated soil arsenic appears to be a potential threat to food security in Bangladesh, where rice is the main crop and staple food, and boro rice accounts for over 50 percent of total rice productions.

5.3 Limitations of the Study

This study has the following limitations:

1) For validation of the developed Arsenic Hazard Map, secondary data from different studies have been used. We know that arsenic concentration in irrigated soil varies significantly both spatially and temporally. However, in many cases, the details of sampling time and methodology of sampling were absent for the secondary data used in this study.
2) High soil arsenic concentration (above 10 mg/kg) was observed from literature in some northen Upazilas, which does not matches with the Arsenic Hazard Map. More studies are needed to better understand these issues.

5.4 Recommendations

Irrigation with As-rich groundwater poses threats to sustainable agriculture and to human health in Bangladesh. This study recommends the following:

1) The Arsenic Hazard Map prepared in this study should be updated as more detailed data and information on distribution of arsenic concentration in irrigation well and soil, irrigation intensity and flood inundation depth become available.
2) Digital Elevation Model (DEM) may be used to produce more accurate hazard map.
3) For continued validation of Arsenic Hazard Map, more primary as well as secondary data on soil arsenic concentration should be generated/ collected; these data may be used to generate (and subsequently update) a soil-As map. The Arsenic Hazard Map prepared in this study may be utilized by relevant authorities to monitor soil arsenic concentration and rice yield in very high-risk and high-risk areas, so that remedial measures may be devised for such areas based on actual field data.

4) Immediate measures (e.g., alternative irrigation sources, crop management practices) are needed to reduce exposure of rice fields to elevated levels of arsenic, especially in high-risk areas.

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APPENDIX-A

(Curve fitting)

```
* Curve Estimation.
TSET MXNEWVAR=24.
CURVEFIT
/VARIABLES=Rice_yeild WITH Soil_As
/CONSTANT
/MODEL=LINEAR LOGARITHMIC QUADRATIC CUBIC POWER
EXPONENTIAL
/PRINT ANOVA
/PLOT FIT
/CIN=95
/SAVE=PRED RESID CIN .
```

Curve Fit

Notes

Output Created		04-Jul-2012 22:04:09
Comments		
Input	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	42
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Cases with a missing value in any variable are not used in the analysis.

Syntax		CURVEFIT /VARIABLES=Rice_yeild WITH Soil_As /CONSTANT /MODEL=LINEAR LOGARITHMIC QUADRATIC CUBIC POWER EXPONENTIAL /PRINT ANOVA /PLOT FIT /CIN=95 /SAVE=PRED RESID CIN .
Resources	Processor Time	00 00:00:00.484
	Elapsed Time	00 00:00:00.485
Use	From	First observation
	To	Last observation
Predict	From	First Observation following the use period
	To	Last observation
Variables Created or Modified	FIT_2	Fit for Rice_yeild with Soil_As from CURVEFIT, MOD_4 LINEAR
	ERR_2	Error for Rice_yeild with Soil_As from CURVEFIT, MOD_4 LINEAR
	LCL_2	95% LCL for Rice_yeild with Soil_As from CURVEFIT, MOD_4 LINEAR
	UCL_2	95% UCL for Rice_yeild with Soil_As from CURVEFIT, MOD_4 LINEAR
	FIT_3	Fit for Rice_yeild with Soil_As from CURVEFIT, MOD_4 LOGARITHMIC
	ERR_3	Error for Rice_yeild with Soil_As from CURVEFIT, MOD_4 LOGARITHMIC
	LCL_3	95% LCL for Rice_yeild with Soil_As from CURVEFIT, MOD_4 LOGARITHMIC
	UCL_3	95% UCL for Rice_yeild with Soil_As from CURVEFIT, MOD_4 LOGARITHMIC
	FIT_4	Fit for Rice_yeild with Soil_As from CURVEFIT, MOD_4 QUADRATIC
	ERR_4	Error for Rice_yeild with Soil_As from CURVEFIT, MOD_4 QUADRATIC
	LCL_4	95% LCL for Rice_yeild with Soil_As from CURVEFIT, MOD_4 QUADRATIC

	UCL_4	95% UCL for Rice_yeild with Soil_As from CURVEFIT, MOD_4 QUADRATIC
	FIT_5	Fit for Rice_yeild with Soil_As from CURVEFIT, MOD_4 CUBIC
	ERR_5	Error for Rice_yeild with Soil_As from CURVEFIT, MOD_4 CUBIC
	LCL_5	95% LCL for Rice_yeild with Soil_As from CURVEFIT, MOD_4 CUBIC
	UCL_5	95% UCL for Rice_yeild with Soil_As from CURVEFIT, MOD_4 CUBIC
	FIT_6	Fit for Rice_yeild with Soil_As from CURVEFIT, MOD_4 POWER
	ERR_6	Error for Rice_yeild with Soil_As from CURVEFIT, MOD_4 POWER
	LCL_6	95% LCL for Rice_yeild with Soil_As from CURVEFIT, MOD_4 POWER
	UCL_6	95% UCL for Rice_yeild with Soil_As from CURVEFIT, MOD_4 POWER
	FIT_7	Fit for Rice_yeild with Soil_As from CURVEFIT, MOD_4 EXPONENTIAL
	ERR_7	Error for Rice_yeild with Soil_As from CURVEFIT, MOD_4 EXPONENTIAL
	LCL_7	95% LCL for Rice_yeild with Soil_As from CURVEFIT, MOD_4 EXPONENTIAL
	UCL_7	95% UCL for Rice_yeild with Soil_As from CURVEFIT, MOD_4 EXPONENTIAL
Time Series Settings (TSET)	Amount of Output	PRINT = DEFAULT
	Saving New Variables	NEWVAR = NONE
	Maximum Number of Lags in Autocorrelation or Partial Autocorrelation Plots	MXAUTO = 16
	Maximum Number of Lags Per Cross-Correlation Plots	MXCROSS = 7
	Maximum Number of New Variables Generated Per Procedure	MXNEWVAR = 24
	Maximum Number of New Cases Per Procedure	MXPREDICT = 1000
	Treatment of User-Missing Values	MISSING = EXCLUDE

Confidence Interval Percentage Value	CIN = 95
Tolerance for Entering Variables in Regression Equations	TOLER = .0001
Maximum Iterative Parameter Change	CNVERGE = .001
Method of Calculating Std. Errors for Autocorrelations	ACFSE = IND
Length of Seasonal Period	Unspecified
Variable Whose Values Label Observations in Plots	Unspecified
Equations Include	CONSTANT

[DataSet0]

Model Description

Model Name		MOD_4
Dependent Variable	1	Rice_yeild
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Power[a]
	6	Exponential[a]
Independent Variable		Soil_As
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Case Processing Summary

	N
Total Cases	42
Excluded Cases[a]	0
Forecasted Cases	0
Newly Created Cases	0

Case Processing Summary

	N
Total Cases	42
Excluded Cases[a]	0
Forecasted Cases	0
Newly Created Cases	0

a. Cases with a missing value in any variable are excluded from the analysis.

Variable Processing Summary

		Variables	
		Dependent	Independent
		Rice_yeild	Soil_As
Number of Positive Values		42	42
Number of Zeros		0	0
Number of Negative Values		0	0
Number of Missing Values	User-Missing	0	0
	System-Missing	0	0

Rice_yeild

Linear

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.900	.809	.804	1.019

The independent variable is Soil_As.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	176.069	1	176.069	169.649	.000
Residual	41.514	40	1.038		
Total	217.582	41			

The independent variable is Soil_As.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Soil_As	-.098	.008	-.900	-13.025	.000
(Constant)	9.276	.330		28.113	.000

Logarithmic

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.850	.722	.715	1.230

The independent variable is Soil_As.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	157.100	1	157.100	103.898	.000
Residual	60.483	40	1.512		
Total	217.582	41			

The independent variable is Soil_As.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
ln(Soil_As)	-3.095	.304	-.850	-10.193	.000
(Constant)	16.256	1.072		15.159	.000

Quadratic

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.903	.815	.805	1.017

The independent variable is Soil_As.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	177.228	2	88.614	85.641	.000
Residual	40.354	39	1.035		
Total	217.582	41			

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	177.228	2	88.614	85.641	.000
Residual	40.354	39	1.035		
Total	217.582	41			

The independent variable is Soil_As.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Soil_As	-.058	.038	-.534	-1.519	.137
Soil_As ** 2	.000	.000	-.372	-1.059	.296
(Constant)	8.657	.671		12.895	.000

Cubic

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.903	.816	.802	1.026

The independent variable is Soil_As.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	177.606	3	59.202	56.275	.000
Residual	39.976	38	1.052		
Total	217.582	41			

The independent variable is Soil_As.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Soil_As	.016	.129	.144	.121	.904
Soil_As ** 2	-.003	.004	-2.076	-.724	.473
Soil_As ** 3	1.820E-5	.000	1.048	.599	.553
(Constant)	7.990	1.302		6.134	.000

Power

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.816	.667	.658	.303

The independent variable is Soil_As.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	7.339	1	7.339	79.969	.000
Residual	3.671	40	.092		
Total	11.010	41			

The independent variable is Soil_As.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
ln(Soil_As)	-.669	.075	-.816	-8.943	.000
(Constant)	50.251	13.276		3.785	.001

The dependent variable is ln(Rice_yeild).

Exponential

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
.895	.802	.797	.234

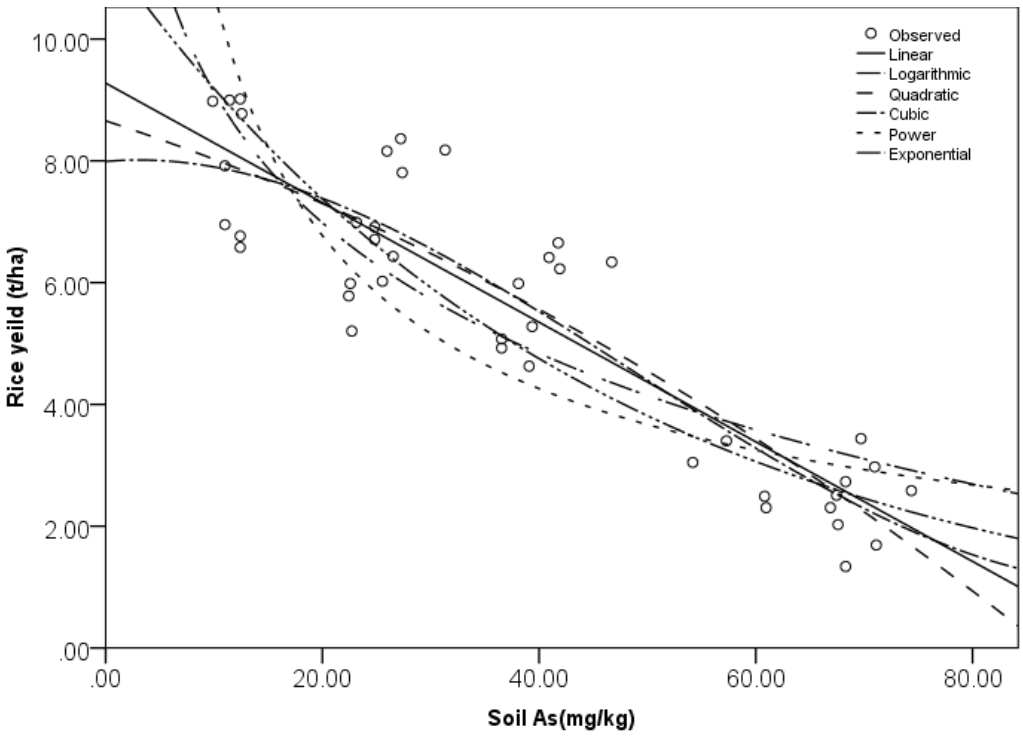
The independent variable is Soil_As.

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	8.825	1	8.825	161.514	.000
Residual	2.186	40	.055		
Total	11.010	41			

The independent variable is Soil_As.

Coefficients

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Soil_As	-.022	.002	-.895	-12.709	.000
(Constant)	11.446	.867		13.209	.000

The dependent variable is ln(Rice_yeild).