Chapter-1

General Introduction

1.1 What is the Arsenic?

Nowadays arsenic is considered as one of the most important environmental single substance toxicants. It is an acute poison, a contact poison, a chronic cumulative poison, and a carcinogen. A member of the nitrogen family, arsenic is an odorless and tasteless semi-metal that occurs naturally in rock and soil. It can combine with other elements to form organic and inorganic arsenicals, the latter being generally more toxic and more prevalent in water. Positioned between germanium and selenium on the periodic chart, arsenic is a metalloid element and thus, has a broad range of chemical activity. Most commonly, arsenic is present in compounds with sulfur and other metals, although it also forms covalent bonds with non-metals such as carbon, hydrogen, and oxygen. Arsenic exists in groundwater in four main inorganic and organic forms: arsenite, arsenate, monomethylarsonic acid (MMA), and dimethylarsinic acid (DMA). These forms vary greatly in their toxicity; in decreasing toxicity, the order of the chemical species is arsenite, arsenate, MMA, and DMA. Unfortunately for the people of Bangladesh and South Asia , the majority of arsenic in groundwater is in the form of the more toxic arsenite and arsenate.

1.2. What is the Arsenic Threat for Human Health?

Arsenic poisoning is accidental or intentional exposure to arsenic in some form. Arsenic can enter one's body through ingestion or inhalation. In many cases, the poisoning takes place by either handling products containing high doses of arsenic without proper protection or ingesting foods or liquids containing unhealthy doses of arsenic. The range of symptoms with arsenic poisoning can range from mild headaches to death, depending on the extent of the exposure to the toxic chemical. Drinking water rich in arsenic over a long period leads to arsenic poisoning or arsenicosis. Many waters contain some arsenic and excessive concentrations are known to naturally occur in some areas. The health effects are generally delayed and the most effective preventive measure is supply of drinking water low in arsenic concentration. Arsenicosis is the effect of arsenic poisoning, usually over a long period such as from 5 to 20 years. Drinking arsenic rich water over a long period results in various health effects including skin problems (such as colour changes on the skin and hard patches on the palms and soles of the feet), skin cancer, cancers of the bladder, kidney and lung, and diseases of the blood vessels of the legs and feet and possibly also diabetes, high blood pressure and reproductive disorders. Absorption of arsenic through the skin is minimal and thus hand-washing, bathing, laundry, etc. with water containing arsenic do not pose human health risks.

Chronic exposure to arsenic has the debilitating effect of slowly destroying its victim, subjecting him or her to the social trauma and physical pain of arsenicosis. Because of the slow process, the evolution of the disease is divided into several stages. Some pictures of hand and feet of severe stage of arsenicosis patients are shown in figures 1.1, 1.2 and 1.3. Depending on the symptoms and the degree of exposure, such stages are divided into three broad categories (Khan and Haque, 2010).

i. Primary stage

Melonosis, Keratosis, Conjunctivitis, Gastroenteritis. In the primary stage, an Arsenicosis patient may develop several symptoms, sometimes simultaneously, such as blackening of some parts of the body or the whole body (Melanosis); thickening and roughness of the palms and soles (Keratosis); redness of the conjunctiva (Conjunctivitis); inflammation of the respiratory tract; and nausea and vomiting (Gastroenteritis).

ii. Secondary stage

Lekomelanosis, Hyper-Keratosis, Non-pitting Edema. If a patient continues to be exposed to arsenic-contaminated water, and if adequate preventive measures are not adopted, then the symptoms advance and become more visible including white intermittent dots within blackened areas (called Leukonelanosis or Rain Drop Syndrome), nodular growth on the palms and soles (Hyper-Keratosis), swelling of the feet and legs (Non-pitting edema), and peripheral neuropathy as well as liver and kidney disorders.

iii. Final or tertiary stage

In the tertiary stage, an Arsenicosis patient’s physical condition deteriorates rapidly and the condition becomes irreversible. Gangrene of the distal organs or other parts of the body, cancer of the skin, lungs and urinary bladder and kidney and liver failure become manifest at this stage.

Figure 1.1 Hand of an Arsenicosis patient

Source: http://phys4.harvard.edu/~wilson/arsenic/arsenic_project_introduction.html

Figure 1.2 Feet of an Arsenicosis patient

Source: http://phys4.harvard.edu/~wilson/arsenic/arsenic_project_introduction.html

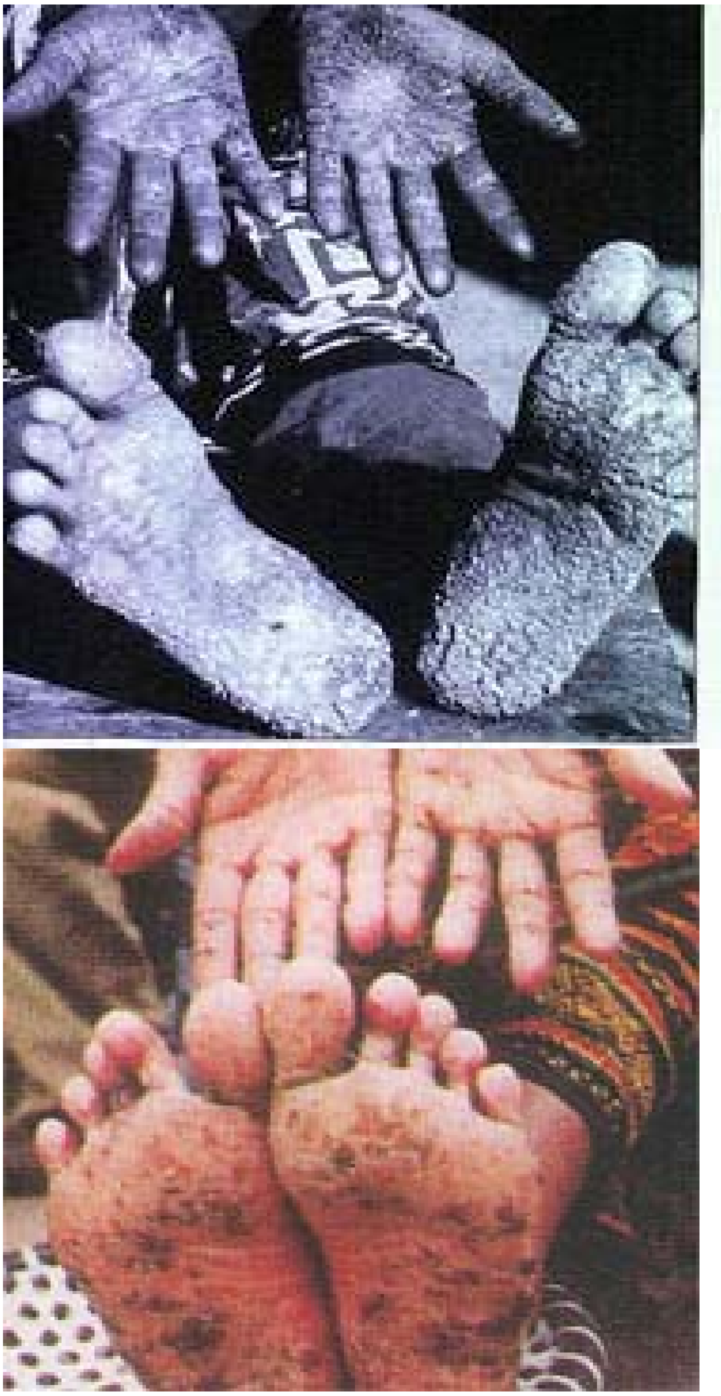


Figure 1.3 Hands and feet of Arsenicosis patients

Source: http://phys4.harvard.edu/~wilson/arsenic/arsenic_project_introduction.html

1.3 Sources of Arsenic

Arsenic is naturally present throughout all environmental media - air, water, and earth, although the highest concentration of arsenic is beneath the earth's surface. Arsenic originates inside the earth and is then transported upward to the air, water, and surface by various natural and anthropogenic processes. Natural processes include volcanic activity, weathering, and biological activity. Anthropogenic sources of arsenic are geothermal power plants, fossil fuel combustion, smelting, mining, and groundwater pumping. In Bangladesh and West Bengal, naturally-occurring arsenic has been found in the groundwater aquifers. Arsenic can be found naturally on earth in small concentrations. It occurs in soil and minerals and it may enter air, water and land through wind-blown dust and water run-off. Arsenic in the atmosphere comes from various sources: vulcanoes release about 3000 tonnes per year and microorganisms release volatile methylarsines to the extent of 20.000 tonnes per year, but human activity is responsible for much more: 80.000 tonnes of arsenic per year are released by the burning of fossil fuels.

1.4 Discovery of Arsenic in South Asia

In 1978, abnormally high levels of arsenic were detected in the groundwater of West Bengal, India and its impact on people was first detected in West Bengal within this subcontinent in 1983. In Bangladesh the presence of arsenic in groundwater was first detected in 1993 at Barogharia union of Chapai Nawabganj district. A few years later, arsenicosis patients were identified; discolored and corroded skin signaled the fatal illness. These were just the beginnings of the arsenic contamination problem in the Bengal Basin. To better understand the source, scope, and effects of arsenic in groundwater, the West Bengal government organized a working group in 1983; however, the working group uncovered very little information about arsenic and consequent efforts to address the problem were minimal. By the late 1980s and early 1990s, efforts to understand and address the arsenic problem were revived. In 1988, government agencies began extensive research and testing programs on the problem.

1.5 International and National Standards for Arsenic Intake

In 1993, the World Health Organization (WHO) has issued a provisional guideline recommending a maximum permissible arsenic concentration of 10μg L^{-1} (micrograms per liter), which is associated with a lifetime excess skin cancer of about 6 per 10,000 persons. Such limits are meant to be set by national authorities, considering local environmental, social, economic and cultural conditions. Most developed countries have adopted the provisional guideline value as a national standard for arsenic in drinking water. On the other hand, most developing countries including Bangladesh still use the former WHO recommended concentration of 50 μg L^{-1}as their national standard which is associated with a higher risk of skin cancer: 30 per 10,000 persons. However, skin cancers are not usually fatal. Table 1.1 uses a sample of countries to illustrate the range of values adopted (7 μg L^{-1} to 50 μg L^{-1}) and table 1.2 shows chronology of recommended WHO values for arsenic in drinking water.

Table 1.1 Currently accepted national standards of selected countries for arsenic in drinking water

Country/region	Standard (μgL^{-1})	Country/region	Standard (μgL^{-1})
Australia	7	Bangladesh	50
European Union	10	Cambodia	50
Japan	10	China	50
USA	10	India	50
Vietnam	10	Lao PDR	50
Canada	25	Myanmar	50
		Nepal	50
		Pakistan	50

Source: Ahmed, 2003

Table 1.2 Chronology of recommended WHO values for arsenic in drinking water

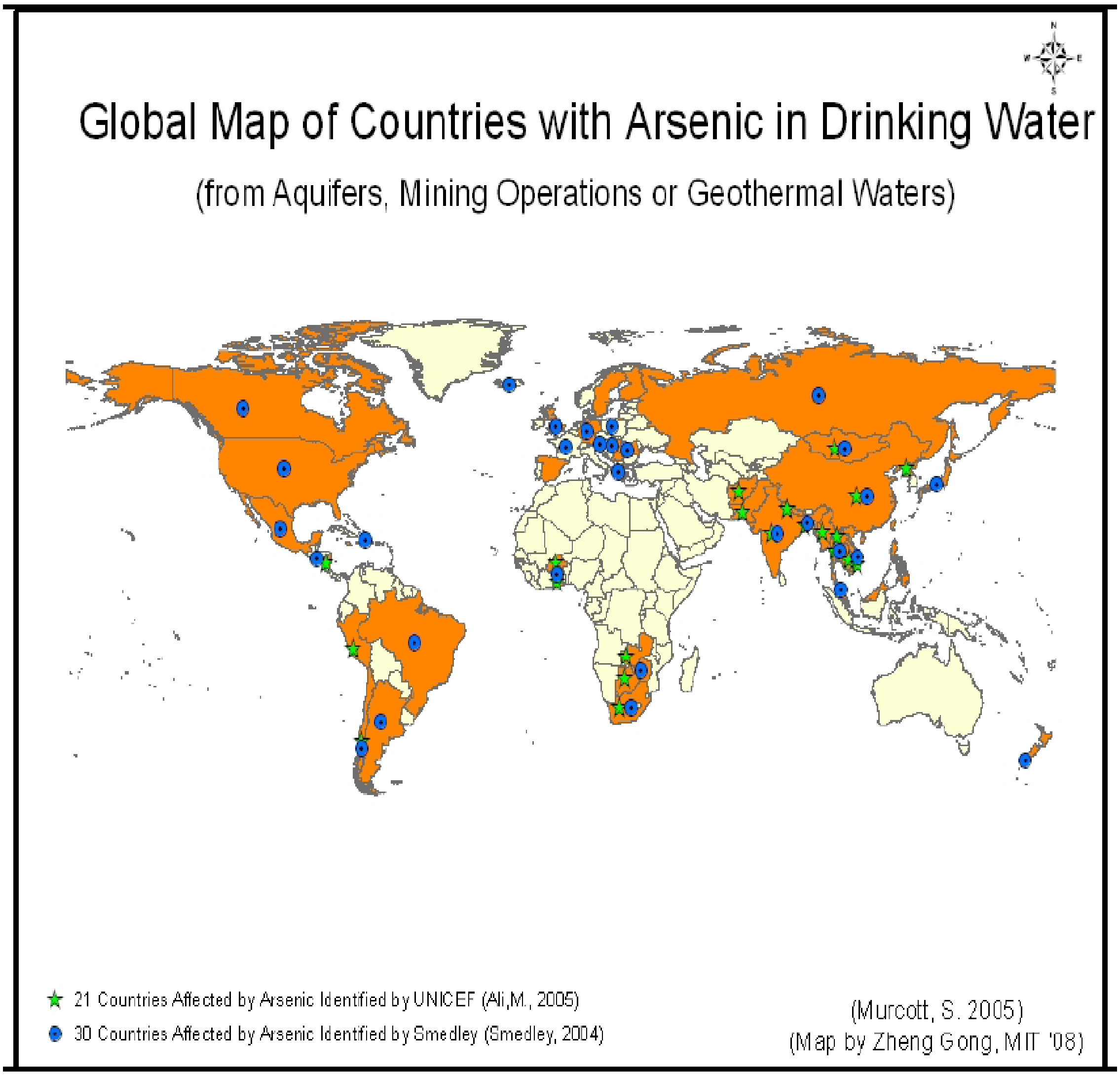
1958	First WHO International Drinking Water Standard 200µgL^{-1}
1963	WHO recommends lowering guide value to 50µgL^{-1}
1974, 1984	Affirmation of 50µgL^{-1} as guide value
1984	WHO guidelines replace International Drinking Water Standard, providing a basis for national standards by individual countries
1993	WHO provisional guideline recommends lowering guide value to 10µgL $^{-1}$

1.6 Situation Analysis

1.6.1 Global Situation

Groundwater is a significant source of drinking water in many parts of the world. Well protected groundwater is safer in terms of microbiological quality than water from open dug wells and ponds. However, groundwater is notoriously prone to chemical and other types of contamination from natural sources or by anthropogenic activities. Reliable data on exposure and health effects are rarely available, but it is clear that there are many countries in the world where arsenic in drinking water has been detected at concentrations greater than the WHO

Guideline Value, 10μg L^{-1} or the prevailing national standards. Arsenic pollution has been reported from more than 70 countries on six continents, and the picture is still incomplete, with no information from large parts of the globe. Since the early 1990s, arsenic contamination of groundwater has been recognized as a public health problem in India, Bangladesh and China and more recently in Cambodia, Iran, Laos, Myanmar, Nepal, Pakistan and Viet Nam. Moreover, problems have already been observed in among others countries: Argentina, Canada, Chile, Greece, Mexico, Mongolia, New Zealand, South Africa, Hungary, Philippines, Taiwan, Thailand, Japan, USA and Russia. Global map of arsenic contaminated countries is shown in Figure 1.4. In total 48 countries with arsenic contaminated drinking water were identified in the literature review (Murcott, 2007) which are presented in the Table 1.3.



Source: http://www.sandia.gov/water/Arsenic2005/2005tech_session/Murcott_pres.pdf

Figure 1.4 Global map of arsenic contaminated countries

Table 1.3 List of 48 countries with arsenic contaminated drinking water

Africa	
1	Botswana
2	Burkina Faso
3	Ghana
4	South Africa
5	Zambia
6	Zimbabwe
South Asia	
7	Afghanistan
8	Bangladesh
9	India
10	Pakistan
11	Nepal
East Asia	
12	China including Taiwan
13	Japan
14	Mongolia
15	North Korea
16	South Korea
17	Malaysia
18	Philippines
19	Russia
South East Asia	
20	Cambodia
21	Lao
22	Myanmar
23	Thailand
24	Vietnam

South Pacific	
25	New Zealand
South America	
26	Argentina
27	Brazil
28	Chile
29	Peru
Central America and Caribbean	
30	Dominican Republic
31	El Salvador
32	Jamaica
33	Mexico
34	Nicaragua
North America	
35	USA
36	Canada
Europe	
37	Austria
38	Finland
39	Germany
40	Greece
41	Hungary
42	Iceland
43	Poland
44	Romania
45	Serbia
46	Spain
47	Sweden
48	U. K.

1.6.2 Asian Situation

The high arsenic groundwater in Asia has become a priority health issue. Around 110 million of those people live in ten countries in South and South-East Asia: Bangladesh, Cambodia, China, India, Laos, Myanmar, Nepal, Pakistan, Taiwan and Vietnam (Brammer & Ravenscroft, 2009). Summary of the frequency distribution of arsenic concentrations, nature, and scale of documented arsenic problems in groundwater are presented in the Table 1. 4 to Table 1.11.

Table 1.4 Summary of the distribution, nature, and scale of documented arsenic problems (>50 μg l^{-1}) in aquifers in south and East Asia

Location	Area extent (km^2)	Population at risk[a]	Arsenic range (μg L^{-1})
Bangladesh	150,000	35,000,000	<1-2,300
China (Inner Mongolia, Xinjiang, Shanxi)	68,000	5,600,000	40-4,400
India (West Bengal)	23,000	5,000,000	<10-3,200
Nepal	30,000	550,000	<10-200
Taiwan	6,000	10,000[b]	10-1,800
Vietnam	1,000	10,000,000[c]	1-3,100
Myanmar	3,000	3,400,000	---
Cambodia	<1,000	320,000[d]	---

- Not available.

a Estimated to be drinking water with arsenic >50 μg L^{-1}. From Smedley, 2003 and data sources there in.

b Before mitigation.

c United Nations Children's Fund (UNICEF) estimate.

d Maximum.

Source: World Bank Regional Operational Responses to Arsenic Workshop in Nepal, 26-27 April 2004.

Table 1.5 Frequency distribution of arsenic concentrations in groundwater from the Huhhot Basin, Inner Mongolia

Well depth	Number of samples (%)			Total samples
	<10 µg L^{-1}	10-50 µg L^{-1}	50 µg L^{-1}	
≤100 m	35 (59)	9 (15)	15 (25)	59
>100 m	6 (43)	0 (0)	8 (57)	14

Percent in the parentheses
Source: Smedley and others, 2003.

Table 1.6 Summary arsenic data for groundwater from tubewells in the Red River Plain, Vietnam, divided into those from the Holocene and Pleistocene aquifers

Aquifers	Number of samples (%)			Total samples
	<10 µg L^{-1}	10-50 µg L^{-1}	50 µg L^{-1}	
Tong (2001) Holocene	117 (45)	62 (24)	81 (31)	260
Tong (2001) Pleistocene	84 (40)	70 (33)	56 (27)	210
Tong (2002) undivided	740(60.2)	335 (27.3)	153 (12.5)	1,228

Percent in the parentheses
Sources: Tong, 2001, 2002.

Table 1.7 Summary arsenic data for groundwater from tube wells in the Mekong Valley of Cambodia

Aquifer	Number of samples (%)			Total samples
	<10 µg L^{-1}	**10-50 µg L^{-1}**	**50 µg L^{-1}**	
Holocene aquifer	301 (50)	185 (31)	113 (19)	599
Pleistocene aquifer	1,184 (95)	59 (5)	3 (0.2)	1,246
Crystalline rocks	708 (96)	24 (3)	2 (0.3)	734
Holocene aquifer	531 (78)	143 (21)	6 (1)	680

Source: Data from UNICEF, 2004; Percent in the parentheses

Table 1.8 Frequency distribution of arsenic concentrations in groundwater samples from Northern Punjab, Pakistan

District	Number of samples (%)			Total samples
	<10 µg L^{-1}	**10-50 µg L^{-1}**	**50 µg L^{-1}**	
Gujarat	33 (87)	3 (8)	2 (5)	38
Jhelum	32 (86)	4 (11)	1 (3)	37
Chakwal	63 (88)	9 (12)	0 (0)	72
Sargodha	49 (83)	7 (12)	3 (5)	59
Attock	68 (92)	6 (8)	0 (0)	74
Rawalpindi	81 (96)	3 (4)	0 (0)	84
Total	326 (90)	30 (8)	6 (2)	364

Percent in the parentheses

Source: Iqbal, 2001.

Table 1.9 Frequency distribution of arsenic concentrations in ground water from the alluvial aquifer of Myanmar

Township	Well type	Number of samples (%)			Total samples
		<10 µg L^{-1}	10-50 µgL^{-1}	50 µg L^{-1}	
Sittway	STW	17 (29	35 (60)	6 (10)	58
	DW	22 (96)	1 (4)	0 (0)	23
Hinthada	STW	56(68)	15 (18)	11 (13)	82
	DW	6 (75)	1 (12.5)	1 (12.5)	8
Kyaungkone	STW	48 (80)	5 (8)	7 (12)	60
	DW	21 (95)	1 (5)	0 (0)	22
	DTW	1(33)	1 (33)	1 (33)	3

Percent in the parentheses
STW: shallow tube well
DW: dug well
DTW: deep tube well (55–70 m)
Source: WRUD, 2001.

Table 1.10 Frequency distribution of arsenic concentrations in analyzed groundwater samples from Nepal

Agency	Number of samples (%)			Total samples
	<10 µg L^{-1}	10-50 µg L^{-1}	50 µg L^{-1}	
DWSS	3,479 (89.3)	289 (7.3)	128 (3.3)	3,896
NRCS	2,206 (79)	507 (18)	77 (3)	2,790
Finnida	55 (71)	14 (18)	9 (12)	78
Tandukar	54 (61)	27 (30)	8 (9)	89
NASC (2003)	17,300 (69)	6,000 (23)	2,000 (8)	25,000

Percent in the parentheses
Sources: Chitrakar and Neku, 2001; Tandukar, 2001; Neku and Tandukar, 2003.

Table 1.11 Present groundwater arsenic contamination status of West Bengal, India

Physical Parameters	Values
Area in sq. km.	88,750
Population in million	80.2
Total number of districts (no. of district surveyed)	19 (19)
Total number of water samples analyzed	1,40,150
% of samples having arsenic > 10 μg L^{-1}	48.1
% of samples having arsenic > 50 μg L^{-1}	23.8
No. of severely arsenic affected districts	9
No. of mildly arsenic affected districts	5
No. of arsenic safe districts	5
Total population of severely arsenic affected 9 districts in million	50.4
Total area of severely arsenic affected 9 districts in sq. km.	38,861
Total number of blocks/ police station	341
Total number of blocks/ police station surveyed	241
Number of blocks / police station having arsenic >50μg L^{-1}	111
Number of blocks / police station having arsenic >10μg L^{-1}	148
Total number of village	37910
Total number of village surveyed	7823
Number of villages/paras having arsenic above 50 μg L^{-1}	3417
People at risk of drinking arsenic contaminated water >10μg L^{-1} (in million)	9.5
People at risk of drinking arsenic contaminated water >50μg L^{-1} (in million)	4.6
No. of districts surveyed for arsenic patients	9
No. of districts where arsenic patients found	7
Villages surveyed for arsenic patients	602
Number of villages where we have identified people with arsenical skin lesions	488
People screened for arsenic patients including children (preliminary survey)	96,000
No. of adults screened for arsenic patient	82,000

Table 1.11. Cont.

Number of registered patients with clinical manifestations	9,356 (9.7%)
No. of children screened for arsenic patient	14,000
No. of children showing arsenical manifestation	778 (5.6%)
Total hair, nail, urine analyzed	39624
Arsenic above normal/toxic level in hair, nail and urine samples	91%, 97% and 92%

Source: SOES, 2006
http://www.soesju.org/arsenic/wb.htm

1.6.3 Situation of Bangladesh

Nevertheless, Bangladesh has made significant strides in accelerating economic and human development. Access to clean water has been a major development target of the government of Bangladesh. After independence, the Government of Bangladesh undertook a massive program to provide bacteriologicaly safe drinking water for the people of the country. Bangladesh started an extensive program to provide safe drinking water at low cost to rural population through hand tube wells (HTWs) in the year 1972. By the year 1997 Bangladesh achieved a remarkable success by providing 97% of the rural population with tube well water supply. Thus the tube well revolution ensured provision of one of the basic human needs- safe drinking water for the rural poor in Bangladesh. The high service level of drinking water supply required little time for collecting water, which has indirect but positive impact on the economic conditions of the poor families. Bangladesh, a poor and densely populated country prone to natural disasters (flood, cyclones, disease etc.) have been hit.

Unfortunately, the country has been hit by another environmental catastrophe in last decade. A large volume of its ground water, the major source of drinking water in the country, has been severely contaminated by arsenic. The deep tube-well was introduced in 1967-68 for irrigation in Bangladesh. The mean As concentration in the shallow wells is 60.5 μgL^{-1} with maximum of 1670 μgL^{-1} and minimum of less than the detection limit (usually less than 50 or 10 μgL^{-1}). The variance of the distribution is large leading to a standard deviation of 123 μgL^{-1}, which is 203% of the mean value. For the deep wells the As concentrations are much lower. The mean concentration is about 3 μgL^{-1}, the minimum is less than the detection limit and the maximum is 108 μgL^{-1} which is 277% of the mean value. Shallow tube-wells were considered, 46% and 27% exceeded 10 µg/L and 50 µg/L respectively. In case of deep tube-well (>150m) samples, arsenic content of only 5% exceeded 10 µg/L and 1% exceeded 50 µg/L (BGS and DPHE, 2001). The cost for shallow tube-well is around 15000Tk. to 40000Tk. (72Tk. = 1US$) and deep tube-well is around 250,0000 Tk. to 300,0000Tk. The National Arsenic Mitigation Information Centre (NAMIC) maintains a very large database of arsenic test results obtained from field tests. This indicates that the prevalence of arsenic is almost nationwide (Table 1.12 and Figure 1.5 to Figure 1.7). Table 1.12 shows those 47 districts, 233 Upazilas, 2,213 unions, and 31,497 villages can be considered arsenic-affected. Arsenic related basic information is presented in the Table 1.13.

Table 1.12 Proportion of wells exceeding 50 µg/L standard at different scales in Bangladesh

Proportion of Wells >50 µg/L	Districts	Upazilas	Unions	Villages	Population (millions)
<= 5%	7	35	668	22,544	22.3
>5-40%	31	145	1,176	14,788	20.8
>40-80%	15	65	621	8,331	11.7
>80–100%	1	23	416	8,378	10.1
Total arsenic-affected	47	233	2,213	31,497	
Total Screened	54	268	2,881	54,041	64.9
Total not screened (likely unaffected)	10	204	1,603	33,278	75.1
Total in Country	64	472	4,484	87,319	140

Source: NAMIC. Tube-well screening summary. Bangladesh Arsenic Mitigation and Water Supply Project, Dhaka, Bangladesh, 2006.

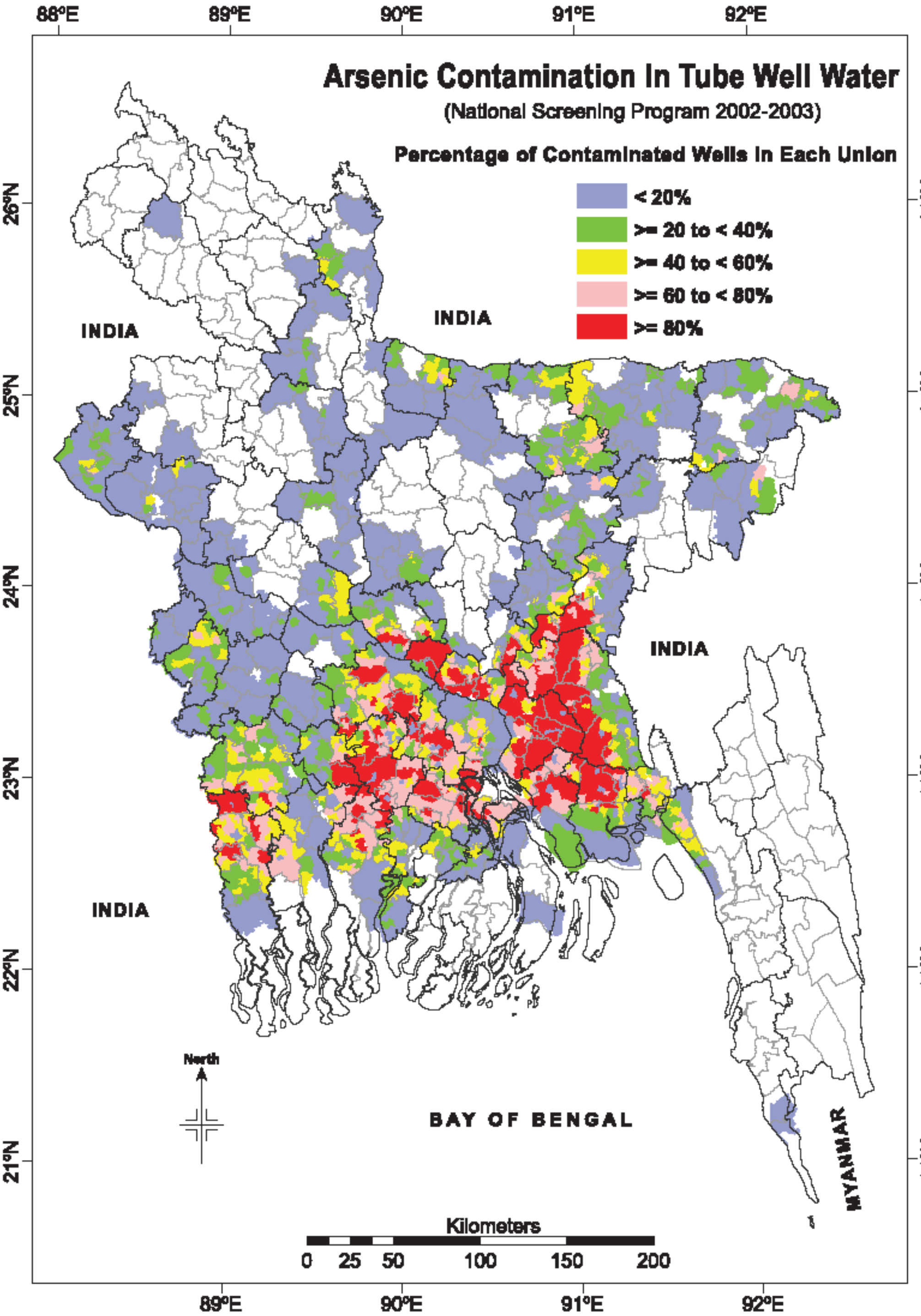


Figure 1.5 Groundwater arsenic contamination in Bangladesh in 2002-2003 (Source: BBS and UNICEF, 2010)

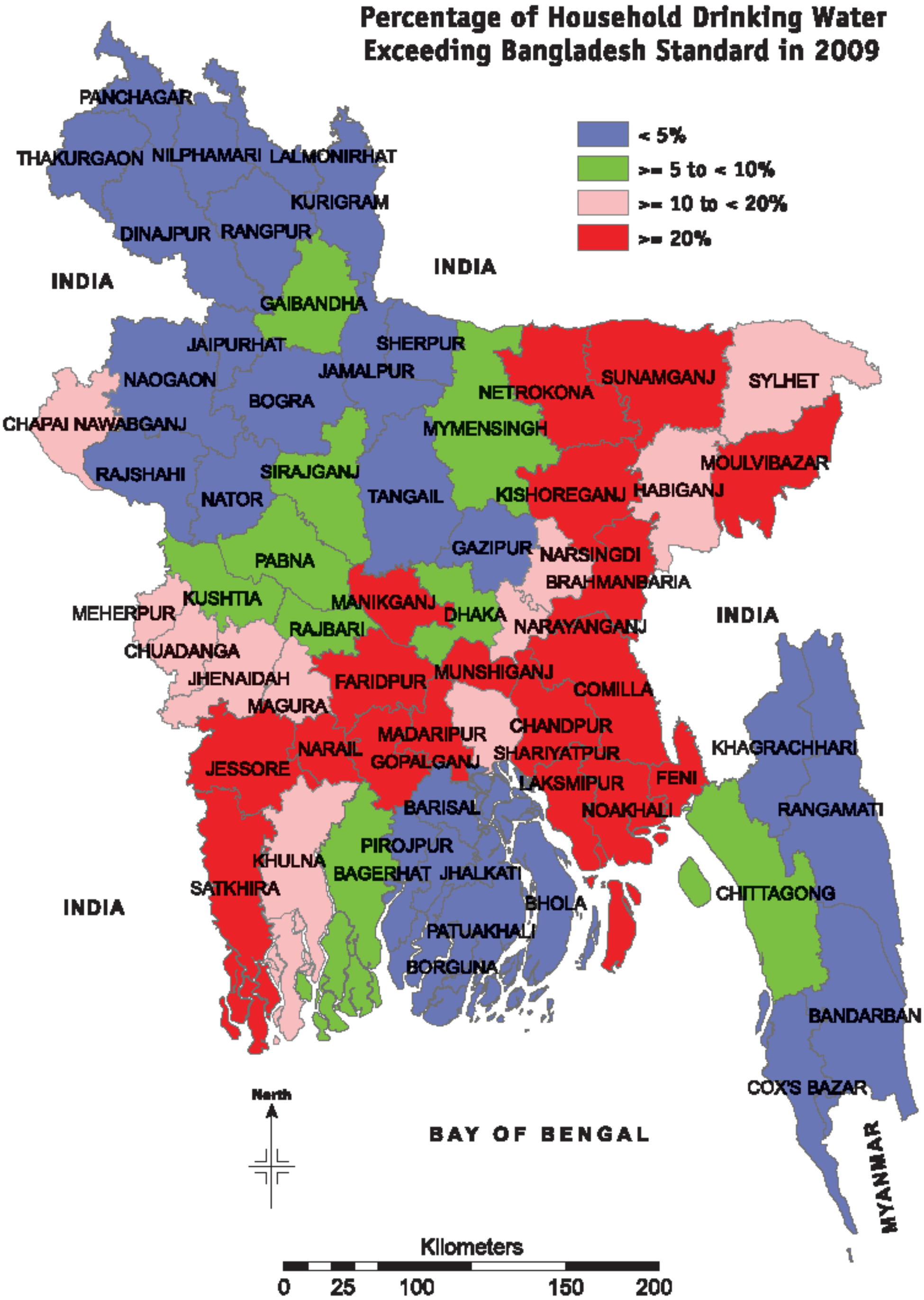


Figure 1.6 Arsenic contamination of household drinking water in Bangladesh in 2009 (BBS and UNICEF, 2010)

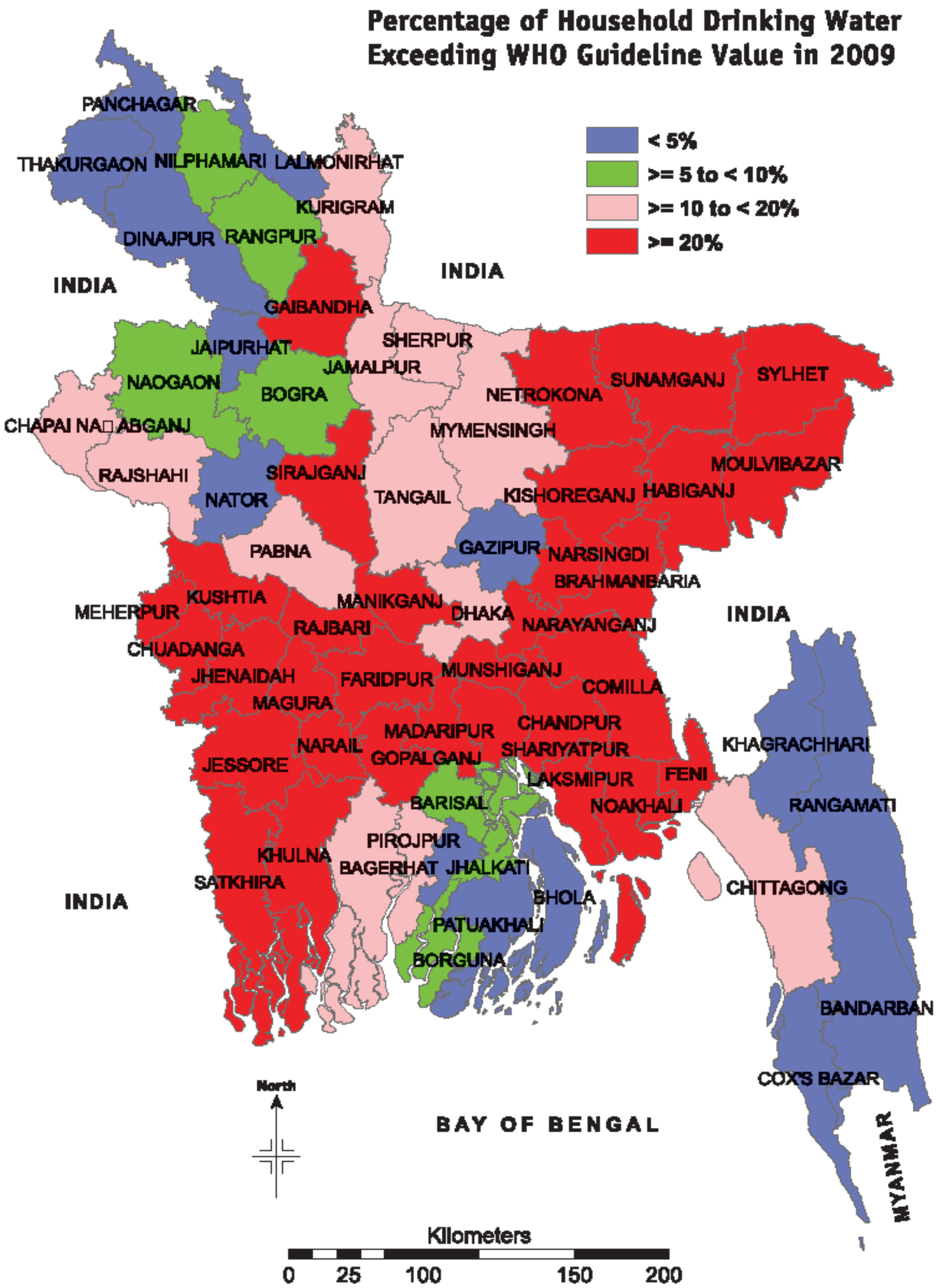


Figure 1.7 Arsenic contamination of household drinking water in Bangladesh in 2009 (BBS and UNICEF, 2010).

Table 1.13 Arsenic related basic statistics of Bangladesh, 2007

Parameters	**Number**	**Percentage**
Estimated number of tube wells	9,750,000	100
Tube wells tested for arsenic	4,950,000	51
Tube wells marked green (safe)	3,350,000	34
Tube wells marked red (unsafe)	1,450,000	15
Estimated total villages in country	87,319	100
Villages screened	54,041	62
Villages not screened (est.)	33,278	38
< 40% wells contaminated Villages	70,610	81
40-80% wells contaminated Villages	8,331	10
80-99% wells contaminated Villages	6,062	7
Villages where all wells contaminated	2,316	3
Actions taken by people to avoid arsenic contamination		
Using arsenic free tubewell water		51
Using treated pond, canal or river water		8
Using rain water tanks or sand filtered water		7
No action		34

Arsenic concentrations in drinking water are so high that the World Health Organization (WHO) describes arsenic contamination of Bangladesh is the largest poisoning of a population in history. A systematic survey throughout the country by the Department of Public Health Engineering (DPHE) and the British Geological Survey (BGS) indicate that tube well water from 59 out of the 64 districts has been contaminated with unacceptable levels of arsenic exposing an estimated 75 million people to the risk of chronic arsenic poisoning in the country. The total numbers of tube well contaminated with arsenic have been estimated to be 1.12 million. In recent times, the number of patients with arsenicosis in Bangladesh is reported to be over 10,000. However, the source of arsenic in ground water remains obscure. Due to drinking arsenic contaminated water for long period a lot of people are suffering from chronic arsenic poisoning and many have already died. So far more than 14,000 patients have been identified and the figure is going up day by day. Survey (BGS) in 2001 revealed that nearly 21 million people of about 47 districts of the country were drinking arsenic contaminated (as above 50μ g/L) ground water. The National Institute of Preventive and Social Medicine (NIPSOM), Bangladesh, estimates that 50 million people are at risk of developing *Arsenicosis,* with *Melanesia* and *Keratosis* as the most common. According to them, people who are already diagnosed with *Arsenicosis* are reported to be either in the primary or in the secondary stage and the number of such patients is increasing. The annual impact of arsenic on health in Bangladesh was estimated by Maddison, Luque, and Pearce (2004) are shown in the Table 1.14. It is an evident of arsenic-related health burden in

Bangladesh. It appears that 3,809 males and 2,718 females will die from cancer every year and a total cancer accumulated of 190,450 males and 135,900 females in a period of 50 years. They estimated around 352,233, 971,230, 90,712, 211,858, 270,122, 373,104, 131,439, 182,762 people will develop keratoses, hyperpigmentation, cough, chest sounds, breathlessness, weakness, glucosuria and high blood pressure, respectively, over 50 years.

Table 1.14 Estimated health impact of arsenic contamination of tube wells in Bangladesh

Impact on health/ type of illness	**Males**	**Females**	**Combined**
Cancer cases:			
Fatal cancers/year	3,809	2,718	6,528
Nonfatal cancers/year	1,071	1,024	2,095
Total cancer fatalities accumulated over 50 years	190,450	135,900	326,400
Arsenicosis cases:*			
Keratoses	277,759	74,473	352,233
Hyperpigmentation	654,718	316,511	971,230
Cough	21,823	68,887	90,712
Chest sounds	144,831	67,025	211,858
Breathlessness	93,247	176,874	270,122
Weakness	132,927	240,176	373,104
Glucosuria	67,887	63,551	131,439
High blood pressure	94,396	88,366	182,762
Total arsenicosis cases in each year	1,487,588	1,095,863	2,583,460

*Figures indicate average number of cases occurring in each year (not number of new cases).

Source: Maddison, Luque, and Pearce 2004, p. 32.

1.7 Ownership of Hand Tube-Wells

A major portion of households have no ownership or investment on hand tube-wells tube but they collect water from their neighbor's or neighbors' tube-wells. The most of hand tube-wells are private but the followings four types of ownership is common in Bangladesh such as (a) one household is owner of a tube-well (comparatively rich household)- there are two types of water use patterns, (i) the water is used only by owner household and (ii) the water is used including neighbors household(s) without investment, (b) share ownership tube well without subsidy and (c) share ownership tube well with subsidy. Some households collect the water without investment from b and c types tube wells.

1.8 Options of Safe Water

If the private tube well of household(s) is classified as "red", the main options to provide safe water are either to find a new safe source of water supply or to remove arsenic from the contaminated source. The options are discussed below;

1.8.1 Arsenic Remove from Existing Contaminated Source

Most of the arsenic removal technologies make use of several processes either at the same time or in sequence. The following methods can be used to treat water and make it arsenic free.

1) Oxidation and stripping, 2) Coagulation, precipitation and filtering using iron

and aluminium salts, 3) Lime softening, 4) lon exchange, 5) Membrane process (reverse osmosis) and 6) Adsorption on activated alumina/activated carbon/activated bauxite/ferric hydroxide.

1.8.2 Switching to Alternative Arsenic Free Water Sources

Three main sources of water can be considered as substitutes for arsenic contaminated shallow tube well water: ground water from deeper aquifers, rain water and surface water. It is not so easy to change water source even if own water source is not safe, unless relatives or close friends who own safe tube-well are living near-by. For your kind information, majority of the household live closely each other in rural Bangladesh, so, this type of households is not so much. Moreover, it depends on situation, it is not easy but it is possible. Among this type of households, some are capable to switch from red to green tube well by themselves.

1.9 Economic Loss for Arsenic Related Health Burden

The present value of output lost was calculated to be US$22.89 billion on the basis of the assumption a constant discount rate of 10% over a 50-year period (WSP, 2005). The study estimates that some 7 to 12 million person-days per year are lost as a result of arsenic exposure. In addition, individuals who are sick spend between 207 (US$ 3.5) million to 369 (US$ 6.25) million taka per year for medical help. The total cost of illness as a result of exposure to arsenic is Tk 557

(US$ 9) to Tk 994 (US$ 17) million per annum or on average nearly 0.6 percent of the annual income of affected individuals (Khan and Haque, 2010).

Information from the National Institute of Preventive and Social Medicine of Bangladesh indicates that the medical expenditure for treating mild to moderate arsenicosis is US$4 to US$5 per month, and the treatment generally lasts from three to six months. As far as arsenicosis cancers are concerned, the medical expenditure ranges from US$300 to US$1,000 per patient. Using this information the World Bank calculated the direct medical cost of treating mild to moderate arsenicosis, as well as arsenicosis cancer. From the available data 8,623 people (6,528 fatal cancers plus 2,095 nonfatal cancers) are expected to develop cancer per year, while 971,230 to 2,583,460 people will develop some other arsenic related disease requiring treatment at a lower cost. Using the upper bound (US$1,000) of the estimates of medical costs provided by NIPSOM for all cases of cancer and the lower-bound estimates of costs ($30) for all other treatments the total annual cost of treating arsenicosis cancer amounted to US$8,623,000 and the cost of treating all other arsenic-related diseases is in the range of US$29,136,900 to $77,503,800 (FAO, UNICEF, WHO and WSP, 2010). It is noted that skin problems is curable or not it depends on severity of skin problem. If patient take necessary action at preliminary stage, it is curable. The patients have to stop drinking arsenic contaminated water and have to take arsenic safe water for drinking and cooking, to eat nutritious food like green leafy vegetables, pulses, nuts, various types of seeds eggs, milk, small fish fruits etc. There is no specific medicine but doctor suggests some vitamin tablets. There is an ointment for hyperkeratosis patient.

1.10 Arsenic Threat and Millennium Development Goals

Access to safe drinking water is a significant determinant in meeting most of the Millennium Development Goals (MDGs) targets through food security, nutrition, prevention of disease, better health, greater educational opportunities and increased income (Table 1.15). Impediments to the supply of safe drinking water constrain the achievement of the MDGs as a whole. Contamination of water supplies with Arsenic thus has a major negative impact on most of the MDGs targets.

Table 1.15 Impact of arsenic contamination on millennium development targets

Millennium Development Goals	Negative impacts of As on MDGs	
	Direct	**Indirect**
Goal 1: Eradicate extreme poverty and hunger	Loss of income and increased poverty due to illness and loss of human productivity and crop yields Reduced nutritional status Cost (time and money) of procuring arsenic-safe water.	Reduced crop production Reduced family income due to sickness or death Food and crop contamination
Goal 2: Achieve universal primary education	Increase dropout due to sickness. Loss of school days for children caring for sick relatives.	Reduced school attendance due to illness, time and money spent collecting water rather than on education Increase works load for parents' illness. Chronic arsenic poisoning has also been found to have slowed children's cognitive development.
Goal 3: Promote gender equality and empower women	Social problems of women caused by skin lesions. Higher drop out rate for girls caring for sick relatives.	Increased water-carrying burdens for women

Table 1.15. Cont.

Goal 4: Reduce child mortality	Arsenic exposure is linked with increased fetal loss and infant mortality in Bangladesh (Rahman, Vahter et al., 2009). Children exposed to arsenic are at much higher risk of developing cancers as adults (Institute of Environmental Medicine, Karolinska Institute Stockholm, Stockholm).	
Goal 5: Improve maternal health	Pregnant women who are exposed to arsenic in drinking water suffer from increased blood pressure and anemia during pregnancy (Smith, Marshall, et al., 2006).	
Goal 6: Combat HIV/AIDS, malaria and other diseases	Exposure to arsenic via drinking water causes skin lesions, internal cancers, and other systemic diseases.	
Goal 7: Environmental sustainability	Irrigation from contaminated aquifers is distributing arsenic at the surface, where it can build up in soils, eventually reaching toxic levels and causing environmental degradation.	Unsustainable agriculture production from degraded soils
Goal 10: Access to safe water	This target likely to be missed due to arsenic contamination in water supplies.	

1.11 Organization of the Dissertation

The following chapters weave together the stories of my dissertation. The first chapter provides a brief technical overview of arsenic and arsenic contamination in the South Asia including Bangladesh. Knowledge of the source and severity of the problems provide a background which play very important role for my motivation to this study.

Chapter 2 investigates the arsenic exposure to human skin, arsenic concentrations in tube well water and urine, and body mass index. Patterns of skin lesion of arsenicosis patients, pathway of arsenic exposure to human body, urinary arsenic, arsenic concentrations in drinking water and body mass index are essential to creating appropriate policies for arsenic poison free public health.

Chapter 3 explores the social and psychological implications of arsenicosis and the determinants of arsenicosis patients' perception about chronic arsenic poisoning for reducing the disease burden and avoidable deaths. This chapter also examines whether men or women were better informed about the social implications of arsenicosis.

Chapter 4 explains the theoretical model which forms the basis of my empirical analyses. This chapter investigates how the factors influence households' knowledge about arsenic contamination. I use spatial statistical models with different spatial weights to investigate the determinants and spatial dependence of households' knowledge about arsenic risk. My analysis extends the spatial model by allowing spatial dependence to vary across the divisions and regions.

Finally, Chapter 5 attempts to address the arsenicosis health status, averting behavior and willingness to pay for arsenic free water. This chapter investigates the determinants to how and to what extent these various factors may influence arsenicosis health status, averting behavior and willingness to pay for arsenic free water by using the ordered logit, binary logit and maximum likelihood regression models, respectively. Among the determinants, the present chapter is focused on whose education is the most influential factor for switching from red source to green source for drinking water.

Chapter-2

Assessment of Arsenic Exposure to Human, Concentrations in Tube Well Water and Urine, and Body Mass Index

2.1 Introduction

Exposure of arsenic from drinking water has been a major public health threat to millions of people in different parts in the world. Bangladesh is facing an increasing threat of arsenic contamination in groundwater which is associated with risk of skin cancer, cardiovascular, black foot disease, hypertension, adverse reproductive - outcomes, neurological disorder (Haque et al. 2003, Smith et. al., 1998) as well as other social and psychological problems (Sarker et. al., 2010). In attempting to eliminate water-borne diseases caused by drinking contaminated surface water, millions of shallow wells were drilled in Bangladesh during the last 30 years that brought geological arsenic to the surface. This caused an estimated 40 million people in this country suffering from arsenic poisoning-related diseases (Alam, 2002). It is a very crucial issue for sustainable public health of Bangladesh, and some systematic investigations have been undertaken to assess the health burden. Typically, epidemiologic studies have relied on a few measures of arsenic (As) in drinking water to estimate exposure. The historical consistency of arsenic concentration is of particular concern with shallow ground water, which might be subject to greater fluctuation than water from a deeper well (NRC, 2001).

The study conducted within highly contaminated areas has found that 17–35% of the populations examined have skin lesions, and up to 3.4% of them have gangrene and ulcers (Hassan et al. 2005). Drinking water in Bangladesh contains mostly inorganic arsenic. Inorganic arsenic, once ingested is excreted through urine in human (Buchet and Lauwerys, 1983). Inorganic arsenic is a naturally occurring toxicant and carcinogen (International Agency for Research on Cancer 2004; National Toxicology Program 2002) that contaminates groundwater supply systems in countries around the world (Smedley and Kinniburgh 2002). Flour and rice also contain inorganic arsenic, particularly if grown or cooked in areas with arsenic contamination in soil and water (Del Razo et al. 2002). The metabolism of inorganic arsenic in the human body results in methylarsonate and dimethylarsinate, which are excreted in urine together with unchanged inorganic arsenic (Aposhian and Aposhian 2006; Cullen and Reimer 1989). A series of reduction and oxidation methylation reactions occur in liver to form MMA and DMA (Kitchin, 2001). Approximately one-third of the hand tube wells in Bangladesh contain arsenic more than 10 μg/L, the recommended level of arsenic in drinking water by the WHO (Kinniburgh and Smedley, 2001).

Some studies have indicated that poor nutritional status may increase the risk of arsenic related health effects (Borgono, et. al., 1977; Hsueh, et. al., 1995; Mazumder, et. al., 1998, Tseng, 1977, Milton et. al. 2010, Sarker, 2011). The respondents with below standard body weight for their age and sex were reported to have an overall 1.6

fold-increase in the prevalence of keratoses in West Bengal, India (Mazumder, et. al., 1998). However, there are uncertainties about the relationship between exposure to As and its clearance in urine as a marker of exposure to As in drinking water. Improved estimates of exposure to As may be obtained by quantization of the amount of arsenic in the urine. In particular, there is limited information on the arsenic concentration in the urine and nutritional status. Moreover, accurate estimation of magnitude and pattern of exposure is critical for a better understanding of the adverse effects of chronic exposure to human body. Therefore, the objectives of this study are to conduct an initial assessment of sevearity and to identfy the pathway of arsenic exposure to human body, to investigate the arsenic concentrations in the drinking water and urine and association between arsenic concentrations in urine and body mass index.

2.2 Methodology

2.2.1 Survey Area

The study area of this investigation is southern region of Bangladesh. Two Upazilas namely Matlab South and Hajigong were selected from out of eight Upazilas of Chandpur district as it is known to be highly contaminated with arsenic in the underground water. The British Geological Survey (Kinniburgh and Smedley, 2001) reported that there is high prevalence of arsenic in tube well water in Chandpur district. The upazila is the second lowest tier of administrative government in Bangladesh. The districts of Bangladesh are divided into sub-districts called Upazilas.

2.2.2 Selection of Survey Sample

A five-stage sampling procedure was undertaken for selection of sample respondents. Firstly, two upazilas of Chandpur were selected purposively from eight upzilas. Secondly, preliminary information on the severity of arsenic exposure to human of total 224 villages of two upazilas was collected from the local NGOs personnel, health workers, and ICDDR, B field workers. Thirdly, thirty villages were selected from 224 villages on the basis of the severity of arsenic exposure. Fourthly, total four villages were randomly selected from severely affected 30 villages for the present study. Finally, a total of 450 adults age 14 and older were selected randomly from 3162 individuals. The target populations of the present survey consist of patients and non-patients who are 14 years or older.

At first, the list of all tube wells (152 tube wells) of four selected villages was made. Then, a total of 86 tube wells were randomly selected from 152 tube wells for the present study. Drinking water samples around 50 ml were collected from 86 tube wells by using 50ml bottle which was acidified with 1% HCl for preservation. Majority of the respondents have no own tube well. They collect their drinking water from neighbors' tube wells. Most of the non-owner respondents collect their water from more than one tube well. Only the respondents who have own tube well, they collect their water from only one tube well. Intensive observation and further study are needed for matching the water samples and respondents.

2.2.3 Survey Instruments

The purpose of the study was described to the respondents and the issue of ethical consent was addressed by informed individual oral consent. A pre-design questionnaire was used to collect the very basic information like age, sex etc. as well as details information about arsenicosis problems if any respondent has arsenicosis problem(s). Four (two men and two women) interviewers were hired based on educational qualification and previous field experience. These four interviewers were thoroughly trained and used for pre-testing the questionnaires and finally, they conducted the survey by face-to-face interview. Height was measured in centimeters and weight was measured in kilograms. Standing height and weight of each participant were measured with the subjects wearing light clothes and not wearing shoes. Total 418 urine samples were collected from respondents for arsenic concentrations test. Thirty two observations were excluded for non-response and refusal of participants. Participation was voluntary and data protection was observed throughout the study. In total 86 water samples were collected from tube wells for examining the arsenic concentration in drinking water.

2.2.4 Assessment of Arsenic Exposure

The total arsenic concentrations of the water (n = 86) and urine (n = 418) were determined by an atomic absorption spectrometer equipped with a flow injection hydride generator and the part of the samples were also measured with inductively coupled plasma mass spectroscopy for cross cheek. Assay accuracy was ensured by inclusion of reference materials: NIST 1640 (trace metal in water; National Institute of Standards and Technology, Gaithersburg, MD, USA), and NIES 18 (Human urine, National Institute of Environmental studies, Tsukuba, Japan). All the measurements were within the certified ranges. Creatinine concentration in urine samples was determined with UV-VIS Spectrophotometric analyzer at 520 nm using a commercial creatinine kit, based on the Jaffe reaction.

2.2.5 Statistical Analysis

This study was used descriptive statistics to describe the data. All analyses were performed by using SPSS package. Descriptive analysis involved calculations of standard deviation, frequency distribution, percentage, mean and tabular statistics for reporting the skin lesion, arsenic concentrations in tube well and urine and body mass index.

2.3 Results and Discussion

2.3.1 Characteristics of Survey Sample

The basic characteristics of survey sample include age, sex, height, weight, body mass index, arsenic concentration in tube well water and urine. The body mass index (BMI) of the respondents was categorized into four different classes, namely underweight (<18.50), normal weight (18.50–24.99), overweight (25–29.99) and obesity (≥ 30). The descriptive statistics of the sample characteristics are shown in Table 2.1. Of the total 418 respondents enrolled in this study, there were 163 male respondents and 255 female respondents with the age of maximum 86 years, minimum 14 years and standard deviation 15.67. The age range of males was 16 to 86 years with standard deviation 16.92; while that of females was 80 to 14 years with standard deviation 14.80. The whole sample average height was 153.86 cm with the ranging from 131.0 to 177.4 cm and standard deviation 8.48 and weight was 46.30 kg with the ranging from 28.2 kg to 78.3 kg and standard deviation 8.41.

It was found that the sample respondents had an average body mass index of 19.52 while the BMI of the sample respondents varied from 14.06 to 33.4 with standard deviation 3.02. The normal weight respondents had an average BMI of 20.65 (range: 18.52 – 24.99), while the underweight respondents had 17.12 (range: 14.06 – 18.49), overweight respondents had 26.00 (range: 24.52 – 28.33), obesity respondents had 32.05 (range: 30.93 – 33.40). The average level of arsenic concentration in the drinking water was 285.37 ±193.13 μg/L with the ranging from 0 to 715.63 μg/L. The mean arsenic concentration in the urine of the sample respondents was 637.85 ± 478.69μg/g. The concentration levels varied from 93.03 – 3198.00μg/g.

Table 2.1 Some basic characteristics of the sample respondents

Characteristics	Maximum	Minimum	Mean	Standard deviation
Age (years)	86	14	36.02	15.67
Male	86	16	37.18	16.92
Female	80	14	35.27	14.80
Height (cm)	177.4	131.0	153.86	8.48
Weight (kilogram)	78.3	28.2	46.30	8.41
Body Mass Index	33.4	14.06	19.52	3.02
Underweight = <18.5	18.49	14.06	17.12	1.14
Normal weight = 18.5–24.9	24.99	18.52	20.65	1.69
Overweight = 25–29.9	28.33	24.52	26.00	1.11
Obesity = BMI of 30 or greater	33.40	30.93	32.05	1.27
Arsenic concentration in tube well (μg/L)	715.63	0	285.37	193.13
Arsenic concentration in urine (μg/g)	3198.00	93.03	637.85	478.69

2.3.2 Skin Lesion of Sampled Arsenicosis Patients

The distribution of skin lesion of surveyed arsenicosis patients is reported in Table 2.2 and some preliminary spots of arsenicosis patients are shown in Figure 2.1. The present study was found that 48 respondents from 418 sample respondents had skin problems based on appearance of skin lesions.

Table 2.2 Information on skin lesion of sampled arsenicosis patients

Type of lesion	Palm	Sole	Dorsum of Hand & Foot	Trunk
Melanosis				
Left	6 (12.50%)	1 (2.08%)	---	Front- 4 (8.33%)
Right	5 (10.41%)	1 (2.08%)		Back-2 (4.16%)
Both	21 (43.74%)	16 (33.33%)		Both-18 (37.49%)
Leucomelanosis				
Left	1 (2.08%)	---	---	Front- -
Right	---	3 (6.25%)		Back-2 (4.16%)
Both	5 (10.41%)	4 (8.33%)		Both- 5 (10.41%)
Keratosis Left & Right	2 (4.16%)	---	Yes-1 (2.08%) No-47 (97.92%)	---
Hyperkeratosis Left & Right	---	1 (2.08%)	Yes-1 (2.08%) No-47 (97.92%)	---

The respondents were selected randomly from the whole (adult) population including both patients and non-patients individuals. The present study was found that 48 respondents from 418 sample respondents had skin problems based on appearance of skin lesions. The present study shows that the highest amount of skin lesion was melanosis in palm (43.74%) and the second highest in trunk (37.49%). Leucomelanosis of arsenicosis patients was found at 2.08% in left palm, 10.41% in both palms, 6.25%% in right and 8.33% both soles, 4.16% in back trunk and 10.41% in both front and back trunk. Among the arsenicosis patients, keratosis was found in both left and right palm of

4.16% of patients and in dorsum of hand and foot of 2.08% of patients. Around four percent of the respondents reported incidence of hyperkeratosis in sole and dorsum of hand and foot.

The melanosis, leucomalanosis and keratosis symptoms were identified around 11%, 2% and 2% of the respondents, respectively in the Hajiganj (Dhaka Community Hospital Trust, 2005). The present study was found that melanosis in palm, sole and trunk and keratosis in the dorsum of hand & feet were the commonest signs in the patients. These findings are in agreement with other studies. The bodily marks of arsenicosis/arsenic poisoning are associated in the early stages with the palms of the hands and the soles of the feet. These stigmata are black patches known in Bengali as *zengoo*. At first blisters *(foskaa)*, sores *(ghaa)*, or *gotta/goottee* (swellings) develop on palms and soles and there is *chulkani* (itching). These *goottee* gradually turn into *zengoo*, which develop slowly. Later the skin becomes dark and spotted due to the deposition of a black pigment. Eventually the spots become thickened *(mota)* and hard *(shokto)*, the worst prognosis being a cancerous gangrene (Hassan, et al., 2005; Zaman, 2001). A similar finding was reported at Hajiganj Upzila of Chandpur district (Rabbani, et al., 2002). A recent study conducted within highly contaminated areas had found that 17–35% of the populations examined have skin lesions and up to 3.4% of them have gangrene and ulcers (Hassan, et al., 2005). Skin lesions were the most common and prime manifestation of arsenic toxicity that had been considered as definite exposure (Alain, et al., 1993; Yeh 1973, Milton, 2002).

Figure 2.1 Spots of the arsenicosis patients

2.3.3 Pathway of Arsenic

Arsenic, a toxicant of natural occurrence in mineral deposits, is used in many human activities such as manufacturing, agriculture, and medicine (WHO, 1981). Arsenical compounds are transported into the environment mainly by water from wells drilled into the arsenic-rich geologic strata or by ambient air during smelting and burning of coal (WHO, 1981; Thornton and Farago, 1997). The main route of arsenic exposure for the general population is via drinking water. The pathway of the arsenic exposure to human body is shown in the Figure 2.2. Arsenite and arsenate are the most common forms of arsenic in groundwater, as well as the most toxic of the four compounds. The pathway they follow through the human body is incredibly important to understanding arsenicosis, the disease caused by chronic arsenic poisoning. Figure 2.2 shows how the human body is exposed to arsenic from different sources. There are three main ways in which arsenic poses a health threat to humans: (1) ingestion through drinking water (including water used for cooking); (2) consumption of food containing arsenic; and (3) breathing of arsenic brought into the air through burning of fuel contaminated with arsenic (e.g. straw or cow dung). Arsenic is not readily absorbed through skin so physical contact with contaminated water, for bathing and washing, is not toxic (BBS and UNICEF, 2010).

When arsenite and arsenate enter the human body, they bind to tissues, inhibit enzyme activity, and interfere with cell respiration and mitosis. In order to reduce the detrimental effects of these compounds, the body uses a detoxifying methylation mechanism to convert arsenite and arsenate to inorganic MMA and DMA. However, during the conversion of inorganic species to organic species, an extremely toxic intermediary compound, MMA is formed. Many scientists are currently studying this compound since it may add significantly to the overall carcinogenicity of inorganic arsenic. Once inorganic forms have been converted to MMA and DMA, they are excreted from the body. Thus, the presence of DMA and MMA in the urine, skin, hair, and nails are often evidence of arsenic poisoning. Urinary arsenic content best indicates recent exposure to arsenic since arsenic appears in the urine within two to eight hours and disappears within seven days. Arsenic content in the skin, hair and nails is more useful for measuring long-term exposure to arsenic.

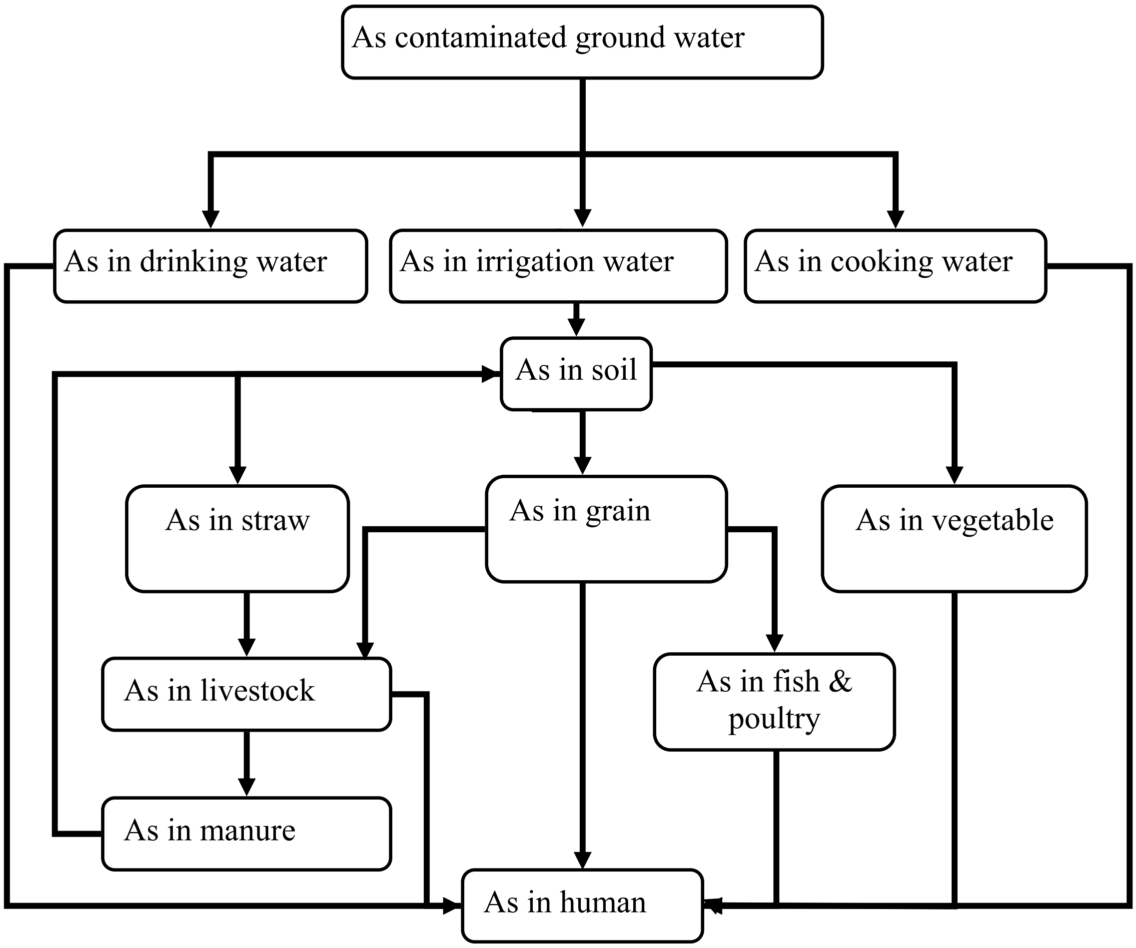


Figure 2. 2 Pathway of the arsenic exposure to human

2.3.4 Assessment of Arsenic in the Tube Well Water Sample

The distribution of the assessment results of the arsenic concentration in the tube well water are presented in Table 2.3. It was found that a total of 8 (9%) tube wells water were contained less than 50 µg/L (maximum allowable limit in drinking water in Bangladesh) of arsenic which was within the national standard. On the other hand, 78

(91%) tube wells water were contained more than 50 µg/L of arsenic, while 47 (55%) were contained from greater than 50µg/L to 500µg/L and 31 (36%) were contained greater than 500µg/L. The present study shows that the percentage of arsenic concentration more than 50 µg/L was higher than other studies. The finding of the current study is comparable with what has been reported in other studies. Previous studies reported that among the country's 7-11 million hand-pumped tube wells, approximately half have been estimated to supply groundwater with an As concentration > 50µg/L (Bangladesh Arsenic Mitigation Water Supply Project 2006; Josephson 2002). Approximately 53% of residents drank water with an As concentration > 50µg/L (Parvez, 2006). The percentage of wells with an As concentration > 50µg/L in other studies ranged from 30% (BGS 2001) to 59% (Chowdhury et al. 2000); the percentage > 300µg/L ranged from 8.4% (BGS 1998) to 20% (Chowdhury et al. 2000). A water quality survey by Bangladesh Bureau of Statistics and UNICEF has found that 12.6% of drinking water samples collected from 13,423 households around the country does not meet the Bangladesh drinking water standard for arsenic (BBS and UNICEF, 2010).

Table 2.3 Distribution of arsenic concentration in the tube well water

Arsenic concentration (µg/L)	Number of tube well	Percentage
≤50	8	9
>50-500	47	55
>500	31	36
Total	86	100

2.3.5 Assessment of Arsenic Concentration in Urine Sample

Urinary arsenic (UAs) concentrations are used frequently in epidemiological and environmental health studies as means of assessing exposure to As. Symptoms of arsenic poisoning include abnormalities of the urinary tract and digestive system, swelling of facial tissues, hair loss, changes in skin texture and color and several types of cancer. While short-term, high level dosages are instantly toxic, most cases of long-term exposure are difficult to detect and diagnose, since the symptoms appear over years and can be mistaken for other diseases. The urine arsenic level is often the preferred method, since it provides more accurate results. The results of arsenic concentration test in urine are presented in the Table 2.4.

Table 2.4 Distribution of arsenic concentration in urine

Arsenic concentration (µg/g)	Number of respondents	Percentage
≤200	45	11
>200-500	174	41
>500-1000	125	30
>1000	74	18
Total	418	100

The arsenic concentration in the urine sample of the 45 (11%) respondents contained smaller than or equal to 200µg/g, 174 (41%) respondents contained from greater than 200 to 500µg/g, 125 (30%) respondents contained greater than 500 to

1000μg/g and 74 (18%) respondents contained greater than 1000μg/g. Average UAs concentration of the present study was higher than the other studies, such as 16 to 2746 μg/g (Maharjan et.al., 2005) and smaller than 11 to 4144 μg/g (Navoni et.al., 2008). The other study reported that the mean arsenic concentrations in the drinking water for the exposed and unexposed (control) population were 218.1 μg/L and 11.3 μg/L, respectively (Islam et al., 2004).

2.3.6 Body Mass Index of Sample Respondents

In rural Bangladesh a major portion of people are underweight. The distribution of body mass index of the sample respondents are shown in Table 2.5. The nutritional status of the sample respondents were evaluated based on their body mass index. It was found that 212 (51%) of the sample respondents were normal weight, while 180 (43%) were underweight, 20 (5%) were overweight and 6 (1%) were obesity. It is therefore, highly likely that these sample respondents represent the broad characteristics of BMI of rural residents. Malnutrition is highly prevalent in rural Bangladesh (Milton, 2004).

Table 2.5 Distribution of body mass index of the respondents

Nutritional status	Number of respondents	Percentage
Underweight = <18.5	180	43
Normal weight = 18.5–24.9	212	51
Overweight = 25–29.9	20	5
Obesity	06	1
Total	418	100

2.3.7 Association between BMI and Arsenic Concentration in Urine

The joint frequency distributions of arsenic concentration in the urine and body mass index are presented in the Table 2.6. As seen in the leftmost column of the body mass index, the proportion of under weight and arsenic concentration in urine is equal to or smaller than 200 µg/L was 7.8 percent only. On the other hand, other 92.22% underweight respondents contained more than 200 µg/g arsenic in urine while 36.7% contained from more than 200 to 500 µg/g, 34.4% contained from more than 500 to 1000 µg/g and 21.1% contained more than 1000 µg/g. The cells in the second column is shown that around 13.7% normal weight respondents contained equal to or smaller than 200µg/g arsenic and 86.3% respondents contained more than 200µg/g arsenic in urine. While 44.8%, 25.9% and 15.6% normal weight sample respondents contained from more than 200 to 500, from more than 500 to 1000 and more than 1000 µg/g arsenic in urine, respectively. In the column three under body mass index, among the overweight and obesity sample respondents 7.7%, 50.00%, 30.8% and 11.5% contained equal to or smaller than 200, more than 200 to 500, more than 500 to 1000 and more than 1000 µg/g arsenic in urine, respectively. In a recent study, an association between nutritional status and chronic exposure to arsenic has been reported among Bangladeshi patients (Milton et. al., 2004). An epidemiological study conducted in West Bengal, India showed malnutrition correlated with increased prevalence of skin manifestations in arsenic exposed population (Mazumder et. al., 1998). The studies were reported that low socio-economic status and poor nutritional status of arsenicosis sufferers people in Taiwan and Chile (Borgono, et. al., 1977; Hsueh, et. al., 1995; Tseng, 1977; Zaldivar, 1977). Lower BMI was reported among the arsenicosis patients compared to the unexposed population in a previous study in Bangladesh (Milton, et al., 2004). However, a study from Atacameño in northern Chile reported no evidence of malnutrition among individuals with arsenic induced skin lesions (Smith, et al., 2000).

Table 2.6 Joint frequency distribution of BMI and arsenic concentration in urine

Arsenic in urine(μg/g)	Body mass index in percentage			Total
	Under weight	Normal weight	Overweight & Obesity	
≤200	7.8 (14)	13.7 (29)	7.7 (2)	10.8 (45)
>200-500	36.7 (66)	44.8 (95)	50.0 (13)	41.6 (174)
>500-1000	34.4 (62)	25.9 (55)	30.8 (8)	29.9 (125)
>1000	21.1 (38)	15.6 (33)	11.5 (3)	17.7 (74)
Total	100.0 (180)	100.0 (212)	100.0 (26)	100.0 (418)

Number of sample respondents in the parentheses.

2.4 Conclusion

The findings described at the present study provide novel information on the urinary arsenic concentration in the highly arsenic contaminated area and a crucial picture of arsenic exposure and body mass index of rural residents as well as arsenic concentrations in drinking water. These results indicate that this population presented a high exposure level and clearly show the critical situation present in these areas, which would lead to increase the health burden, social discrimination and other problems. This study has successfully examined biomarker- arsenic in urine and arsenic concentration in drinking water and body mass index. Additional research is needed to further characterize the other biomarkers and health impact of arsenic exposure. The findings of the study are expected to be useful to take appropriate steps for mitigating the present arsenic crisis for rural livelihood pattern improvement as well as the overall improvement of Bangladesh.

Chapter-3

Perception of Social and Psychological Implications of Arsenic Poisoning and Arsenicosis Patients' Knowledge about Arsenic Poisoning through Groundwater [*]

3.1 Introduction

Arsenic contamination of drinking water is one of the great concerns for public health throughout the world. According to the International Agency for Research on Cancer (IARC, 2004) around 100 million people in the world, including about 13 million in the United States, are chronically exposed to inorganic arsenic. Although >20 countries have been affected by arsenic contamination of drinking water, the situation is perhaps the most devastating in Bangladesh because of the number of affected people (Parvez et al., 2006). Nationwide, 6528 people will die from cancer every year and a total of 326,400 people in a period of 50 years and around 2.5 million people will develop keratoses, hyperpigmentation, cough, chest sounds, breathlessness, weakness glucosuria and high blood pressure over that period (Maddison et al., 2004).

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[*] This chapter has benefited from presentations of the Human exposure: Social and economic impacts session 3B at the Second International Congress Arsenic in the Environment (As 2008) held in Valencia, Spain and the Environment V: Environment and Health session at 55th North American Meetings and conference of the Regional Science Association International (2008), held in New York, U. S. A.. Previous version of this chapter has been published in the International Journal of Environmental Research and Public Health, Volume 7, pp. 3644-3656.

Systematic survey throughout the country by the Department of Public Health Engineering and the British Geological Survey have estimated that nearly 21 million people of about 47 districts are drinking arsenic contaminated ground water (BGS and DPHE, 2001) which is well above the standard limit of 0.05μg L^{-1} of Bangladesh (the WHO guide line value is 0.01μg L^{-1} (WHO, 1981)). Securing arsenic-free ground-water has been technically problematic in many parts of Bangladesh (Chowdhury et al., 2000; Frisbe et al., 2002; Dhar et al. 1997). A variety of state agencies and NGOs are searching for optimum mitigation strategies, in order to reduce the risk from drinking poisoned groundwater (Caldwell et al., 2003).

Arsenic patients may not feel ill or look ill, other than some skin pigment discoloration, but they are stripped of their status in society and adopt a virtual identity as 'dangerous' people (Hassan, et al., 2005). Chronic arsenic exposure is associated with many human health conditions, including skin lesions and cancers of the liver, lung, bladder and skin (Ahsan et al., 2000; Mazumder et al., 1998; Smith et al., 1998) as well as other noncancer health effects such as adverse reproductive outcomes, neurological disorders and impaired cognitive development in children (Ahmad et al., 2001; Calderon et al., 2001; Mukherjee et al., 2003; Wasserman et al., 2004). Arsenic contamination has had a profound impact at both the individual and community levels. Reports have attributed disease and death caused by arsenic toxicity to lack of knowledge about the source of this metal (Hadi, 2003). Fear of contagiousness has separated families, created social isolation in schools and led to avoidance of people living in highly contaminated regions (Dhaka Community Hospital Trust, 2005). Therefore, it is important to identify the determinants of the patients' perception about arsenicosis and to examine the gender differences of social and psychological sufferings from chronic arsenic poisoning for reducing the disease burden and avoidable deaths. The present study explores the arsenicosis patients' perception and problems by examining four specific questions; First, what are the socio-demograpic conditions of arsenicosis sufferers? Second, What is the major problems of arsenicosis sufferers in case of child development, getting marriage and married life? Third, do substaintial gender differences exist in the perception of social and psychologial implications of arsenocosis? Finally, how do the different determinants associate with arsenicosis patients' knowledge?

3.2 Material and Methods

3.2.1 Study Area

Two Upazilas namely Hajiganj and Matlab out of 7 Upazilas of Chandpur district were selected as they are known to be highly contaminated with arsenic in underground water and located in southern region of Bangladesh. The upazila is the second lowest tier of administrative government in Bangladesh. The districts of Bangladesh are divided into sub-districts called Upazila. At present, there are 482 upazilas in Bangladesh.The British Geological Survey (BGS and DPHE, 2001) reported that there is high prevalence of arsenic in tube well water in southeast and southern Bangladesh. The melanosis, leucomalanosis and keratosis symptoms were identified around 11%, 2% and 2% of the respondents, respectively in the Hajiganj (Islam et al., 2010). It is characterized by densely populated area and agrarian economy producing principally rice, wheat, vegetables, jute, fish, milk and poultry.

3.2.2 Data Collection

The study is based on primary data. The target populations of the present study consist of patients only who are selected based on appearance of skin lesions. Field survey, interview, communication and interaction with different stakeholders were conducted for primary data collection. A three-stage sampling procedure was undertaken for sample respondents selection. Firstly, two Upazilas were selected purposively from seven upzilas of Chandpur district. Secondly, preliminary information about the patients based on appearance of skin lesions has been collected from the department of public health engineering, local NGOs personnel, health workers, family planning workers, extension personnel and ICDDR, B field workers, and thirdly, then total 150 skin lesion patient respondents were selected from the list of 458 patients for the present study. Extra 30 patients were selected to accommodate unavailability, non-response and refusal of the participants. Sample respondents were selected by using simple random sampling frame work. Finally, a total of 90 female and 90 male respondents were interviewed for the present study. The female respondents were more than male respondents because the response rate was higher for female respondents than male respondents. The response rate of respondents was 88%. A pre-design pre-tested interviewer made questionnaire was used to conduct the survey. Two trained interviewers (one man and one woman) conducted the survey by face-to-face interview.

Attention was given to the wording of the questions during questionnaire design, so that the respondents found it simple and could understand it easily.

3.2.3 Variables

The socio-economic variables include age, sex, family size, house hold income, occupation, source of drinking and cooking water. Family members were categorized into adult male, adult female and children (less than 12 years). The highest level of educational attainment was categorized into three levels, namely illiterate/no education, below Secondary School Certificate (SSC), and Higher Secondary Certificate (HSC). House-hold income was calculated based on respondents' self report. Respondents were asked to classify their job into one of five different occupations, namely housewife, agriculture, business, service, and others. The source of water was classified into five categories; tube well, pond, rainwater harvest, river and canal. Social implications of the chronic arsenic poisoning from drinking ground water was evaluated by asking the question "Do you think that the arsenicosis is a cause of dislike of other people to participate of social activities?" The perception of respondents regarding the psychological implications of the chronic arsenic poisoning from drinking ground water was evaluated by asking indirect question. To assess the psychological implications of arsenicosis, the respondents were asked the question "Do you think that the arsenicosis is an evil spirit/God's curse/sin/ contagious disease?" Knowledge regarding the chronic arsenic poisoning from drinking ground water was evaluated by asking whether the respondent had a clear knowledge of adverse health effects of arsenic. The respondents were asked the question "Do you think that the drinking of arsenic-contaminated water is a cause of health problems?" If the answerer was 'yes', then again the respondents were asked the question about arsenic related diseases, “Do you know that the arsenic-contaminated water is a cause of Melanosis, Leucomelanosis, Keratosis, Hyperkeratosis?” Those who know the arsenic-contaminated water is a cause of above mentioned diseases, the respondents consider as they have clear knowledge about adverse health effect of arsenic-contaminated drinking water. The dependent variable was valued at one if the respondent has clear knowledge about adverse health effect of arsenic-contaminated drinking water and zero if he/she has no clear knowledge. Knowledge refers to what is known, as through study or experience and perception means the ability to see, hear, or become aware of the true nature of something.

3.2.4 Statistical Analyses

This study used descriptive statistics to describe the data and logit regression model to explore the determinants of the respondents’ perception about arsenic exposure to human health. All analyses were performed by using SPSS package.

3.2.4.1 Descriptive Statistics

Descriptive analyses involved calculations of frequency distribution, percentage, mean and tabular statistics for reporting the socioeconomic characteristics, skin lesion, social and psychological implications of arsenicosis. Chi-square test was used to find out the association between social and psychological implication of arsenicosis and gender of respondents.

3.2.4.2 Logit Regression

Logit regression is used for prediction of the probability of occurrence of an event. Logit regression allows one to predict a discrete outcome from a set of variables that may be continuous, discrete, dichotomous, or a mix of any of these. Generally, the dependent or response variable is dichotomous, such as presence/absence or success/failure of an event. The logit model given by Gujarati (1995) is:

$$L_i = \ln\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_i X_i + U_i$$

Where,

L_i = the log of odds ratio; L_i is called logit.

P_i = the probability of success,

then, 1-P_i = the probability of failure

$P_i/1-P_i$ = odds ration of success

X_i = independent variables

U_i = residual term

β_0 = intercept

β_i = coefficient of respective explanatory variables

To determine respondents' perception about arsenicosis the following Logit model was fitted to the empirical data,

$$L_i = \ln\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i} + U_i$$

Where,

L_i = 1 if the respondent has clear perception about arsenicosis and 0 otherwise

P_i = the probability of the respondents' clear perception about arsenicosis

X_1 = educational qualification of the arsenicosis patient (year of schooling)

X_2 = household income of the arsenicosis patient (in Tk. per year)

X_3 = age (in years)

X_4 = 1 for male respondent

X_4 = 0 for female respondent

X_5 = 1 for married respondent

X_5 = 0 for unmarried respondent

X_6 = duration of suffering from arsenicosis (in years)

β_1 to β_6 are coefficients of the respective explanatory variables.

3.3 Results

3.3.1 Socio-Demographic Background

The socioeconomic and demographic characteristics of surveyed arsenicosis patients are presented in Table 3.1. Respondents comprised 60 males and 90 females. The average age of the respondent was 50 ± 19 years. Mean age ± SD of male and female were 54 ± 15 and 47 ± 21 years, respectively. The average number of adult male, adult female and children per family were found to be 2.34, 2.52 and 1.12, respectively. About 52% of respondents had no formal education but 46% respondents had primary and 2% of respondents had secondary and higher secondary education. Agriculture was the main source of income and the average monthly income of respondent household was 3874Tk. (US$56.97) per month.

Table 3.1 Socio-demographic characteristics of the surveyed Arsenicosis patients

Characteristics	Values
Average age of the respondent (years)	**50 ± 19**
Male	54 ±15
Female	47 ± 21
Average family member (No)	**5.97 ± 3.5**
Adult male	2.34 ± 2.0
Adult female	2.51 ± 1.5
Children	1.12 ± 2.2
Literacy	
No education	78 (52%)
Below S.S.C.	69 (46%)
S.S.C. and H.S.C.	3 (2%)
Average monthly household income (Tk.)	3874 ± 3252
Major occupation of the respondents	
Agriculture	33 (22%)
Business	12 (8%)
Service	9 (6%)
Housewife	85 (57%)
Others	11 (7%)
Source of drinking water	
Tube wells	123 (82%)
Pond	12 (8%)
River	13 (9%)
Canal	9 (6%)
Rain water	33 (22%)
Source of cooking water	
Tube wells	33 (22%)
Ponds	111 (74%)
Others	6 (4%)
Responsible for water collection	
Men	12 (8%)
Women	138 (92%)

Number of respondents in the parentheses, 68 Tk. = 1 $US

The major occupation of respondents were 57%, 22%, 8%, 6% and 7% for housewife, agriculture, business, service, and others, respectively. Respondents reported that the main source of drinking water was tube well. On the other hand, respondents in the study area stated that the majority (74%) used pond water as a major source for cooking purposes.

3.3.2 Social Implication of Arsenicosis

Attempts were made to learn of the feelings of the arsenic patients regarding participation in their social activities. A considerable portion of the respondents reported that their neighbors dislike the arsenic patients' participation in their social activities.

3.3.2.1 Gender Wise Distribution of Perception of Social Implications

Table 3.2 examines whether men or women were better informed about the social implications of arsenicosis. Among the total respondents 37% reported that arsenic exposure had social implications and 63% reported that arsenicosis had no social implications. When examined against gender it was found that more males (57%) thought that arsenicosis had a social implication than females (24%).

Table 3.2 Distribution of respondents by gender and their perception on any social implication of arsenic exposure

Sex of respondent	Social implication of arsenicosis		
	Yes	No	Total
Female	22 (24)	68 (76)	90 (100)
Male	34 (57)	26 (43)	60 (100)
Total	56 (37)	94 (63)	150 (100)

Percent in the parentheses

3.3.2.2 Arsenic Poisoning and Child Development

Physical and mental development of a child in an arsenic-affected family may be interrupted because of different reasons. A considerable percentage of respondents (28%) assumed that unhappy family life may hamper psychological development of the children. The reported reasons for this were as follows: the child might be deprived of love and affection due to arsenic-related problems of the father and/or mother; children might be neglected socially due to parent’s unhealthy condition; father’s and/or mother’s illness may result in increased workload and create physical and mental pressure on the children.

3.3.2.3 Arsenicosis Problems for Seeking Marriage

Victims may face a crisis in maintaining their usual emotion, love and affection within their daily life. Women with arsenicosis usually suffer the most in this regard. A majority of the respondents (64%) informed that a girl might face difficulties in getting married due to arsenicosis. The reasons mentioned for facing difficulties by the girls were as follows: girls look unattractive and less glamorous due to arsenic poisoning (41%); nobody likes to get married to a girl patient (8%); and a newly married arsenic-affected girl may act as transmitting superstition (4%). According to 12 per cent of the respondents, men having arsenicosis were not feeling confident in getting married and eight per cent of the respondents thought that men who had signs of arsenic exposure to the body were discouraged by their friends, relatives and neighbors in getting married. Findings show that men became disinterested in marrying a girl who had signs of arsenicosis due to various reasons, e.g. such a girl would cause unhappy family condition; such a girl would be sexually malfunctioned; arsenic causes considerable physical damage to a girl; additional money will be required for treatment of a newly married woman.

3.3.2.4 Problems in Married Life

About one third of the respondents (32%) mentioned that married couples who were suffering from arsenic poisoning may face unhappy conjugal or family life. Findings show that an unhappy conjugal situation might arise from the following reasons: anxiety and possibility of ending a marriage, physical disability due to arsenicosis. About one fourth of the respondents (27%) indicated that a marriage might end in divorce if the wife suffered arsenicosis. The anticipated reasons were as follows: arsenic problem of a married women may deteriorate the conjugal relationship with her husband (11%); the husband may lose attraction to his wife because of his wife's deteriorating physical appearance (4%); the husband's fear of getting infected from his wife (2%); and superstition (6%).

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3.3.3 Perception of Psychological Implications of Arsenicosis

Table 3.3 shows the relationship of gender with the perception of psychological implications of arsenicosis. The distribution of the respondents regarding psychological implications varied substantially between the sexes. It is evident that males (53%) were less conversant than females (91%) with the psychological implication of arsenicosis.

Table 3.3 Distribution of respondents by gender and their perception about psychological implication of arsenicosis

Sex of respondent	Psychological implication of arsenicosis		
	Yes	No	Total
Female	82 (91)	08 (09)	90 (100)
Male	32 (53)	28 (47)	60 (100)
Total	114 (77)	36 (23)	150 (100)

Percent in the parentheses

3.3.4 Logit Analysis for the Respondents' Knowledge about Arsenicosis

Logit model was applied to determine the respondents' knowledge about arsenicosis. In this model the explanatory variables were education of respondent, household income, age, gender (dummy), marital status (dummy) and duration of suffering from arsenicosis of respondents. The results of a logit equation for respondents' knowledge about arsenicosis are presented in Table 3.4. The logit analysis showed that two variables namely education of the patient and household income, were statistically significant at 1% and 5% level, respectively.

Table 3.4 Results of the estimated logit equation of respondents' knowledge about arsenicosis (t statistics in parentheses)

Variables	Coefficients
Education	1.907** (4.362)
Income	1.421* (2.377)
Male respondent (dummy)	0.431 (1.032)
Age	0.804 (1.482)
Respondent is married (dummy)	0.031 (.603)
Symptoms present longevity	0.137 (0.321)
Intercept	-1.704** (9.864)

**significance at 0.01 probability level, *significance at 0.05 probability level

3.4 Discussion

In the present study shows that the average household size of 5.97 was slightly higher than the average 5.3 of Chandpur district (BBS, 2008). The respondents were also asked the question “Who is responsible for water collection in your family?” The response was 92% women and 8% men. This is consistent with other findings. In rural Bangladesh, domestic water collection and management is predominantly undertaken by women and girls, who spend considerable amount of time and energy under various conditions on a daily basis to collect drinking water for their families (Crow et al., 2002). It is rare for men to participate in domestic water collection (Hanchett et al., 2004).

Arsenic poisoning causes a wide range of health problems as well as social and psychological sufferings such as community refusal, social discrimination, unhappy conjugal life, child development problems, mental despondency etc. Some family members also do not like to talk and hesitate to come close to arsenicosis patients. Studies found that social and economic loss for people in arsenic areas were acute and rapidly worsening (WHO, 2000). Arsenic-related weakness and illness causes further economic damage, as people suffering from arsenicosis were increasingly unable to work (Ahmed, 2002). Most of the arsenicosis patients can not afford their treatment cost which leads to social crisis and distress selling (Sarker, 2008). Men are more active in social activities than women; this may possibly be due to cultural differences between men and women. Gender difference was statistically significant ($p<0.01$). It is consistent with a previous study showing that the social implications of arsenicosis for men and women do vary (Hanchett et al., 2004). Besides health effects, arsenicosis also generates problems in social and daily life and disturbs the marriage system. There are reports of broken marriages and problems in getting married. Women afflicted with skin spots or lesions (the first visible symptoms of arsenicosis) have been reported to be treated as contagious and often abandoned or denied marriage. In the same village, women/girls with visible signs of arsenicosis are facing more difficulty in getting married compared to men; increased dowry is often demanded of the woman/girl's family (Hanchett et al., 2004). Arsenicosis would not only pose a threat for getting married but it also creates many problems within married life. A study found that 8% females reported that they had been abandoned by their husbands (Howard, 2010). Nearly 53% of the women identified the biggest problem to be marriageability issues and rejection of women (Sultana, 2006). Gender difference of psychological sufferings was statistically significant ($p<0.001$). Sufferings from water poisoning differ for male and female according to social status and locations (Meinzen-Dick et al., 1998; Van Koppen et al., 1996; Bruns et al., 2000).

The results indicate that with the increase in schooling years and house-hold income of the patient, the probability of the respondents' heightened perception about arsenicosis would be greater. Socio-economic status variables were related to the knowledge of the health problems of arsenic exposure (Hadi, 2003). A previous study (Parvez et al., 2006) found that people with higher socio-economic status (non labor occupation of the head of the household and better housing) were more aware of the health effects of arsenic. On the other hand, findings of other health surveys have shown that awareness is related to knowledge of a correct behavioral or lifestyle modification (Eloundou-Enyegue et al., 2005; Piechulek et al., 2003), but these studies are not associated with perception of arsenicosis.

The main strategies should be aimed at ensuring the arsenic free water, awareness raising program(s) and finally, income generating activities for rural poor people. Women should be trained up to know about alternative ways to get arsenic free water. To ensure the participation of the female local leaders, especially female ward members and upazila vice-president in the awareness build up program. False belief, lack of resources and treatment facilities are major barriers in overcoming arsenicosis patients' problems.

There were several limitations in this study. For practical reasons, 150 sample respondents were selected for analysis. This study was based on cross sectional data. The present study was not adjusted for other risk factors such as physical activity and smoking. The most of the data were collected by using self reported data which might be affected by the differential reporting behavior of men and women. It is plausible that both the occurrence of any health problems and their consequences are worse in less advantage socioeconomic groups, but we were not able to test this in our data because the size of our sample did not allow us to separate the households into more detailed income brackets.

3.5 Conclusion

The current study examined the social implications of arsenic poisoning and its seriousness. The study found that arsenicosis has negative social and psychological implications which leads to social discrimination, uncertainty, injustice, human rights violation and threats to family and conjugal life. Women were less educated and psychologically more vulnerable than men. These findings suggest that special education/training programs may need to target individuals with low income and education status in order to improve perception about consequences of chronic arsenic poisoning; this would be an important element for abating the increasing social crisis.

A nation-wide large-scale study based on the current survey will be of high utility to assess the real burden of arsenicosis on various occupations, socio-economic segments, gender and age groups. In view of the increasing burden of arsenicosis this should be considered as an essential part of the national poverty alleviation and human development strategy of Bangladesh.

Chapter-4

Spatial Analysis of Households' Knowledge about Arsenic Contaminated Drinking Water*

4.1 Introduction

Econometric models taking into account spatial interactions among economic units have been increasingly used by economists over the last several years and some important advances have been done in both theoretical and empirical studies. Spatial econometrics is becoming more popular in many scientific fields including social sciences. More recently, spatial interaction has increasingly received more attention in mainstream econometrics as well, both from a theoretical as well as from an applied perspective (Anselin, 2001; Anselin, 2002; Anselin & Bera, 1998). Spatial econometric techniques have been developed to effectively capture spatial processes in natural or experimental data (Anselin, 1988, 2001; Haining, 1990; Coughlin *et al.,* 2004). Spatial econometric models have been applied to numerous economic issues (Coughlin *et al.,* 2004), among the issues examined are: 1) the decision by farmers to adopt new technologies (Case, 1992); 2) the location of foreign direct investment in China (Coughlin and Segev, 2000); 3) cross border shopping (Garrett and Marsh, 2002); 4) the adoption of environmental treaties by European countries (Murdoch *et al*., 2003);

* This chapter has benefited from presentations of the 2nd World Conference of the Spatial Econometrics Association, 2008, held in New York, U. S. A. and 55th North American Meetings and conference of the Regional Science Association International, 2008, held in New York, U. S. A..

and 5) state fiscal decisions (Case *et al*., 1993, Brueckner and Saavedra, 2001, and Hern´andez-Murillo, 2003). Spatial dependence not only means lack of independence between observations, but also a spatial structure underlying these spatial correlations (Anselin & Florax, 1995).

The knowledge literature establishes that many factors influence human knowledge. Household knowledge about arsenic contaminated drinking water is greatly influenced by myriad observed and unobserved socioeconomic and arsenic related factors. Since the attributes associated with the built environment and natural amenities are spatially located, it is reasonable to hypothesize that household's knowledge about arsenic contaminated drinking water is spatially correlated on neighboring socioeconomic, demographic and environmental attributes. The government, NGOs, social workers, health workers, donor agencies, environmental specialists, local school and mass media can play important role to disseminate the knowledge among villagers. In rural areas, radio can play an important role in public information, education and knoledge disseminastion as a local popular media, such as folk theatre, song etc. Arrange the special eduation/training program and campaign at national, regional or local level.

The modeling of spatial variation of arsenic threat in south Asia is a very important issue for a number of reasons. Natural arsenic (As) pollution of drinking water supplies has been reported from over 70 countries, a serious health hazard to an estimated 150 million people world-wide (Brammer & Ravenscroft, 2009). The high arsenic groundwater in Asia has become a priority health issue. Around 110 million of those people live in ten countries in South and South-East Asia: Bangladesh, Cambodia, China, India, Laos, Myanmar, Nepal, Pakistan, Taiwan and Vietnam. In South Asia, Bangladesh is the most arsenic affected country and it has been recognized as a big threat and challenge to public health. World Bank, UNICEF, WHO agreed that Bangladesh is in dire straits regarding the arsenic problem. It is estimated that more than 65% of the population of Bangladesh live in arsenic contaminated areas (Chowdhury, 2001) and are at risk of drinking water containing >50µg/L (Ng & Moore, 2005). Approximately 20 million people have already developed signs of arsenicosis. As a therapeutic measure, selenium has been reported to counteract arsenic toxicity (Wang, 2001). A good numbers of research are being carried out on the cause, characteristics and consequences of arsenic pollution on skin lesion. Only a few numbers of studies have been done on social and economic point of view (Caldwell, Mitra & Smith, 2003; Hanchett, 2004; Paul, 2004; Hassaan, Atkins & Dunn, 2005; Nahar, Hossain & Hossain, 2007; Sarker, 2008) however, it is important to note that these studies ignore any spatial patterns that may be present in the data although it is a very crucial and critically important issue. When the spatial dependence is ignored, the ordinary least squares (OLS) estimates will be inefficient, the t and F-statistics for tests of significance will be biased and the R^2 measure of fit will be misleading (LeSage & Pace, 2004, Anselin, 1988). In other words, the statistical interpretation of the regression model will be wrong. Since the attributes associated with the built environment and natural amenities are spatially located, it is reasonable to hypothesize that health disorders like arsenicosis are spatially clustered based on neighboring socioeconomic, demographic and environmental attributes. While the application of explicit spatial econometric methods has recently shown a tremendous increase in the social sciences in general and economics in particular (Anselin, 2001), to date, there have been only a few of studies that employed spatial regression analysis in the study of health related data in South Asia. It is very important for us to identify the efficient and consistent influencing factors of the arsenic related issues in the arsenic affected areas at first, before planning of any mitigation methods and intervention programs for arsenic free water. With this background, my study is focused on detecting the determinants of households' knowledge about arsenic contaminated drinking water, investigating how neighborhood effects can be viewed as spatial models and performing model comparisons for different specifications. The current study is important for several reasons. First, the present study is the first to address the spatial dimension for environmental health problem awareness in Bangladesh, second, this methodology provides consistent and efficient estimation and third, my results have important implications for policy both at the regional and national level, especially those involving the design of regional coordination for arsenic free drinking water.

4.2 Methods

4.2.1 Spatial Regression Model

The standard regression model specifies a functional relationship between a dependent variable y_i (the response variable measured at site/location i) and a set of explanatory variables $x_{1,i}, \ldots\ldots x_{k,i}$ (measured at site i), so that

$$y_i = \beta_0 + \beta_1 x_{1,i} + \beta_2 x_{2,i} + \ldots\ldots\ldots\ldots + \beta_k x_{k,i} + \varepsilon_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where β_0 to β_k are regression coefficients and ε refers to the error or disturbance term.

In matrix notation (1) can be written:

$y = X\beta + \varepsilon$ …………………..…………………………………………………….. .(2)

Where X is an (n x (k+1)) matrix of observations on the explanatory variables, with the first column consisting of 1s; y and ε are n x 1 vectors and β is a (k+1) vector. If E (εε) = $\sigma^2 I$, where I is the nxn identity matrix then the arrangement properties of the attributes are irrelevant to the specification of the model.

The method of OLS estimation is referred to as a Best Linear Unbiased Estimator (BLUE). The OLS estimates β by minimizing the sum of squared prediction errors, hence, least squares. In order to obtain the BLUE property and make statistical inferences about the population regression coefficients from the estimated b, certain assumptions about the random error of the regression equation need to be made. These include: a) the random errors have a mean of zero ($E[\varepsilon_i] = 0$) (there is no systematic misspecification or bias in the population regression equation); b) the random errors have a constant variance, $var[\varepsilon_i] = \sigma^2$ (homoskedasticity) and are uncorrelated, $E[\varepsilon_i \varepsilon_i] = 0$, for all i, j; and c) the random errors have a normal distribution. These assumptions may not be always satisfied in practice.

Most econometrics techniques on cross-section data are based on the assumption of independence of observations. However, economic activities become more and more correlated over space with modern communication and transportation improvements. On the other hand, technological advances in communications and the geographic information system make spatial data more available than before. Spatial correlations among observations received more and more attentions in regional, real estate, agricultural, environmental and industrial organizations economics (Lee, 2004). Spatial dependence refers to a situation where a variable shows patterns of similarity or dissimilarity across space. If there is a systematic pattern in the spatial distribution of a variable, it is said to be spatially auto correlated. If, for example, the pattern on a map is such that nearby or neighboring areas are more similar than more distant areas, the pattern is said to be positively spatially auto correlated. When a value observed in one location depends on the values observed at neighboring locations, there is a spatial dependence. Spatial dependence arises when an observation at one location, say y_i is dependent on neighboring observations y_j,

$y_j \in Y_i$……………………………………..…………..………………………(3)

We use Y_i to denote the set of observations that are "neighboring" to observation i, where some metric is used to define the set of observations that are spatially connected to observation i. For general definitions of the sets Y_i, i= 1,……,n, typically at least one observation exhibits simultaneous dependence, so that an observation y_j, also depend on y_i. That is, the set Y_j contains the observation y_i, creating simultaneous dependence among observations. In parallel to time series analysis, spatial stochastic processes are categorized as spatial autoregressive (SAR) and spatial moving average (SMA) processes, although there are several important differences between the cross-sectional and time series contexts (Anselin and Bera, 1998). The benefits of modeling spatial autocorrelation are many: the residual errors will have much lower spatial autocorrelation (i.e. systematic variation). With the proper choice of W, the residuals should, at least theoretically, have no systematic variation. If the spatial autocorrelation coefficient is statistically significant, then SAR will quantify the presence of spatial autocorrelation. It will indicate the extent to which variations in the dependent variable (y) are explained by the average of neighboring observation values. Finally, the model will has a better fit (i.e., a higher R squared statistic).

In the standard linear regression model equation (1) or (2), spatial dependence can be incorporated in two distinct ways: as an additional regressor in the form of a spatially lagged dependent variable (Wy), or in the error structure ($E[\varepsilon_i \varepsilon_j] \neq 0$).

4.2.1.1 Spatial lag model

A spatial lag model is a formal representation of the outcome of processes of social and spatial interaction. Spatial lag or regressive spatial autoregressive model, includes a spatial lagged dependent variable on the right hand side of the regression specification (Anselin, 1988). A dependent variable y in place i is affected by the independent variables in both place i and j. With spatial lag in OLS regression, the assumption of uncorrelated error terms is violated; in addition, the assumption of independent observations is also violated. As a result, the estimates are biased and inefficient. The relations among the variables in the presence of spatial lag are shown in the Figure 4.1. If the response variable values y_i are related to each other, a pure spatial autoregressive model simply consists of a spatially lagged version of the dependent variable, y:

$$y = \rho W y + \varepsilon \qquad (4)$$

As can be seen this is similar to a standard linear regression model where the first term is constructed from a N by N spatial weighting matrix, W, applied to the observed variable, y, together with a spatial autoregression parameter, ρ, which typically has to be estimated from the data that reflects the strength of the spatial dependencies between the elements of the dependent variable. Formally, a spatial lag for y at i is then expressed as

$$[Wy]_i = \sum w_{ij} y_j \quad \text{……………………………………………………………………(5)}$$

j = 1, …,N

or, in matrix form as Wy

After the correction term ρWy is introduced the component of the residual error vector ε are then assumed to be generated from independent and identical standard normal distributions.

For an individual observation the basic spatial lagged autoregression equation is simply:

$$y_i = \rho \sum_j W_{ij} y_j + \varepsilon_i , \ldots \varepsilon \sim N(0, \sigma^2 \mathrm{I}_n) \quad \text{……………………………………………(6)}$$

Since the dependent variable, y, appears on both sides of the equation (4), it can be re-arranged to give:

$$y = (\mathrm{I} - \rho W)^{-1} \varepsilon \quad \text{…………………………………………………………………...(7)}$$

where the matrix I-ρW is referred to as a spatial filter, with I as an identity matrix of dimension N by N and the other notation as before.

From the equation (7), we can obtain an expression for the variance of y as:

$$\mathrm{var}(y) = E(yy) = (\mathrm{I} - \rho W)^{-1} E(\varepsilon\varepsilon)(\mathrm{I} - \rho W)^{-1} \quad \text{………………………………………..(8)}$$

Hence,

$$\mathrm{var}(y) = E(yy) = (\mathrm{I} - \rho W)^{-1} C (\mathrm{I} - \rho W)^{-1} \quad \text{…………………………………………….(9)}$$

Where C is the variance-covariance matrix

This derivation has made no distributional assumptions regarding the response variable or the errors. In this model the spatial weights matrix, W, is effectively raised to the power 1, so only first-order neighbors are included in the autoregressive function, and for this reason this model is therefore sometimes described as having a 'first-order' specification. If we add additional predictor variables, x, to the pure spatially lagged autoregression model described earlier we have a mixed regressive spatial autoregressive model (MRSA):

$$y = X\beta + \rho Wy + \varepsilon \quad (10)$$

As can be seen this is the same as a standard linear regression model with the addition of the autoregressive component.

A mixed regressive-spatial autoregressive specification can be interpreted in three different ways. In a first perspective, the main focus is on the spatial dependence. One is interested in finding out how the variable y relates to its value in surrounding locations (the spatial lag), while controlling for the influence of other explanatory variables. This is the case when the spatial pattern in a dependent variable is actually due to the spatial pattern of other variables with which it is strongly correlated.

A second interpretation is when the interest is really in the relation between the explanatory variables and the dependent variable, after the spatial effect has been controlled. This is often referred to as spatial filtering or spatial screening (Getis, 1990). In other words, once the spatial effect has been filtered out on the left hand side of the expression, the correct relationship with the other explanatory variables can be assessed.

Finally, the model can be viewed in its nonlinear form, as a description of the mean or expected values for the dependent variable in function of the exogenous explanatory variables (i.e., as a reduced form). This nonlinear form clearly illustrates that how the expected value of the dependent variable at each location is a function not only of explanatory variables at that location, but of the explanatory variables at all other locations as well.

As before, we can re-arrange this expression (10) to solve for y which no longer contains any spatially lagged dependent variables on the right hand side.

$$y = (\mathrm{I} - \rho W)^{-1} X\beta + (\mathrm{I} - \rho W)^{-1} \varepsilon \quad \text{……………………………………………………..(11)}$$

The design of this kind of mixed model incorporates spatial autocorrelation together with the influence of other (spatial) predictor variables. The objective of this revised approach is to obtain a significant improvement over a standard OLS model. The level of improvement will depend on how well the revised model represents or explains the source data and to an extent this will vary depending on the detailed form of the weighting matrix W.

4.2.1.2 Spatial Error Model

A second approach to spatial autoregressive process or spatial autoregressive modeling is known as the spatial error model. The error term in a regression can be considered to contain all ignored elements. If some of these show a significant spatial pattern, it will be reflected in a spatial pattern for the error terms. Hence, the indication of such a spatial pattern in regression residuals may lead to the discovery of additional variables that should be included in the model. The error terms across different spatial units are correlated. With spatial error in OLS regression, the assumption of uncorrelated error terms is violated. As a result, the estimates are inefficient. The relationship among the variables and error term in spatial error are shown in the Figure 4.2. Spatially correlated errors may occur due to spatial correlation among the independent variables, spatial heterogeneity in functional form, omitted variables and spatial correlation in the dependent variable when a spatially lagged dependent variable is not included in the model (Anselin, 1988). From an economic perspective, the spatial error model is commonly seen as a nuisance in that it captures autocorrelation in measurement errors, or in the fact that ignored variables spillover across the observations in a spatial manner (Anselin & Bera 1998). To establish a parallel with more commonly addressed econometric issues, consider heteroskedasticity in standard least squares models. If we knew the explicit heteroskedastic form of the error terms, we would simply reweigh to obtain consistent standard errors, ignoring altogether any economic interpretation. Spatial error models can be seen in the same light, we need to address the non-spherical nature of the covariance matrix to obtain (unbiased and) efficient estimates (Novo, 2004). The concept of spatial autocorrelation attributed to Cliff and Ord (1973) has been object of different definitions and in general sense, it implies the absence of independence among the observations, showing the existence of a functional relation between what happens at a spatial point and in the population as a whole. The existence of spatial autocorrelation can be expressed as follows:

$Cov\ (X_j, X_k) = E\ (X_jX_k) - E(X_j)E(X_k) \neq 0$

X_j, X_k being observations of the considered variables in units j and k which could be measured in latitude and longitude, surface or any other spatial dimension.

Spatial error autocorrelation is a special case of a non-spherical error covariance matrix, in which the off-diagonal elements are nonzero, i.e.,

$E[\varepsilon_i\varepsilon_j] \neq 0$, for $i \neq j$ ……………………………………………………………(12)

or, in matrix notation, E[εε] =∑

where ∑ ≠ I, with as the identity matrix.

The value and pattern of the non-zero covariances are the out come of a spatial ordering. The most common choice is a spatial autoregressive process,

$$\varepsilon_i = \lambda \sum_j w_{ij}\varepsilon_j + u_i \ldots\ldots (13)$$

With λ as the autoregressive parameter and u_i as a random error term, typically assumed to be i.i.d. In matrix notation, the spatial error model is defined as:

$$\varepsilon = \lambda W\varepsilon + u \ldots\ldots (14)$$

Hence the basic model is as per the standard linear model, but now the error term is assumed to be made up of a spatially weighted error vector, λWε, and a vector of *iid* errors, u. We can re-arrange the expression of equation (14) for ε**,**

$$\varepsilon = (\mathrm{I} - \lambda W)^{-1} u \ldots\ldots (15)$$

With E[uu]= σ^2I, hence the error variance-covariance matrix takes on the following form:

$$E(\varepsilon\varepsilon) = \sigma^2 \left[(\mathrm{I} - \lambda W)\ (\mathrm{I} - \lambda W)'\right]^{-1} \ldots\ldots (16)$$

where, $\psi = y - X\beta - \rho W y, \varphi = \mathrm{I} - \lambda W$ and ***I*** is a N X N identity matrix.

The linear models make a set of restrictive assumptions, most importantly, that the target (dependent variable *y*) is normally distributed conditioned on the value of predictors with a constant variance regardless of the predicted response value. Generalized Linear Square (GLS) is an extension of the linear modeling process that violates the classical assumption. Generalized Linear Models relax the requirement of equality or constancy of variances which are often violated in practice. Generalized

Linear Models have the form

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots\cdots\cdots\cdots + \beta_k X_{ik} + D\varepsilon_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(17)$$

where, $(D\varepsilon)'(D\varepsilon) = \sigma^2\Omega$

ε_i is a random error assumed to have a normal distribution and **Ω** is a positive definite matrix.

The spatial model is as follows:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots\cdots\cdots\cdots + \beta_k X_{ik} + \rho W y_i + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(18)$$

So, spatial weight model is also GLM.

4.2.2 Spatial Weights Matrix

The spatial weights matrix W is a N X N positive squared, non-stochastic matrix, whose elements w_{ij} show the intensity of interdependence between the spatial units i (in the row of the matrix) and j (column) in which the rows and columns correspond to the cross-sectional observations. A weight matrix summarizes the spatial relationships in the data. Note that the space in which the observations are located need not be geographic; any type of space is acceptable, as long as the researcher can specify the spatial interactions. Spatial can appear in many forms. The data can come from regions (e.g. districts) or points (e.g. houses). The data may be located on a regular grid or lattice, but this is not necessary. The numbers in the weight matrix can indicate whether or not a relationship is present or they can indicate the strength of the relationship. The former weighting schemes are called discrete and the latter, continuous.

Many alternative weighting schemes for W have been used in the literature. It is important to note that the elements of the weights matrix are exogenous to the model; that is, it is assumed that the researcher knows how the observations are related to each other. Typically, they are based on the geographic arrangement of the observations or contiguity. Formally, the membership of observations in the neighborhood set for each location is expressed by means of a square contiguity or spatial weights matrix (W), of dimension equal to the number of observations (N), in which each row and matching column correspond to an observation pair i.j. The cross-sectional spatial weights matrix formalizes the potential correlation among districts for which many alternative weighting representations are possible. I consider the binary join matrix and the inverse distance spatial weights matrix specifications of W in my empirical models to highlight any differences in spatial patterns of household knowledge.

4.2.2.1 Binary Contiguity/Join Matrix

One of the most common weights matrix in spatial econometrics literature is the binary joins matrix/ binary contiguity matrix (Anselin, 1988; Case, 1992; Cliff & Ord, 1981; Coughlin & Garrett, 2004) where $w_{ij} = 1$ if observations i and j ($i \neq j$) share a common border, and $w_{ij} = 0$ otherwise. Consequently, two spatial units are either neighbors or are not, hence the use of the term binary contiguity. By convention, the diagonal elements of *W* are set to zero (implying that locations are not neighbors of themselves). Because the weight matrix shows the relationships between all of the observations, its dimension is always N X N, where N is the number of observations.

$$W = \begin{bmatrix} 0, w_{12} \cdots\cdots\cdots\cdots w_{1j} \\ w_{21}, 0 \cdots\cdots\cdots\cdots w_{2j} \\ \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \\ \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \\ \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \\ w_{i1}, w_{i2} \cdots\cdots\cdots\cdots 0 \end{bmatrix} \quad \text{...(19)}$$

A limitation of the binary joins matrix is that it assumes equal weights across all bordering spatial neighbors and does not allow the effective capture of spatial distances across all cross sectional. For the estimation of spatial regression models, I used row-standardized binary spatial weights matrix for meaningful interpretation of the results. The row standardization consists of dividing each element in a row by the corresponding row sum, hence it is effectively including a weighted average of neighboring values into the regression equation.

4.2.2.1.1 Row Standardized Spatial Weight Matrix

For the estimation of spatial regression models, the spatial weights matrix should be row-standardized to yield a meaningful interpretation of the results, but not necessary to row normalized the weight matrix. Row normalizing gives the weight matrix some nice theoretical properties. For example, row normalizing allows the weight matrices from different weighting schemes to be compared, since all elements must lie between 0 to 1 (inclusive). Row normalizing also allows λ to be bounded by -1 and 1. The row standardization consists of dividing each element in a row by the corresponding row sum; hence it is effectively including a weighted average of neighboring values into the regression equation. In this specification, the elements of matrix W are row-standardized by dividing each w_{ij} by the sum of each row i, so that they satisfy the following conditions

(i) $0 \le w_{ij} \le 1$ and

(ii) $\sum_j w_{ij} = 1$ for each row i.

Each element in the new matrix thus becomes:

Standardized $w_{ij} = w_{ij} / \sum_i w_{ij}$ ……………………………………………………..(20)

$$W = \begin{bmatrix} 0, w_{12} / \sum w_{1j} \cdots\cdots\cdots w_{1j} / \sum w_{1j} \\ w_{21} / \sum w_{2j}, 0 \cdots\cdots\cdots w_{2j} / \sum w_{2j} \\ \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \\ \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \\ \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \; \vdots \\ w_{i1} / \sum w_{ij}, w_{i2} / \sum w_{2j} \cdots\cdots\cdots 0 \end{bmatrix} \quad \ldots\ldots(21)$$

A side effect of this standardization is that the sum of all elements in W equals N, the number of cross-sectional observation. Since the row sum in row i (for w_{ij}) and row j (for w_{ji}) are not necessarily the same, the resulting row-standardized weights matrix is likely to become asymmetric, even though the original matrix may have been symmetric.

4.2.2.2 Inverse Distance Matrix

A limitation of the binary joins matrix is that it assumes equal weights across all bordering spatial neighbors and does not allow the effective capture of spatial distances across all cross sectional units. Thus, I also considered the various measures of spatial distance that have been discussed in the literature (Bodson & Peeters, 1975; Coughlin & Garrett, 2004; Dubin, 1988; Garrett & Marsh, 2002; Hern´andez-Murillo, 2003). Measures of spatial contiguity include the distance specification between districts, where $w_{ij} = 1/d_{ij}$, the inverse distance squared, where $w_{ij} = 1/ d^2_{ij}$ and exponential distance decay, where $w_{ij} = \exp(-d_{ij})$. As the distance between districts i and j increases (decreases), w_{ij} decreases (increases), thus giving less (more) spatial weight to the district pair when $i \neq j$. In all cases, $w_{ij} = 0$ for $i = j$. While there is no consensus on how distance between cross-sectional units should be measured, I follow Hern´andez-Murillo (2003) and Coughlin *et al., (*2004) and consider the distance between district population centers.

4.2.3 Association between Rho (ρ) and Lamda (λ)

The scalar ρ is the spatial lag coefficient, positive spatial correlation exists if $\rho > 0$, negative spatial correlation if $\rho < 0$, and no spatial correlation if $\rho = 0$ and λ is the spatial error coefficient. The errors are positively correlated if $\lambda > 0$, negatively correlated if $\lambda < 0$, and spatially uncorrelated correlated if $\lambda = 0$. The cases under the consideration of the models (10) and (14) are following:

Case (i): ρ = 0, λ = 0

Under this assumption, spatial lag weight matrix component ρWy and spatial error weight matrix component $\lambda W\varepsilon$ will be zero and estimating the parameter β, and then the general spatial model (10) and (14) reduce to the standard regression model. There is no spatial or serial error correlation in this model.

Case (ii): $\rho \neq 0$, $\lambda = 0$

The second case focuses on the spatial lag and ignoring the presence of spatial error correlation. If setting $\lambda = 0$ and estimating (ρ, β), it is spatial lag model which is clearly more meaningful. The general spatial model equation (10) and (14) tends to spatial error model (14). In such models, the dependent variable in location i is not only determined by covariates (X) specific to location i, but also by the value of the same dependent variable at other locations. Anselin and Bera (1998) suggest two interpretations of the spatial lag model. Either, it suggests true contagion (spatial spillovers, copy-catting or diffusion). This requires, however, that the observed spatial units match the true economic units and that the spillover is modeled theoretically. Or, the alternative interpretation results from situations where there is a mismatch between the true spatial scale and the observed one, e.g., census vs. economic units.

Case (iii): $\rho = 0$, $\lambda \neq 0$

The third case focuses on the error term and ignoring the presence of spatial lag correlation. If $\rho = 0$ and estimating the other parameters λ and β, then the general spatial model (10) and (14) take the equation (10) form. This case in the error term may arise through omitted variables that have a spatial dimension, such as climate, industrial patterns, or exogenous shocks (Abreu et al., 2004). Spatial error dependence is likely to be a problem in social science applications using cross sectional data due to the poor choice of spatial units, but also due to the predominance of spatial interaction and spatial externalities. In practice, this aspect of regression modeling is typically ignored, since the focus of attention in cross-sectional data tends to be on heteroskedasticity (i.e., unequal error variance). However, given that the consequences of ignored spatial error dependence are at least as serious as those of ignored heteroskedasticity, it should be standard practice to test regression residuals in cross-sectional studies.

Case (iv): $\rho \neq 0, \lambda \neq 0$

The fourth case considers the both spatial lag and spatial error term. In spatial lag + error models all three parameters (ρ, λ and β) are estimated. These models may be viewed in practice as resulting from poorly specified lag matrices Wy which results in spatial interactions in the error terms that need to be taken into account $W\varepsilon$ (Anselin and Bera, 1998). The most general spatial lag model and error model under the case four takes the following form;

$$y = \rho Wy + X\beta + \lambda W\varepsilon + \mu \quad \text{.....(22)}$$

4.2.4 Empirical Models

4.2.4.1 District Model

Examining the spatial effects on households knowledge about arsenic threat in drinking water of Bangladesh, I used the basic model of spatial correlation developed by Cliff and Ord, 1981; Anselin, 1988 and Coughlin *et al.,* 2004 allows for spatial dependence in the dependent variable or in the error component. However, dependence in space is more complicated than in the time setting because of four reasons: first, time is one dimensional whereas space has at least two dimensions; second, time has natural order (direction) whereas space has no natural direction; third, time is regularly divided because of regular astronomical phenomena whereas spatial observations are attached to geographic properties of the surface of the earth; fourth, time-series observations are draws from a continuous process whereas, with spatial data, it is common for the sample and the population to be the same (Pinkse et al., 2007).

The following district model was used for detecting the spatial effect:

$$y = \rho W y + \beta_0 + \beta_1 hhsize + \beta_2 lrate + \beta_3 pdensity + \beta_4 dwrate + \beta_5 asstatus + \beta_6 rmtwell + \varepsilon, where, \varepsilon = \lambda W \varepsilon + \mu \quad \ldots.(23)$$

where y is the percentage of households who have known about arsenic contaminated drinking water for a district of Bangladesh, *hhsize* is the house hold size, *lrate* is literacy rate, *pdensity* is the population density in per square kilometer, *dwrate* is daily wage rate of agricultural labour and *asstatus* is the binary variable taking value 1 for the districts that are under arsenic risk (average arsenic concentration >10µg/L) according DPHE/BGS survey and 0 otherwise, *rmtwell* is percentage of red marks tube well in a district.

4.2.4.2 Divisional and Regional Models

The basic spatial model detailed above assumes that the influence of spatial dependence is the same for all districts. To reveal differences in spatial correlation for geographic regions, I modify equation (21) to allow for different spatial correlation coefficients in four divisions and two regions of Bangladesh. I use four ex-administrative divisions in the contiguous 64 districts. The spatial model with regional/divisional spatial correlation coefficients may be written as:

$$y = \sum_{k=1}^{D} \rho_k W_k y + X\beta + \varepsilon \quad \ldots\ldots (24)$$

where, $$\varepsilon = \sum_{k=1}^{D} \lambda_k W_k + u = \left(\mathrm{I} - \sum_{k=1}^{D} \lambda_k W_k \right)^{-1} u \quad \ldots\ldots (25)$$

Here, D denotes the total number of divisions/regions and ρ_k and λ_k denote the spatial lag and spatial error lag coefficients, respectively, for division k. Each coefficient, ρ_k, measures the average correlation between a district in region k and the spatially weighted household knowledge of all other districts. W_k remains the (N × N) spatial weights matrices w_k. Each matrix W_k is constructed by pre-multiplying by a dummy variable that equals unity if district *i* is located in division/region *k*, and zero otherwise. In the case of a contiguity matrix, household knowledge in district *i* located in region *k* to be affected by household knowledge of all districts *j* that border district *i*, regardless of whether district *j* is in the same division/region as district *i*.

4.2.5 Model Comparison

To compare models, I consider the Akaike`s Information Criterion (AIC)

(Akaike, 1974) and the Bayesian Information Criterion (BIC) (Schwartz, 1978) based on the ML method. AIC, a penalized log likelihood criterion is defined by

$$AIC = -2\ \ell + 2K \quad (26)$$

Where ℓ is the log likelihood and k is the number of parameters.

$$SC = -2\ \ell + K \ln(n) \quad (27)$$

Where n is the number of observations.

In theory, the lower AIC and SC/BIC are the better specification.

4.2.6 Background of the Explanatory Variables

Literacy rate

Literacy rate is an important determinate for households' knowledge about arsenic contaminated drinking water. There is a high degree of illiteracy in rural Bangladesh. It is very difficult to convince people that the water from their tube wells could be poisonous for arsenic contamination because presence of arsenic cannot be determined using odor, color or taste. Moreover, arsenic creates a further problem because of its long time lag between drinking of contaminated water and appearance of health effects.

Daily wage rate of agricultural labour

Daily wage rate of agricultural labor is a proxy variable of another important socioeconomic covariate per capita income. Bangladesh is mainly an agricultural country. Agriculture is the single largest producing sector of the economy and it contributes about 22% to the total Gross Domestic Product (GDP) of the country. This sector also accommodates major portion of labor force. GDP growth rate of Bangladesh mainly depends on the performance of the agriculture sector.

Population density

Population density is a proxy variable for development indicator, employment opportunity and urbanization which is measured by the number of human inhabitants per square kilometre.

Household size

Average household size of different districts as proxy measures of lack of awareness. Household size/household member means a group of persons, living together and taking food from same kitchen. Large household size indicates social backwardness. They are belief some social or and religious superstition (false believe) which might has indirect impact on households' knowledge about arsenic contaminated drinking water. There are some peoples who expect support from children. Children can help in domestic work or and on farm work and or they can participate in labor market.

Arsenic status

Arsenic risk status is another arsenic pollution related variable. It is a dummy variable which takes the value 0 if a district arsenically safe and takes the value 1, if a district arsenically unsafe. Arsenically safe refers to a district average arsenic concentration is less than or equal to 50µg/liter and unsafe refers to a district average arsenic concentration is more than 50µg/liter.

Percentage of red mark tube well

Percentage of red marks tube well is one of the arsenic pollution related variables. The government has tried to inform people about the presence of arsenic in drinking water sources through a binary color coding system. The Department of Public Health Engineering is responsible for marking arsenic-contaminated and arsenic-free tube wells as red and green, respectively, and warned the villagers against drinking water from the red tube wells. A green-colored tube-well water is safe for human health and a red-colored tube is not safe for human health.

4.2.7 Data Sources

The data was used in this paper collected from the following six sources:

(i) Bangladesh Multiple Indicator Cluster Survey (MICS) 2006 (BBS & UNICEF, 2007) for percentage of households who have known of arsenic contamination drinking water and percentage of red marks tube well: MICS 2006 was conducted in 1,950 primary sampling units and covered as many as 62,463 households throughout the country during June through October, 2006. For sampling purpose, the whole country was divided into five strata, namely municipal, city corporation, rural, slum and tribal areas. The number of Primary Sampling Units (PSUs) was 384 in municipal areas, 156 in city corporations, 1,280 in rural areas, 52 in slums and 78 in tribal areas. Each PSU was an enumeration area of population census 2001 and comprising around 100 households. From each PSU 35 households were selected systematically for enumeration. The data collection and entry was done by the local consulting firm, Mitra and Associates, with close supervision and guidance from the Bangladesh Bureau of Statistics.

(ii) Statistical Pocketbook of Bangladesh (BBS, 2008) for average household size of different districts

(iii) Statistical Yearbook of Bangladesh (BBS, 2008) for literacy rate

(iv) Population Census 2001 for population density characteristics of different districts

(v) Directorate of Agricultural Extension personnel for daily average wage rate of agricultural labour and

(vi) Finally, aggregate data set of Groundwater Studies for Arsenic Contamination in Bangladesh for determining the arsenic risk status of different districts which was conducted by British Geological Survey and the Department of Public Health Engineering (BGS/DPHE, 2001), Bangladesh. The final data set for this survey consisted of samples from 3,534 tubewells from 61 of 64 districts and from 433 of the 496 upazilas of Bangladesh. The sampled area was approximately 129,000 km^2, compared with a total area for Bangladesh of about 152,000 km^2.

4.3 Results and Discussion

4.3.1 Descriptive Statistics of Variables

Table 4.1 provides descriptive statistics for the variables employed in the models. These statistics provide mean, maximum and minimum values and standard deviation.

4.3.2 Spatial Framework of Different Districts

The spatial relationship among locations in a spatial framework is often modeled via a contiguity matrix. A simple contiguity matrix may represent a neighborhood relationship defined using adjacency. Figure 4.3 shows a girded spatial framework with location of 64 districts and entries of sixty four districts of figure 4.3 are shown in Table 4.2.

4.3.3 Spatial Estimates with Binary Join Weights

Table 4.3 presents the spatial estimation results. Column [1] in table 4.3 corresponds to a standard regression model where no spatial effects among the neighboring districts are taken into account. The coefficients represent the effects of the explanatory variables on household knowledge about arsenic pollution. Column [2] corresponds to a specification where the spatial interaction among the districts is accounted. This model suggests that the knowledge of households about arsenic risk depends positively on neighboring districts households' knowledge. Columns [2], [3] and [4] present the results from three alternative specifications in which I account for spatial effect using binary join spatial weights to determine contiguity among the districts. As I discussed before, this scheme considers as neighbors only those districts that are adjacent to each other. Column [2] corresponds to the model with a spatial lag in the dependent variable, column [3] corresponds to the model with a spatial dependence in the error term and column [4] corresponds to the model with a spatial lag and error term. As I can see from the table, the spatial dependence coefficients are statistically significant. In particular, the spatial lag coefficient ρ indicates the presence of interaction among the districts. Specifications [1] through [4] suggest that the literacy rate of districts has a positive impact on the knowledge of arsenic pollution of households. The same is true for daily wage rate of agricultural labour and arsenic status of a district. Household size and population density per square kilometer have negative impact on the knowledge of arsenic pollution of households but the household size is statistically significant in all models and population density per square kilometer is not significant in case of spatial lag and spatial lag & error model. In the models corresponding to the binary spatial weights, the spatial lag in the dependent variable is statistically significant from zero at the 1 percent level and the spatial lag in the error term is not statistically significant. The results from a join spatial model (spatial lag +error) is shown in column [4]. The numerical interpretation of the estimated coefficients is as follows. The findings in column [2] of table 4.3, for example, suggest that a 1% increase the literacy rate, on average, an increase of about 0.20 percentage households' knowledge about arsenic pollution. A decrease of household size, 1 person per household induces increase 5.43 percentage households' knowledge about arsenic pollution. The interpretation for the dummy variable is straightforward, as the coefficient indicates that the district arsenically not safe the households who know about arsenic pollution is about 7.14 percent higher, on average, than the districts which is arsenically safe. The results from the models that both the spatial lag (column 2) and error (column 3) models reveal that the spatial lag and error coefficients are significantly different from zero. However, the Akaike Information Criterion (AIC), Schwarz Criterion (SC) and the log-likelihood statistics all reveal that the spatial lag model presented in columns 2 is provided a better fit than the spatial error model. The results from the model that include both the spatial lag and error term (column 4) reveal that only the spatial lag coefficient is significantly different from zero. The findings are presented in table 4.3 suggest that spatial dependence in district households' knowledge may be the best model using a spatial lag. This is supported by the AIC and SC, which are directly comparable across models and weigh the explanatory power of a model (based on the maximized value of the log-likelihood function).

4.3.4 Spatial Estimates with Inverse Distance Weights

An alternative definition of neighborhood effects in the households' knowledge about arsenic pollution allows knowledge of household in nearby districts that are not necessarily adjacent to affect a specific district. In this case, the use of inverse-distance spatial weights is more appropriate to identify spatial interactions among the distance spatial weights of districts. Columns [2] through [4] in table 4.4 present the estimation results using spatial weights computed as the inverse distance between districts' population centers. The results are qualitatively similar to those in table 4.3. The results from a joint spatial model, in column [4], suggest spatial interaction in both the dependent variable and in the error term. The coefficients for the spatial lag in columns [2] and [4] are positive, supporting the conclusion that there is a positive interaction in the households' knowledge among the districts. The spatial coefficients are statistically significant in model 2 and model 4 but the spatial error coefficients are statistically insignificant in model 3 and model 4. The AIC, BIC and log likelihood statistics suggest that the spatial models show better fit than non-spatial model (column1of table 4.4). Among the four specifications, log likelihood value is lowest for joint (spatial lag + error) model (column 4) and AIC and SC are lowest in spatial lag model (column 2). The findings from table 4.4 suggest that the spatial lag model is the best model for expressing the spatial dependence of district households' knowledge.

4.3.5 Divisional and Regional Spatial Estimates

Table 4.5 presents the results from four specifications that allow for regional and divisional differences in the spatial correlation coefficients by using binary joins and inverse distance contiguity. Because my results in table 4.3 and table 4.4 indicate that a spatial lag models are the appropriate specifications, therefore, I only consider for divisional and regional differences in spatial lag coefficients among the four specifications. Column 1 reports the estimates from the spatial lag model that allows for regional-specific spatial lag coefficients at the administrative division level, while Column 3 allows regional-specific spatial lag coefficients at the regional (North, South) level when neighbors are defined as common border. I find considerable evidence that the effects of spatial correlation in the dependent variable vary by division. As reported in column [2] of table 4.5 two regional correlation coefficients are positive and statistically significant at the 1 percent level; furthermore, visual inspection of the estimated coefficients suggests differences in the magnitude of spatial correlation between a district in a given region and all other districts. The regressions that allows for division level spatial coefficients (column 1 of table 4) provides a same picture with the region level model (column 3). Estimates of positive and significant spatial correlation in four divisions range from 0.6923 to 0.6236 when neighbors are defined by binary joins matrix and 0.3760 to 0.3166 when spatial weight are defined by inverse distance matrix. Estimates of spatial correlation in two regions are 0.6197 and 0.6526 when neighbors are defined by binary joins matrix and 0.3332 and 0.3328 when spatial weights are defined by inverse distance matrix. All spatial coefficients for region are positive and statistically significant (P<0.01). The AIC, BIC and log likelihood statistics suggest that the binary joins matrix contiguity spatial models show better fit than inverse distance spatial weights matrix models in both regional and divisional models.

4.3.6 Equality of Spatial Coefficients of Divisional and Regional Models

The spatial coefficients in the Dhaka, Chittagong, Khulna and Rajshahi divisions as well as Northern and Southern regions of Bangladesh are substantially larger when neighbors are defined by common border as opposed to inverse distance. The results from the divisional and regional specific models in table 4.5 suggest that the spatial effects on district households' knowledge are more or less homogeneous across divisions and regions. Further evidence is reported in table 4.6 on basis of table 4.5, where I present the results of the seven pair wise hypothesis tests of the equality of the spatial correlation coefficients when neighbors defined as common border from the fourteen possible pair wise equality tests at the divisional level and regional level. There are six pair wise equality tests for model 1 at the divisional level and one pair wise equality test for model 3 at the regional level of table 4.5. Using the common-border (binary join matrix) neighbor definition, the test results are shown that the spatial correlation for districts in each division is statistically homogenous from the correlation in other divisions, with the exception of the Rajshahi and Khulna divisions. The test results (column 2 and 4 of table 4.5) indicate that spatial correlations are not significantly different across all divisions and regions when neighbors are defined by the inverse distance.

4.4 Conclusion

In this study, I estimate spatial econometric models to explore the spatial dependence in the knowledge of households about arsenic pollution like environmental health problem. This study is the first to directly model and provide estimates on the spatial interdependence of a district households' knowledge about arsenic contaminated water and the approach taken here affords the estimation of consistent and efficient coefficients. The results from spatial models strongly indicate that the households' knowledge about arsenic contaminated drinking water are combination of the household characteristics, arsenic related factors of individual districts and the households' knowledge of their neighbors districts. Five characteristics- literacy rate, daily wage rate of agricultural labor, household size, arsenic status and percentage of red mark tube well are significantly related to household knowledge of a district. Based on the AIC, SC and log likelihood, all of the spatial models are preferred to the without spatial weight specification, but the spatial lag model that utilizes the binary joins contiguity weights matrix provides the best fit of the data. The models in which I assume a common spatial lag coefficient for all districts, this results indicate that one percentage increase in the average households' knowledge of neighboring districts generates between a 0.33 and 0.61 percentage increase of a given district households' knowledge, depending on the specification. Using either a binary or inverse distance weights matrix in the estimation of spatial effects, this results provide strong evidence that significant spatial correlation exists in district, divisional and regional level models. These results suggest that district should pay particular attention to policies in neighboring districts and policy maker should realize that improving the households' knowledge level in neighboring districts are likely to affect households' knowledge in their own district, therefore, a key issue for policy development is how to stimulate educational attainment, promote daily wage of agricultural labor and decrease household size and population density could increase household knowledge and result in sustainable development and poverty alleviation of regions that are both knowledge on arsenic pollution and economically lagging. This needs to be addressed both in terms of national level policies and more emphatically within regional and sub-regional development strategies than it has been hither.

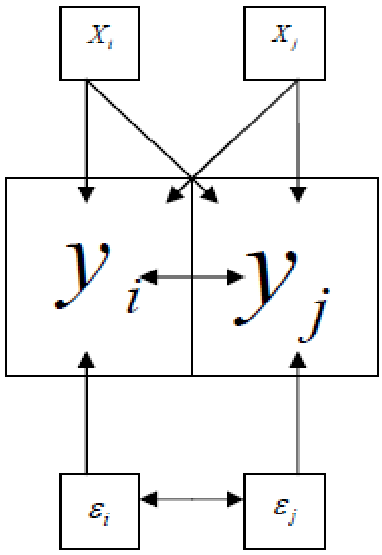

Figure 4.1 Relationship among the variables in case of spatial lag

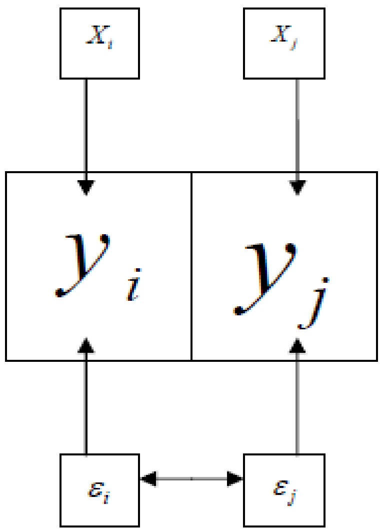

Figure 4.2 Relationship among the variables in case of spatial error

Table 4.1 Descriptive statistics of variables

Variables	Mean	Maximum	Minimum	Standard Deviation
Households who have knowledge about arsenic contamination (%)	77.98	98.50	30.80	18.48
Household size	4.74	5.94	3.85	0.46
Literacy rate (%)	43.78	65.90	28.00	8.52
Population density (per sq. km)	951.64	5857.60	65.39	732.11
Daily wage rate of agricultural labour (TK.)	185.31	250.00	130.00	12.22
Arsenic status (Dummy)	0.72	1	0	0.45
Red mark tube well (%)	10.03	10.59	0	49.52

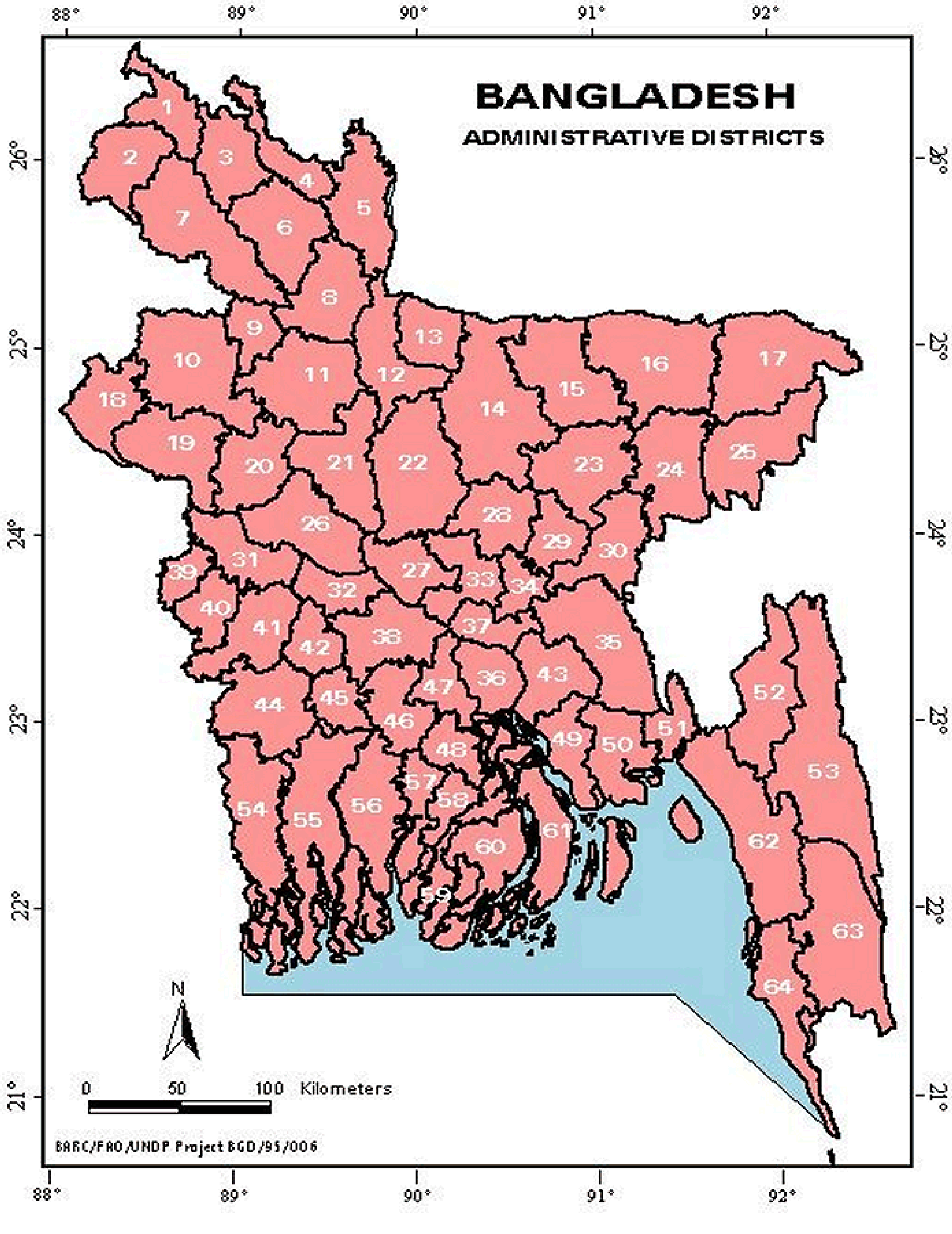

Figure 4.3 Spatial framework of 64 districts of Bangladesh

Table 4.2 Entries of sixty four districts of Figure 4.3

District code	Name of district	District code	Name of district
1	Panchagarh	33	Dhaka
2	Thakurgaon	34	Narayanganj
3	Nilphamari	35	Comilla
4	Lalmonirhat	36	Shariatpur
5	Kurigram	37	Munshiganj
6	Rangpur	38	Faridpur
7	Dinajpur	39	Meherpur
8	Gaibandha	40	Chuadanga
9	Jaipurhat	41	Jhenaidah
10	Naogaon	42	Magura
11	Bogra	43	Chandpur
12	Jamalpur	44	Jessore
13	Sherpur	45	Narail
14	Mymensingh	46	Gopalganj
15	Netrokona	47	Madaripur
16	Sunamganj	48	Barisal
17	Sylhet	49	Lakshmipur
18	Nawabganj	50	Noakhali
19	Rajshahi	51	Feni
20	Natore	52	Khagrachari
21	Sirajganj	53	Rangamati
22	Tangail	54	Satkhira
23	Kishoreganj	55	Khulna
24	Habiganj	56	Bagerhat
25	Maulvibazar	57	Pirojpur
26	Pabna	58	Jhalakathi
27	Manikganj	59	Barguna
28	Gazipur	60	Patuakhali
29	Narsingdi	61	Bhola
30	Brahmanbaria	62	Chittagong
31	Kushtia	63	Bandarban
32	Rajbari	64	Cox's Bazar

Table 4.3 Spatial estimates with binary weights of the knowledge of households about arsenic contaminated drinking water

Variables	Coefficients			
	No Spatial Effect (1)	Spatial Lag (2)	Spatial Error (3)	Spatial Lag & Error (4)
Constant	15.1360 (14.5759)	8.7413 (11.2115)	12.9440 (13.1759)	8.7855 (11.1376)
Literacy rate (%)	0.3059** (0.1418)	0.1986** (0.1004)	0.2729** (0.1284)	0.19311*** (0.0936)
Daily wage rate of agricultural labour (TK.)	0.3918*** (0.0567)	0.1770*** (0.0540)	0.3738*** (0.0514)	0.1921*** (0.0561)
Population density (per sq. km)	-0.0040** (0.0016)	-0.0015 (0.0013)	-0.0033** (0.0015)	-0.0015 (0.0013)
Household size	-6.6984*** (2.3774)	-5.4292*** (1.8318)	-4.8504** (2.2013)	-5.0904*** (1.8563)
Arsenic status (Dummy)	12.27132*** (3.0532)	7.1476*** (2.4615)	0.6760*** (2.8404)	6.9766*** (2.4523)
Red mark tube well (%)	0.3576*** (0.1090)	0.2079** (0.0864)	0.3147*** (0.0991)	0.2109*** (0.0859)
Rho	--	0.6108*** (0.0911)	--	0.5551*** (0.1088)
Lamda	--	--	0.6892*** (0.1812)	0.1695 (0.1836)
Log Likelihood	-224.6958	-207.6679	-218.1715	-207.2441
AIC	465.3916	433.3358	454.3429	434.4882
BIC	482.6626	452.7657	473.7729	456.077

Standard error in the parentheses. Asterisks ** and *** indicate statistical significance at the 5% and 1% levels, respectively.

Table 4.4 Spatial estimates with inverse-distance weights of the knowledge of households about arsenic contaminated drinking water

Variables	Coefficients			
	No Spatial Effect (1)	**Spatial Lag (2)**	**Spatial Error (3)**	**Spatial Lag & Error (4)**
Constant	15.1360 (14.5759)	8.1300 (13.4457)	14.49067 (14.4775)	7.8598 (13.3989)
Literacy rate (%)	0.3059** (0.1418)	0.2718** (0.1298)	0.3123** (0.1409)	0.2767** (0.1295)
Daily wage rate of agricultural labour (TK.)	0.3918*** (0.0567)	0.3015*** (0.0576)	0.3752*** (0.0587)	0.2925*** (0.0587)
Population density (per sq. km)	-0.0040** (0.0016)	-0.0042*** (0.0015)	-0.0037** (0.0017)	-0.0039** (0.0015)
Household size	-6.6984*** (2.3774)	-4.9151** (2.2261)	-6.0343*** (2.4506)	-4.5208** (2.2865)
Arsenic status (Dummy)	12.27132*** (3.0532)	9.3102*** (2.9065)	11.7663*** (3.0713)	9.0447*** (2.9195)
Red mark tube well (%)	0.3576*** (0.1090)	0.3191*** (0.1000)	0.3447*** (0.1089)	0.3116*** (0.1002)
Rho	--	0.3332*** (0.0930)		0.3260*** (0.0932)
Lamda	--	--	1.4065 (1.4052)	0.9158 (1.2951)
Log Likelihood	-224.6958	-218.8461	-224.1988	-218.597
AIC	465.3916	455.6921	466.3975	457.194
BIC	482.6626	475.1221	485.8275	478.7828

Standard error in the parentheses. Asterisks ** and *** indicate statistical significance at the 5% and 1% levels, respectively.

Table 4.5 Divisional and regional spatial estimates of the knowledge of households about arsenic pollution

Variables	Coefficients			
	Divisional Spatial Lag		Regional Spatial Lag	
	Binary join (1)	Inverse distance (2)	Binary join (3)	Inverse distance (4)
Constant	-1.8912	2.5762	1.0168	8.2198
	(14.2902)	(17.5653)	(12.5161)	(15.6276)
Literacy rate (%)	0.2549**	0.2196**	0.2448**	0.2792**
	(0.1210)	(0.1078)	(0.1161)	(0.1403)
Daily wage rate of agricultural labour (TK.)	0.1826***	0.3260***	0.1812***	0.3014***
	(0.0574)	(0.0631)	(0.0534)	(0.0581)
Population density (per sq. km)	-0.0023	-0.0036**	-0.0016	-0.0042***
	(0.0014)	(0.0017)	(0.0013)	(0.0015)
Household size	-4.6135**	-4.2527	-4.8057**	-4.9236**
	(2.3269)	(2.778)	(1.8682)	(2.3505)
Arsenic status (Dummy)	8.1779***	8.7845***	7.0255***	9.3110***
	(2.4742)	(2.9862)	(2.4305)	(2.9075)
Red mark tube well (%)	0.1666**	0.3287***	0.2168**	0.3190***
	(0.0819)	(0.1149)	(0.0856)	(0.1007)
ρ_1 (Dhaka)	0.6532***	0.3166***		
	(0.1001)	(0.1030)		
ρ_2 (Chittagong)	0.6547***	0.3448**		
	(0.1108)	(0.1431)		
ρ_3 (Khulna)	0.6236***	0.3685***		
	(0.0932)	(0.1097)		
ρ_4 (Rajshahi)	(0.6923)***	0.3760***		
	(0.1025)	(0.1106)		
ρ_1 (North)			0.6526***	0.3328***
			(0.0953)	(0.0995)
ρ_2 (South)			0.6197***	0.3332***
			(0.0901)	(0.0931)
Log Likelihood	-206.1423	-217.9901	-206.8093	-218.846
AIC	436.2846	459.9802	433.6186	457.692
BIC	462.1912	485.8868	455.2074	479.2808

Standard error in the parentheses. Asterisks ** and *** indicate statistical significance at the 5% and 1% levels, respectively.

Table 4.6 Spatial coefficients equality with binary join weights for divisions and regions

	Dhaka	Chittagong	Khulna	Rajshahi	North	South
Dhaka	----	ns	ns	ns		
Chittagong	ns	----	ns	ns		
Khulna	ns	ns	----	*		
Rajshahi	ns	ns	*	----		
North					----	ns
South					ns	----

Asterisk * indicates statistical significance at the 10% and ns means statistical insignificance.

Chapter-5

Modeling of the Factors Influence on Self-Perceived Health Status, Averting Behavior and Willingness to Pay [*]

5.1 Introduction

In recent years, many economists have been examining the factors that determine the self-perceived health status, given that individual well being and social welfare are central issues to be addressed in economics. The increased use of self-assessed health measures in both research and for shaping policy has been striking in the area of health economics. Health status has been found to be strongly associated with economic measures such as household income or wealth as well as with rank-related indicators such as occupational prestige (Lynch & Kaplan, 2000; Wilkinson, 1997). Many studies on social epidemiology have investigated the association between health and socioeconomic factors. It is now widely recognized that inequalities in health status associated with socioeconomic status are substantial (Kawachi & Kennedy, 1997; Subramainan et al., 2001; Oshio and Kobayashi, 2010).

The relationship between socioeconomic characteristics and health has been well documented in the health economics literature for many decades (Fox, 1989;

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Lynch & Kaplan, 2000; Townsend & Davidson, 1982). Increased incidences of chronic disease as well as low self-perceived health are existed in the lower socio-economics status (SES) classes (Dalstra et al., 2005; Warren et al., 2004). An understanding of the causal pathways that lead to this SES and health relationship is important for effective policy interventions to reduce the burden of ill-health. Specifically, education leads to knowledge, credentials and social networks, which in turn leads to employment, giving individuals a sense of purpose and attachment to the community; employment is a source of income which gives access to improved housing, nutrition, material wealth and other resources, all which can lead to better mental and physical health states (Lynch & Kaplan, 2000; Ross & Mirowsky, 1999; Karmakar and Breslin, 2008). Studies by Cavelaars et al. (1998) and Dalstra et al. (2005) have found specific associations between low education and poor health outcomes. In particular, evidence suggesting that income and educational attainment significantly affect the health which has important implications on economic and educational policies (Smith, 1999; Lleras-Muney, 2005; Oshio and Kobayashi, 2010). Education does not solely improve access to the labor market, but also influences health by increasing knowledge, problem-solving skills, disposition, values and esteem, thus giving individuals a greater measure of personal control (Liberatos et al., 1988; Ross & Mirowsky, 1999). Ross and Mirowsky contend that this personal control leads people to make better decisions and initiate health-enhancing behaviors with the knowledge that their actions will have a positive influence on their health.

Smoking behavior, alcohol consumption, exercise and obesity are healthy lifestyle factors that have been known to influence self-perceived health and other physical health outcomes (Bhattacherjee et al., 2003; Manderbacka et al., 1999). Explanations on the differential health outcomes often highlight socioeconomic inequality as a fundamental cause for variations in their well-being (Adler & Ostrove, 1999; Huisman et al., 2003; McDonough &Walters, 2001; Roy and Chaudhuri, 2008).

Education and income are the most powerful components of SES for arsenicosis health perception (Sarker, 2010). The importance of each component may differ between and within countries and cultures (Kagamimori et al., 2009). Over periods of time, such efforts have exhibited impressing results in many parts of the world. Some development specialists and policy makers have also been taking important steps in this regard. The majority of previous studies, however, have focused on developed countries. On the other hand, self perceived health statuses in developing countries are limited. The health status of Bangladesh can be substantially improved despite the prevailing distress health conditions. The intended progress might have been hampered by different socioeconomic, political, and environmental factors. Thus, in this study, the first address to investigate how and to what extent these various factors may influence an individual's self-perceived arsenicosis based health status among the individuals in Bangladesh.

The objective health status data of arsenicosis is not available at present. Moreover, the data collection of objective heath status is very difficult, costly and time consuming. The health outcome used in this analysis is self-perceived health. Subjective health measurement is contributing to the evaluation of health problems, the burden of diseases and health needs at the population level. Self perceived health status is not a substitute for more objective indicators but it is an important measure in determining health status and health-related quality of life.

When rural people had developed the habit of drinking tube well water, arsenic was found in tube well water in many parts of Bangladesh too high concentration which has drastically reduced the coverage of safe water. The government has tried to inform people about the presence of arsenic in drinking water sources through a binary color coding system. The Department of Public Health Engineering is responsible for marking arsenic-contaminated and arsenic-free tube wells as red and green, respectively, and warned the villagers against drinking water from the red tube wells. A green-colored tube-well water is safe for human health and a red-colored tube is not safe for human health. The green colour refers to tube-wells that have a concentration of arsenic of less than or equal to 50μg/liter, the red colour refers to tube-wells that have a concentration of arsenic more than 50μg/liter.

However, since the discovery of arsenic in ground water in the nineties, Bangladesh has struggled once again with the problem of delivering safe water. Aftab, Haque and Khan (2006) have shown that raising awareness on arsenic-related health risks leads to adoption of averting technologies. The impact of switching from red to green source of water reduces probability of sickness by 4.6 percent, by far the largest gain in terms of reducing sickness. An estimated 28-50 million Bangladeshis are at risk from arsenic contaminated water. For a population of 28 million people exposed to arsenic risks, this is equivalent of 6.92 million workdays lost per year or a 350 million taka loss in income for affected individuals. For the higher estimate of 50 million people at risk, this is equivalent of 625 million taka loss in income. Hence, 350 million to 625 million taka is the total benefit in terms of avoiding workday losses by switching to green source of water. Given the range of population at risk, the equivalent savings in terms of medical expenditure avoided by switching to green source of water is between 206.61 and 368.94 million taka per year (Khan and Haque, 2010).

Switching from arsenic-contaminated tube-well to non-contaminated (or arsenic free) has distinct implication on time cost. Estimates show an 11-fold increase in the time-burden to obtain arsenic-free water compared to the earlier contaminated source. Before switching to the arsenic- free source, it took only about 20 minutes a day for an average household to obtain drinking water, and it has raised to about 220 minutes after switching to the (new) arsenic-free source. Although the shift to groundwater helped in controlling waterborne diseases (Mahmood and Ball 2004).

Nonetheless, either due to limited alternative sources of water or for other reasons, many households continue to use water from the “unsafe” tube-wells. Currently 16% population is covered by arsenic mitigation technology and it is expected that the coverage will be increased to about 22% by 2015 (GED & UNDP, 2009). Therefore, the present study also addresses to examine the factors that influence the respondents to switch from red tube well to green tube for drinking water.

Willingness to pay for arsenic-free, safe drinking water in rural Bangladesh which investigated the factors that influence demand for arsenic-free, safe drinking water. A critical problem in valuation of an environmental product like the facilities for safe drinking water is that the explicit markets for environmental quality do not usually exist. As a result, the assignment of a monetary value for an environmental product is primarily based on non-market data such as the results of surveys. Respondent's willingness to pay (WTP) for getting benefits expressed in money terms is a central concept of this framework. In this approach, respondents (consumers) are offered a hypothetical market, in which they are asked to express the WTP for existing or potential environmental conditions not reflected in any real market.

Annual total willingness to pay for switching from red to green sources of water was Taka 1056.82 ($18) per household (Khan and Haque, 2010). The estimated average willingness to pay of poor households (monthly household income less than Tk. 3600) was Tk 44 per month, plus an initial payment of Tk. 838 for public stand posts and Tk. 68 per month plus an initial payment of Tk. 1401 for a domestic connection by using the CV method (Ahmad et al., 2006). However, in this study, they did not measure WTP for any specific arsenic-free water at the household level.

Interventions to supply arsenic-free drinking water require varying investments at the community level as well as household actions to obtain safe drinking water. Invariably, this means that households have to bear some portion of the costs or full of such investments. But, what are households willing to pay for arsenic-free water? In this chapter, I also try to address this question by estimating the costs, households bear for avoiding consumption of arsenically unsafe water.

5.2 Methodology

5.2.1 Study Area

The literacy rate is only 68% and the population of about 260,0263 with population density per square kilometer 1297 in Chandpur district. Three Upazilas namely Hajiganj, Matlab South and Matlab North out of 8 Upazilas of Chandpur district were selected as they are known to be highly contaminated with arsenic in underground water and located in southern region of Bangladesh. The upazila is the second lowest tier of administrative government in Bangladesh. The districts of Bangladesh are divided into sub-districts called Upazila. The area is approximately 100 km south from Dhaka, the capital city of Bangladesh.

5.2.2 Data Collection

The current study is based on cross-sectional primary data. A two-stage sampling procedure was undertaken for sample respondents selection. Firstly, three Upazilas were selected purposively from eight upzilas of Chandpur district. Secondly, then 300 respondents were selected by two-stage cluster sampling. Preliminary information on the severity of arsenic exposure to human of total 554 villages of three upazilas was collected from the local NGOs personnel, health workers, ICDDR, B field workers and local government and rural development department. A total forty five villages were selected from 554 villages on the basis of the severity of arsenic exposure. Then, six villages were randomly selected from severely affected 45 villages for the present study. A total of 50 respondents per village were randomly selected for interview. Extra 10% respondents were selected to accommodate unavailability, non-response and refusal of the participants. A pre-design pre-tested questionnaire was used to conduct the survey for collecting the information from respondents on socio-demographic variables including arsenicosis status of the respondents, household size, household's total monthly income, drinking water status, nutritional status, averting status of tube well and willingness to pay for arsenic free water. Four trained interviewers (three men and one woman) conducted the survey by face-to-face interview. Attention was given to the wording of the questions during questionnaire design, so that the respondents found it simple and could understand it easily. The target populations of the present survey consist of patients and non-patients. Firstly, the outlining and the aims of the study were described to the respondents and the issue of ethical consent was addressed by informed individual oral consent. Secondly, respondents were asked the pre-design questions. Height was measured in centimeters and weight was measured in kilograms. Standing height and weight of each participant were measured with the subjects wearing light clothes and not wearing shoes. The study was conducted during March 2010 to July 2010. The characteristics and scoring of respective variables consider for this study are presented in Table 5.1.

5.2.3 Definition of Variables

The variables used in the present study are defined in this section. The arsenicosis health status, averting status and willingness to pay for arsenic free water are dependent variables. The explanatory variables are classified into five groups: demographic, education, income, nutritional status and lifestyle factor. The choice of these variables was guided by the determinants of health status literature.

5.2.3.1 Dependent Variables

5.2.3.1.1 Arsenicosis Health Status

Arsenicosis health status (AHS) is an ordered latent-class dependent variable which reflects how the respondents rated their health by using a three-point scale ranging from good to very bad, denoted by AHS (coded as a categorical variable that ranges from 1 equals good to 3 equals very bad). Arsenicosis conditions are measured on the basis of self-reported symptoms of respondents. The AHS was assessed by using a standard question, in general, would you say 'do you have any arsenicossis problem(s)?' Last few years some organizations are working on arsenic contaminated drinking, arsenicosis and related problems although it is not sufficient. Arsenic is also arsenic in our mother tongue. So, comparatively, it is easy to understand. Therefore, some people know about arsenicosis. If the respondent did not know arsenicosis, then, the respondent was asked the question as proxy 'do you have any skin lesion problem (s)?' If answer was yes, then again the respondent was asked the question about the seriousness of arsenicosisus.

5.2.3.1.2 Averting Status

Averting behavior is adoption of any alternative technology to reduce arsenic concentration in drinking water. It is precautionary step on the part of the household. Averting means if any one drinking water collecting tube well is classified as unsafe, then, switching to alternative arsenic-free water source, it may be to find someone those tube-well is green and who allows him/her to use the safe tube-well or installed new tube well or reinstalled the present tube well in more deeper aquifer. In addition, switching to deep tube well or other community water supply system also averting but, still, there is no deep tube well for drinking water or community water supply system in my study area. It is not necessary to pay additional cost for safe water or to invest in safe well for averting. It depends on household intension, economic and social status as well as availability of alternative safe water source(s). Averting decision is done at the household level rather than at the individual level. It should be noted that respondents were excluded from the calculating of the descriptive statistics of averting cost in Table 5.2 who were switch to green water source without cost or investment. Averting status (AVSTA) is binary dependent variable which indicates weather a family is switch for arsenic free water (from red to green) or not. AVSTA was evaluated by asking the question "Do you have arsenic in your tube well?" If the answerer was 'no', then again the respondents were asked the question about AVSTA "Did you avert your source of drinking water?" The dependent variable AVSTA is valued at one if the respondent has switched from red to green source for drinking water and zero otherwise. There is no record about averting time income and food consumption of the respondents. Moreover, averting time is also different for different respondents. So, the present income and food consumption are used as proxy variables for the decision time income and food consumption.

5.2.3.1.3 Willingness to Pay

The present study was estimated the WTP for arsenic free water at the household level that a household pays to the owner of green tube-well whose present drinking water is unsafe. It is a payment for one-time investment. The estimates of willingness to pay obtained in this study indicate the possibility of introducing a demand driven program to expand an arsenic free drinking system in rural Bangladesh with the potential contribution from household. People are expected to run their water supply systems through community based techniques like deep tube well on a cost sharing principles with involvement of institutions like NGOs, government agencies etc. The present study suggests that the less expensive option with subsidized or without subsidized that the average cost is less than 1714.58Tk. may be acceptable to households.

Willingness to pay (WTP) for arsenic free water was estimated by the contingent valuation (CV) method. The CV method directly question individuals as to how much they are willing to pay for change in quantity or quality or both of a particular commodity. If a respondent was drinking arsenic contaminated water then the respondent was asked the question “Do you want to pay for arsenic free water?” If the answerer was ‘yes’, then again the respondents were asked the question “How much money want to pay for arsenic free water?”

5.2.3.2 Explanatory Variables

5.2.3.2.1 Demographic Variables

Demographic variables include age (age of the respondents in years), age^2

(age-squared), gender (equals 1 if female; 0 if male), household size (number of person in the family) and body mass index. BMI is used as a standard measure of weight independent of height. BMI is calculated by dividing weight in kilograms by height squared in meters [weight (kg)]/[height $(m)^2$]. The World Health Organization and the International Obesity Task Force defined cut off points of BMI based on associated co-morbidities. A BMI above 25 is classified as overweight, and a BMI greater than 30 is defined as obesity (Gibson, 2005).

5.2.3.2.2 Traditional Socioeconomic Status Variables

Traditional socioeconomic status variables include education level of respondent, household head education, highest education of the family members and household monthly income. Education level measures in year of schooling and household monthly income is based on the gross monthly self reported family income of the household.

5.2.3.2.3 Lifestyle Factor

Smoking status is used as a proxy variable for lifestyle factor. Smoking is another indicative dummy variable which takes the value 1 if an individual smokes and takes the value 0, if an individual does not smoke. The selection of the variable-smoking status is guided by the determinants of health status literature. There are many studies that smoking has negative impact on health status. My research question is 'does smoking status has any impact on arsenicosis health status

5.2.3.2.4 Nutritional Variables

Nutritional variables include vegetable consumption and protein intake conditions. Vegetable consumption and protein intake are also dummy indicator variables which represent whether an individual consumes sufficient amount of vegetable and protein or not. It takes the value 1 if an individual consumed sufficient amount of vegetable and protein in the last week of the interview and 0 other wise.

5.2.3.2.5 Arsenic Status

Arsenic status of tube well condition is proxy variables for environmental pollution. It is also another indicative dummy variable which takes the value 0 if a tube well arsenically safe and takes the value 1, if a tube well arsenically unsafe. Arsenically safe refers to tube-wells that have a concentration of arsenic of less than or equal to 50µg/liter and unsafe refers to tube-wells that have a concentration of arsenic more than 50µg/liter.

5.2.4 Estimation Method

Data analysis was carried out using Stata 9.0 statistical software (Stata Corp LP, TX, USA). In the present study, three different regression techniques are used for covering three topics.

Firstly, maximum likelihood order logit is used to identify the factors which influence the arsenicosis status of respondents. Order logit regression is used to estimate the relationships between an ordinal dependent variable and a set of independent variables. An ordinal variable is a variable that is categorical and order, here is arsenicosis based health status of respondents. In order logit, an underlying score is estimated as a linear function of the independent variables and a set of cutoff level. The probability of observing outcome corresponds to the probability that the estimated linear function, plus random error, is within the range of the threshold level estimated for the outcome. An ordered latent class variable of arsenicosis health status is considered to be explained by the individual's demographic, socioeconomic, lifestyle factor, nutritional status. Denoting individual *i*'s unobserved latent arsenicosis health status as H_i^*, the model can be written as:

$$H_i^* = X_i{}'\beta + u_i \qquad \text{where } u_i \sim (0, 1)$$

The vectors X' represent socioeconomic, demographic, nutritional and lifestyle characteristics. The individual's health status, H_i, is equal to k, if $\mu_{ik} < H_i^* \leq \mu_{ik+1}$ where the parameter k= 1, 2, 3, represents three arsenicosis health categories, "good" "bad" and "very bad" health. The parameter μ_{ik}, which varies from $-\infty$ to $+\infty$, denotes the unknown threshold levels of health categories that are to be estimated together with parameters β. Thus, the probability, *P*, of having a certain health status can be defined as:

$$(1)\quad \Pr[H_i = 1 \mid X] = \frac{1}{1+\exp(-K_1 + X\beta)}$$

$$(2)\quad \Pr[H_i = 2 \mid X] = \frac{1}{1+\exp(-K_2 + X\beta)} - \frac{1}{1+\exp(-K_1 + X\beta)}$$

$$(3)\quad \Pr[H_i = 3 \mid X] = 1 - \frac{1}{1+\exp(-K_2 + X\beta)}$$

Five different specifications with varying covariates are estimated for arsenicosis health status. The first model only controls for demographics support factors, and then gradually include additional explanatory variables. Model 1 controls for demographic factors, including age, age^2 (age-squared), gender, household size, BMI. Model 2 adds control on education and model 3 adds another important socioeconomic covariate income. Model 4 adds a control for nutritional status measured by self-reported vegetable and protein consumption but protein consumption status is dropped for multi-collinearity. Model 5 (full model) adds another control for lifestyle factor measured by smoking status.

Secondly, dichotomous logits are used to explore the determinants of averting behavior for arsenic free water. Two different specifications with varying covariates education of household head and highest education of the household members are estimated to investigate the question ‘whose education is the important for averting for arsenic free water?’.

Finally, maximum likelihood regression analysis is used to examine whether the magnitude and direction of association between the covariates- age, age square, gender, household size, education, income, vegetable consumption, protein consumption, participation of NGO(s) activities and outcome variable- the willingness to pay for arsenic free water. Contingent valuation method (CVM) is used for valuation of arsenic free water.

The most widely used method of valuation of non-market benefits is contingent valuation which is applied as an effective valuation technique to address a wide variety of issues such as water and other environmental pollutions (Whittington, 1990; Aguilar & Sterner, 1995; Ahmed et al., 2004; Gunatilake, 2006). Demand for valid and widely approved valuation method has led to comparison of the properties of the methods for valuing non-market goods and CV seems still to qualify the most reliable valuation method. One of the underlying assumptions of CVM is that people are willing and able to report a monetary valuation of their preferences for a given goods or services. One advantage of the method is that a hypothetical scenario can be created for goods and services for which no real market exists. A critical problem in valuation of an environmental product like the facilities for arsenic free drinking water is that the explicit markets for environmental quality do not usually exist. As a result, the assignment of a monetary value for an environmental product is primarily based on non-market data such as the results of survey. Drinking water supply services in the rural area of Bangladesh are not generally traded in the markets, therefore, no information on market demand or competitive market prices is available to value benefits in Bangladesh. Information on markets for bottled drinking water and other forms of traded water is sometimes available. However, such markets in developing countries are available only to a limited segment of the society. Consumer's willingness to pay for getting benefits expressed in money terms is a central concept of this framework. In this approach, respondents are offered a hypothetical market, in which they are asked to express the WTP for existing or potential environmental conditions not reflected in any real market. The most common form of questioning on hypothetical futures is called the contingent valuation method. It involves directly asking individuals what they would be willing to pay for particular goods or services contingent on some hypothetical change in the future.

5.3 Results and Discussion

5.3.1 Descriptive Statistics

Descriptive statistics of the study sample are presented in Table 5.2 and Figure 5.1. Table 5.2 presents the mean, maximum and minimum values and standard deviation of the dependent variables and covariates.

In this sample, the average age and body mass index of the respondent are 41.73 ± 13.90 years and 21.57 ±3.36, respectively. The average household size and monthly income are 5.62 ±2.04 and 8778 ± 4725 Tk. (1 US$ = 69Tk.), respectively. In this sample, only 4.67% baseline tube wells are arsenically safe. Among the unsafe tube wells, 16.08% respondents switched from unsafe to safe water tube well. Among the rest of the unsafe tube well water consumers, 90.83% want to pay for arsenic free water and other 9.17% do not want to pay for arsenic free water (Figure 5.1).

5.3.2 Arsenicosis Health Status

Results of the maximum likelihood order logit regression analyses for arsenicosis health status are presented in Table 5.3. The dependent variable is an ordered latent-class variable which indicates the ordered arsenicosis health categories of "good," "bad," and "very bad". The different measures of arsenicosis status are regressed for explanatory variables in which added in order of demographic factors, traditional SES, nutritional status and lifestyle factor in five different specifications. There are strong associations between age, age^2, gender, household size, BMI and arsenicosis status of respondents, as shown in Model 1 which controls for demographic factors. One of the important traditional socio-economic factor educational qualification is added in Model 2; education also has significant effect on the arsenicosis health status. Another important socio-economic factor income is added in Model 3; income also significantly adds to the model. Nutritional factor is added in Model 4; the vegetable consumption status, which represents an individual's nutritional status, is negatively significantly correlated with arsenicosis status. Lifestyle factor is added in Model 5; the results show that the expected probability of a smoker being arsenicosis is increased by 3.244 units in log odds scale. As age increases, expected health status (HS) tends to decrease by 0.36 units in ordered log odds scale while the other variables in the model are held constant. The household size is increase a unit, the expected HS in ordered log odds scale is decrease by 0.53 units. The expected HS would raise by 0.38 units in a log ordered scale when BMI is increase a unit. A unit increase in educational attainment would raise the expected HS in ordered log odds scale by 0.26 units. Similarly, a 1,000Tk. increase in monthly income would raise the value of expected health by 0.2 units. The sufficient vegetable consumption would raise the expected HS by 1.19 units.

There are numerous discussions and debates under way among the experts concerning micro-credit. There are some success stories in micro credit, the micro credit has developed women's micro entrepreneurship in rural Bangladesh and has increased their family income and standard of lives, increased awareness, developed capabilities and empowered women to contribute socio-economic status of individuals, groups and the nation as a whole (Sultana et al., 2010). The positivists have acknowledged that micro-credit provides an effective mechanism for alleviating poverty, improving women's status and empowering them by creating an environment for small businesses (Pitt and Khandker, 1996; Mayoux, 1999; Littlefield *et al*., 2003; Lakwo, 2006).

Despite the success stories, the positive impact of micro credit on poverty alleviation and women's empowerment, the overall condition of the poor women in rural Bangladesh is not at a satisfactory level. The credit institutions are not much care about the extreme poor (Sultana et al., 2010). Moreover, Some studies have reported that the high rates of interest charged by the credit institutions, less/un-successful at reaching the vulnerable poor, little or no control over loans of women borrowers, unchanging levels of poverty, etc. (Mallick, 2002; Goetz and Gupta, 1995; Amin *et al*., 2003). Even though, micro credit is an attractive tool for producing better outcomes in terms of income and assets, it is more effective for relatively wealthier borrowers compared to non-wealthy borrowers (Rahman *et al*., 2009).

There is no doubt that the situations of women in Bangladesh are improving but still there are some problems. It should be noted that a number of programs have succeeded in bringing women into public decision making processes and groups. Direct election of women to union and up-zilla parishads is the best examples. In the case of arsenic problem, it seems that involvement of women is not at a satisfactory level. Women of all groups generally have lower status and less social value than men. Women tend to eat last and least in their household. Therefore, if they live in poor families they are the most likely family members to be malnourished. Women are on average less educated, younger and have less earning power than their husbands. For their lower status, the needs of women for health care are taken less seriously by others and at times even by women themselves. It is considered not feminine to bother people with one's health problem, even when felling very ill. The tradition, rather, is on women's attending carefully to others health needs. Men typically have more economic power than women. A recent study found that in terms of the probability of sickness from arsenic was higher for female than male due to the poor health status of the female in a poor household and food habits where men often get more nutritious food than women (Khan and Haque, 2010).

The estimated ordered logit constant1 and constant2 are adjacent level health category, "good" and "bad" versus "very bad" and "good" versus "bad" and "very bad", respectively, when the other covariates are evaluated at zero. The significant effects of age, age square, household size and BMI on arsenicosis health status are appearing in every specification. The pseudo R-square, log likelihood, Akaike information criterion, Bayesian information criterion change from 0.27 to 0.49, -114.83 to -80.99, 243.67 to

178.56, 269.60 to 217.302, respectively, after adding the covariates in the different specifications. Table 5.4 presents the marginal effects of an individual's arsenicosis risk for the variables presented in the model 5 of Table 5.3. Marginal effects are calculated for dummy variable which are a discrete change in probability from zero to one.

5.3.3 Switching from Red to Green Source

The maximum likelihood logit estimations for averting status of respondents' tube well are presented in Table 5.5. The regression results show that what matter most to the household averting status is likely to be the education of the household head, not the highest education of the family members. In both specifications include household size, household monthly income, vegetable consumption, protein intake, participation of NGO(s) activities as covariates. Empirical results show that the income, protein consumption status, participation of NGO(s) activities and level of educational attainment have a significant positive impact on a household switching from red tube well to green tube well. None of the model indicates that vegetable consumption status has significant effect on averting status. In contrast, household size shows a significant impact on averting status in the model 1 and insignificant impact in the model 2. The coefficient of household head education in the first specification is weakly significant, indicating that the effect of highest education of the household members on probability of switching from red tube well to green tube well is stronger. The AIC, BIC, log likelihood and Pseudo R^2 statistics also suggest that the highest education of the family members is more influential factor for averting status of a household.

Table 5.6 presents the marginal effects of a household averting status for the variables shown in the model 1 and model 2 of Table 5.5. The marginal effect of protein consumption indicates that an increase in protein consumption status significantly increases the probability of a household to switch green tube well by 11.8 % to 11.5%. If the respondent's household has active participation with NGO(s), the probability of switching to green tube well is increased by about 27% to 30%. NGOs can do awareness build up activities, for example, special education/training program, camping etc. Even though the level of education has a significant effect on the probability of a household being green tube well, its marginal impact is shown to be small. The estimations indicate that as the level of education of household head increases, the probability of being green marks tube well increases 0.7%. On the other hand, the level of education of highest education of the family members increases, the probability of switching to green marks tube well increases 1.2%.

5.3.4 Willingness to Pay for Arsenic Free Water

The WTP distribution of respondents is presented in the Table 5.7 and estimated demand curve for arsenic free water is presented in the Figure 5.2. The frequency of respondents who are willing to pay greater than or equal to that amount has been calculated for each payment point. WTP of the respondents indicate their demand for arsenic free water at particular price. The WTP distribution shows that the change in density of WTP of the respondents is the highest in the interval between 500Tk. to 1000Tk. and the value is 19.17. If the price is higher than 500TK. the number of respondents who are willing to pay will drop dramatically (Figure 5.2).

Maximum likelihood multiple regression model is applied to determine the relationship between the explained and explanatory variables for WTP. In this model the explanatory variables are age, age square, sex, household size, education, household income, vegetable consumption and participation of NGO(s). The results of the regression equation of WTP for arsenic free water are presented in Table 5.8. The regression analysis shows that four variables namely education level of respondents, household monthly income, vegetable consumption and participation of NGO(s) are statistically positively significant. In contrast, female respondents are negatively significantly influence respondents' WTP for arsenic free water.

The model explained 67% of the total variation influence on WTP for arsenic free water. One unit increase of house hold income would increase WTP by 0.08 taka while the other variables in the model are held constant. The coefficient of the dummy for gender appeared that the average WTP for arsenic free water of male would be higher by Tk. 514 than female respondents. Similarly, NGO(s) participation would be higher WTP for arsenic free water by 410 taka. NGOs can do awareness build up activities, for example, special education/training program, camping etc. Investment of this sector is not profitable. So, micro-credit is not feasible for solving the arsenic related problems directly

5.4 Conclusion and Policy Recommendation

The present study, first attempts to address the shortage of arsenic contaminated developing countries studies on the arsenicosis health status as well as averting behavior and willingness to pay for arsenic free water. While the disparities by SES have been firmly established with decades of research and highly debated, the current study has empirically analyzed the determinants of arsenicosis based health status, averting behavior and WTP for arsenic free water through estimating order logit model, binary logit and maximum likelihood regression, respectively. These findings have several policy implications those agencies and policy initiatives operating at local and or national levels concerned with tackling the arsenic contaminated drinking water related problems that are primarily concerned with sound health and poverty alleviation agenda. Since Bangladesh has committed to the Millennium Development Goals, arsenic contaminations in drinking water is challenge for the goal tenth (access to safe water), moreover, it is a threat for the most of the MDGs. Therefore, the country should be relentless in its efforts to meet these goals and incentives and investments in this sector will be rewarding.

The results provide evidence that the age, gender, household size, BMI, education, income, vegetable consumption, smoking status are important tools for reducing the arsenicosis risk. Binary logit analysis shows that income, protein consumption, participations of NGO(s) activities and highest education of household members are significantly influential factors for switching from red to green source for reducing the potential arsenicosis risks like melanosis, keratosis, etc. Maximum likelihood regression analysis results also reveal that gender, educational attainment, household income, vegetable consumption, participation of NGO(s) activities are significant determinates for WTP for arsenic free water.

The study finds that education is an important tool in reducing the risk of arsenicosis disease in Bangladesh. Similarly, reduction of poverty is another important policy variable which can also successfully reduce the risk of arsenic-related diseases. Consequently, poverty reduction and education should be pursued as a policy to reduce the impact of arsenic poisoning. The estimates of willingness to pay obtained in this study are indicative of the possibility of introducing a demand driven program to expand the arsenic free drinking water in rural area. Therefore, key issues for policy development are how to create income generating activities, how to reduce gender discrimination and provide greater opportunities for educational attainment of rural peoples of developing countries like Bangladesh can enhance their ability to access in arsenic free drinking water. The government, NGOs, social workers, health workers, donor agencies and environmental specialists should work together to provide a solution because many of the issues that need to be addressed when tackling the arsenic problem, such as dissemination of information, ensuring choice and options, monitoring of water quality.

The NGOs can play important role for solving the arsenic related problems through expansion of micro credit program. Distribution of loan for arsenic affected household head will be effective way to overcome the arsenic crisis through economic empowerment of household. Specially, women should have easy access to micro credit in the arsenic affected area, then, the economic power of women will be increase. They will be able to take care of their health and participation of decision making process will be enhanced.

Table 5.1 Data characteristics and variable scoring

Variables	Category	Scoring
Dependent variables		
Arsenicosis status	good fair poor	1 2 3
Averting status	switching from red to green tube well	dummy
WTP for Arsenic free water	money in taka	quantitative value
Independent variables		
Age	in year	quantitative value
Age square	In year^2	
Gender	female male	dummy
Smoking status	smoker non-smoker	dummy
Household size	number of household members	quantitative value
Education	in year of schooling	quantitative value
Income	in taka	quantitative value
Protein intake	Sufficient Insufficient	dummy
Vegetable consumption	Sufficient Insufficient	dummy
Body mass index		quantitative value
Participation of NGOs activities	involved with NGO not involved	dummy
Tube well status	Red/unsafe Green/safe	dummy

Table 5.2 Descriptive statistics of variables

Variables	Mean	Maximum	Minimu	Standard
Arsenicosis status	1.20	3	1	0.51
Averting status	0.23	1	0	0.42
Averting cost	9282.61	15000	4000	3352.70
WTP for Arsenic free water	1714.58	3000	100	978.88
Age	41.73	75	17	13.90
Gender	0.35	1	0	0.48
Household size	5.62	14	2	2.04
Body mass index	21.57	33.41	15.35	3.36
Smoking status	0.26	1	0	0.44
Education	6.41	16	0	4.06
Education of household head	6.03	16	0	4.29
Highest education in the family	10.13	16	5	3.30
Income	8778	25000	2000	4725
Protein intake	0.39	1	0	0.49
Vegetable consumption	0.64	1	0	0.48
Participation of NGOs	0.30	1	0	0.46
Tube well status	0.80	1	0	0.40

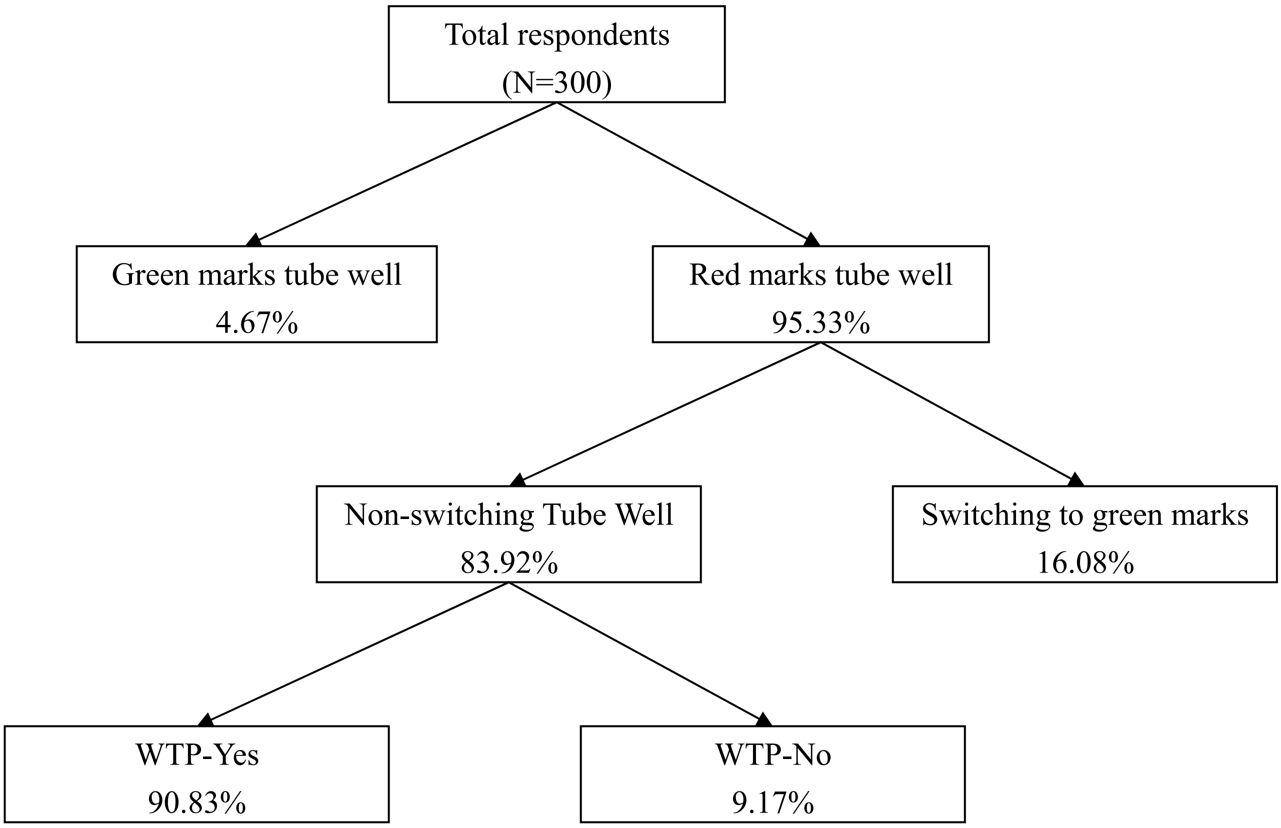

Figure 5.1 Summary of tube well status and WTP

Table 5.3 Order logit regression results on arsenicosis based health status

Variables	(1)	(2)	(3)	(4)	(5)
age	0.465***	0.332***	0.313**	0.307**	0.359***
	(0.133)	(0.129)	(0.125)	(0.124)	(0.135)
age^2	-0.005***	-0.004***	-0.004***	-0.003***	-0.004***
	(0 .001)	(0.001)	(0 .001)	(0.001)	(0 .001)
gender	1.073***	0.097	-0.189	-0.063	1.831**
	(0.409)	(0.469)	(0.493)	(0.500)	(0 .739)
hhsize	0.309***	0.306***	0.423***	0.414***	0.534***
	(0.087)	(0.091)	(0.108)	(0.108)	(0.121)
BMI	-0.405***	-0.353***	-0.327***	-0.295***	-0.378***
	(0.088)	(0.092)	(0.092)	(0.093)	(0.106)
Education		-0.336***	-0.269***	-0.257***	-0.260***
		(0.077)	(0.079)	(0.085)	(0.088)
Income			-0.0003***	-0.0002**	-0.0002**
			(0.0001)	(0.0001)	(0 .0001)
Vegconsumption				-1.278**	-1.189**
				(0.532)	(0.566)
smoking status					3.244***
					(0.763)
constant1	6.360***	3.411***	2.845***	3.622***	4.468***
	(2.223)	(1.239)	(0.918)	(1.342)	(1.380)
constant2	7.999***	5.723***	3.745***	4.590***	6.811***
	(3.014)	(2.154)	(1.325)	(1.654)	(2.325)
Prob > chi^2	0.0000	0.0000	0.0000	0.0000	0.0000
NOB	300	300	300	300	300
Pseudo R^2	0.271	0.346	0.388	0.410	0.486
Log likelihood	-114.834	-103.045	-96.505	-92.927	-80.999
AIC	243.668	222.091	211.011	201.706	178.561
BIC	269.595	251.721	244.345	238.744	217.302

Standard error in the parentheses. Asterisks ** and *** indicate statistical significance at the 5% and 1% levels, respectively.

Table 5.4 Marginal effect of risk of being arsenicosis

Variables	No Arsenicosis/ good health	Primary stage of arsenicosis	Advance stage of arsenicosis
age	-0.005	0.004	0.0005
age^2	0.00006	-0.00005	-5.66e-06
*gender**	-0.038	0.034	0.004
hhsize	-0.007	0.007	0.0007
BMI	0.005	-0.005	-0.0005
Education	0.004	-0.003	-0.0003
Income	2.16e-06	-1.94e-06	-2.14e-07
*Vegconsumption**	0.016	-0.014	-0.002
*smoking status**	-0.131	0.117	0.014

(*) dy/dx is for discrete change of dummy variable from 0 to 1

Table 5.5 Coefficients from the binary logit regression on the switching from red to green tube well

Variables	**(1)**	**(2)**
house hold size	0.161**	0.120
	(0.081)	(0.081)
income	0.00008**	.00009**
	(0.00004)	(0.00004)
protein intake	1.374**	1.366**
	(0.555)	(0.556)
vegetable consumption	0.886	0.876
	(0 .548)	(0.551)
participation of NGO activities	2.076***	2.274***
	(0.550)	(0.575)
education of household head	0.078 *	
	(0.045)	
highest education of household member		0.124**
		(0 .058)
Prob > chi^2	0.0000	0.0000
NOB	286	286
Pseudo R^2	0.262	0.269
Log likelihood	-105.727	-104.777
AIC	225.455	223.554
BIC	251.047	249.146

NOB means number of observations. Standard error in the parentheses. Asterisks *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels, respectively.

Table 5.6 Marginal effect of switching from red tube well to green tube well

Variables	(1)	(2)
house hold size	0.015	0.011
income	8.91e-06	9.36e-06
*protein intake**	0.118	0.115
*vegetable consumption**	0.093	0.091
*participation of NGO activities**	0.274	0.303
education of household head	0.007	-
highest education of household member		0.012

(*) dy/dx is for discrete change of dummy variable from 0 to 1

Table 5.7 Distribution of WTP data

WTP	No of respondents	Respondents % (≥WTP)	Change in density
≥ 0	240	100	9.17
≥ 500	218	91	19.17
≥ 1000	172	72	4.58
≥ 1500	161	67	17.08
≥ 2000	120	50	15.83
≥ 2500	82	34	17.50
≥ 3000	40	17	13.33
≥ 3500	8	3	1.25
≥ 4000	5	2	0.83
≥ 4500	3	1	0.42
≥ 5000	2	1	0.83

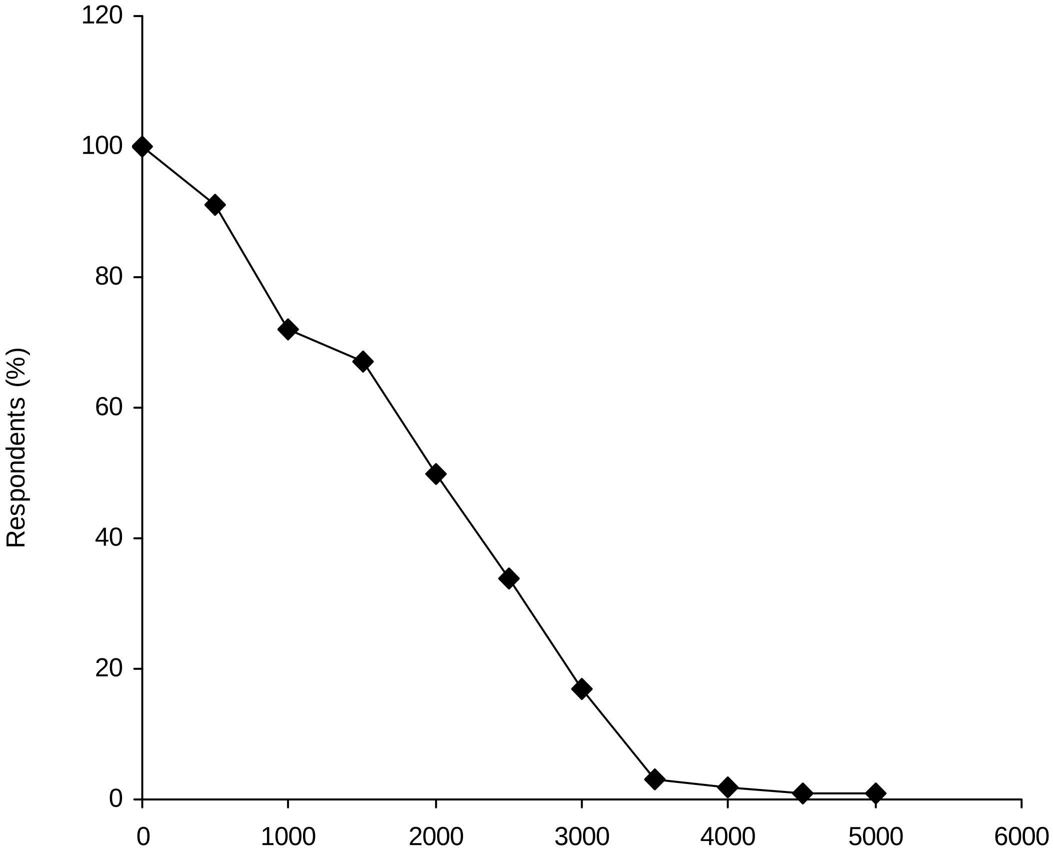

Figure 5.2 Demand curve for arsenic free water

Table 5.8 Maximum likelihood regression coefficients of willingness to pay for arsenic free water

Variables	Coefficients	Standard error
Age	1.871	35.584
Age^2	0.126	0.371
gender	-514.027**	206.464
household size	14.395	37.207
education	48.091**	19.150
income	0.084***	0.018
vegetable consumption	447.165**	190.750
participation of NGO(s)	409.590**	180.638
observations	240	
R^2	0.667	
Adjusted R^2	0.634	

Standard error in the parentheses. Asterisks ** and *** indicate statistical significance at the 5% and 1% levels, respectively.

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