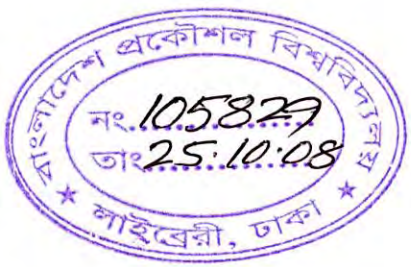
Assessment of Health Risk from exposure to Arsenic in selected Arsenic affected areas of Bangladesh



By

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M. ENGG. IN CIVIL AND ENVIRONMENTAL ENGINEERING

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The project report titled "Assessment of Health Risk from Exposure to Arsenic in Selected Arsenic Affected Areas of Bangladesh" submitted by Mst.Mahafuza Rahman Roll No. 040404140(F), Session April 2004 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of M.Engg. in Civil and Environmental Engineering on March 22, 2008.

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To

My Father

Abstract

Estimation of population exposed to different levels of As in drinking water has been made for 21 As-affected upazilas covered under the BAWMSP survey. In the highly affected 7 upazilas (80-100% contaminated wells), about 64% of population is exposed to As concentration above the Bangladesh drinking water standard of 50 ppb. In the 7 upazilas with 60-80% contamination, population exposed to unsafe level of As is about 55%, while in the 7 upazilas with 40-60% contamination, it is about 37%. Overall, about 54.7% of the population in the 21 upazilas is exposed to unsafe level of As in their drinking water. Population exposed to As concentration above the WHO guideline value of 10 ppb could not be estimated from the survey data, since the lowest reported As concentration range in the BAMWSP database is 0-50 ppb.

In the As affected areas, percentage of population exposed to unsafe level of As (i.e. > 50 ppb) is somewhat less than the percentage of contaminated wells, possibly suggesting that some people are using As-safe water from sources other than their contaminated wells. For example, in the 7 upazilas with 80-100% contaminated wells, the average percentage of contaminated wells is about 87.9%, while percentage of population exposed to contaminated water (i.e. As > 50 ppb) is about 63.5%.

Model predictions of the number of arsenicosis patients using two sets of model parameters did not match the actual patient data. Parameters of Yu et al. (2003) over-predicted the total arsenicosis patients by a factor of over 70; parameters of Ahmed (2003) under-predicted patient number among population exposed to relatively low level of arsenic (below 100 ppb) and significantly over-predicted patient number among population exposed to relatively high concentrations of As. The model parameters of Yu et al. (2003) were derived from a study in West Bengal; which suggests that if health effects in Bangladesh eventually become similar to those experienced in West Bengal, a huge number of people would be come affected with arsenicosis.

Model parameters estimated in this study also failed to match the actual data. This is not surprising because the survey data show that prevalence of arsenicosis does not correlate well with As concentration, while the health risk model assumes prevalence to increase with increasing As in drinking water. Survey data show that the actual prevalence ratio among population exposed to relatively low As concentration (e.g., up to 100 ppb) is quite high; while the prevalence ratio appears to show a decreasing trend as As concentration exceeds 500 ppb, especially among female population.

It appears that in the As affected areas, drinking As safe water (As < 50 ppb) does not guarantee safety from adverse health effects. For example, among a total of 2832 arsenicosis patients identified in the 21 upazilas, about 43% are drinking water with As concentration below 50 ppb. Other parameters, e.g., arsenic exposure through food chain, food habit and nutrition, genetic makeup probably have significant influence on the prevalence of arsenic. However, the data gathered during the BAMWSP survey do not allow analysis of such parameters. Many could however question the reliability of As measurements made during the BAMWSP survey using field kits. Along with efforts to better understand the health effects of arsenic, efforts should also be made to develop better models for predicting long-term health effect of arsenic in Bangladesh and in other countries.

CANDIDATE'S DECLARATION

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

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Name of the Candidate

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Chapter 1

Introduction

1.1 BACKGROUND

The presence of elevated levels of arsenic in groundwater has become a major concern in Bangladesh, India, and several other countries. The contamination scenario in Bangladesh appears to be the worst detected so far worldwide, both in terms of area and population affected. Arsenic contamination has primarily affected the shallow aquifer (usually less than 100 meters [m]), and there is a distinct regional pattern, with the greatest contamination in the south and southeast and least in the northwest (BGS and DPHE 2001; BAMWSP 2005). Out of 465 upazilas (sub-districts) in Bangladesh, 271[1] have been affected with significantly high concentrations of arsenic. Estimates of population exposed to a concentration of arsenic above the Bangladesh drinking water standard of 50 µg/L vary from about 20 million to over 36 million people (DCH 2000; BGS and DPHE 2001). According to the BGS and DPHE (2001), 35 million people are exposed to an arsenic concentration in drinking water exceeding the national standard of 50 µg/L and 57 million people are exposed to a concentration exceeding the WHO standard of 10 µg/L. These estimates are however based on relatively limited data.

Characteristics skin lesions (hyper-pigmentation, hypo-pigmentation and keratosis, often collectively referred to as arsenicosis) are the hall mark of high arsenic exposure. As regards manifestation in a person's body the symptom of As toxicity may take several months to several years to be visible. The latency period for these skin lesions range from 5 to 10 years, though shorter latency is possible. This period differs from person to person depending on the quantity and volume of As ingested, nutritional status of the person's immunity level of the individual and the total time period of arsenic ingestion

[1] In Meherpur 1 upazila has been divided to create 2 upazilas

(Quamruzzaman et al., 2000). Malnutrition and poor socio economic conditions aggravate the hazard of As toxicity. Although arsenicosis is not an infectious contagious and hereditary disease, arsenic toxicity brings about many social problems for the victims and their families (Khan and Ahmed, 1998). Melanosis may occur anywhere in the body often showing rain drop like pigmentation or diffuse dark brown dappling. Keratosis is small corn like elevation usually 0.4 to 1 cm in diameter found on the palm along its lateral border, fingers and on the sole and heels. Arsenic is a known carcinogen and chronic exposure to As can cause cancer of skin and other internal organs. Studies have shown that As also cause several nonmalignant adverse health effect like weakness, edema, conjunctive congestion, diabetes mellitus, hypertension, adverse respiratory effects. Emerging evidence suggests a positive association between chronic As exposure and adverse reproductive outcome. Higher spontaneous abortion, still birth and pre-term birth rates among the chronic arsenic exposed population compared to the unexposed population was first reported in Bangladesh in 2001. A hospital-based case control study in Texas USA showed an increase of still birth among the study population residing near an As based agriculture plant. Adverse pregnancy outcome were reported from Sweden.

Actual data on patients suffering from arsenicosis is relatively limited. DCH and SOES conducted survey for arsenicosis patients in 64 districts and found patients with arsenical skin lesions in 32 of them. They examined 24,664 people in the affected villages and 33.6% of them were diagnosed as patients with arsenical skin manifestation. A total of 2167 hair samples, 2165 nail samples, 220 skin samples and 830 urine samples were analyzed and an average of 94% of them were found to have arsenic concentration above the normal limit. A report from the National Institute of Preventive and Social Medicine stated that they had more than 800 arsenicosis patients in their list. At the skin department of Bangabandhu Medical University, 250 patients with arsenical skin lesions have been investigated and treated. It is obvious that if systematic survey is conducted in the areas with high level of arsenic in groundwater, more patients will be found.

There have some efforts on estimation on arsenicosis patients based on available dose-response function for arsenic exposure (e.g., Yu et al., 2003; Ahmed, 2003). Yu et al. (2003) estimated that the prevalence of arsenicosis in Bangladesh annually could be up to two million cases if consumption of contaminated water continues. For skin cancer it could be up to one million cases, and the incidence of death from arsenic-induced cancer could be 3,000 cases. Some efforts have also been made for developing dose-response function in the context of Bangladesh (Ahmed, 2003). But a major limitation in these efforts was non-availability of data on arsenic exposure and corresponding prevalence of arsenicosis.

Recently, under the leadership of the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP), a detailed survey was carried out in 271 upazilas that are most-affected by As contamination (BAMWSP, 2005). In this survey, a total of 4,946,933 tube wells were screened for arsenic and over 66 million people were surveyed for arsenicosis, among which 38,430 chronic arsenicosis patients were identified, although many fear it to be the "tip of the iceberg" considering the usual delayed effect of arsenic on an exposed population (Ali, 2006). The database developed based on the BAMWSP survey provides an opportunity to test the applicability of the available dose response relationships in assessing carcinogenic and non-carcinogenic health risks from As exposure. It also provides an opportunity to develop dose-response functions for health risks from As exposure in the context of Bangladesh.

1.2 OBJECTIVE OF THE STUDY

The objectives of this thesis are to estimate the population exposed to different level of As in tubewell water, assess health (arsenicosis) risks from exposure to arsenic based on available dose-response function and compare predicted risks with actual patient data from the BAMWSP survey for selected As-affected areas of Bangladesh. Specific objectives include:

1. Estimation of population exposed to different levels of arsenic concentration in selected As-affected areas based on the BAWMSP survey.
2. Prediction of population at risk of arsenicosis in selected areas of Bangladesh and compare predicted risks with actual patient data from the BAMWSP survey, and
3. Estimation of parameters of available dose response functions using the arsenic exposure and patient data from BAMWSP survey.

1.3 METHODOLOGY

In this study, the database from a detailed screening of tubewells and a survey of arsenicosis patients in 271 of the most arsenic-affected upazilas of the country carried out by BAMWSP has been extensively used. The database from this survey contains detailed information on different aspects, including As concentration of each water source and population using each water source. The arsenicosis patients identified in the survey could also be traced back to the water source they use. The database collected from NAMIC (National Arsenic Mitigation Information Centre) has been used for assessing population exposed to different levels of As in selected arsenic-affected upazilas of the country. Arsenicosis risk has been assessed in selected upazilas based on the dose-response model used by Yu et al. (2003) and Ahmed (2003). The predicted risks have been compared with actual arsenicosis patient data contained in the survey database. Based on the comparison, the applicability of the risk models in the context of Bangladesh has been assessed. Finally, new model parameters for the risk models have been estimated based on the As exposure and patient data for the selected As-affected upazilas.

1.4 ORGANIZATION OF THESIS

The remainder of this report is organized in four additional Chapters and one Appendix. In Chapter Two, an account of different health resulting from exposure to As has been given. This Chapter also presents information on arsenic related health effects in different parts of the world. It also focuses on the health effects of exposure in Bangladesh, as reported in different studies. Chapter Two also presents the principles of health risk assessment along with an overview of As risk assessment studies conducted in Bangladesh.

Chapter Three provides an assessment of the number of people exposed to different concentrations of As in selected As-affected upazilas. It presents the estimates of population at risk of arsenicosis based on the health risk models used by Yu et al. (2003) and Ahmed (2003). It also presents a comparison between the estimated risk and the actual number of patients identified in the BAMWSP survey for the selected upazilas. The applicability of the health risk models has also been discussed. In Chapter Four, new model parameters have been estimated for the health risk models based on the arsenic exposure calculated earlier and the patient data from the BAMWSP survey. The last chapter, Chapter Five, presents the major conclusions from this study and recommendations for future study.

Chapter 2

Health Effects of Arsenic and Health Risk Assessment

2.1 INTRODUCTION

Arsenic is a naturally occurring element present in the environment in both organic and inorganic forms. Inorganic arsenics, the more toxic form, is found in groundwater, surface water and many foods. Chronic exposure to arsenic has been found to result in a variety of adverse health effect including skin and internal cancer and cardiovascular and neurological effects. Exposures to organic forms of arsenic also occur through ingestion of food and metabolism of ingested organic arsenic. The effects of all forms of organic arsenic are not as well characterized as those for inorganic arsenic, are these are subjects for future research.

This Chapter provides a brief overview of the health effects of arsenic, including information on reported health effects of arsenic in Bangladesh and other arsenic affected areas of the world. This Chapter also presents the principles of health risk assessment and provides an overview of arsenic risk assessment studies conducted in Bangladesh.

2.2 HEALTH EFFECTS OF ARSENIC

2.2.1 General Health Effects

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; Guha Mazumder et al., 1998, Smith et al 1992), as well as other non-carcinogenic health effects, such as adverse reproductive outcomes, neurological disorders, and impaired cognitive development in children (Ahmed, 2001).

The USEPA has identified arsenic as a known human carcinogen based on increased risk of lung cancer in worker exposed to air born arsenic and dose dependent increase in cancer risk in Taiwan. The International Agency for Research on Cancer (IARC) has also classified arsenic as a human carcinogen. Epidemiological studies have shown evidence of carcinogen risk by both inhalation and ingestion. The most common types of malignancy reported are skin cancer, lung cancer, liver cancer, prostate cancer and bladder cancer. Reports of other cancers include leukemia, other hematopoeitic cancer and cancer of the breast, colon, stomach, parotid gland, nasopharynx, larynx, buccal cavity, kidney and others. Hutchison identified arsenic as a carcinogen because of the high number of skin cancer occurring on patients treated with arsenic.

The international agencies for research on cancer (IARC) classified inorganic arsenic compounds as skin and lungs (via inhalation) carcinogens. In the period following the classification concerned, concerns have been raised over the possibility of arsenic in drinking water causing a number of other cancers. The following discussion on arsenic health effect at different parts of the world are based on a comprehensive report prepared by the National Research Council (NRC, 2000) of the United States. According to the National Research Council report (NRC, 2000), arsenic exposure interfere with the action of enzymes, essential actions and transcriptional events in cells in the body, and a multitude of multi systemic non-cancer effects might ensue. The discussion focuses on selected non-cancer effects from chronic ingestion of arsenic bearing drinking water. The following section summarizes these effects.

Cutaneous Effect

The most widely noted non-cancer effects of chronic arsenic consumption are skin lesions. The first symptoms to appear after initiation of exposure are hyper pigmentation (dark spots on the skin) and hypo pigmentation (white spots on the skin). Some physicians collectively refer to those symptoms as melanosis. Hyperpigmentation

commonly appear in a raindrop pattern on the trunk or extremities but also on mucous membranes such as the tongue.

Over time, arsenic exposure is associated with keratosis on the hands and feet. Keratosis is a condition where skin hardens and develops into raised wart-like nodules. These nodules become more pronounced over time, sometimes reaching 1 cm in size (NRC, 2000).

Limited evidence indicates that hyperpigmentation and keratosis due to arsenic exposure might serve as markers of susceptibility of other outcomes. In small study in England on cancer among patients treated with medical arsenic noted that cancer deaths occurred only among those with prior skin manifestation due to arsenic. In a further follow up of that cohort, a three fold increased risk of bladder cancer mortality was found and all 5 deaths occurred in patients with previous sign of arsenic poisoning. However, Tseng et al. (1977) noted that skin cancer often appear at the sites of existing keratosis (NRC, 2000).

The youngest age reported for patients with hyperpigmentation and keratosis is 2 years. For Bangladesh, Guha Mazumder et al. (1998) suggest a minimum time gap of five years between first exposure and initial cuteneous manifestations. The distinctive appearance of these skin lesions has been used as indicators of arsenic exposure, when it has not been possible to ascertain arsenic concentration in well water.

Cardiovascular Effects

Acute or sub-acute exposure to inorganic arsenic ranging from milligram to gram per liter has induced the rapid appearance of serious cardio vascular manifestations, including hypertension, congestive heart failure and cardiac arrhythmia.. Chronic ingestion of inorganic arsenic has been associated with peripheral vascular disease (Black foot disease). The most prominent reports of arsenic related peripheral vascular disease have originated from southern Taiwan. This condition results in gangrene in the

extremities particularly in feet and usually occurs in conjunction with skin lesions (NRC, 2000).

Gastrointestinal Effects

With acute or sub-acute exposure, arsenic might induce gastro intestinal disturbances, ranging from mild abdominal cramping and diarrhea to severe life threatening hemorrhagic gastroenteritis, associated with mild to moderate heptocellular necrosis.

Hematological Effects

Acute and chronic arsenic poisoning might result in anemia, leukopenia and thrombocytopenia.

Pulmonary Effects

In a study among a total of 180 resident of Chile, exposed to drinking water containing arsenic at 0.8 mg/l, 38.8% of subjects with abnormal skin pigmentation complained of chronic cough, compared with 3.1% of 36 subjects with normal skin (NRC, 2000).

Neurological Effects

Acute inorganic arsenic intoxication that produces initial gastrointestinal or cardiovascular symptoms can be followed by the delayed onset of central or peripheral nervous system involvement, ranging from headache and mild confusion to florid encephalopathy, seizures and comma (NRC, 2000).

Effect on Reproduction and Pregnancy

In a cross-sectional study conducted in Bangladesh, 285 married females of reproductive age (between 15 years to 49 years) with history of at least one pregnancy, no history of smoking and drinking water from tubewell prior to and during the pregnancy were studied to determine the association between chronic arsenic exposure through drinking

water and spontaneous abortion, still birth and neonatal death. Excess spontaneous abortion, stillbirth and preterm birth rates among the chronic arsenic exposed population as compare to the unexposed population were reported from Bangladesh first in 2001. Increased risk of infant mortality (divided into three subcategories: stillbirth, neonatal, and post natal) was reported earlier from Chile. A hospital-based case control study in Texas, USA reported an increase of stillbirths in relation to environmental arsenic exposure among the study population residing near an arsenic-based agriculture plant. Adverse pregnancy outcomes were also reported from Sweden.

2.2.2 Health Effects in Bangladesh

The catastrophic health crisis caused by arsenic poisoning of drinking water in Bangladesh and West Bengal could be the biggest mass poisoning in human history. Especially in Bangladesh the condition is worst. In acute arsenic problem areas, more than 90% of shallow tube wells are contaminated. The pattern of distribution of arsenic affected tubewell is erratic for which changes cannot be predicted even within short distances (Ahmed, 2001).

Before the comprehensive BAMWSP survey, surveys of arsenicosis in Bangladesh include those by AAN (1999), Ahmed et al. (1999), Ahsan et al. (2000), Biswas et al. (1998), Chowdhury et al. (2000), Milton and Rahman (1999), Quamruzzaman et al. (2000), Rahman et al. (1999), SOES/DCH (2000) and Tondel et al. (1999) [as reported by Yu, et al., 2003].

School of Environmental Studies, Jadevpur University, Kolkata, India and Dhaka Community Hospital, Dhaka, Bangladesh conducted a 4 years survey in different parts of Bangladesh up to 2000 (Quamruzzaman et al., 2000). They surveyed 8, 18,924 people in Bangladesh who were drinking water from 61,631 hand tubewells in 64 districts. They found that 2,327 people (0.28%) have symptoms of arsenicosis and the most of the

patients were male (59%). They reported a weak correlation between the arsenic contaminated wells (0.01mg/l) and the prevalence of arsenicosis in a village.

About 3332 hair, 3321 nail, 373 skin scale and 1043 urine samples from people living in arsenic affected villages (including patients) had been analyzed and 92% sample on average contains arsenic above the normal level. Thus, many may not be showing arsenical skin lesion but may be sub clinically affected. Further if it is true that arsenic toxicity appears after several years of exposure, then the picture may actually be far grimmer than it appears at present and children of our future generation at greater risk.

From the affected villages they identified 1351 children (below 11 years) and out of that 17% have arsenical skin lesions. When they compared the magnitude of arsenic calamity of Bangladesh with West Bengal, they found Bangladeshis are much more affected. Out of total 55,000 hand tubewells they have analyzed so far from West Bengal only 45 contains arsenic above 0.01 mg/l, whereas in Bangladesh it is 211 out of 12000 hand tube-wells analyzed. Out of the 42 districts where arsenic has been found above 0.05 mg/l, they had surveyed 27 districts for arsenic patients, and in 25 districts they identified people suffering from arsenic induced skin lesions such as melanosis, leuco-melanosis, keratosis, hyperkeratosis, dorsum, non petting edema, gangrene, skin cancer, etc. During their preliminary field survey up to 1999, in 118 arsenic contaminated villages of 54 thanas of 27 districts, they had found arsenic patients in 112 villages in 25 districts. They examined at random affected villages, 816 people including children, and out of them 29.3% are found to have arsenic skin-lesions. When only adults are considered the affected population is 2504 out of the total examined adults of 7364.

In another study, SOES/DCH (2000) surveyed 17896 people from 214 arsenic affected villages and found that 3688 (20.6%) had arsenic skin lesion and Tondel et al. (1999) interviewed and examined 1481 patients in four villages and found that 430 (29%) patients had skin lesions (Husain and Bridge, 1999).

Bangladesh arsenic mitigation water supply project (BAMWSP, 2005) conducted a nationwide tubewell screening program which involved tubewell screening of 190 arsenic prone upazilas and identification of arsenicosis patients. They screened 3035964 tubewells and found 29.19% tube wells to be contaminated with arsenic. Among a total of 10,372,612 people surveyed they identified 29500 arsenicosis patients.

UNICEF also conducted an extensive tubewell screening program, which involved tubewell screening of 43 arsenic prone upazilas in two phases and identification of arsenicosis patients. They screened 1063662 tube wells and found 30.15% tube wells to be contaminated with arsenic. Among a total of 7119492 people surveyed they identified 4430 arsenicosis patients (i.e., prevalence 0.062%).

Ahsan et al. (2000) examined the association between drinking water and urinary arsenic levels and skin lesions among 167 residents of three contiguous villages in Bangladesh. 36 subjects (21.6%) had skin lesions (melanosis, hyperkeratosis, or both) of which 13 (36.1%) occurred among people who were drinking water containing less than 50 ppb arsenic. The risk for skin lesion in relation to the exposure estimates based on urinary arsenic was elevated more than 3 fold. While risk for skin lesion in relation to the exposure estimate based on arsenic in drinking water were less strongly elevated. The study suggests that urinary arsenic may be a stronger predictor skin lesion than arsenic in drinking water in this population.

From their study, Milton et al. (1999) reported arsenic level of drinking water ranged from 136 to 1000 ppb, and the overall crude prevalence among the exposed subjects for chronic cough and chronic bronchitis was three times the prevalence in the control population and the females were subjected to greater risk than males.

WPP also conducted an extensive tubewell screening program, which constituted of the tubewell screening of 15 arsenic prone upazilas in Rajshahi and Chapai Nawabgonj districts and identification of arsenicosis patients. They screened 215446 tubewells and

found 13% tube wells to be contaminated with arsenic. Among a total of 3585983 people surveyed they identified 2343 arsenicosis patients.

JICA AAN (2002) arsenic mitigation project conducted tubewell screening and household survey for patient in Sharsha upazila in Jessore district. A total of 32647 tubewells were screened, among which 24% were contaminated. Among the total household of 75830, a total of 312 subjects were identified as arsenicosis patients.

Discrepancies in the reported prevalence ratios of arsenicosis may be due to differences in such factors as the arsenic concentrations in the surveyed region. The quantity of contaminated water ingested, the age cohort surveyed, the nutrition of people surveyed, the procedure to recruit participants and the diagnostic criteria for arsenicosis. Despite such variations the surveys establish a relationship between the ingestion of arsenic contaminated water and the occurrence of arsenicosis.

2.2.3 Health Effects: Global Scenario

Over the past two to three decades, occurrence of high concentrations of arsenic in drinking-water has been recognized as a major public-health concern in several parts of the world. There have been a few review works covering the arsenic-contamination scenario around the world. With the discovery of newer sites in the recent past, the arsenic contamination scenario around the world, especially in Asian countries has taken a turn for the worse. The following section briefly describes the arsenic contamination scenario in different countries of the world, based on Ahmed (2003).

Argentina:

- The first notification of water borne arsenicosis was as early as the beginning of the 20^{th} century.
- The term "Bell Ville disease" was used to describe skin manifestations caused by arsenic.
- Estimated 2 million people are exposed within about 1 km^2 affected area.

Cambodia:

- First detected during 1999/200, 100 samples indicating 9% above WHO provisional guideline value (GV) of 0.01 mg/L.
- Since then, 1,739 samples have been tested in 15 provinces indicating 5%above Cambodian provisional level of 0.05mg/l and 14% above WHO GVof 0.01 µg/L
- Arsenic in some wells in Kandal province found to be above 1.0 mg/L.Suspected arsenicosis patients found the province show urgent need for wide scale testing.
- Peri-urban areas around Phnom Penh may be affected.
- Possibly 2 million people are at risk.

Mexico

- The Lagunera Region of Northern Mexico has been reported to have arsenic problems.
- The area affected is 32000 km^2.

Chile:

- The arsenic contamination has been found in one province, Region II extending over an area of 125 000 km^2 and inhabited by 400 000people.
- In 1957 and following 12 years drinking water contained 800 - 1300 µg/L arsenic.
- In 1962 the first cases of arsenicosis were reported.
- All sorts of specific as well as non specific arsenic intoxications have been reported since.
- In 1970, a treatment plant was completed reducing the arsenic contents to 40 µg/L.
- It is estimated that 7% of the deaths from 1989-1993 are caused by previous exposure to arsenic.

USA:

- USA is probably the only (mildly) arsenic affected country which has carried out a nation wide survey of arsenic occurrence in drinking water.

- About 347000 people had received public supplied water containing more than 50 μg/L.
- About 2.5 million people had received public water supplies containing more than that 10 μg/L.
- Studies from 1972to 1982 showed correlation with specific skin alterations and neurological abnormalities.

Hungary:

- Population exposed to arsenic contamination is about 29000.
- Arsenic concentration was found in the ranges of >2 to 176 μg/L.

Vietnam

- Arsenic in ground water was first detected in Hanoi in 1997 where arsenic content of 29% of the wells were above 0.05 mg/L.
- In most affected districts ground water with average arsenic concentration of 430 μg/L and maximum arsenic concentration of 3000 μg/L is directly used as drinking water.

Taiwan:

- The arsenic problem in Taiwan was first reported in 1968, now best known and most studied case of arsenic contamination.
- It is Taiwan that gave arsenicosis the name "Black Foot disease"
- Survey of over 83000 wells showed that 19% of the wells had arsenic levels over 50 μg/L.
- 100,000 inhabitants were exposed to arsenic from well water containing 10-1820 μg/L of arsenic, on an average about 500 μg/L of arsenic for over 40 years.
- Studies in Taiwan provided data to develop dose-response relationships for skin, bladder and lung cancers.
- Black foot diseases is shown to indicate an increased risk for bladder and lung cancer.

Thailand:

- In 1996 arsenic is reported to occur in some shallow as well as deep wells in southern Thailand.
- Area affected is 100 km^2
- The Concentrations found are between 1 and 500 µg/L.

Pakistan:

- Some arsenic contaminated water sources have been found in Panjab and Sindh provinces in the Indus basin.
- Preliminary study indicated that about 1% sources were contaminated with arsenic exceeding 50 µg/L and 11% source had arsenic content within 10 µg/L.
- Epidemiological studies of selected households in 3 affected districts Gujarat, Jhelum and Sargodha identified 40 confirmed (220/ 100,000) and 76 borderline (420/100,000) arsenicosis cases.

Nepal:

- Arsenic contaminated tubewell have been identified in 20 Terai districts.
- Estimated population exposed to arsenic exceeding 50 µg/L and 10 µg/L respectively 550,000 (2.4% of population) and 3.1 million (13.6%).
- Cases of arsenicosis have been confirmed in arsenic affected areas.

China:

- The first case of arsenic poisoning was discovered in 1990. Many of the arsenic affected areas are located in the arid region.
- More than 30000 cases of arsenicosis diagnosed so far. More serious effects were detected including high cancer mortality.
- An estimated 5.63 and 14.66 million people in 29 out of 32 provinces of China drink water containing arsenic exceeding 50 and 10 µg/L respectively. The highest concentration detected in the well water was 2400 µg/L.

India:

- Arsenic contamination was first discovered in 1982.
- The affected area is about 23000 km^2.
- About 6.97 million people living the affected areas are exposed to high arsenic content in drinking water.
- Estimated 300,000 people are likely to be sufferings from various stages of arsenicosis.
- Arsenic contaminated areas have recently been found in the state of Bizarre.

Table 2.1: Different areas of the world with significant arsenic affected people during the last century

Country	Period of time	No of arsenic affected people	Symptom in skin in %
India(West Bengal)	1978-1995	1000000	20
Taiwan	1961-1985	103000	19
Chile	1958-1970	130000	16
Argentina	1938-1981	10000	Innumerous
Mexico	1963-1983	200000	21
Thailand	1987-1988	14000	18

1. Poland
2. Brazil
3. New Zealand
4. Spain
5. Hungary
6. Lane County, Western Oregon, USA
7. Monte Quemodo, Cordoba, North Region Lagunera, Argentina
8. Region Lagunera, North Mexico
9. Taiwan
10. Antofagasta, Chile
11. Lassen county, California, USA
12. Sri Lanka
13. Nova Scotia, Canada
14. Fairbanks, Asaska
15. Millard County, Utah, USA
16. Fallon, Nevada, USA
17. Inner Mongolia, China
18. Xinjiang Uighur, China
19. Banglades
20. India
21. Viet Nam
22. Afghanistan
23. Pakistan
24. Egypt
25. Ghana
26. Cambodia
27. Sweden
28. Finland
29. United Kingdom
30. Germany
31. Romania
32. Bulgaria
33. Greece
34. The Philippines
35. Australia
36. Myanmar
37. Iran
38. Japan
39. Lao PDR
40. Nepal
41. Switzerland
42. Thailand

Figure 2.1: Global scenario of arsenic poisoning

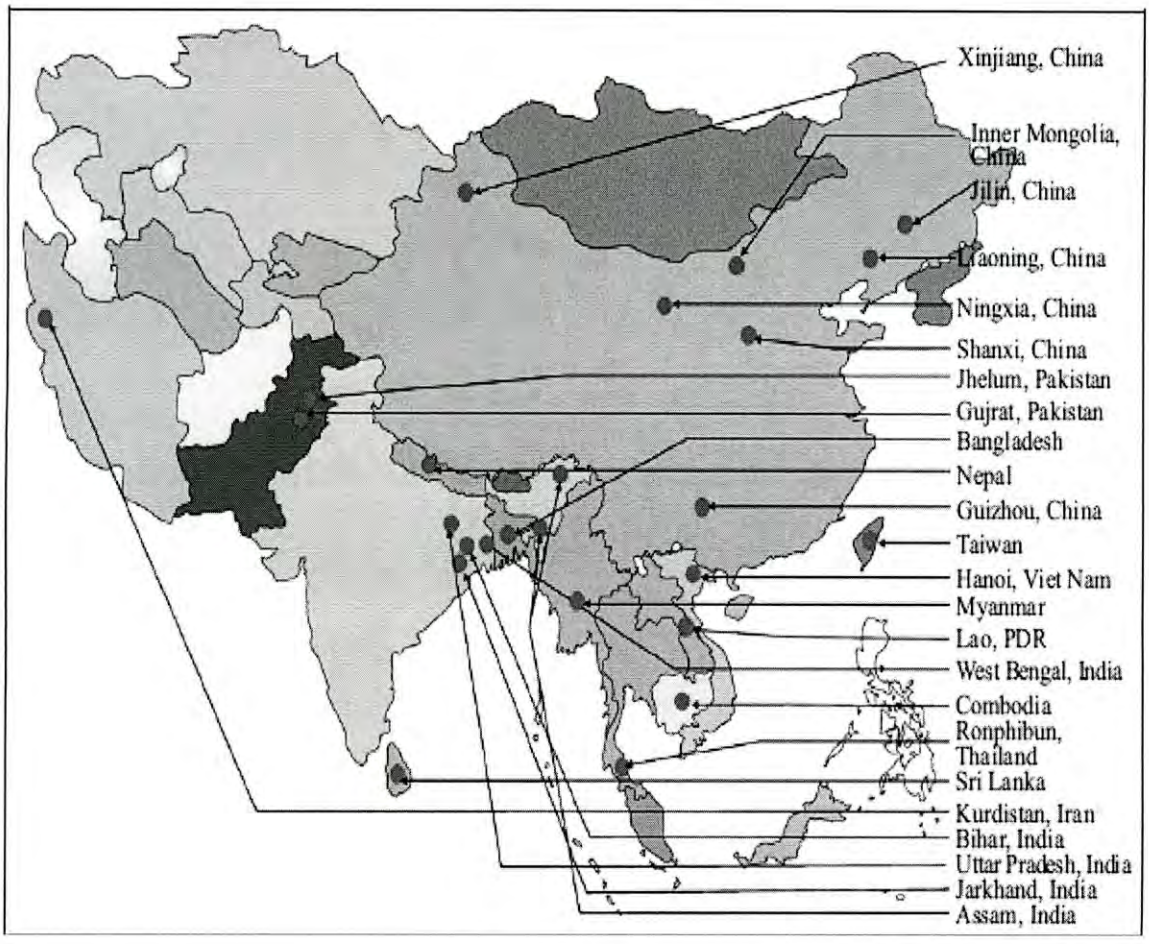

Figure 2.2: Current arsenic contamination situation across Asia

2.3 RISK ASSESSMENT

2.3.1 Principles of Risk Assessment

Adverse risks of arsenicosis depend strongly on the dose and duration of exposure. Specific dermatological effects are characteristics of chronic exposure to arsenic. Salient dermatological features are melanosis (*pigmentation*) and keratosis (*rough, dry, papular skin lesions*), both may be spotted or diffuse. Chronic exposure to arsenic may also cause reproductive, neurological, cardiovascular, respiratory, hepatic, haematological,

and diabetic effects in humans. Ingestion of inorganic arsenic is an established cause of skin, bladder, and lung cancer.

In a generic sense, risk assessment may be considered to be a systematic process for arriving at estimates of all the significant risk factors or parameters associated with an entire range of exposure scenarios in connection with some hazard situation. This process seeks to estimate the likelihood of occurrence of adverse effects resulting from exposures of human and ecological receptors to chemical, physical and/or biological agents that are present in the environment. It involves the characterization of potential adverse consequences or impacts to human and ecological receptors following their exposure to environmental, technological, or other hazards. The process consists of a mechanism that utilizes the best available scientific knowledge to establish case-specific responses that will ensure justifiable, cost-efficient and defensible decisions, about hazardous situations.

In general, risk assessment - which seems to be one of the fastest evolving tools for developing appropriate strategies in relation to environmental management decisions, seeks to answer the following questions:

- What could potentially go wrong?
- What are the chances for this to happen?
- What are the anticipated consequences if this should indeed happen?

So we have to find out the risk assessment to:

- Determine whether potentially hazardous situations exist, i.e. determine baseline risks and the possible need far corrective action.
- Provide a consistent process for evaluating and documenting public and environmental health threats associated with a potential hazardous situation.

- Estimate potential health risks associated with use of several chemicals and consumer products, to ensure the development and implementation of acceptable public health policies.
- Determine the relative size of different problem situations, in order to facilitate priority setting, where necessary.
- Determine whether there is a need for an immediate response action
- Identify corrective action strategies.
- Provide basis far comparing and choosing between remedial action alternatives.
- Provide a basis for determining levels of chemicals that can remain at a given locale, and still be adequately protective of public health and the environment.
- Provide for the risk management informational needs of property owners and general community.

Risk assessment is broken into four basic steps focused on the scientific aspects of the process:

1. Hazard identification (which chemicals if any will cause adverse effects?)
2. Toxicity (dose-response) assessment (what is the relationship between an exposure dose and an adverse health effect in humans?).
3. Exposure assessment (what exposures are currently experienced or likely to occur under different condition?)
4. Risk characterization (what is the estimated incidence of health impairment to a given population

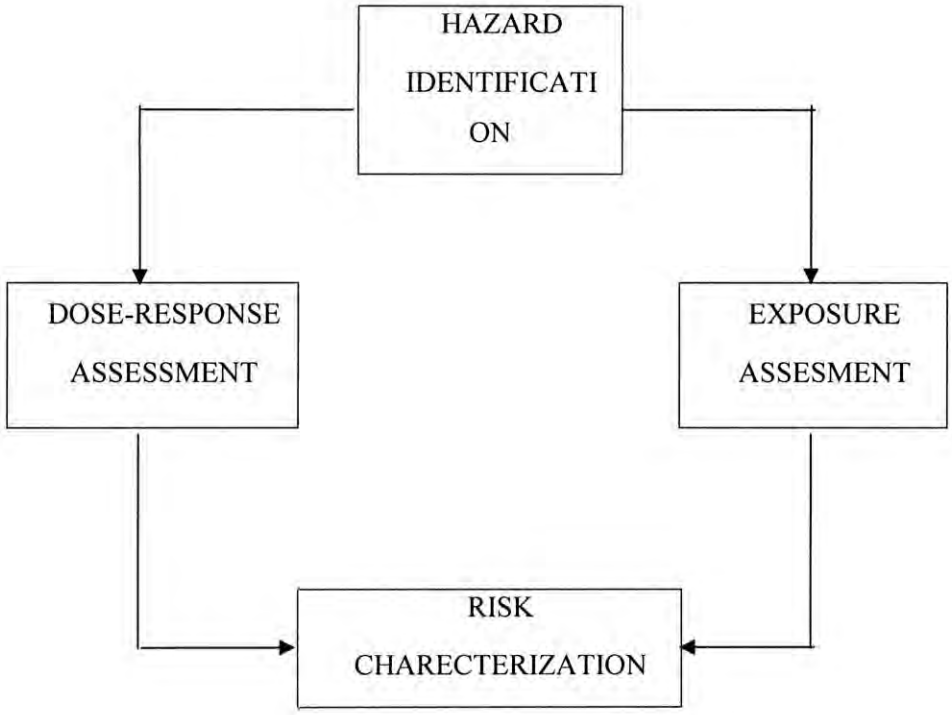

Fig. 2.3: Elements of risk assessment

Risk characterization is the process of estimating the probable incidence or prevalence of adverse impacts to potential receptors under a set of exposure conditions. Typically the risk characterization summarizes and then integrates outputs of the exposure and toxicity assessments in order to qualitatively and/or quantitatively define risk levels. This usually will include an elaboration of uncertainties associated with the risk estimates. Exposures resulting in the greatest risk can be identified in this process; mitigation measures can then be selected to address the situation in order of priority, and according to the levels of imminent risks, to the extent feasible, the risk characterization should include the distribution or risk amongst the target populations. The EPA has recommended that health risks be calculated separately for carcinogenic and non carcinogenic chemicals. The non carcinogenic materials use a summary statistic called the total Hazard Index (total HI) while carcinogenic potential is estimated by the total Incremental Lifetime Cancer Risk (total ILCR). These methods include a scoring system

that allows the assessor to sum the total health risk hazard, assuming the risks can be treated additively which may or may not be a valid assumption.

Risk based target levels may generally be established for various environmental contaminants (such as arsenic) by manipulating the risk and exposure models previously discussed. This involves a back calculation process to yield a media concentration that is based on health protective exposure parameters (i.e. results in a non cancer hazard index ≤ 1 and/or a carcinogenic risk $\leq 10^{-6}$, for example). The target levels arc typically established for both carcinogenic and non carcinogenic effects of the environmental contaminants, with the more stringent value usually being selected as an environmental quality criterion; invariably, the carcinogenic limit tends to be more stringent in most situations where both values exist.

2.3.2 Risk Assessment Studies in Bangladesh

A few arsenic risk assessment studies have been conducted in Bangladesh (e.g., Yu, et al.,2003; Ahmed, 2003). Recently ITN (BUET) used a model, referred to as Quantitative Health Risk Assessment (QHRA) model, for estimating health risks of arsenic considering skin, lung and bladder cancers as end points (Ahmed et al., 2006); risks were expressed in terms of DALYs (Disability Adjusted Life Years). However, the QHRA model did not consider arsenicosis.

Yu et al. (2003) used age-adjusted data to estimate dose-response functions; that is for each type of arsenicosis and each gender. They estimated the prevalence ratio of arsenicosis as a function of the arsenic concentration in the groundwater ingested. They estimated dose-response functions of the quadratic-exponential form:

$$P(c)(male/female) = 1 - \exp(-(q1c + q2c^2))$$

Where P(c) denotes the fraction of the gender with the type of arsenicosis, and c denotes arsenic concentration (ppb), and parameters ($q1$ and $q2$ are non-negative. The values of these parameters for arsenicosis in Bangladesh, as given by Yu et al. (2003) are presented in Table 2.2.

Table 2.2: Parameters for estimating non-carcinogenic health effects (Yu et al., 2003)

Gender	Hyperpigmentation		Keratosis	
	q1	q2	q1	q2
Male	2.678×10^{-4}	0	1.223×10^{-4}	0
Female	1.217×10^{-4}	0	6.416×10^{-4}	2.717×10^{-4}

Yu, et al. (2003) estimated the parameter values using data of West Bengal from the survey conducted by Mazumder et al. (1998). They assumed the following for the estimation.

(a) The exposure period in West Bengal was approximately equal to the present exposure period in Bangladesh;
(b) All cases of arsenicosis are due to drinking arsenic-contaminated groundwater (e.g., arsenic from food is negligible); and
(c) There is no concentration threshold, i.e. a concentration below, which there is no arsenicosis.

The prevalence ratio of an arsenicosis type for both genders is a weighted average of that for males and females. Yu, et al. (2003) estimated the proportion of male and female of Bangladesh are 51.5% and 48.5%, respectively. Thus, the gender-adjusted dose response functions are:

$$P(c)total = 0.515xP(c)_{male} + 0.485xP(c)_{female}$$

Where $P(c)_{male}$ and $P(c)_{female}$ are the dose-response function for males and females.

Yu et al. (2003) estimated that the prevalence of arsenicosis in Bangladesh annually could be up to two million cases if consumption of contaminated water continues. For skin cancer it could be up to one million cases, and the incidence of death from arsenic-induced cancer could be 3,000 cases.

Ahmed (2003) estimated the model parameters using patient data of 14 upazilas collected by the Dhaka Community Hospital as a part of different studies conducted with BAMWSP, SOES (School of Environmental Studies, Jadavpur University), UNICEF and a few other organizations. The important characteristic of this database is accuracy at the individual exposure levels, which was measured by AAS. The parameter values estimated by Ahmed (2003) are reported in Table 2.3.

Table 2.3: Parameter values for estimating non-carcinogenic health effects (Ahmed, 2003)

Gender	Arsenicosis	
	q1	q2
Male	3.092×10^{-6}	0
Female	2.59×10^{-6}	0

Again the gender adjusted dose response functions are:

$$P(c)total = 0.515xP(c)_{male} + 0.485xP(c)_{female}$$

Where $P(c)_{male}$ and $P(c)_{female}$ are the dose-response function for males and females.

By applying the model Ahmed (2003) predicted total cases of non-carcinogenic arsenicosis among a rural population of 99 million in Bangladesh to be 31,300 (that is a prevalence rate of 0.031%). This was much lower than that obtained by Winston et al. (2001). Comparison with actual data showed extremely poor relationship between arsenicosis prevalence rate and the average content of groundwater in respective upazilas.

Chapter 3

Assessment of Non-carcinogenic Health Risk in Selected Arsenic Affected Areas

3.1 INTRODUCTION

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; Guha 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 (Ahmed, 2001; Mukherjee et al. 2003). Inorganic As is a natural element of the earth's crust. More than 100 million people worldwide have been estimated to be chronically exposed to As from drinking water containing high As levels (Chowdhury et al. 2000; Dhaka Community Hospital Trust 2000). Although more than 20 countries have been affected by As contamination of drinking water, the situation is the most devastating in Bangladesh because of the number of affected people. Among the country's 7-11 million hand pumped tubewells, approximately half have been estimated to supply groundwater with an As concentration > 50 μg/L - the maximum allowable limit in drinking water in Bangladesh (Bangladesh Arsenic Mitigation Water Supply Project 2005) Among the country's total population of 130 million, 35 million people are believed to be exposed to an As concentration in drinking water > 50 μg/L, and 57 million people to a concentration >10μg/L, and thus are at higher risk of developing cancer and other As-related, life-threatening diseases [British Geological Survey (BGS) 2001; Dhaka Community Hospital Trust 2000; Milton and Rahman 1999].

This Chapter presents as assessment of population exposed to different levels of As in selected 21 As affected upazilas of Bangladesh based on data contained in the BAMWSP

nationwide survey. This Chapter then presents an assessment of non-carcinogenic health risks from As exposure in these selected upazilas based on the health risk models used by Yu et al. (2003) and Ahmed (2003). The health risks figures obtained from the models have been compared with actual patient data for each upazila. Based on this comparison, the applicability of the risk models in predicting arsenic health risks have been assessed.

3.2 METHODOLOGY

3.2.1 Database of BAMWSP

National screening programme of arsenic was conducted by BAMWSP. It covered majority of the arsenic affected upazilas; they screened 190 out of 271 arsenic prone upazilas[2]. BAMWSP, in association with a number of stakeholders/agencies, has already completed screening program in 190 upazilas. Data entry has also been completed for 180 upazilas. These data are being used by BAMWSP and other agencies for mitigation activity planning. The major portion of data came from the national screening program for tubewell screening and patient identification conducted by BAMWSP and other stakeholders.

It was agreed by all the stakeholders that all the informations collected and generated by different stakeholders will be submitted to the National Arsenic Mitigation Information Centre (NAMIC). Being a part of BAMWSP, NAMIC was directly involved in processing the BAMWSP screening data that is the major portion of the national screening program. This survey was conducted with the help of support organizations, NGOs, Local Government Organizations and involving local people. BAMWSP and their supporting organization screened near about 5 million tubewells and identified 38,430 patients in different part of the Bangladesh. Data from the major stakeholders in the form of electronic format are also being collected continuously.

[2] In Meherpur 1 upazila has been divided to create 2 upazilas

All the stakeholders used the same format for survey, but due to the insufficient data management, different stakeholders except BAMWSP could not provide all the information listed in the format. All the information are fully available for the 189 upazilas surveyed by the BAMWSP. For example, UNICEF did not survey all the households; they surveyed only those households that have a tubewell. But BAMWSP, WPP, AAN surveyed all households. UNICEF did not identify patients in each household; they conducted village level camps to identify patients.

In surveyed database there were various kind of information about tubewell, patients and household members. Regarding tubewell information depth of tubewell, time of construction, arsenic concentrations, owners of tubewells (NGO/Pri/NGO), number of users and types of tubewell (S/D/T) are included. In patient information patient's age, sex, address, symptoms of arsenicosis, duration of disease etc were collected. In household information data number of household user (male/female) and source of drinking water were included.

3.2.2 Health Risk Model and Applications

Health impacts resulting from arsenic exposure can be assessed from application of a suitable health risk model. A risk model gives indication of future risks so that we can take necessary measures to fight against the up it. In this study, a model was used to assess arsenicosis situation in selected arsenic affected areas of Bangladesh. The model predictions were compared with the actual patient data from the BAMWSP.

In the BAMWSP database, the arsenic concentration data ("tube well information" file in the database) and patient information data ("patient information" file in the database) have been stored in two different databases. Arsenic concentration of the tubewell being used by a particular patient could be traced back from the household and tubewell identification numbers contained in the database. However, while using the database, it was found that for many *upazilas* the information contained in the database do not allow

this analysis (that is finding arsenic concentration of tubewell water being used by a patient listed in the "patient information" database). As a result the health risk model could not be applied to all *upazilas*. It was decided that the arsenic affected *upazilas* will be divided into three categories; areas with (i) 40-60% contaminated wells, (ii) 60-80% contaminated wells, and (iii) 80-100% contaminated wells; and equal number of *upazilas* will be selected from each group for application of the risk model.

At first, for each of the 190 BAMWSP surveyed upazilas for which patient information are available in the database, the percentage of contaminated well (i.e., tubewells having more than 50 ppb As) was determined (see Fig. 3.1). Then the upazilas were categorized according to the percentage of affected tubewells as 40-60%, 60-80% and 80-100%. Then, *upazilas* for which patient information could be linked with arsenic concentration information were identified. It was found that this like could be established only for a limited number of *upazilas*. Among these, 7 *upazilas* from each category of affected area were selected for assessment of risk of arsenicosis (see Fig. 3.2 and Tables 3.3 to 3.5).

According to the database, there are 203,050 tubewells in these 21 *upazilas*. The arsenic concentration and the number of users of each of these tubewells were then recorded. For determining the population exposed to different concentrations of arsenic, the population of each upazila (total about 6 million in the selected 21 *upazilas*) were then categorized according to different levels of arsenic they are exposed to (0-50, 50-100, 100, 100-500, 500, 500-1000, > 1000 ppb). At the same time, the number of patients against each exposure level were determined for each of the 21 upazilas.

Information contained in the BAMWSP database suggests that people in the affected upazilas are using the contaminated wells for many years to decades. Thus, they are chronically exposed to arsenic and are at risk of developing symptoms of arsenicosis. The total population as well as male and female population of each upazila was determined from information contained in the database. Patients in selected upazila were

divided into male and female group. The risk model, described in Chapter 2, was used to assess only the non-carcinogenic effects of arsenicosis, Using the model and the selected model parameters (either from Yu et al., 2003 or Ahmed, 2003), *P(c) male* and *P(c) female* were calculated using the following quadratic-exponential equation:

$$P(c)(male/female) = 1 - \exp(-(q1c + q2c^2)) \quad (3.1)$$

Where *P(c)* denotes the fraction of gender with the type of arsenicosis, and *c* denotes arsenic concentration (ppb), and parameter *q1, q2* are non-negative. Parameter values reported by both Yu et al. (2003) (Table 3.1) and Ahmed (2003) (Table 3.2) were used for estimating *P(c)* values. Total number of patients predicted by the model was then determined by multiplying the *P(c)* values with respective total male or female populations. The predicted patients were then compared with actual patients reported in the BAMWSP survey.

Table 3.1: Parameter values from Yu et al. (2003) for estimating non-carcinogenic health effects

Gender	Hyper pigmentation		Keratosis	
	q1	q2	q1	q2
Male	2.678×10^{-4}	0	1.223×10^{-4}	0
Female	1.217×10^{-4}	0	6.416×10^{-4}	2.717×10^{-4}

Table 3.2 Parameter values from Ahmed (2003) for estimating non-carcinogenic health effects

Gender	Arsenicosis	
	q1	q2
Male	3.092×10^{-6}	0
Female	2.59×10^{-6}	0

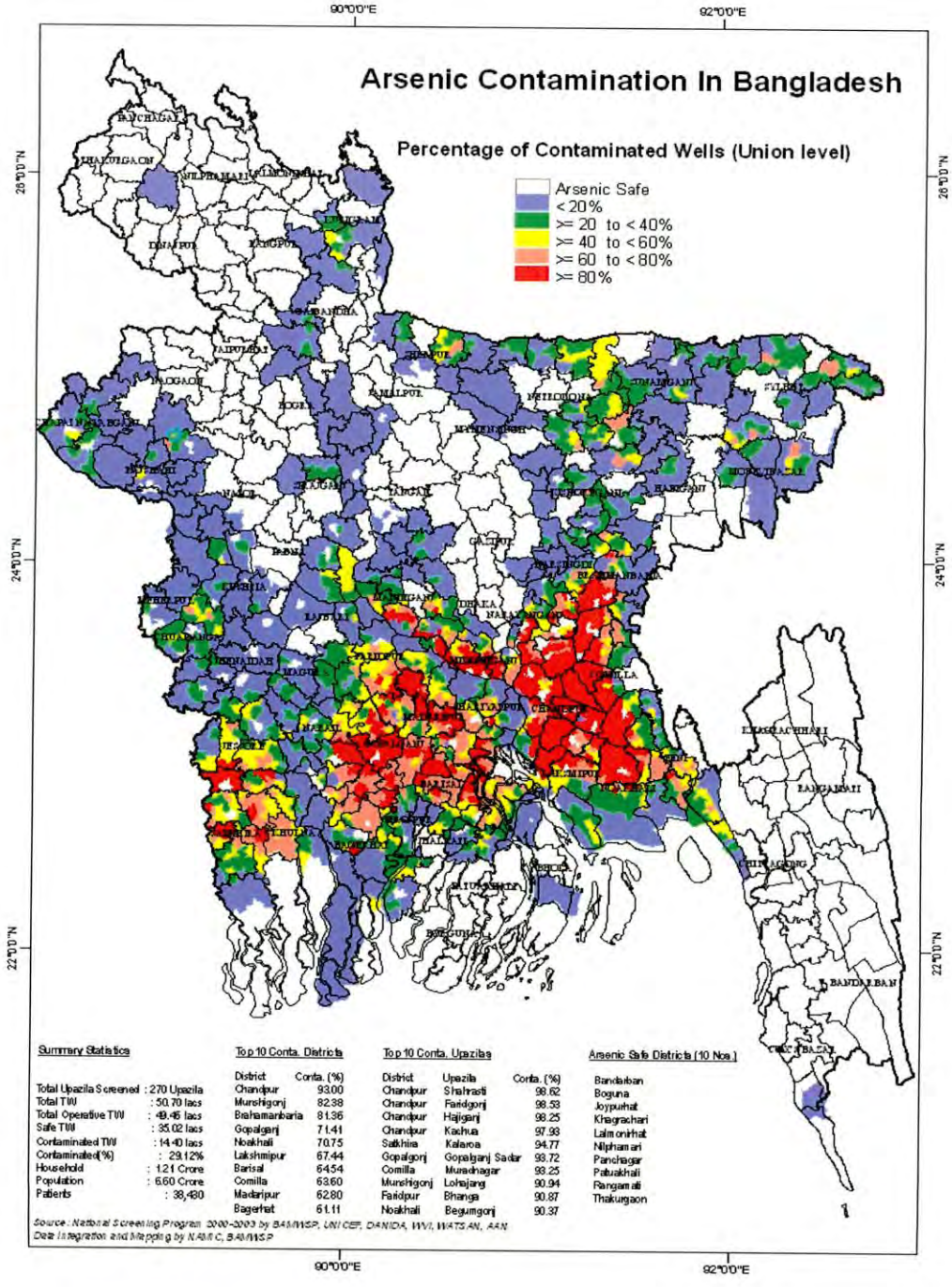

Fig: 3.1: Map showing the percentages of contaminated (i.e., > 50 ppb As) wells in different part of Bangladesh (Source: BAMWSP, 2005)

Fig: 3.2: Map showing the 21 upazilas selected for this study

3.3 RESULT AND DISCUSSION

3.3.1 Arsenic Contamination in the Selected Areas

As noted earlier, the As affected areas of Bangladesh were categorized according to the percentage of affected tubewells as 40-60%, 60-80% and 80-100%, and 7 upazilas from each category was selected for risk assessment. Figure 3.1 shows the As affected areas of Bangladesh in terms of percentage of contaminated wells. The selected 7 upazilas with 80-100% contamination wells include Kolaroa, Lohagonj, Chandina, Raipur, Gazaria, Tungipara and Dohar. Upazilas with 60-80% contaminated wells include Debhata, Chandpur sadar, Asasuni, Kalkini, Harirampur, Brahmanpara and Banaripara. And lastly upazilas with 40-60% contaminated wells include Gosairhat, Meghna, Damudya, Alphadanga, Darmopasha, Naria and Jhalokathi Sadar. Detail information on location and tubewells in these 21 selected upazilas are listed in Tables 3.3 to 3.5.

In the 7 upazilas with 80-100% contaminated wells, total population is 2,760,357; total number of tubewells is 80,640 and the total number of contaminated tube wells are 70,897. Thus, on an average 87.9% of wells in these 7 upazilas are contaminated (Table 3.3). In the 7 upazilas with 60-80% contaminated wells, total population is 1,752,150; total number of tubewells is 73,745 and the total number of contaminated tube wells is 50,052; average contamination is 67.9% (see Table 3.4). In the 7 upazilas with 40-60% contamination, total population is 1,457,208; total number of tubewells is 48,665 and the total number of contaminated tube wells is 22,159; average contamination is 45.5% (Table 3.5).

Table 3.3: Important statistics of 7 selected upazilas with 80-100% contaminated wells

District	Upazilla	No of Union	No of Village	Total TW	No of conta TW	% of conta	Total population
Sathkhira	Kolaroa	12	136	17003	16114	94.77	363471
Munshigonj	Lohagonj	10	100	9878	8983	90.94	571390
Comilla	Chandina	12	209	17585	15889	90.36	491165
Laxmipur	Raipur	10	51	10712	9258	86.43	550817
Munshigonj	Gazaria	8	118	8880	7296	82.16	465800
Gopalgonj	Tungipara	5	59	2877	2354	81.82	114786
Dhaka	Dohar	7	87	13705	11003	80.28	202928
Total		64	760	80640	70897	87.9	2760357

Table 3.4: Important statistics of 7 selected upazilas with 60-80% contaminated wells

District	Upazila	No of Union	No of Village	Total TW	No of conta TW	% of conta	Total population
Sathkhira	Debhata	5	102	8541	6539	76.56	260034
Chandpur	Chandpur Sadar	14	104	11679	8860	75.86	186115
Sathkhira	Asasuni	11	236	11136	7316	65.70	240339
Madaripur	Kalkini	15	190	11164	7262	65.05	315070
Manikganj	Harirampur	13	242	13275	8360	62.98	246880
Comilla	Brahmanpara	8	73	14699	9716	61.94	226991
Barisal	Banaripara	8	77	3251	1999	61.90	276721
Total	-	74	1024	73745	50052	67.9	1752150

Table 3.5: Important statistics of 7 selected upazilas with 40-60% contaminated wells

District	Upazila	No of Union	No of Village	Total TW	No of conta TW	% of conta	Total population
Shariatpur	Gosairhat	7	198	5441	2665	48.98	205713
Comilla	Meghna	7	94	9738	4585	47.08	129950
Shariatpur	Damudia	8	119	4295	1977	46.03	177157
Faridpur	Alphadanga	6	118	7131	3208	44.99	191069
Sunamgonj	Dharmapasa	10	321	2763	1237	44.77	126929
Shariatpur	Naria	15	218	14824	6559	44.25	382191
Jhalokathi	Jhalokathi Sadar	9	174	4473	1928	43.10	244199
Total	-	62	1242	48665	22159	45.5	1457208

3.3.2 Population Exposure to Different Concentration of Arsenic

Population exposed to different concentrations of As have been estimated for the 21 selected upazilas. Information on the total number of tubewells and their As concentrations, and total number of users of each tubewell were taken from the BAMWSP database. Then for each upazila, the total population against each concentration range (as specified in Tables 3.6 to 3.8) was calculated. Figures 3.3 to 3.5 show the population exposed to different concentrations of As for 3 different categories of As affected areas.

Table 3.6: Population exposed to different As concentration in the selected upazilas with 80-100% contaminated wells

As Conc range (ppb)	Population exposed to Arsenic							% population exposed to As
	Kolaroa	Lohagnj	Chandina	Raipur	Gazaria	Tungipara	Dohar	
0 - 50	61263	60436	61120	409980	323743	45137	58777	36.47
>50 - <100	43226	71250	200555	56778	17167	9249	20751	14.97
100	59434	5883	42835	16137	40053	14025	36401	7.68
>100 - < 500	191478	102390	185701	62875	48275	29977	57616	24.24
500	37586	330411	695	2182	18357	12173	24045	15.21
>500 - <1000	7321	701	217	2533	11303	3242	2633	1.00
≥1000	749	319	42	332	6902	983	2705	0.43

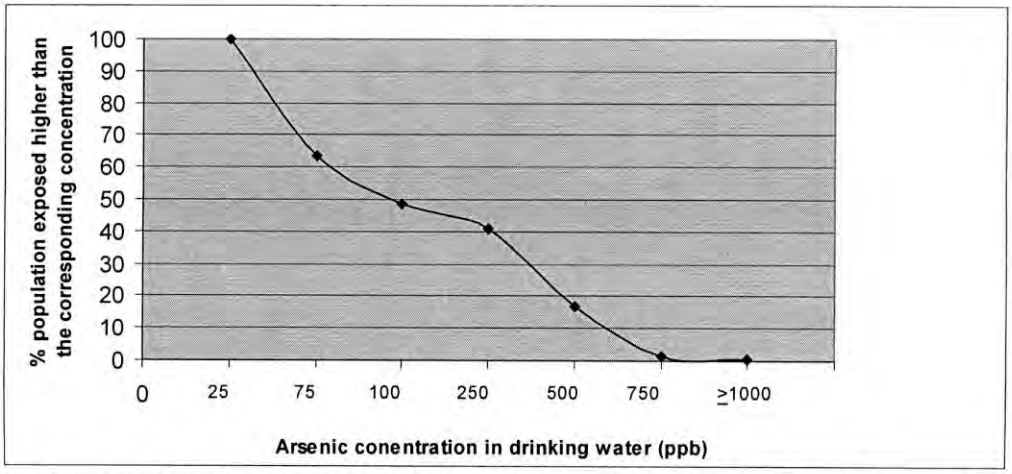

Figure 3.3: Population exposed to different levels of arsenic in selected 7 upazilas with 80-100% contaminated wells

Table 3.7: Population exposed to different As concentration in the selected upazilas with 60-80% contaminated wells

As Conc range ppb	Population exposed to Arsenic							% population exposed to As
	Debhata	Chandpur Sadar	Asasuni	Kalkini	Hariram-pur	Brahman-para	Banari-para	
0 - 50	112253	6275	110101	163056	91577	82934	223873	44.54
>50 - <100	28017	23655	52017	52315	56385	100600	12329	18.34
100	32896	1756	12017	21956	44510	12698	15844	7.99
>100 - < 500	65712	134756	65361	91854	36917	30684	14991	24.82
500	14508	1792	447	4448	10496	69	6045	2.13
>500 - <1000	4287	9756	396	2794	2853	6	1571	1.22
≥1000	2361	8125	0	307	4142	0	2068	0.96

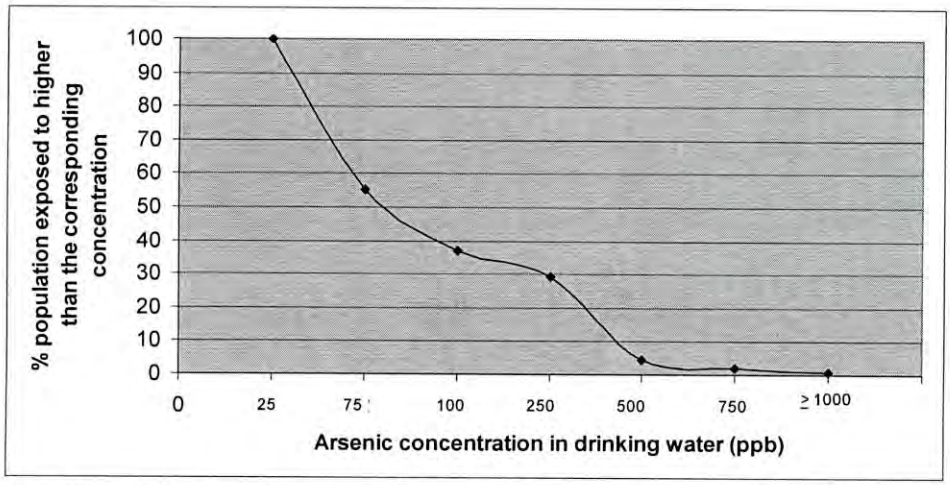

Figure 3.4: Population exposed to different levels of arsenic in selected 7 upazilas with 60-80% contaminated wells

Table 3.8: Population exposed to different As concentration in the selected upazilas with 40-60% contaminated wells

As Conc range ppb	Population exposed to Arsenic							% population exposed to As
	Gosairhat	Meghna	Damudia	Alpha-danga	Dharma-pasa	Naria	Jhalokathi Sadar	
0 - 50	126487	68349	124248	74584	119975	268332	191569	63.10
>50 - <100	25694	26365	23771	22542	81588	41727	27760	7.65
100	3255	11824	6342	44445	3163	22424	10573	3.13
>100 - < 500	49943	21318	20301	49279	7868	46816	7919	6.24
500	85	1582	694	219	15	2501	3839	0.27
>500 - <1000	105	417	69		20	188	1363	0.07
≥1000	144	95	1732	0	0	203	1116	0.10

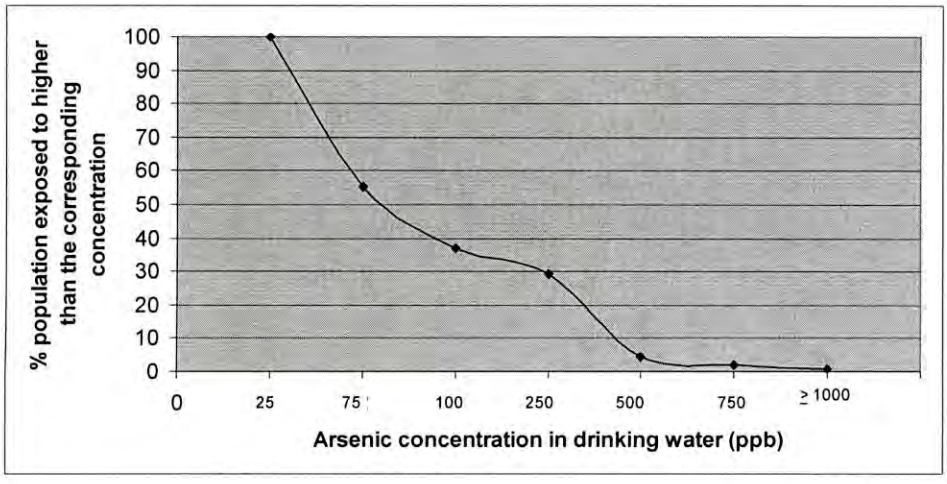

Figure 3.5: Population exposed to different levels of arsenic in selected 7 upazilas with 40-60% contaminated wells

These tables and figures show that in the highly affected (i.e., 80-100% contamination) 7 upazilas, about 64% of the population is exposed to As concentration above the Bangladesh drinking water standard of 50 ppb. In the 7 upazilas with 60-80% contamination, population exposed to unsafe level of As is about 55%, while in the 7 upazilas with 40-60% contamination, it is about 37%

3.3.3 Non-carcinogenic Health Risks

Noncarcinogenic health effects are those which cause only the skin manifestations like Keratosis, Hyperpigmentation, etc. by chronic arsenic exposure. Table 3.9 shows estimated number of non-carcinogenic patients in areas with 80-100% contaminated wells. The estimates have been made using the risk model with parameter values of Yu et al. (2003) and Ahmed (2003). In these 7 upazilas, the total population is 2760357, of which 62,931 people are predicted to suffer from hyperpigmentation and 30,626 from keratosis if model parameter of Yu et al (2003) are used. On the other hand if model parameters of Ahmed (2003) are used only 955 arsenicosis patients are predicted. Thus, the model parameters of Yu et al. (2003) predict a total of 93,557 patients (i.e., about 3.4% of total population), while those of Ahmed (2003) predict only 935 patients.

Table 3.9: Estimated non-carcinogenic patients from model for areas with 80-100% contaminated wells

Upazilla Name	Total population	Hyperpigmentation (Yu et al. 2003)		Keratosis (Yu et al. 2003)		Arsenicosis from Ahmed (2003)	
		Male	Female	Male	Female	Male	Female
Kolaroa	363471	11054	4845	5166	2611	133	105
Lohagonj	571390	4556	1982	2115	1062	54	42
Chandina	491165	9111	3959	4221	2115	108	85
Raipur	550817	4725	2052	2188	1096	56	44
Gazaria	465800	6954	2894	3085	1573	80	63
Tungipara	114786	2652	1168	1245	632	32	25
Dohar	202928	4971	2188	2333	1184	60	48
Total	2760357	43843	19088	20353	10273	523	412

Similar results were predicted by the model for areas with relatively lower level of contamination (see Table 3.10 and 3.11). For example, in areas with 60-80% contaminated wells, Yu et al. (2003) parameters predicted a total of 64,412 arsenicosis patients (i.e., about 3.7% of total population), including 42,555 hyperpigmentation are 21,857 keratosis patients, while Ahmed (2003) parameters predicted 639 arsenicosis patients.

Table 3.10: Estimated non-carcinogenic patients from model for areas with 60-80% contaminated wells

Upazilla Name	Total population	Hyperpigmentation (Yu et al. 2003)		Keratosis (Yu et al. 2003)		Arsenicosis from Ahmed (2003)	
		Male	Female	Male	Female	Male	Female
Debhata	260034	4948	2172	3316	1173	60	47
Chandpur Sadar	186115	7002	3104	3310	1692	86	68
Asasuni	240339	3320	1442	1538	770	39	31
Kalkini	315070	5052	2202	2348	1180	60	48
Harirampur	246880	4301	1899	2025	1031	53	41
Brahmanpara	226991	2516	1089	1161	580	29	24
Banaripara	276721	2433	1075	1150	583	30	23
Total	1752150	29572	12983	14848	7009	357	282

On the other hand, in areas with 40-60% contaminated wells, Yu et al. (2003) parameters predicted a total of 31,813 arsenicosis patients (i.e., about 2.2% of total population), including 21,533 hyperpigmentation are 10,280 keratosis patients, while Ahmed (2003) parameters predicted 351 arsenicosis patients (Table 3.11).

Table 3.11: Estimated non-carcinogenic patients from model for areas with 40-60% contaminated wells

Upazilla Name	Total population	Hyper pigmentation (Yu et al. 2003)		Keratosis (Yu et al. 2003)		Arsenicosis from Ahmed (2003)	
		Male	Female	Male	Female	Male	Female
Gosairhat	205713	2444	1062	1132	567	29	23
Meghna	129950	1531	665	710	356	18	14
Damudia	177157	1741	763	814	411	21	17
Alphadanga	191069	2749	1193	1272	637	60	26
Dharmapasa	126929	1156	670	715	356	18	14
Naria	382191	3424	1485	1584	792	40	32
Jhalokathi Sadar	244199	1845	805	858	432	22	17
Total	1457208	14890	6643	7085	3195	208	143

Thus, the total arsenicosis patients predicted by the risk model using the two sets of parameter [i.e., Yu et al. (2003) and Ahmed (2003)] differ by a factor of about 100. It should be noted that the model parameters used by Yu et al. (2003) are derived from a study conducted in Taiwan, and these of Ahmed (2003) have been derived by fitting limited data on arsenicosis patients in Bangladesh. From the discussion presented in the following section it is obvious that the Yu et al. (2003) parameters predict number of arsenicosis patient that are orders of magnitude higher than the present prevalence of arsenicosis. In fact in most cases the number of patient predicted by the Ahmed (2003) parameters are also higher than the present number of patients found in BAMWSP survey. Hence the parameters used by Yu et al. (2003) do not appear to be appropriate for describing the present level of arsenicosis in Bangladesh. The following section

provides a comparison of model predictions with actual data in each of the 21 upazilas selected in this study.

3.3.4 Comparison of Model Results with Actual Patient Data

The actual patient data from the BAMWSP survey have been compared with model prediction using two sets of parameter (Yu et al., 2003 and Ahmed, 2003). It has been found that there is a huge difference between the predictions from the dose-response model and actual patient data. It should be noted that according to the model, the fraction of population suffering from arsenicosis, i.e. P(c), depends on concentration of arsenic only, but the number of predicted patients depends on the population exposed to the particular concentration. Hence higher As concentration or larger population exposure or both would result in higher number of predicted patients. Generally it is thought that higher concentration of arsenic would result in larger number of patients. But according to the BAMWSP survey data, the scenario is not that straight forward. In many areas it has been found that concentration of arsenic in tube well water is not very high but patient number is very high. On the other hand, large number of patient has been found in some areas where As concentration is not very high. In some cases, however, the predictions using Ahmed (2003) parameters are comparable to the actual patient data. As noted earlier, predictions using Yu et al (2003) parameters were about 100 times higher than those obtained using Ahmed (2003) parameter values. Hence while comparing model predictions with actual data, the predictions made with the parameters of Ahmed (2003) have been considered.

Table 3.12 shows a upazila-wise comparison of actual number of total patients (from BAMWSP survey) and the number of patients predicted by the model. It shows that for 4 upazilas (Chandpur Sadar, Brahmanpara, Alphadanga and Dharmapasa), the model predictions matched quite well with total number of patients. In 5 upazilas (Tungipara, Assasuni, Banaripara, Damudia and Naria), the number of actual patients are actually higher than those predicted by the model. In the remaining 12 upazilas, the total number

of patients predicted by the model is significantly higher than the actual number of patients found in the survey.

Table 3.12: Comparison of actual patient and model predictions

Upazila	Actual Patient	Model Prediction	
		Yu et al. (2003) Parameter	Ahmed (2003) Parameter
Kolaroa	629	23,677	238
Lohagonj	104	9,717	96
Chandina	133	19,406	193
Raipur	404	10,062	100
Gazaria	27	14,102	143
Tungipara	109	5,699	57
Dohar	36	10,676	108
Debhata	97	12,627	107
Chandpur Sadar	132	15,109	154
Asasuni	259	8,357	70
Kalkini	91	10,782	108
Harirampur	39	9,572	94
Brahmanpara	34	5,345	53
Banaripara	103	5,264	53
Gosairhat	39	5,206	52
Meghna	19	3,264	32
Damudia	122	3,730	38
Alphadanga	96	7,617	86
Dharmapasa	27	3,298	32
Naria	275	287	72
Jhalokathi Sadar	57	16,430	39
Total	2,832	200,227	1,925

Figures 3.6 through 3.26 show comparison of actual patient data (i.e., total arsenicosis patients from BAMWSP survey) with model predictions [using Ahmed (2003) parameters]. For each upazila, the comparison has been made for each of the 10 selected range of As concentrations. Each of these figures shows the actual and the predicted number of patients for each of the selected arsenic concentration ranges.

Some very interesting observations can be made from the comparisons presented in Table 3.12 and Figures 3.6 to 3.26. As noted earlier, for 5 upazilas (Chandpur Sadar, Kalkini, Lohagonj, Alphadanga and Debhata) the model predicted total number of patients matched quite well with the actual number of patients. Figures 3.6 to 3.10 show the comparison of model prediction and actual number of patients for these 5 upazilas for different concentration ranges of As. These figures show that although the match between model predictions and total number of patients is quite good in terms of total number of patients, the predicted patients in different concentration range did not match with actual patient data. In all cases, the model consistently under-predicted the patient number for population exposed to lower level of As (up to about 100 ppb), while over-predicted patient number of higher As exposure (over 100 ppb). For example, in Chandpur Sadar, the model predicted only a couple of patients among population exposed to As concentration of 0-50 ppb, while the survey reported 52 patients among these population. On the other hand, in Alphadanga, the model predicted over 50 patients among population exposed to a As concentration of 100-500 ppb; however the survey reported only a couple of patients in this group.

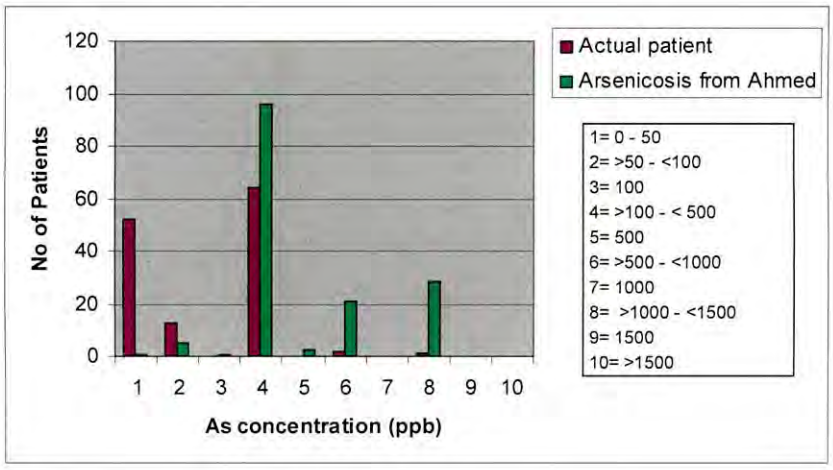

Figure 3.6: Comparison of actual patient with model predictions at Chandpur Sadar

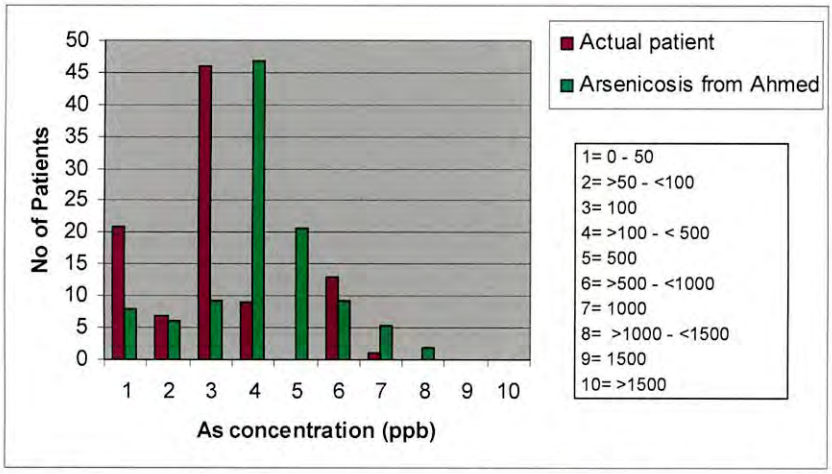

Figure 3.7: Comparison of actual patient with model predictions at Debhata

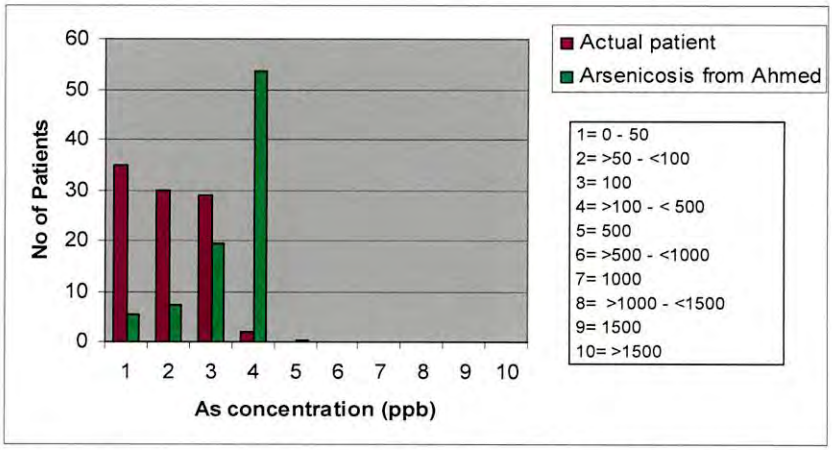

Figure 3.8: Comparison of actual patient with model predictions at Alphadanga

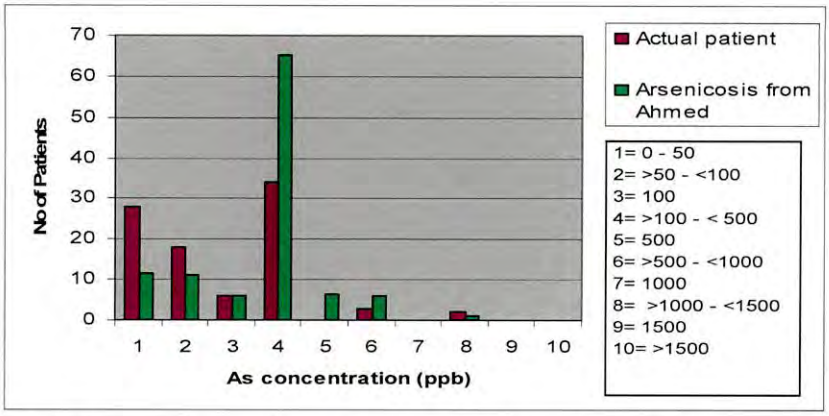

Figure 3.9: Comparison of actual patient with model predictions at Kalkini

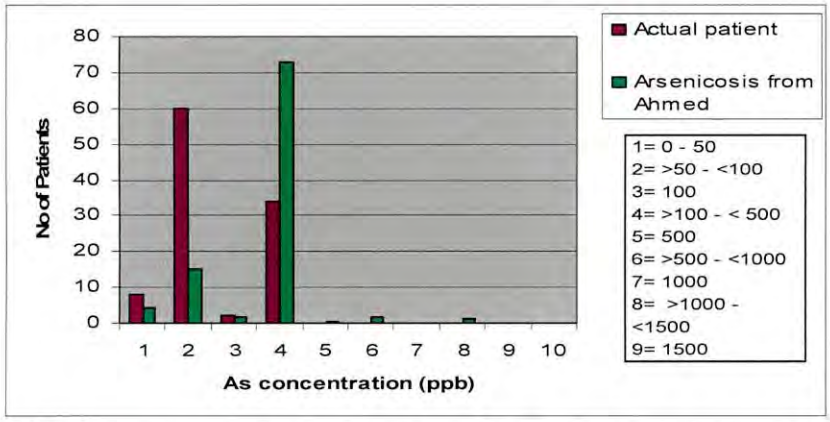

Figure 3.10: Comparison of actual patient with model predictions at Lohagonj

As noted earlier, in 7 upazilas, the actual total number of patients is actually higher than the total predicted number of patients. In each of these 7 upazilas (Assasuni, Fig. 3.11; Banaripara, Fig. 3.12; Damudya, Fig. 3.13; Naria, Fig. 3.14; Koloroa, Fig. 3.15; Tungipara, Fig. 3.16; Raipur, Fig 3.17), the reason for under-prediction of patient number compared to actual number is the same. That is the model predicted lower number of patients among population exposed to relatively lower level of As (up to about 100 ppb; in some cases up to 500 ppb), while in reality relatively larger number of arsenicosis patients were found among these population during the BAMWSP survey.

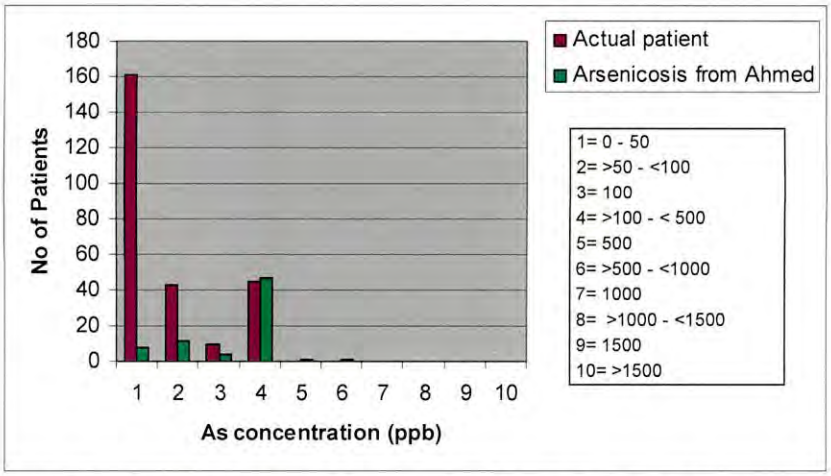

Figure 3.11: Comparison of actual patient with model predictions at Assasuni

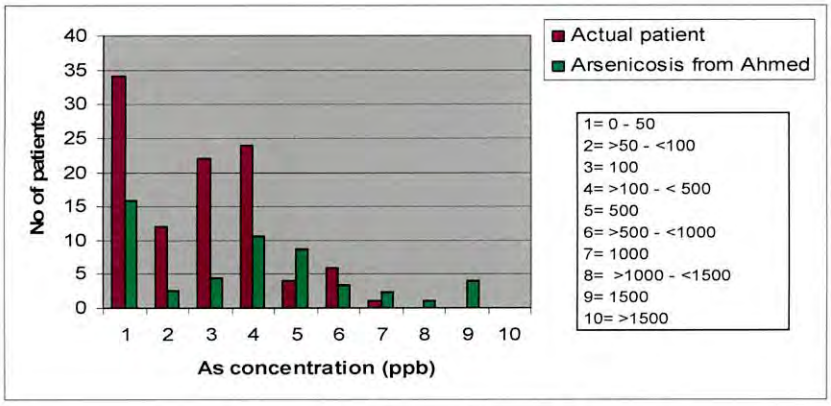

Figure 3.12: Comparison of actual patient with model predictions at Banariapara

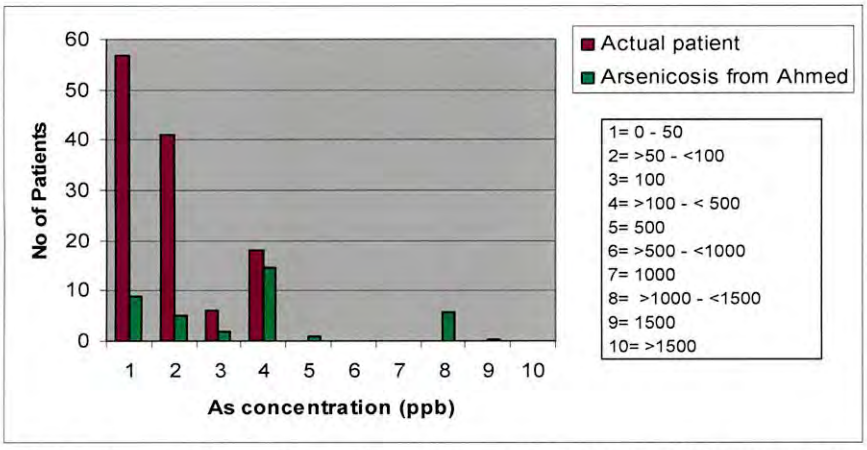

Figure 3.13: Comparison of actual patient with model predictions at Damudia

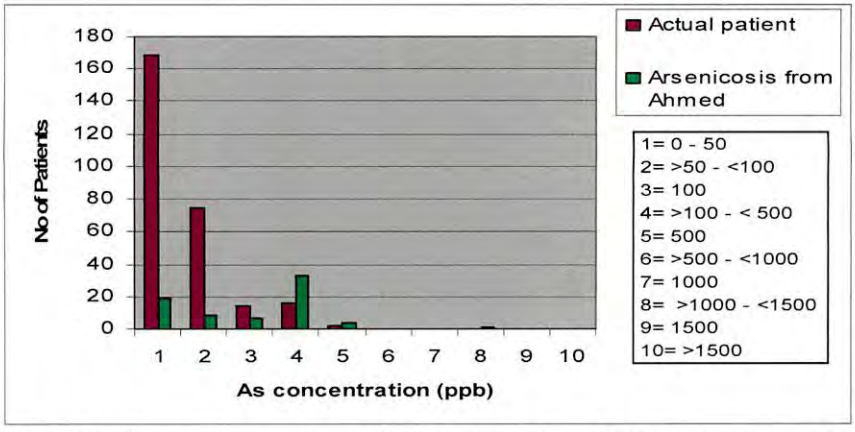

Figure 3.14: Comparison of actual patient with model predictions at Naria

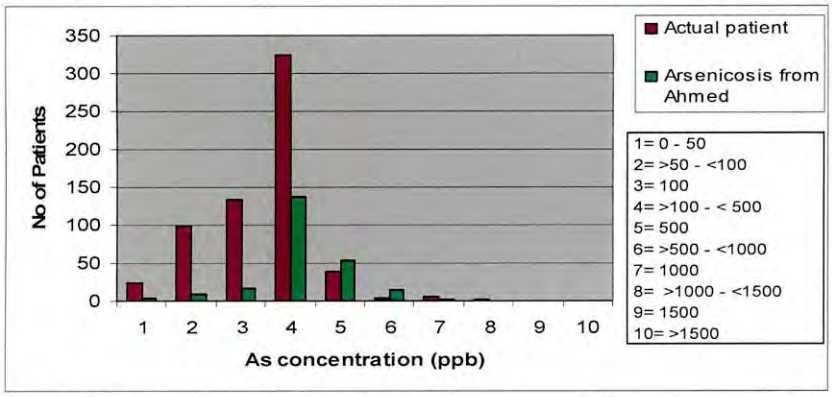

Figure 3.15: Comparison of actual patient with model predictions at Kolaroa

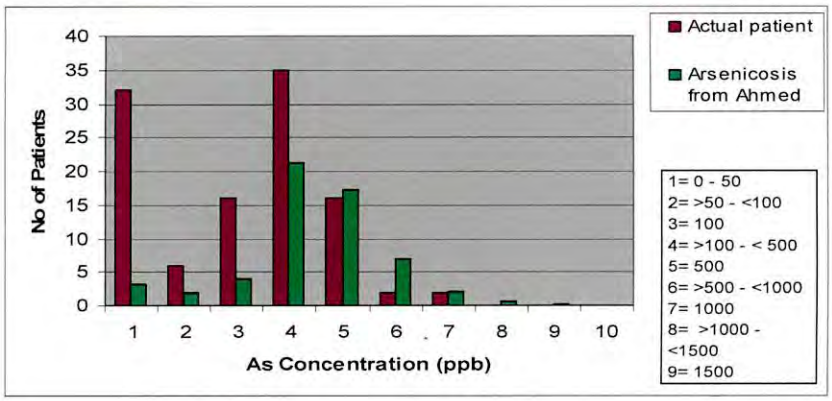

Figure 3.16: Comparison of actual patient with model predictions at Tungipara

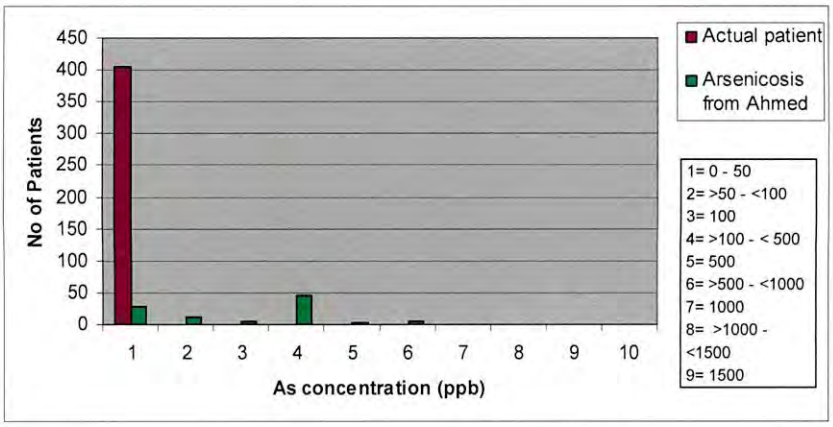

Figure 3.17: Comparison of actual patient with model predictions at Raipur

In each of the remaining 9 upazilas (Figs. 3.18 to 3.26), the total number of arsenicosis patients predicted by the model was much higher than the actual number of patients

reported in the BAMWSP survey. This is primarily because the model predicted much higher arsenicosis patients among population exposed to high level of As (above 500 ppb), while in reality relatively smaller number of patients were reported by the BAMWSP survey for these group of people.

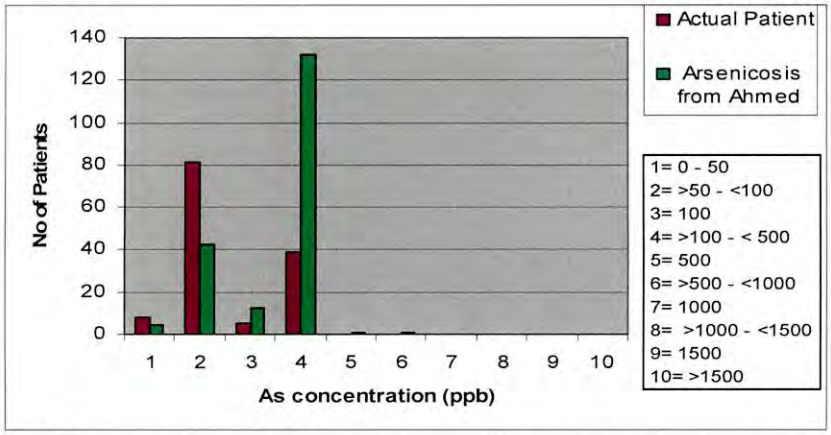

Figure 3.18: Comparison of actual patient with model predictions at Chandina

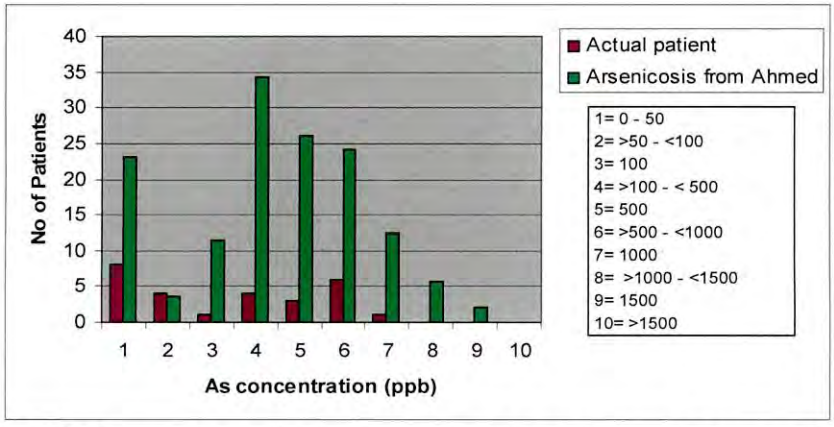

Figure 3.19: Comparison of actual patient with model predictions at Gazaria

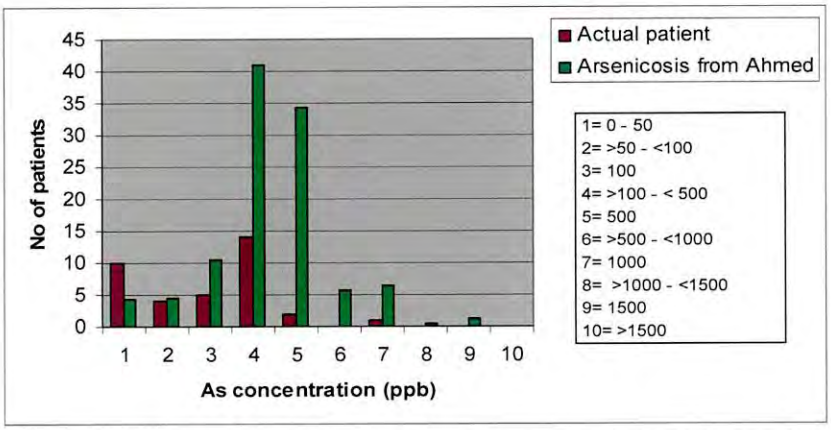

Figure 3.20: Comparison of actual patient with model predictions at Dohar

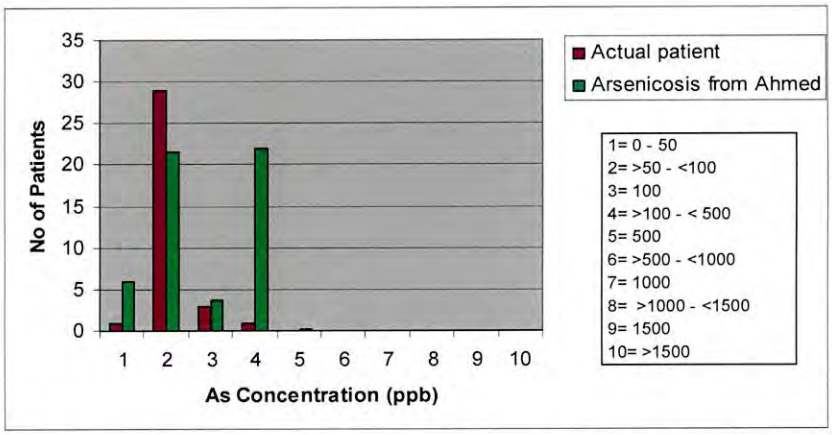

Figure 3.21: Comparison of actual patient with model predictions at Brahmanpara

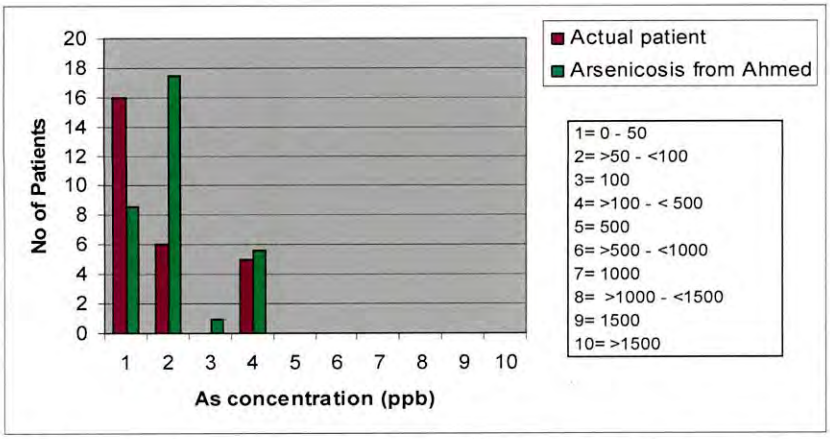

Figure 3.22.: Comparison of actual patient with model predictions at Dharmapasa

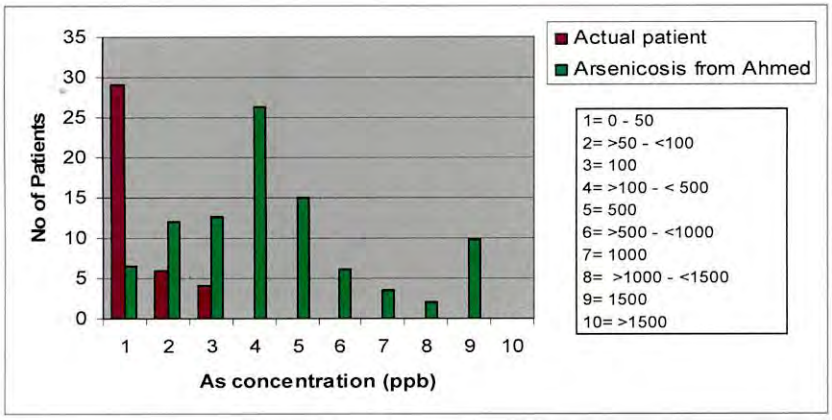

Figure 3.23: Comparison of actual patient with model predictions at Harirampur

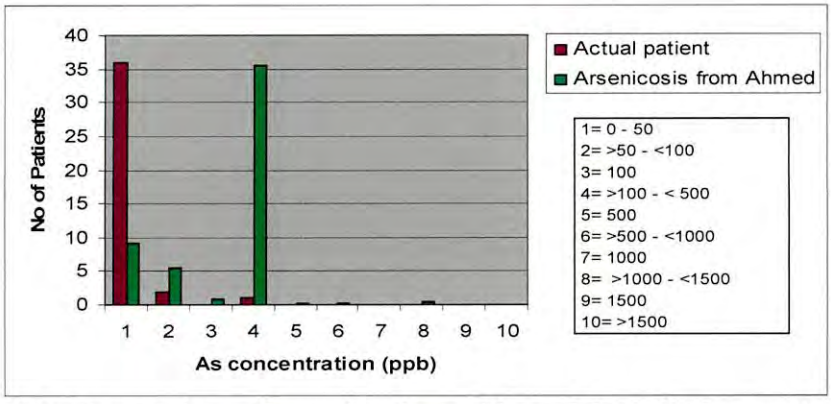

Figure 3.24: Comparison of actual patient with model predictions at Gosairhat

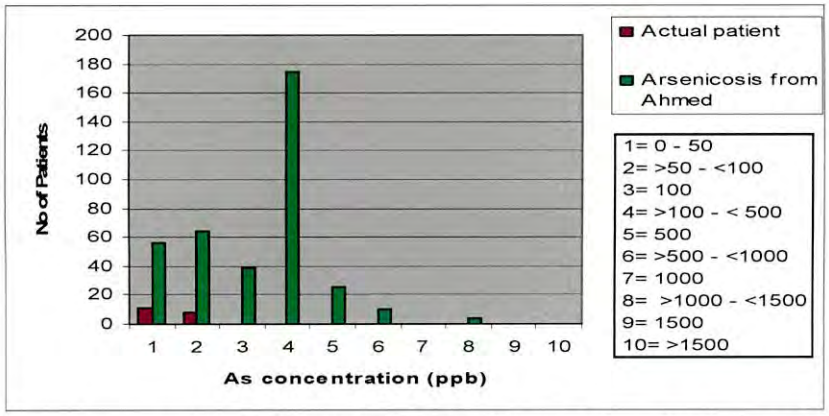

Figure 3.25: Comparison of actual patient with model predictions at Meghna

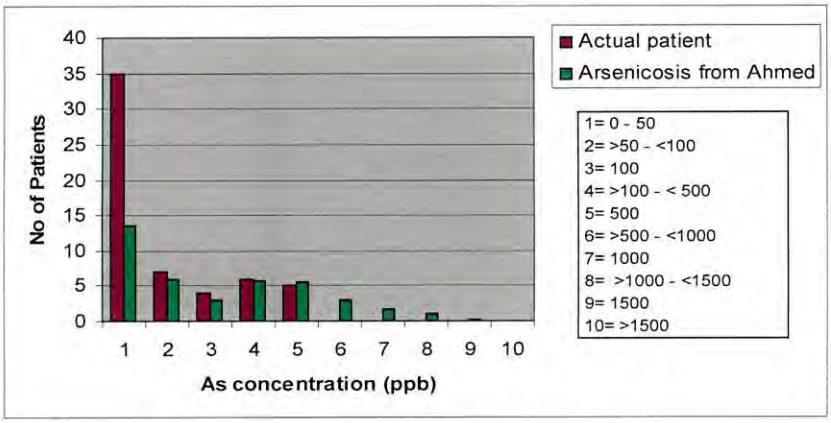

Figure 3.26: Comparison of actual patient with model predictions at Jhalokathi

3.4 SUMMARY

Estimation of population exposed to different concentrations of As suggest that percentage of population exposed to unsafe level of As is somewhat less than the percentage of contaminated wells. For example, in the 7 upazilas with 80-100% contaminated wells, the average percentage of contaminated wells is about 87.9%, while percentage of population exposed to contaminated water (i.e. As > 50 ppb) is about 63.5%. Similarly in the other two categories of areas (i.e. 60-80% and 40-60% contaminated wells), percentages of contaminated wells are 67.9% and 45.5%, while the corresponding percentage of population exposed to contaminated water are 55.4% and 36.9%, respectively.

Model prediction of the number of arsenicosis patients using two sets of model parameters differ by a factor of about 100. The model parameters of Yu et al. (2003) were derived from a study in arsenic affected areas in Taiwan and yielded very high number of arsenicosis patients. It suggests that if health effects similar to those experienced in Taiwan occur in Bangladesh, a huge number of people would be come affected with arsenicosis.

The model predictions of total number of arsenicosis patients using parameter values taken from Ahmed (2003) matched well with actual data in 5 upazilas, lower in 7 upazilas, while higher in the remaining 9 upazilas. In general, the model under-predicted patient number among population exposed to relatively low level of arsenic (below 100 ppb); while significantly over-predicted patient number among population exposed to relatively high concentrations of As. It would be interesting to see if a new set of model parameters could be developed for better prediction of present level of arsenicosis. Chapter 4 presents the results of such an effort.

Chapter 4

Estimation of Health Risk Model Parameters Based on BAMWASP Survey Data

4.1 INTRODUCTION

Chapter 3 presents a comparison between actual patient data from the BAMWSP survey and the risk model predictions of arsenicosis patients for 21 arsenic affected upazilas of the country. It shows that there is a large difference between the actual data and model predictions. Number of arsenicosis patients predicted by the risk model using the parameter values of Yu, et al. (2003) were about two orders of magnitude (i.e. about 100 times) higher than the actual patient data. Model predictions using the parameter values of Ahmed (2003) also did not match the actual patient data very well.

An attempt was therefore made to estimate values of model parameters based on the BAMWSP survey data on number of patients and arsenic concentration of tubewell. As noted earlier, the BAMWSP survey database lists both arsenic concentration and patient information (e.g., male/female patient) against a household identification number and hence this database could be used to determine arsenic exposure level of the each patient identified in the survey. The information contained in the database was used to estimate the model parameters *q1* and *q2*. The risk model was then applied using the newly estimated parameters to predict number of arsenicosis patients in the 21 upazilas selected earlier, as well as 6 new arsenic affected upazilas. This Chapter presents the results of model parameter estimation and compares the new model predictions with actual patient data for the 27 upazilas. Based on the modeling exercise, the applicability of the risk model in predicting arsenicosis in Bangladesh has also been discussed.

4.2 METHODOLOGY

For estimating model parameter using the available patient data, *P(c), male* and *P(c), female* values were calculated for 6 different arsenic exposure ranges. These ranges are 0-50 ppb, 50-100 ppb, 100 ppb, 100-500 ppb, 500 ppb, and 500-1000 ppb. Total number of male and female exposed to each of these concentration ranges were determined from information contained in the BAMWSP database, assuming percentage of male and female to be 51.5% and 48.5%, respectively.

P(c), male and *P(c), female* values for each range of arsenic exposure were then calculated as follows:

P(*c*) *male (x-y ppb) = Actual number of male patient among population exposed to x-y ppb of As / (Total Population exposed to x-y ppb As x 0.515)*

P(*c*) *female (x-y ppb) = Actual number of male patient among population exposed to x-y ppb of As / (Total Population exposed to x-y ppb As x 0.485)*

The calculated P(c) values for male and female population are presented in Appendix A. The calculated prevalence rations [i.e., *P(c)* values] were plotted against corresponding to As concentration separately for male and female. In the absence of actual As concentration, the mid of the As exposure range was selected as As concentration. For example, for the exposure range 0-50 ppb, a concentration of 25 ppb was used in the plot (see Figs. 4.1 and 4.2). The following equation was then fitted to the data [i.e., *P(c)* versus As concentration plots] to estimate the values of model parameters (non-negative) *q1* and *q2*.

$$P(c)(male/female) = 1 - \exp(-(q1c + q2c^2)) \qquad (4.1)$$

For the purpose of fitting, the above equation was modified in the following form:

$$1 - P(c) = \exp(-(q1c + q2c^2)) \quad (4.2)$$

Or, $$Q(c) = \exp(-(q1c + q2c^2)) \quad (4.3)$$

Or, $$\ln Q(c) = -q1c - q2c^2 \quad (4.4)$$

Or, $$Q'c = q1c + q2c^2 \quad (4.5)$$

The quantity $Q'c$ [$=-ln\{1-P(c)\}$] was calculated for each concentration range and plotted against the mid value of the concentration range. The parameters q1 and q2 were then estimated by fitting a polynomial line to this plot (see Figs. 4.1, 4.2).

The estimated model parameters (i.e., *q1* and *q2*) were then used to predict male and female patients in 7 of the 21 upazilas selected earlier, as well as 6 newly selected upazilas (Alamdanga, Feni, Tala, Nangolkot, Devidar, Damudia).

4.3 RESULTS AND DISCUSSION

4.3.1 Estimation of Model Parameters

At first efforts were made to estimate both the model parameters *q1* and *q2* separately for male and female using the calculated P(c) (from patient data) for selected arsenic concentration ranges. Figure 4.1 and 4.2 shows the *Q'(c)* versus *c* plots and the fitted line for male and female, respectively, including the fitted equation (according to Eq. 4). The plots show that in both cases, the value *q2* becomes negative. It is also clear that this happens because the calculated prevalence ratios [i.e. *P(c)*] actually show a decreasing trend as arsenic concentration increases. This is inconsistent with the basic assumption in the model, which is that prevalence increases as arsenic concentration increases.

Failing to fit the data with the two parameters, the parameter *q2* was set equal to zero and the *Q'(c)* versus *c* plots were fitted with the linear equation [$Q'c = q1c$] and the parameter q1 was estimated. Figures 4.3 and 4.4 show the fits for male and female, respectively. In both cases, the value of *q1* was found to be 2.0×10^{-6}. Table 4.1 shows

the estimated parameter values for arsenicosis for male and female. Figures 4.5 and 4.6 show *P(c)* versus concentration (*c*) plots along with model fits with estimated parameter *q1*.

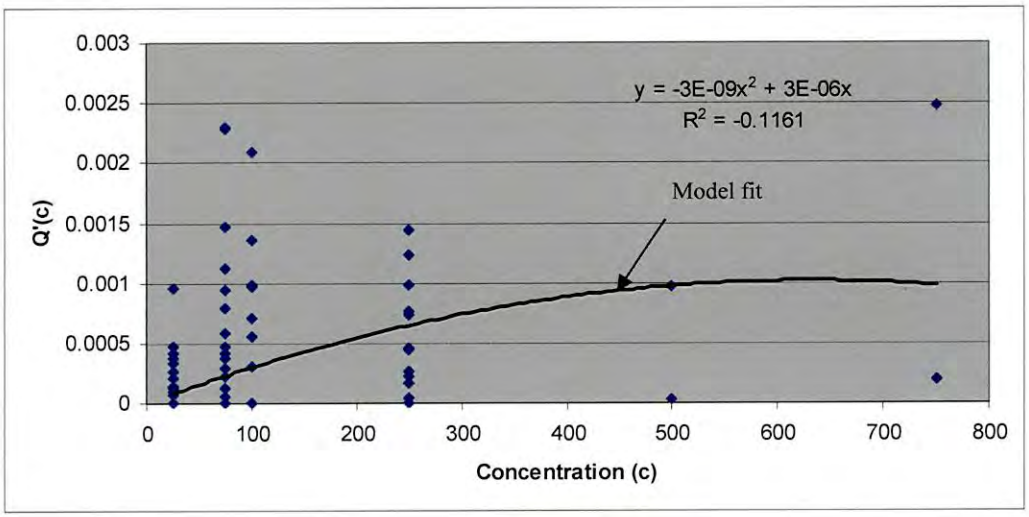

Figure 4.1: *Q'(c)* versus *c* plot and polynomial fit showing values of *q1* and *q2* for male

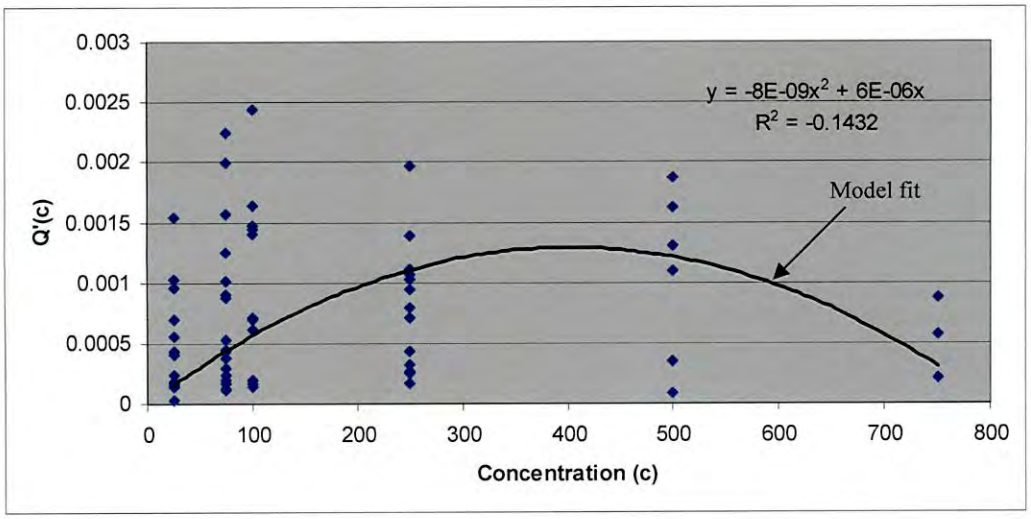

Figure 4.2: *Q'(c)* versus *c* plot and polynomial fit showing values of *q1* and *q2* for female

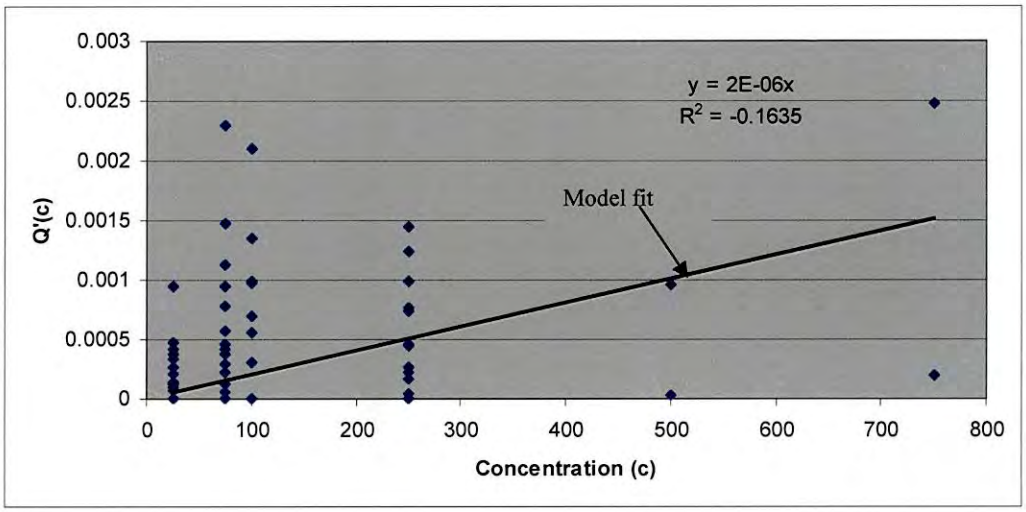

Figure 4.3: *Q'(c)* versus *c* plot and liner fit showing value of *q1* for male

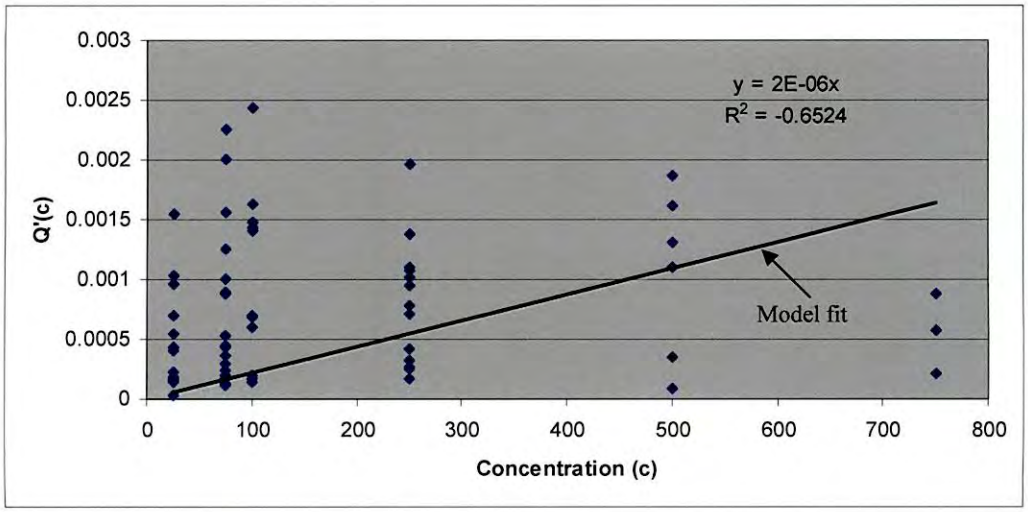

Figure 4.4: *Q'(c)* versus *c* plot and liner fit showing value of *q1* for female

Table 4.1: Parameter value estimated from BAMWSP data

Gender	Arsenicosis	
	q1	*q2*
Male	$2x10^{-6}$	0
Female	$2x10^{-6}$	0

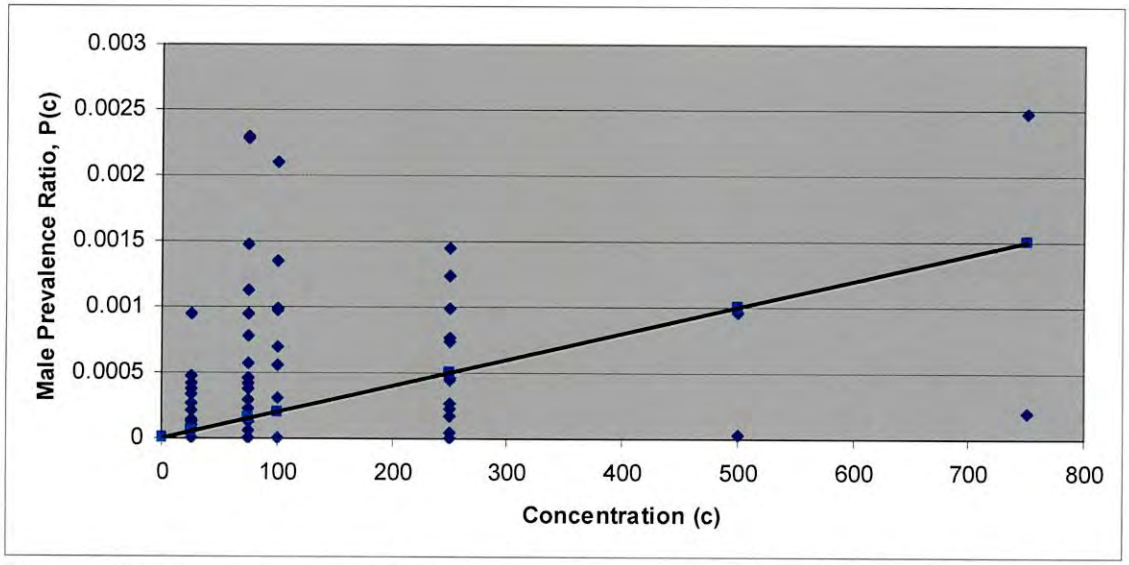

Figure 4.5: Actual male prevalence ratio vs. As concentration along with the model fit

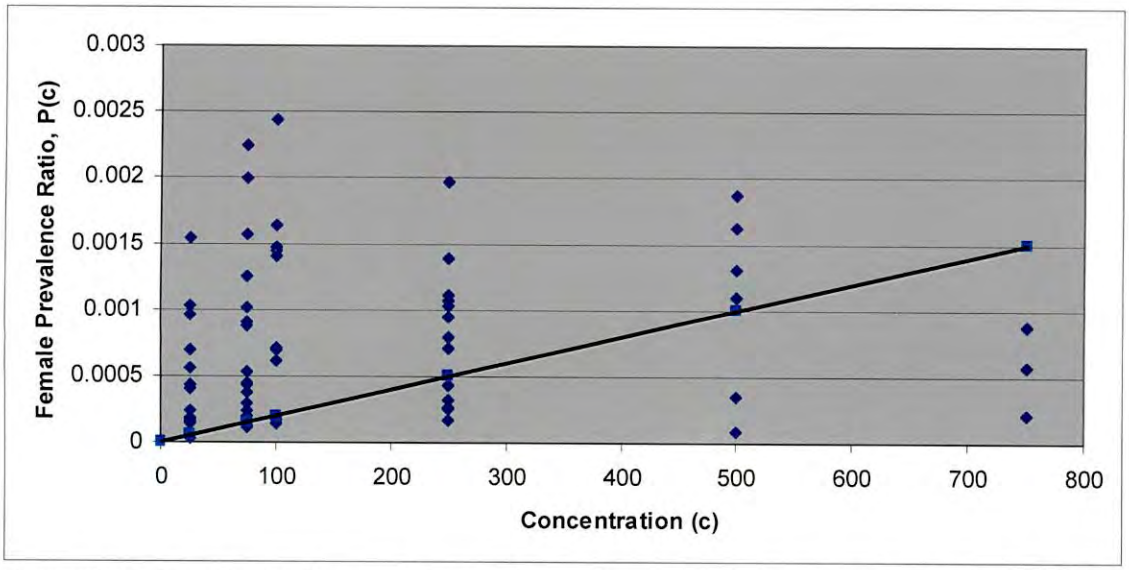

Figure 4.6: Actual female prevalence ratio vs. As concentration along with the model fit

Figures 4.5 and 4.6 show some very interesting features. They show that actual prevalence ratios are not correlated at all with arsenic concentration. For both male and female, the prevalence ratio among population exposed to As concentration of 0-50 ppb (plotted as 25 ppb in the figures) is quite significant. This means that in the arsenic affected upazilas, significant number of patients have been identified among population who are apparently drinking "safe" water according to Bangladesh standard. Among population exposed to higher concentration of As, both high and low prevalence ratios were found among the survey population/areas. The prevalence ratio appears to show a decreasing trend as As concentration exceeds 500 ppb, especially among female population.

It is also clear from the model fits shown in Figs. 4.5 and 4.6 that the risk model performs very poorly in describing the actual prevalence ratios. This is not surprising because the risk model inherently assumes that the prevalence ratio increases as arsenic concentration increases; whereas the actual data from the survey show that prevalence of arsenicosis patients has little or no relationship with to arsenic concentration through drinking water.

4.3.2 Model Application with Estimated Parameters

Although it is obvious that the dose-response model would not be able the fit actual data very well, efforts were made to compare the model predictions with the estimated parameter ($q1$) with actual patient data. The comparison was made for 7 of the 21 upazilas selected earlier, as well as 6 new upazilas. Table 4.2 shows a comparison between actual patient data and the model predictions.

Table 4.2: Comparison of model predictions with actual patient data

Upazila Name	Actual Patient	Model Parameter		
		Yu et al. (2003)	Ahmed (2003)	This Study
Kolaroa	629	23677	238	166
Raipur	404	10062	100	70
Tungipara	109	5699	57	38
Asasuni	259	8357	70	49
Banaripara	103	5264	53	32
Alphadanga	96	7617	86	41
Damudia	122	3730	38	22
Alamdanga	400	-	-	70
Feni	305	-	-	72
Tala	192	-	-	72
Nangolkot	735	-	-	58
Debidar	724	-	-	49
Ramgonj	727	-	-	66

Table 4.2 shows that the model parameters reported by Yu et al. (2003), which are based on West Bengal patient data highly overestimate the arsenic patient, whereas model parameters of both Ahmed (2003) and the present study underestimates the actual patient.

From Figs. 4.5 and 4.6, it is obvious that in the model would underestimate patients among population exposed to relatively low (up to few hundred ppb) concentration of arsenic, whereas it would overestimate patients among population exposed to very high concentration of arsenic (above 500 ppb).

The patient data gathered during the BAMWSP survey clearly suggest that arsenic concentration of drinking water alone cannot explain the observed prevalence of arsenicosis. Analysis made in the present study suggests that any risk model based on only arsenic concentration will not be able to describe the present prevalence of arsenicosis in Bangladesh. Other parameters, e.g., arsenic exposure through food chain, food habit and nutrition, genetic makeup probably have significant influence on the prevalence of arsenic. However, the data gathered during the BAMWSP survey do not allow analysis of such parameters.

The very high prevalence of arsenicosis patients among both male and female population drinking water with arsenic concentration below the Bangladesh standard is very alarming. Table 4.3 shows the total patient in each of the 21 selected upazilas and the number and percentage of patients who are exposed to arsenic concentration within the Bangladesh standard (0-50 ppb). Percentage of arsenicosis patients who are apparently drinking As-safe water (i.e. water with As below 50 ppb) varies from a low of 2.9% in Brahmanpara to 100% in Raipur. Figure 4.7 shows about 43% of the 2751 total arsenicosis patients in the 21 upazilas, about 43% are drinking water with As concentration below 50 ppb. Figure 4.8 shows that the fraction of patients among population exposed to different As concentration levels shows a decreasing trend as As exposure level exceeds about 100 ppb.

Table 4.3: Total patient and patients exposed to 0-50 ppb arsenic

Upazila	Total Patient	Patient who are exposed to 0-50 ppb As	Upazila	Total Patient	Patient who are exposed to 0-50 ppb As
Raipur	404	404 (100%)	Banaripara	103	34 (33%)
Gosairhat	39	36 (92.3%)	Kalkini	91	28 (30.7%)
Harirampur	39	29 (74.3%)	Tungipara	109	32 (29.6%)
Naria	275	169 (61.5%)	Gazaria	27	8 (29.6%)
Assasuni	259	159 (61.4%)	Dohar	36	10 (29.3%)
Jhalakathi Sadar	57	35 (61.4%)	Debhata	97	16 (16.5%)
Dharmapasa	27	16 (59.3%)	Lohagonj	104	8 (7.7%)
Meghna	19	11 (57.9%)	Chandina	133	8 (6%)
Damudia	122	57 (46.7%)	Kolaroa	629	25 (4%)
Chandpur Sadar	132	52 (39.4%)	Brahmanpara	34	1 (2.9%)
Alphadanga	96	35 (36.5%)	--	--	--

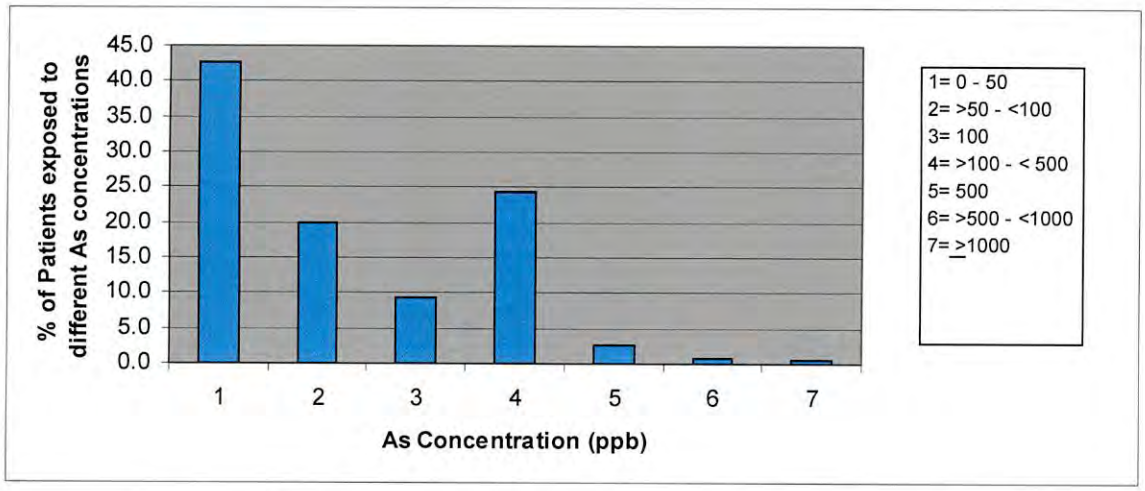

Figure 4.7: Distribution of patients as a function of As exposure level

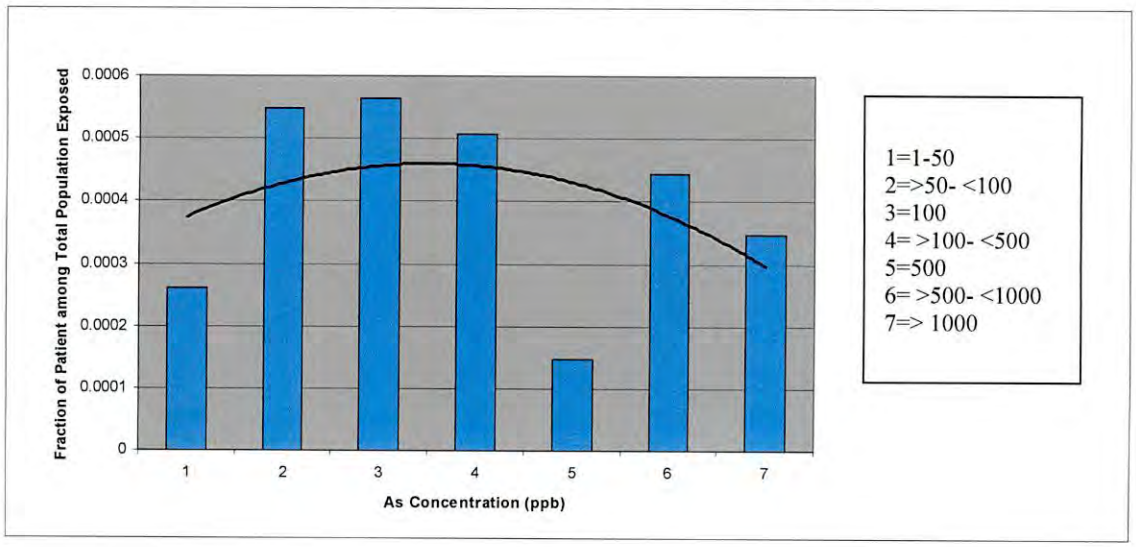

Figure 4.8: Fraction of population suffering from arsenicosis for different levels of arsenic exposure

Assuming that the arsenic tests carried out during the field survey are acceptable, it suggests that in the arsenic affected areas drinking water with arsenic concentration below the Bangladesh standard does not guarantee safety from adverse health effects. It probably indicates that either the current as standard is not stringent enough and/or that arsenic exposure through food chain is probably significant and should be taken into consideration while setting arsenic standard.

Chapter 5

Conclusions and Recommendations

5.1 CONCLUSIONS

This study analyzes the data gathered during the BAMWSP survey of 271 As affected upazilas of the country, with a view to estimate the fraction of population exposed to different levels of As in drinking water and to assess relationship between As concentration in drinking water and health impacts (i.e. occurrence of arsenicosis). The ability of a well known As health risk model to predict arsenicosis in the affected areas has been tested by comparing model predictions with actual patient data. Through this exercise, some major limitations of the available risk models in predicting arsenicosis has been identified.

The major conclusions from this study are as follows:

(1) In the arsenic affected areas, about 50% of the population (54.7% in the 21 upazilas selected in this study) could be exposed to As concentrations above the Bangladesh standard of 50 ppb. In the severely affected areas, exposed population could be over 60% (63.4% in the 7 upazilas selected in this study with 80-100% contaminated wells).

(2) Population exposed to As concentration above the WHO guideline value of 10 ppb could not be estimated from the survey data, since the lowest reported As concentration range in the BAMWSP database is 0-50 ppb.

(3) In the As affected areas, percentage of population exposed to unsafe level of As (i.e. > 50 ppb) is somewhat less than the percentage of contaminated wells, possibly suggesting that some people are using As-safe water from sources other than their contaminated wells. For example, in the 7 upazilas with 80-100%

contaminated wells, the average percentage of contaminated wells is about 87.9%, while percentage of population exposed to contaminated water (i.e. As > 50 ppb) is about 63.5%.

(4) Total number of arsenicosis patients in the 21 selected upazilas predicted by the risk model using Yu et al. (2003) and Ahmed (2003) parameters are 200227 and 1925, respectively against the actual patient of 2,823.

(5) Parameters of Yu et al. (2003) over-predicted arsenicosis patients by a factor of over 70. Although total number of patients predicted by the parameters of Ahmed (2003) is close to the total number of actual patients, a detailed analysis revealed that it significantly under-predicted patient number among population exposed to relatively low level of arsenic (below 100 ppb), while significantly over-predicted patient number among population exposed to relatively high concentrations of As.

(6) The model parameters of Yu et al. (2003) were derived from a study in West Bengal; which suggests that if health effects in Bangladesh eventually become similar to those experienced in West Bengal, a huge number of people would be come affected with arsenicosis.

(7) Prevalence of arsenicosis does not correlate well with arsenic concentration in drinking water. The actual prevalence ratio among population exposed to relatively low As concentration (e.g., up to 100 ppb) is quite high; while the prevalence ratio appears to show a decreasing trend as As concentration exceeds 500 ppb, especially among female population.

(8) It appears that in the arsenic affected areas, drinking As safe water (As < 50 ppb) does not guarantee safety from adverse health effects. For example, among the 2832 arsenicosis patients identified in the 21 upazilas, about 43% are drinking water with As concentration below 50 ppb. Many could however question the reliability of As measurement through field kits in this regard.

(9) Available health risk models, all of which assumes that prevalence of arsenicosis is a function of arsenic concentration in drinking water, will perform poorly in describing present level of arsenicosis in Bangladesh.

5.2 RECOMMENDATIONS

Based on the outcome of this study, the following recommendations are made for future studies:

(1) Detailed study should be carried out in the As affected areas to assess As exposure from different sources (water, food, etc). This will provide better understanding of the relationship between As exposure and occurrence of arsenicosis.

(2) A multidisciplinary research is recommended involving extensive epidemiological and cross-sectional survey in Bangladesh regarding issues such as arsenic exposure through water and food chain, food habit and nutrition, genetic makeup, prevalence of arsenicosis among different segments of population, and so on.

(3) The health impacts of arsenic like hyper-pigmentation, keratosis, melanosis, etc are typically gradual but more studies are needed to develop better understanding of the transition from one level to another level.

(4) Along with efforts to better understand the health effects of arsenic, efforts should also be made to develop better models for predicting long-term health effect of arsenic in Bangladesh and in other countries.

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Appendix

Table A.1: Actual dose response function by using data of BAMWSP (80 - 100% contaminated areas):

Upazila	Pc	As concentration in ppb						
		25	75	100	250	500	750	1000
Gosairhat	Pc Male	0.000338	0.000000					
	Pc female	0.000228	0.000160		0.000041			
Meghna	Pc Male	0.000170	0.000368					
	Pc female	0.000151	0.000235					
Damudia	Pc Male	0.000129	0.000024		0.000987			
	Pc female	0.000137	0.000126		0.000262			
Alphadanga	Pc Male	0.000260	0.001120	0.000699	0.000079			
	Pc female	0.000691	0.001555	0.000603				
Dharmapasa	Pc Male	0.000129	0.000024		0.000987			
	Pc female	0.000137	0.000126		0.000262			
Naria	Pc Male	0.000463	0.001443	0.000520	0.000207	0.000776		
	Pc female	0.000807	0.002125	0.000736	0.000484	0.000824		
Jhalokathi sadar	Pc Male	0.000013	0.000070	0.000551	0.000736	0.001012		
	Pc female	0.000024	0.000446	0.000195	0.000781	0.001611		

Table A.2: Actual dose response function by using data of BAMWSP (60 - 80% contaminated areas) :

Upazilla	Pc	As concentration in ppb						
		25	75	100	250	500	750	1000
Debhata	Pc Male	1.2948E-04	2.3799E-05		0.000987			
	Pc female	1.3749E-04	1.2636E-04		0.000262			
Chandpur Sadar	Pc Male	5.570E-03	0.0005746		0.000259		0.000199	
	Pc female	1.117E-02	0.00052298		0.000704		0.000211	
Asasuni	Pc Male	1.393E-03	0.00078391	0.00097	0.000446			
	Pc female	1.536E-03	0.00087204	0.00069	0.000946			
Kalkini	Pc Male	1.040E+00	0.81757793	1.94175	1.205223		1.294498	
	Pc female	9.573E-01	1.08518719	2.06186	1.137576		0.687285	
Harirampur	Pc Male	2.120E-04	0	0.00000	0.000000			
	Pc female	4.278E-04	0.0001097	0.00005	0.000000			
Brahmanpara	Pc Male	0.000E+00	0.00028952	0.00031	0.000063			
	Pc female	2.486E-05	0.00028694	0.00016	0.000000			
Banaripara	Pc Male	1.214E-04	0.00094497	0.00135	0.001813	0.000964	0.002472	0.00236
	Pc female	1.842E-04	0.00100342	0.00143	0.001375	0.000341	0.005250	

Table A.3: Actual dose response function by using data of BAMWSP (40 - 60% contaminated areas) :

Upazilla	Pc	As concentration in ppb						
		25	75	100	250	500	750	1000
Gosairhat	Pc Male	0.000338	0.000000					
	Pc female	0.000228	0.000160		0.000041			
Meghna	Pc Male	0.000170	0.000368					
	Pc female	0.000151	0.000235					
Damudia	Pc Male	0.000129	0.000024		0.000987			
	Pc female	0.000137	0.000126		0.000262			
Alphadanga	Pc Male	0.000260	0.001120	0.000699	0.000079			
	Pc female	0.000691	0.001555	0.000603				
Dharmapasa	Pc Male	0.000129	0.000024		0.000987			
	Pc female	0.000137	0.000126		0.000262			
Naria	Pc Male	0.000463	0.001443	0.000520	0.000207	0.000776		
	Pc female	0.000807	0.002125	0.000736	0.000484	0.000824		
Jhalokathi sadar	Pc Male	0.000013	0.000070	0.000551	0.000736	0.001012		
	Pc female	0.000024	0.000446	0.000195	0.000781	0.001611