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Arsenic in food chain through irrigation water-soil-crop pathway: Risk assessment for sustainable agriculture of Bangladesh

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Abstract

Elevated level of groundwater arsenic (As) in Bangladesh has resulted as a massive calamity of exposing a large population to health risk and affecting livelihood and sustainable development of the country. Natural sources are responsible this arsenic contamination and it has adverse impact from the local to regional level. The extensive use of arsenic contaminated groundwater in irrigation poses a potentially long term detrimental effect to human health as well as it is an environmental hazard. Numerous previous studies have emphasized on human As ingestion through drinking water. The current study focused on As ingested through the food chain. A detailed daily dietary intake survey was conducted using a Food Frequency Questionnaire (FFQ) to estimate the daily intake of As and thereby assess the risk of As contamination in groundwater for sustainable development of agriculture. This study was conducted in Matlab Upazila, south east Bangladesh, one of the hotspots for As contamination in groundwater. In ten irrigation wells water was sampled to establish the water chemistry and determine the total As concentration. This study observed that irrigation water contained 0.006 to 0.513 mg/L of total As. The agricultural soils of Matlab upazila have become highly contaminated with As due to the excessive use of As-rich groundwater (1.85 to 5.02 mg/kg). From the household survey, it was observed that daily water consumption by an adult ranged between 4 to 8 L. According to the AsMat field study the As concentration of most Matlab tube wells water contained more than 0.05 mg/L. Thereby, an adult is expected to have an intake 0.2 to 0.4 mg of As/day from drinking water. Concentrations of As in rice grain (with husk) from the As contaminated field were varied from 0.01 to 0.15 mg/kg. On the other hand, the rice grains (without husk) of study area contained below the detection limit of 0.02 mg/kg of As. According to the FFQ of this study it was found that the average daily rice consumption by an adult of this area was between 450 to 1020 g raw rice grains. In the present study, the average As concentrations in rice grain (without husk) were 0.02 mg/kg. With the consideration of this value, an adult of study area is expected 0.01 to 0.16 mg of As daily intake with rice. The concentration of As found in the present study is much lower than the permissible limit in rice (1.0 mg/kg) according to the WHO recommendation.

Key words: Groundwater, Arsenic, Irrigation, Soil, Plant uptake, Food Frequency Questionnarie, Rice

Sammanfattning

Förhöjda halter av arsenik i grundvatten i Bangladesh har exponerat en stor del av befolkningen för hälsorisker och har påverkat levnadsförhållanden och utveckling i landet. Föroreningen är naturlig och den har haft negativ inverkan både på lokal och regional nivå. The stora användningen av grundvatten för bevattning utgör en potentiell risk på sikt för mänsklig hälsa liksom den utgör en generell miljörisk. Många studier har inriktats på intag av arsenik genom dricksvattnet. Denna studie är fokuserad på intag av arsenik genom födoämneskedjan. En detaljerad undersökning med hjälp av en matfrekvensundersöknings enkät (Food Frequency Questionnaire, FFQ) har genomförts for att bestämma det dagliga intaget av arsenik och därigenom uppskatta risken med arsenik i grundvatten som ett hot mot långsiktig utveckling av jordbruket. Denna studie har utförts i Matlab Upazila, sydöstra Bangladesh, en av de svårt drabbade områdena vad gäller arsenik i grundvatten. Tio bevattningsbrunnar provtogs for att bestämma grundvattenkemin och total halt av arsenik. Det fastställdes att bevattningsvattnet innehöll från 6 till 513 μg/L total arsenik. De odlade jordarna i Matlab Upazila har blivit gravt förorenade av arsenik genom användandet av arsenikrikt grundvatten (1,85 till 5,02 mg/kg). Från en hushållsundersökning framkom att det dagliga vattenintaget för en vuxen varierade från 4 till 8 liter. Från AsMat studien framgår att arsenikhalten i flertalet brunnar är mer än 0,05 mg/l. Av detta framgår att en vuxens intag genom dricksvatten är mellan 0,2 och 0,4 mg arsenik per dag. Halten arsenik i ris, med skal, från arsenikförorenade fält varierade från 0,01 till 0,15 mg/kg. Men arsenikhalten i ris utan skal i studieområdet var under detektionsgränsen för analys och mindre än 0,02 mg/kg. Enligt FFQ i denna studie var det dagliga intaget av ris i området mellan 450 och 1020 g av råris. I studien var genomsnittliga arsenikkoncentrationen utan skal 0,02 mg/kg. Med dessa siffror blir det dagliga intaget av arsenik via ris från 0,01 mg till 0,16 mg. Koncentrationen i ris som framkommit i denna studie är mycket lägre än den hälsogräns som WHO rekommenderar på 1,0 mg/kg.

Nyckel ord: Grundvatten, Arsenik, Bevattning, jord, växtupptag, Matfrekvensundersöknings enkät, Ris

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1. Introduction

Groundwater is an important natural resource for domestic and industrial water supply as well as agricultural purposes. But the over exploitation of groundwater resources especially, As contaminated groundwater is now the major concern to the sustainable agriculture. This issue makes a wide range of problems on terms of water quality as well as quantity and it is emerged during the past three decades on the world wide. The source of As in sediment and soil is the result of minerals weathering in the crustal rocks, in particular oxidation of primary sulphide minerals (Bhattacharya et al., 2002a; Smedley and Kinniburgh, 2002). Geologic sources are often associated with groundwater As, but anthropogenic sources also extremely important in some locations of As in ground (Bhattacharya et al., 2007). The both organic and inorganic As contamination present from natural and anthropogenic sources or salinization bear the threat of the suitability of groundwater for drinking purposes which is further poses the threat to the sustainability of livelihood development (Jakariya, 2007).

During the wet season, most of Bangladeshi agricultural soils have been exposed to groundwater due to irrigation, rain water and sometimes to floodwater from rivers or ponds (Roychowdhury et al., 2002). As a result, high concentration of As in the water and soil is infiltrating Bangladesh's food chain through crops and it raising serious health concerns for millions of residents, specialists warns (IRIN, 2008). Likewise, the interaction of As contaminated irrigated water and soil may also influenced on both water and soil properties, such as pH, texture, organic carbon, reactions with free iron oxide, or phosphorus which may drastically reduce the yield of rice, resulting in the shortage of the staple food grain. A national survey indicated accumulation of high amounts of As in rice grains (0.4 to 1.0 mg/kg) present in areas where the concentrations of As in irrigation water and soils are high. This is creating a real food-related health hazard for the local communities (Chandiramani et al., 2007). There have also an undesirable levels of As observed in some other crops, like vegetables, tubers, fruits, and even wheat in Bangladesh (Chandiramani et al., 2007).

About 33 percent of total arable land of Bangladesh is now under irrigation facilities (BBS, 1996). Most of the above mentioned lands are irrigated with groundwater which comes from deep tube wells, shallow tube wells and hand tube wells. According to the report of BADC (2005), a total of 925,152 shallow and 24,718 deep tube wells were used for irrigation during the 2004 dry season. Among them groundwater irrigation covered about 75% of the total irrigated area. Most of groundwater is contaminated with As which is used for irrigation purposes in Bangladesh (Khan et al., 1998). The use of As contaminated irrigation water create hazard both in soil environment and in crop quality. About twenty percent loss of crop (cereal) production happened due to high concentration (20 ppm) of As in plant body (Davis et al., 1998). Like other heavy metals, As also toxic elements to plant like other heavy metals and its discharge into the environment must be carefully controlled and minimized (Martin et al., 1993).

Arsenic in groundwater is not only the problem in Bangladesh. This is a global problem. It is equally extended to other country in the world. In 1968, Taiwan affected in a large-scale health problem caused by naturally occurring As. During the decade of the seventies, As contaminations was identified in Chile. West Bengal, India, Ghana, Mexico and several other countries were recognized to arsenic contamination during the decade of eightie's. In large scales, Bangladesh was recognized in nineties. In early 1996, As contamination of groundwater was reported first in Bagerhat, Satkhira and Kustia, three south-western Bangladesh districts bordering the Indian state of West Bengal (FEJB, 2001; The Daily Star, 2002). They also reported that some 61 out of 64 districts across the country face the hazard of As poisoning. At first large epidemiological studies conducted in Taiwan and later in Chile suggested that the safe level (standard) at 50 μg/L may have to be revised downward (Keast, 2001). On the basis of some research studies WHO set a provisional guideline value of 10 μg/L, down from an earlier figure of 50 μg/L. Globally, the current situation of As poisoning on terms of population affected are shown in Table 1.

Table 1: *Population affected by arsenic in groundwater used for drinking*

Country	Population affected
Taiwan	20 000
Inner Mongolia	50 000
Obuasi, Ghana	Unknown
Cordoba, Argentina	10 000
Antofagasta, Chile	20 000
Lagunera, Mexico	20 000
Cornwall, Britain	Effect unknown
W. Bengal, India	38, 000 000
Bangladesh	50, 000 000

Source: (WHO/UNICEF, 2000)

Arsenic contamination of groundwater in Bangladesh is the biggest calamity in the world in terms of the affected population. About 30 million people in Bangladesh poses major health risks due to the presence of significant concentrations of As in groundwater and its affect on the crop production (Chowdhury et al., 2001). Arsenic in groundwater is also alarming problem in Bangladesh, India and several other countries of Southeast Asia (Bhatacharya et al., 2007). The level of naturally occurring As in groundwater in the region of Southeast Asia and its affects are shown in Table 2. The inhalation and ingestion of As is perhaps the responsible for human carcinogen (Centeno et al., 2002; Chen and Ahsan, 2004), affecting skin and lungs (IARC, 2004). The chronic levels of As exposure adversely impact on human health which is the reason for skin disorders (Tondel et al., 1999; Ahmad et al., 1997; Rahman et al., 2001), cardiovascular disease (Wang et al., 2007), neurological complications (Mukherjee et al., 2003), reproductive disorders (Ahmad et al., 2001), respiratory effects (Milton et al. 2001; Mazumder et al., 2000), diabetes mellitus (Rahman et al., 1998) as well as various types of cancers including skin, lung, bladder, and kidney (Chen et al., 1992; Smith et al., 1998; Bates et al., 1992; Chiou et al., 1995) and reviewed in detail by Kapaj et al.(2006).

The presence of As in food through the water-soil crop routes has raised a worldwide concern in terms of food safety. This triggers a potential dietary risk to human health as wells as the risk of environmental hazards. The world Health Organization (WHO) recommendation the acceptable level of As in drinking water is 50 μg/L in Bangladesh, on the other hand the global standard is 10 μg/L. The accumulation of groundwater As in the soil fields and then its entering into the food chain through the crops is the major (Huq et al., 2001; Duxbury et al., 2003).

Table 2: *Naturally occurring As in groundwater in the regions of Southeast Asia*

Country/region	Population at risk (millions)	Level of As (µg/L)	Year of discovery	Drinking Water standard for As (µg/L)	References
Bangladesh	32	bdl-4730	1992	50	Chakraborti et al. (2008); Samanta et al. (1999)
Cambodia	0.3	1–1610	2000	50	World Bank Policy Report (2005); Berg et al. (2007)
China(Inner Mongolia, Xinjiang, and Shanxi)	5.6	50–4440	1980s	50	Sun et al. (2001); World Bank Policy Report (2005)
West Bengal, India	6.5	bdl-3880	1983	50	Chakraborti et al. (2002); Samanta et al. (1999)
Bihar, India	Unknown	bdl-2182	2002	50	Chakraborti et al. (2008)
Uttar Pradesh, India	Unknown	ND-3191	2003	50	Ahamed et al. (2006); Chakraborti et al. (2008)
Jharkhand, India	Unknown	ND-1018	2003	50	Chakraborti et al. (2008); Bhattacharjee et al. (2005)
Manipur, India	Unknown	ND-502	–	50	Chakraborti et al. (2008)
Assam, India	Unknown	19–657	2004	50	Mukherjee et al. (2006a)
Chhattisgarh, India	10,000	? 10–880	1999	50	Chakraborti et al. (1999); Pandey et al. (1999)
Lao PDR	Unknown	ND-112	2001	50	World Bank Policy Report (2005)
Myanmar	3.4		2001	50	World Bank Policy Report (2005)
Nepal	0.5	ND-2620	2001	50	Tandukar et al. (2001); World Bank Policy Report (2005)
Pakistan	Unknown	ND-906	2000	50	Nickson et al. (2005)
Taiwan	0.1	? 0.15–3590	1960s	10	Chiou et al. (2001); Smedley and Kinniburgh (2002)
Vietnam	10	1–3050	2001	10	Berg et al. (2001, 2007)

ND: not detected; Source: (Rahman et al., 2009)

Groundwater is widely used for irrigation purposes in the south eastern Asian countries which are affects on crop quality and yield, particularly for rice production (Meharg and Rahman, 2003). Continuous add of As in the soil from As-contaminated irrigation water may reduce crop yields, and thereby thus affecting the nutritional status and economy of rural farming communities.

By considering the affects of As poisoning to human health and environment, As became the top priority issue of the Government of Bangladesh, the various donor agencies and NGO's. Till now the main attention of As research is drinking water. But the key link between As and soil crops interaction is still unfocused. Arsenic in irrigation water poses a potential threat to soils and crops. Consequently it goes the food chain generally and then finally posses threat to human health. On average, a Bangladeshi adult drinks about 4 to 5 L of water a day and consumes about 450 g of rice. Assuming 200 μg/L As in the drinking water and about 0.5 mg/kg in rice grain, the total daily intake of As would be around 1.2 mg, which may not be safe for human (http://www.cimmyt.org).

With the above discussion the key research field of this studies was located the pathway of As being incorporated in the food chain through the water-soil-crop pathway. This research work also focused on the measurement of total amount As release through irrigation pumping water and then the determination of As adsorption by the soil and crops under diverse conditions and farm management systems. Then, the further research investigation was that have any health hazard by consuming those As containing crops, and if so, then the determination of which level and which conditions it will be dangerous for human health as well as environmental hazards. At this point, much more information and knowledge were collected to make this research smoothly.

1.1 Objectives

The main objective of this study is to investigation As entering into the food chain through groundwater-soil-crop pathway. These studies also investigated to identify the possible risks of irrigating with As contaminated water to the human health as well as environmental hazards. The overall goals of this paper to address and guideline in preparing mitigation plan for adaptation and recommends steps towards enhancing the share of surface water sources in the irrigation water supply system in the near future in Bangladesh.

1.2 Hypothesis

Previous studies have indicated that Matlab Upazila had upper and lower aquifer with different redox conditions. Most of the irrigation well was installed between the 75 m to 350 m depth. In upper horizon contains the redox level below iron oxidation which is greyish in colour, on other hand in lower horizon consist oxidized aquifer in which iron exists as stable iron oxides. The oxidising sediments have a high capacity to absorb As and it is reddish in colour due to iron oxy-hydroxide coatings on the sediment particles. The source of groundwater in the reduced and oxidised aquifers is regional. The cross contamination of reduced water leached through the clay aquitard to the oxidised sediments which is limited and negligible. In lower red aquifer consists low concentration of As and Fe in the groundwater because of the presence of specific redox layer and the adsorption of available As by iron oxy-hydroxides.

2. Arsenic Geochemistry

2.1. Overview

Arsenic is a metalloid which is belongs to group V of the Periodic table. It has metallic as well as non-metallic characteristics. It is the 20th most common element in the earth's crust. It is found naturally bound into over 200 different mineral compounds (WHO, 2001). Arsenic occurs in the environment in several oxidation forms like -3, 0, +1, +3 and +5. But in natural water chemistry this is found as an inorganic form mostly as oxy-anions of trivalent As [As (III)] or pentavalent arsenate [As (V)]. Arsenopyrite (FeAsS) is the most common As minerals. The average As concentration in sediments is 2 mg/kg DW (dry weight) but can fluctuate depending on type of the soil (Stollenwerk et al., 2007).

Arsenic can enter in the environment through the both source of geogenic and anthropogenic. In agriculture, As has been used in a variety of products such as herbicides, pesticides and wood preservatives (Ali and Ahmed, 2003). In natural water As occurs in a wide range of concentration, from less than 0.5 µg/L to more than 5000 µg/L. Generally, concentrations of As are less than 10 µg/L in freshwater and often lower than 1 µg/L (van Loon and Duffy, 2005). The presence of high concentration of As in groundwater is not only dependent of the concentration of As in the soil. It also dependent on the constituents and environmental condition of the soil which have a greater influence on As speciation and mobility (Ahmed, 2003). The mobility of As in the ground is controlled by pH, redox conditions, biological activity and adsorption reactions (Ahmed, 2003). The adsorption/desorption processes are among the most important factors controlling the concentration of geogenic As in groundwater (Sracek et al., 2004). The processes are controlled by pH and redox condition. In soil, the most important sites for As adsorption are aluminum, Fe- and manganese (Mn) oxyhydroxides (Smedley and Kinniburgh, 2002).

In nature, Fe (III) oxy-hydroxides are widespread distributed especially ferrihydrite, goethite and magnetite. These oxides are often form small particles with a large specific area and it has a large capability to bind dissolved elements to the surface, for example As and phosphate ($PO4^{3-}$) have a large impact of the mobility of these elements in the sediment/water system. The similarities on terms of dissolution, deposition, adsorption and ion exchange between As (V) and orthophosphate which make PO_4^{3-}, one of the main competitive ions for As adsorption (Dzomback and Morell, 1990).

The mechanism of As adsorption to Fe(III) oxihydroxides is a inner surface bonding by the involve of ionic as well as covalent bonding. Covalent bonding depends significantly to the particularly electron configurations of both the surface group. The complex ion and is therefore referred to as specific adsorption (Sposito, 1989). Covalent adsorbed As is bound to the surface of Fe (III) oxyhydroxide (with oxygen) through Fe-oxygen bonds. The ionic bonding is a non-specific adsorption. This refers to the weak dependence on the electron configuration of the surface group and adsorbed species (Sposito, 1989). The negatively charged As-oxiyanions are bonding to the positively charged Fe (III) oxyhydroxides. This process is strongly dependent of the pH due to the charge of Fe (III) oxyhydroxides and As-oxiyanions is related to the pH.

Groundwater pH can promote the mobility of As because As adsorption depends on pH. Likewise, redox reactions can control the aqueous As concentration by their effect on Ass speciation, and therefore on adsorption-desorption reactions (Ali and Ahmed, 2003). Arsenic is mobilized in reducing environments, where the Fe (III)- oxyhydroxides easily gets dissolved and reduced to Fe (II) after consumption of the more favored electron acceptors (Nickson et al., 1999). Arsine (AsH_3) is the best volatile form of As which is the colorless and poisonous. After arsine, inorganic As (III) has been considered the most toxic species, however recent studies have shown that most ingested As (V) is reduced to As(III) (Welch and Stollenwerk, 2003). Therefore both ingestion and exposure species may result same toxicological effect.

2.2. Arsenic in groundwater of Bangladesh

The source of As in groundwater of Bangladesh is geogenic and it is not occurred for anthropogenic activities (Ahmed et al., 2004). The discovery of As contamination started from the Indian state of West Bengal bordering Bangladesh, especially along the flood-plains of the Ganges-Bhagirathi Rivers (Khan, 1997). That time the most vulnerable to As contamination were identified in the border of western districts, particularly the south-western region of Bangladesh.
The background fact of this incidence is that both state bordering sites have same depositional history and geological history which is commonly known as the Ganges delta. Moreover, the aquifer of the both contamination region are hydrological connected. This issue of As contamination of groundwater emerged one of the biggest environmental health calamities of

more than 100 million people at risk on Ganges delta region of Bangladesh and India (Bhattacharya et al., 2009). The river system transports the sediments, such as sand, silt and clay, from the Himalayan mountain range in the north and from the Indo-Burman Hills in the east. The mountains are weathered by wind, rain, ice and grinding (McArthur, 2006). Arsenic from the weathered minerals sorbs to the Fe (III) oxyhydroxides. This material is deposit and accumulated in the delta. Year after year new material deposits and older sediments are buried (McArthur, 2006).

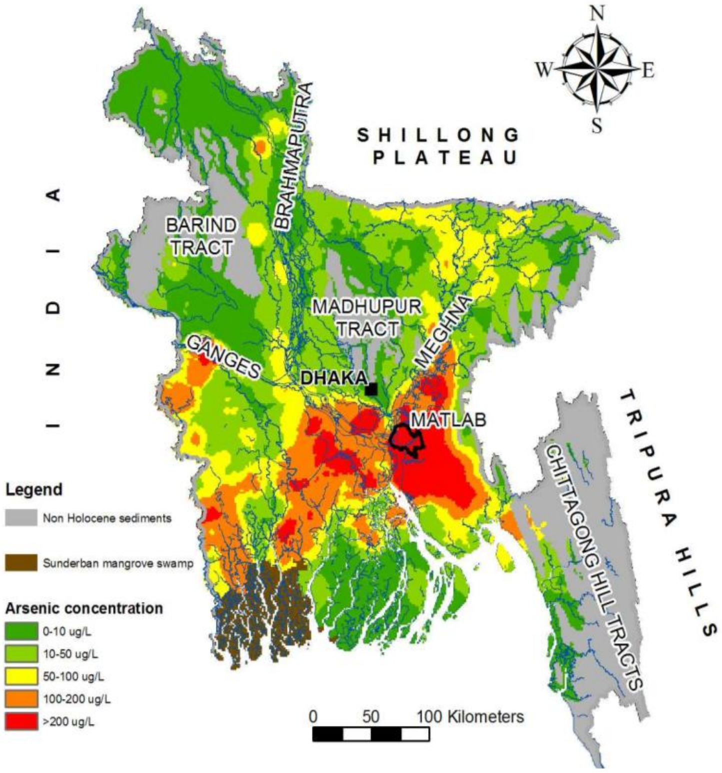

Figure 1. *Map of Bangladesh with the three large rivers Ganges, Brahmaputra and Meghna. The map shows geomorphology and arsenic concentration in groundwater as well as the location of the proposed study area in Matlab. Data from BGS and DPHE (2001).*

The surface geology of Bangladesh is dominated by alluvial sediments from the Quaternary period (Bivén and Häller, 2007). Quaternary period are divided into two major epochs (Holocene and Pleistocene) which is extended from two million years ago to present year. Pleistocene aquifers were created two millions years to ten thousand years ago. On the other hand, Holocene aquifers created from ten thousand years until present time. The As-enrichments are mainly restricted to the Holocene alluvium (Figure 1). These alluviums cover about 70% of the uppermost aquifers in Bangladesh (DPHE and BGS, 2001, Ahmed et al., 2004). DPHE and BGS (2001) divided the Holocene aquifer system in the BDP into shallow (<150 m) and deep (>150 m) aquifers. The shallow aquifer is further subdivided into the upper (0-50 m) and the lower (50-150 m) shallow aquifers. The shallow aquifers in many regions contain water with As concentrations >50 μg/L. The environment in these aquifers is reducing and the sediments are generally grey or black in colour. The colour is due to high contents of organic matter, biotite and other dark coloured ferromagnesian and opaque minerals (Brömssen 2007; McArthur et al. 2004). Tube wells with water containing As <10 μg/L have been found to be located in oxidised sediments, that are brown or red in colour and are normally in the lower shallow and in the deep aquifers (McArthur et al., 2004; van Geen et al., 2004). The color may be due to the presence of Fe (III) oxyhydroxides.

2.2.1. The complexity of the groundwater arsenic problem in Bangladesh

The main feature of the existing problem situation is its complexity. To know the better understanding of As problem issues, it is important to highlight the history of As in Bangladesh by using different visuals like the 'timeline' diagram. This diagram is used to indicate relevant facts about the history of the As contamination in groundwater. To draw this diagram this study collected the needed information through interviews, secondary data and searched relevant websites (see Figure 2).

1940s – 1950s: During the period of 1940s to 1950s, most of Bangladeshi people use surface water like river, ponds and lakes water in their daily domestic purposes. As a result water related diseases i.e., cholera and typhoid epidemically attacks their health.

1970s – 1980s: In this period campaign start against the consumption of surface water. Researchers suggested stopping deaths relating to surface water consumption. UNICEF proposed to use tube wells water instead of surface water. With the partnership of Bangladesh government, UNICEF installed 1 million tube wells. Privately, 2.5 million to 3 million tube wells installed with loans on easy terms from other aid agencies. At the end of this program it was observed that approximately 90% of total populations were covered with safe drinking water within walking distance.

Late 1980s and early 1990s: But after the success of UNICEF project a growing numbers of people still attacks to water related dangerous diseases even they use tube wells water. Some scientist observed some symptoms of As poisoning and then they begin to do research.

1993: In 1993, Government and World Health Organization (WHO) "officially" informed about the As poisoning. But no actions were taken.

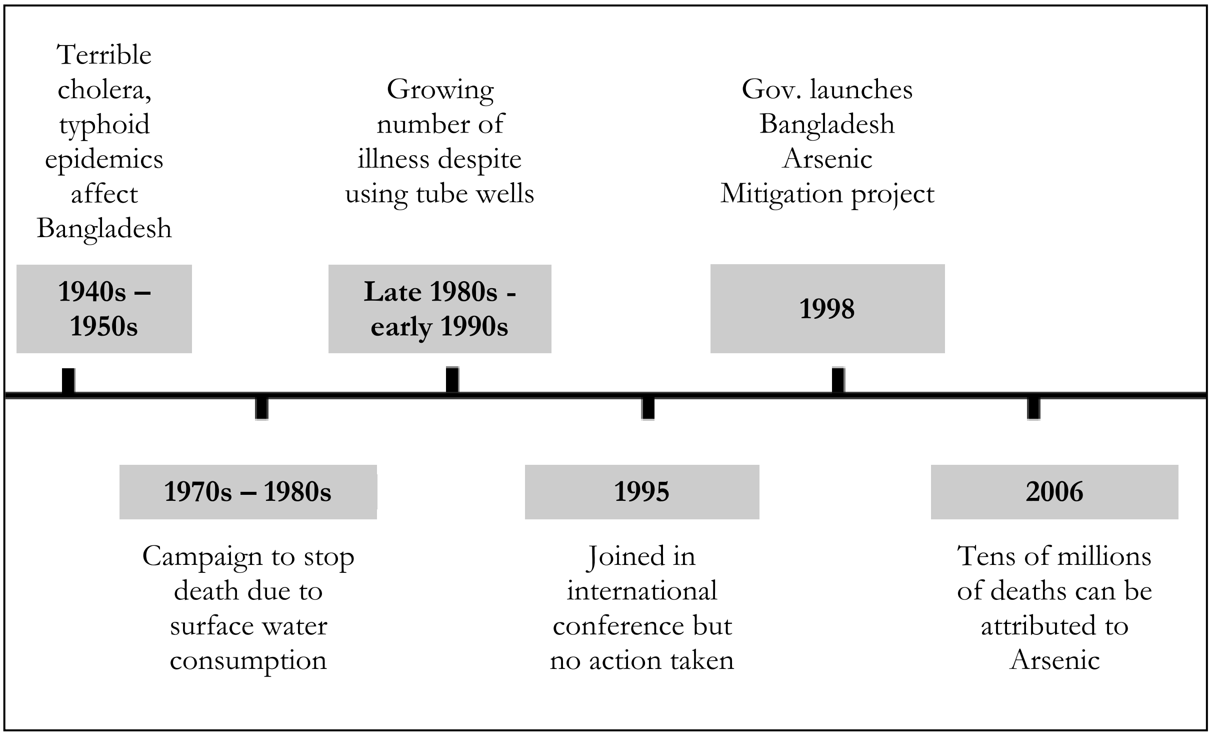

Figure 2: *Time history of groundwater arsenic in Bangladesh*

1995: Again the government of Bangladesh and UN agencies joined in international conference which held in Calcutta. But still no actions were taken in this issue.

January 1997: Bangladesh government with the help of aid agencies start to survey of As toxicity. In January 1997, they surveyed 14 districts out of 64.
1998: With the help of World Bank, Bangladeshi government launched Arsenic Mitigation and Water Supply Project (BAMWSP). World Bank gave $32.4 million loan for this project.
First half of the 00s: Projects were continued to protect against As poisoning. Researchers begin to identify As contaminated and As free tube wells. They pained tube wells with red and green color. Red color pained tub wells were considered as a As contaminated water and green color were As free safe water. Money and resources also used for treatment of sick people.
2006: In 2006, World Health Organization estimated that 10 millions of deaths can be attributed to As. Millions of dollars are spent to protect this. To date, 73 millions of Bangladeshi people are identified who are affected by As and it will be rapidly spread if nothing is done (Alfinio Flores, 2006).

2.2.2. Mind Mapping

The possible food chain pathways of terrestrial ecosystem through which human may be exposed to As poisoning from multiple sources as they are one of the top most consumers of the ecosystem has been developed through mind mapping and presented in Figure 3.

According to the World Health Organization (WHO), Bangladeshi people lived in greatest risk of As poisoning and they estimated that the population of Bangladesh exposed to high levels of As vary from a low of 28-35 million to a high of 77 million, more than half the country's population. On the other hand, World Bank described As poisoning as one of the world's primary environmental challenges. On the basis of interview of study areas people and based on secondary information from the website, the tentative pathway of As enter to human body through the pumping water- soil-crops route are shown by mind mapping in Figure 3 (drafted by Zia Uddin Ahmed of BRRI).

Table 3: *Percentage of Groundwater Surveyed in 1998 by British Geological Survey with Arsenic Levels above 50 µg/L*

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

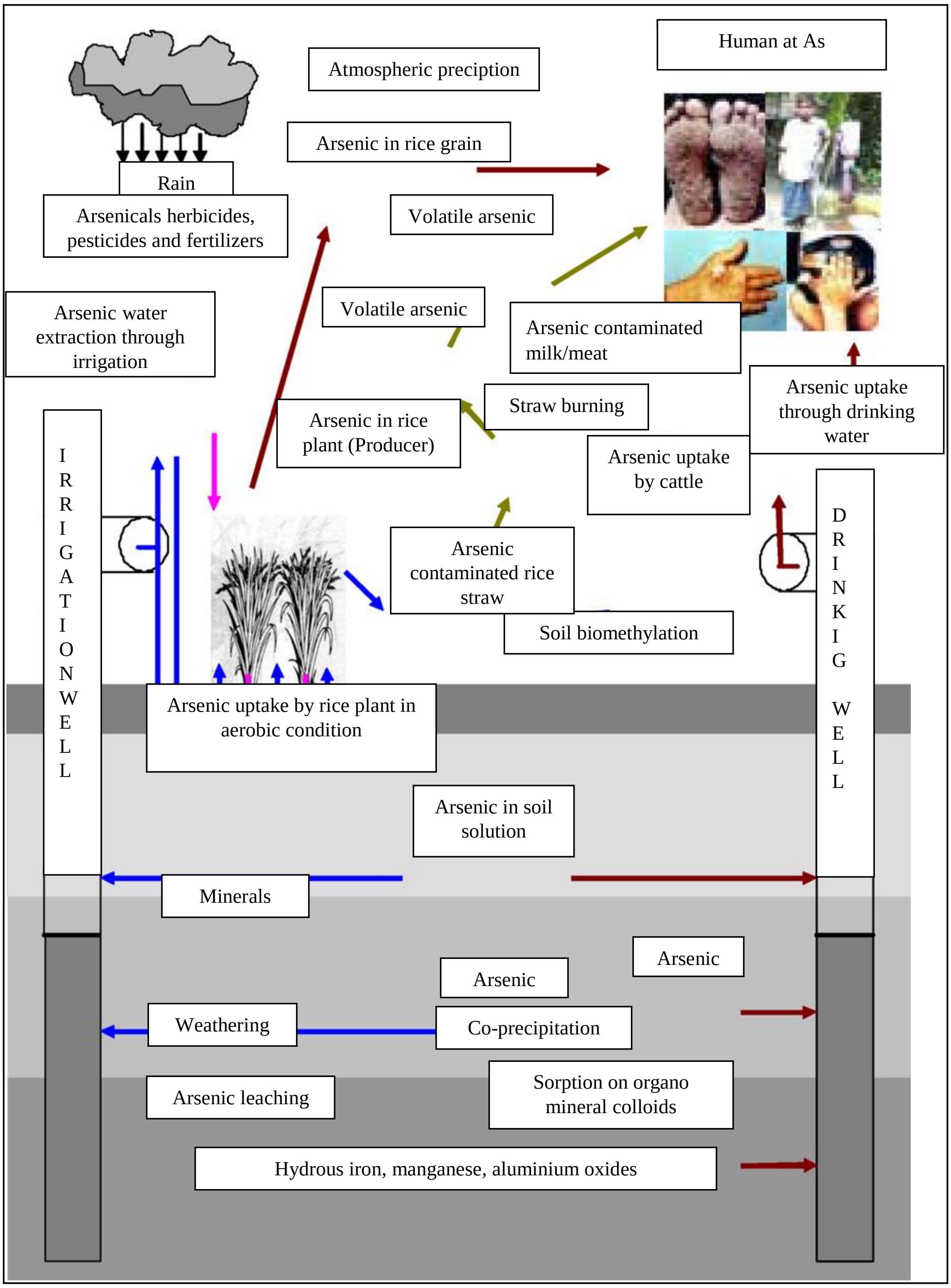

Figure 3: *Mind mapping - showing the possibility of arsenic affect human through water-soil-crops pathway*

2.3. Risk of arsenic contaminated groundwater in Bangladesh

British Geological Survey (BGS) conducted a study in 1998. They collected 2022 water samples from the 41 As-affected districts of Bangladesh. Among them 35% of these water samples were found to have As concentration above 50 µg/L in the laboratory analysis (Table 3). NIPSOM and SOES (1996) conducted a study in Rajarampur village of Nawabganj district and this study observed 29% of the 294 tube-wells tested had arsenic concentrations greater than 50 μg/L. Further, SOES and DCH jointly conducted a study from August 1995 to February, 2000 and during this period; they tested 22003 tube-well water samples which was collected from 64 districts in Bangladesh. They reported that out of 64 districts in Bangladesh, As in groundwater is above 10 μg/L in 54 districts and above 50 μg/L in 47 districts. According to Dainichi Consultant (2000), As contamination of groundwater in Bangladesh is approximately 85% of the total area of Bangladesh and about 75 million people are live in risk. The statistics data of As calamity in Bangladesh are presented in Table 4.

2.3. Study Area

This study was carried out in Matlab Upazila of Chandpur district in Bangladesh. It is located approximately 60 km south-east of Dhaka and near the confluence of the Ganges (Padma) and Meghna Rivers. The study area is 2×1 km^2 about 3 km east of the Meghna. During the monsoon, these areas are naturally flooded in every year. Currently, several organizations are doing research work on this place. For instance, International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR, B) and Bangladesh Rural Advancement Committee (BRAC) work with Arsenic Mitigation Project in Matlab (AsMat) and Sustainable Arsenic Mitigation (SASMIT).

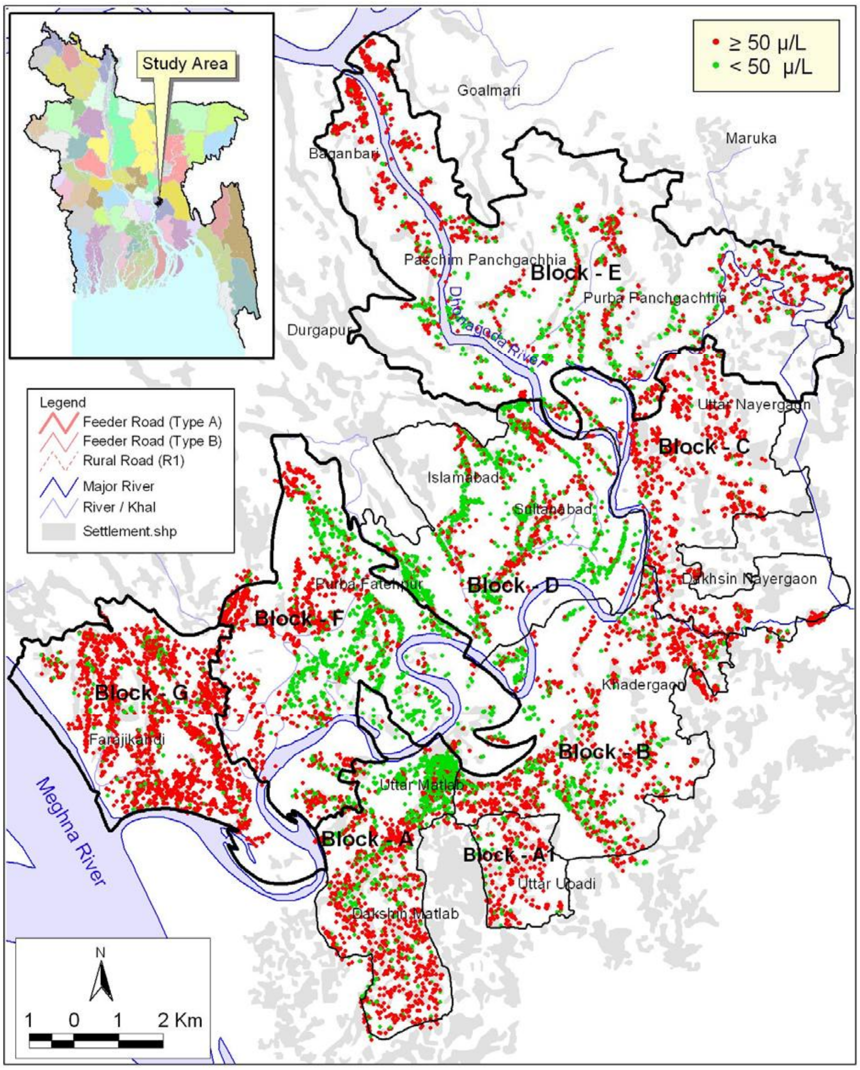

Figure 4: *Location map of Matlab Upazila showing the prevalence of tubewells (TWs) with As-concentrations ≥50 μg/L (red circles) and those <50 μg/L (green circles). Inset is the map of Bangladesh showing the location of Matlab Upazila (reproduced from Jakariya et al., 2007).*

Table 4: *Statistics of Arsenic Calamity in Bangladesh*

Total Number of Districts in Bangladesh	64
Total Area of Bangladesh	148,393 km^2
Total Population of Bangladesh	125 million
GDP Per Capita (1998)	BDT 60.00 (US$2)
WHO Arsenic Drinking Water Standard	10 μg/L
Bangladesh Arsenic Drinking Water Standard	50 μg/L
Number of Districts Surveyed for Arsenic Contamination	64
Number of Districts Having Arsenic above 50 μg/L in Groundwater	59
Area of Affected 59 Districts	126,134 km^2
Population at Risk	75 million
Potentially Exposed Population	24 million
Number of Patients Suffering from Arsenicosis	8500
Total Number of Tube-wells in Bangladesh	4 million
Total Number of Affected Tube-wells	1.12 million

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

Today approximately 95 % of the 220 000 peoples in Matlab upazila use tube wells as a source of potable water (ICCDR,B, 2007) as well as for irrigation purposes. The quantity of water use for irrigation purposes is much higher than the quantity use for drinking water. About 80% of the domestic tube wells have As levels above the Bangladesh drinking water standard (von Brömssen et al., 2007). The distribution of high As tubewells were found to vary significantly in the different villages of Matlab Upazila (BRAC, 2003; Wahed et al., 2006; Jakariya, 2007) shown in Figure 4. The Matlab field research area is unique in the world of public health research, due to a defined population with detailed demographic surveillance for the past 40 years (BRAC University, 2007). This research has been maintained by the International Centre for Diarrhoeal Diseases Researches, Bangladesh (ICDDR,B), located in Matlab since 1963. The surface geology of Matlab upazila is divided into reducing and oxidising aquifers with their representative colours and chemistry. Occasionally a clay aquitard is present at a depth of 30 -50 meters, separating the aquifers. The tube wells in Matlab are situated in both the aquifers, but the tube wells with high As concentrations are mainly located in the reduced aquifer (Jonsson and Lundell, 2004; Brömssen et al., 2007).

3. Materials and Methods

Bearing the principles of Integrated Water Resources Management (IWRM), this research work were conducted by using Soft System Methodology (SSM) in which at first the overall situations were addressed as problematic situations by the use of questionerie survey and interview. The areas with potential As contamination were identified by field survey through interview of local stakeholders and the analytical laboratory data of collected irrigation water, soil and rice sample from the study area. In next steps, by analysing data we tried to formulate root definition and conceptualised mitigation model for sustainable agriculture aspects. This research works addressed the gender equity and bottom-up approach for better understanding of As enter into human food chain through groundwater – soil – crop interaction.

3.1. Field Survey, Interview and Questionnaires Design

Five local stakeholders were interviewed during the field survey of this study. To getting an overall quantitative view this study deals with a detailed household survey using an interviewer administered semi-quantitative questionnaire is called Food Frequency Questionnaire (FFQ). Arsenic contaminated region like Bangladesh, it is necessary to determine the total As in their daily intake of dietary food. With the consideration of socio-economic status of Matlab upazila, a Food Frequency Questionnaire (FFQ) was designed to assess the As uptake through daily consumed food. This questionnaire contained the information of water usage and sources. By this field survey, this study justified the knowledge of local people about the As problem. This questionnaire also gathered the information of pattern of water use, density of irrigation wells and the use of water etc.

Food Frequency Questionnaire was designed not only the basis of dietary pattern of study area, but also included the information of spatial landscape, socio-demographic indicators, and geographic locations of this area. The nature of questionnaire was open ended in where stakeholder can reflect their opinion in details. The FFQ was designed in four sections:

(1) Collection of information about general household,
(2) Household information about the water and rice,
(3) Information of other food uptake, and
(4) Justification of knowledge about As poisoning.

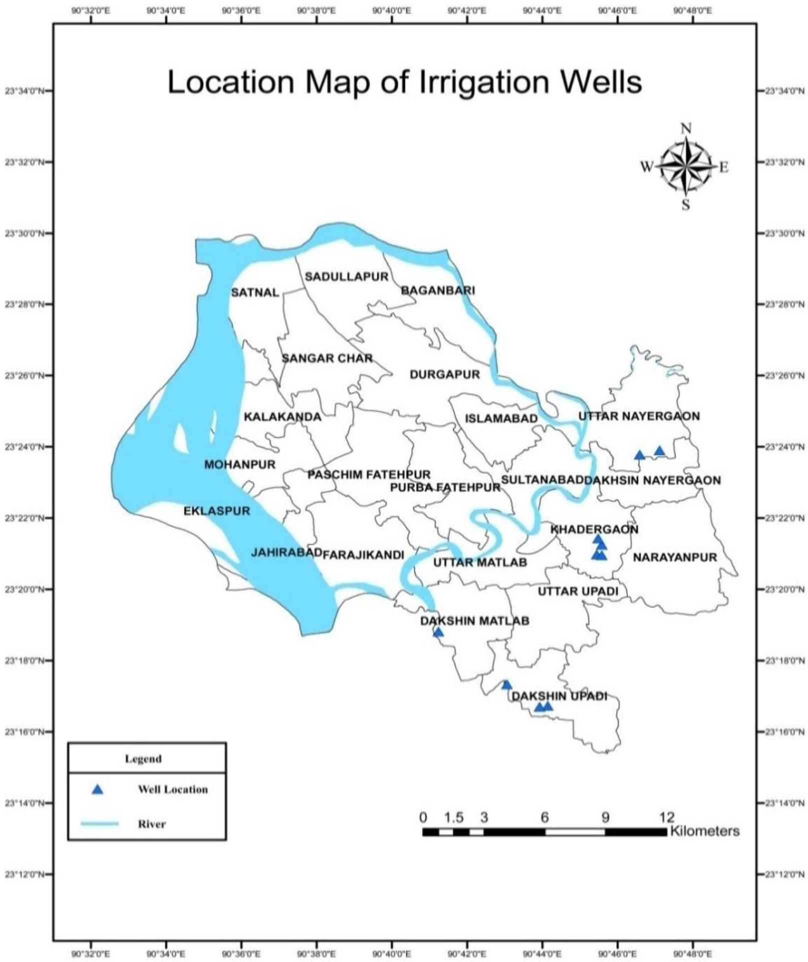

Figure 5: *Map of Matlab upazila showing the irrigation well sites.*

3.2. Field Work

The field work consisted in two stages. In first stage, field work was conducted on February/March, 2009 during the irrigation seasons. The objective of first stage field trips was to collect information about irrigation wells, field survey by interviewing different local stakeholders and thereby water and soil sediment sampling. The second stages were conducted on May, 2009 during the harvesting season of rice.

The field work was initiated by collecting of information about irrigation wells from the study areas. Information was collected from Matlab Upazila Agriculture office, Agriculture Extension office, DPHE, Local NGOs and Local peoples. On the basis of their information, ten irrigation wells were selected from different union of Matlab upazila. Water samples were collected from these ten irrigation wells. Among these ten irrigation wells, four wells were selected dependent on the level of As present in irrigation wells. Soil samples were collected from these four irrigation wells point for further Laboratory analysis. In second stage, after two months rice grain samples were collected from the ten paddy fields during the harvesting time. The paddy fields were irrigated with those irrigation wells water which was selected for water sampling.

3.2.3. Selection of irrigation wells

The local stakeholder of Matlab upazila, mostly used different types of irrigation wells in their farming system. These are Deep well (DW), Shallow Well (SW), Low Lift Pump (LLP) irrigation wells. In all, 14 deep irrigation wells were identified based on field survey and interview of local stakeholders, NGO's and different governmental institutions (Appendix C). Among the 14 deep irrigation wells, five deep irrigation wells and surrounding five shallow irrigation wells were selected for collecting water sampling. The location maps of selected ten irrigation wells are shown in Figure 5. These ten irrigation wells were located in the four different union of Matlab south thana i.e., Daksin Upadi, Matlab Daksin/Pourasova, Khadergaon and Uttar Nayergaon union (Appendix B).

3.2.4. Field measurements

At each selected irrigation wells points, water conductivity, water pH, redox potential (Eh) and total As concentration was measured. A rubber plug with a plastic pipe was attached to the pump and connected to the flow through cell. The measurements were made by using a 'flow-through-cell' (Figure 6).

Figure 6: *The flow through cell used for field measurements.*

Electrical conductivity of each irrigation wells were measured until the reading reached stabilisation. For the P^{H} electrode, standards buffer solution 4 and 7 were used and calibrated once a day. The conductivity meter was calibrated with a 0.01M potassium chloride (KCl) solution at 1412QS at Dhaka University.

The Eh meter was calibrated with a standard Zobell's solution at Dhaka University. The redox potential values were measured in field by using the relation (Equation 1) which was corrected accordingly Appelo and Postma (1993).

$$Eh = E_{meas} + E_{ref} \qquad \text{(Eqn. 1)}$$

where E_{meas} is the measured potential and E_{ref} is 244 mV

3.2.5. Water sampling

Three representative water samples were taken at each site of irrigation wells. The samples were filtered with 0.2 µm Sartorius filters. The first type of water sampling was only filtered with 0.2 µm Sartorius filters and it was stored in a 50 ml plastic bottle. The second types of water sampling was filtered and acidified with 14 M absolute nitric acid and it was put in a 50 ml plastic bottle. The third type of water sampling was filtered with As speciated and then acidified and stored it in a 50 mL plastic bottle. For As speciation, a disposable Cartridge was used that only permit As (III) to pass through the column (Figure 7).

Figure 7: *Water sampling for arsenic speciation studies using online filter and cartridge.*

3.2.6. Field measurement of Arsenic

At each irrigation wells point, Wagtech Arsenator (Wagtech, 2009) was used to determine the inorganic As concentration in the field (Figure 8). About 50 mL of water sample was collected in the reaction vessel. Then two different reagents, sulfamic acid and powdered zinc, were added, the cap was put on and the vessel gently swirled. Under the flap of the cap a test strip was positioned so that the arsine gas produced in the vessel came in contact with the reaction pad on the test strip. The vessel was left to react for 20 minutes, and was swirled twice during this period. The color generated on the strip indicates the amount of As in the sample and was compared with a color chart.

Figure 8: *Measurements of total As concentration in field by using Digital Arsenator*

3.2.7. Collection of soil core samples

On the basis of As concentration of irrigation water, four irrigation wells sites were selected for soil sampling. Among them one was As free, one was less, one was medium and the rest one was high As containing irrigation wells. Each irrigation site was divided into three sub points. The first sub point was located 11 m far from the irrigation pump. The second sub point was located 11 m far from the first sub point. Similarly, the third and last sub point was 11 m far from the second sub point and all three sub points were the same direction from the irrigation pump. Soil samples were collected from three different horizons i.e.; 5.1-10.2 cm, 35.6-40.6 cm and 71.1-76.2 cm deep from the surface soils at each sub points.

Figure 9: *Soil sampling using pit opening method*

Soil samplings were conducted by using the pit opening method (Figure 9). In this method, 76.1 cm deep pit was dig with the use of hand augur. After dig the pit soil sample were collected from the above mentioned three different depths of soil horizons.

3.2.8. Collection of rice grain sample:

Rice grain samples were collected from the ten selected irrigation wells location paddy field. About 250 gm of rice grain were collected from the paddy field which was irrigated by selected irrigation wells water. The locations of paddy field are shown in appendix L. Samples were collected during harvest and sun dried immediately after collection, tagged properly, air tied in polyethylene bags and kept in room temperature for further laboratory analysis.

3.3. Laboratory analysis:

The collected water, soil and rice grain samples were brought to Sweden for laboratory analysis. These collected samples were analysed at the Department of Land and Water Resource Engineering at the Royal Institute of Technology (KTH), Environmental Geochemistry department of Stockholm University and Institute of Land and environment, SLU.

3.3.1. Analysis of water samples

3.3.1.1 Alkalinity

Alkalinity is a measure of the buffering capacity of water, i.e. the capacity of bases to neutralize acids. It was determined according to the standard method SS-EN ISO 9963-2 where hydrochloric acid (HCl) was used as a titrant. The end point was set at pH 5.4 and the volume HCl consumed during titration was noted. The alkalinity was calculated in terms of the total concentration of HCO_3^- using the relation (Equation 2):

$$A = V_{HCl} * C_{HCl} * \frac{W(HCO_3^-)}{V_{sample}} \qquad \text{(Eqn. 2)}$$

where:

- A is the concentration of alkalinity in mg/L
- C_{HCl} is the concentration of hydrochloric acid in mmol/L (20 mM)
- V_{sample} is the volume of the sample in ml
- V_{HCl} is the volume of HCl consumed by the sample, expressed in ml
- $W(HCO_3^-)$ is the molar weight of bicarbonate ion in g/mol

Filtered water samples were used for the analysis.

3.3.1.2. Cations

31 cations were analysed by inductively coupled plasma (ICP) emission spectrometry (Varian Vista-PRO Simultaneous ICP-OCE with SPS-5 autosampler) at Stockholm University,. Among the analysed ions, the major cations were sodium (Na), potassium (K), magnesium (Mg) and calcium (Ca) together with other trace elements such as As, Fe and Mn. All samples had been filtered and acidified in the field which gave the respective total cation concentrations in the water. As(III) was analyzed from the field speciated samples. The concentration of As(V) was calculated as the difference between As(tot) and As(III).

3.3.2. Analysis of soil samples

3.3.2.1. Determination of soil color

The colors of the soil samples were determined according to the Munsell color chart. Field moist soils were used to determine the soil color. Soil colors were identified at the Land and water Resource Engineering laboratory in KTH. Sediment colors of different pits in field conditions are shown in Figure 10.

3.3.2.2. Soil pH

pH measurements are affected by the soil: solution ratio and the solution type. Although the pH of a soil is more closely related to a pure water: soil solution, due to extracted ion buffering effects more consistent and reliable measurements are obtained when taken in dilute salt solutions. Soil pH were determined by using the below procedure in the laboratory of Land and

Water Resource Engineering department in KTH. 0.01 M $CaCl_2$ was prepared by dissolving 219.08 g $CaCl_2$ $(H_2O)_6$ in 600 mL distilled water and diluted to 1000 mL. 10 g of air-dried and sieved (< 2 mm) soil samples were weighed into a plastic beaker. with 0.01M $CaCl_2$ in a 1:2.5 soil solution ratio. Add 25 ml distilled water or salt solution and stir for ca. 1 minute (soil:$CaCl_2$ = 1:2.5). The pH is measured in the supernatant after 1 h of standing and a second short stirring.

3.3.2.3. Soil Moisture

Soil moisture content expressed as the ratio of the mass of water present to the dry weight of the soil sample, or by volume as ratio of volume of water to the total volume of the soil sample. To find out the soil moisture content it needs to drying the soil to constant weight and then measuring the soil sample mass after and before drying.
According to Black C.A. (1965), Soil moisture was determined at Department of Land and Water Resources Engineering at KTH according to the following procedures.

Figure 10: *Soil samples from the different pits of study area.*

Aluminum tin was weighted and record this weight (w1). About 10 gm of soil samples placed in the tin and record this weight as W2 (wet soil + tare). The sample placed then into the oven at 105ºC, and dry for 24 hours or overnight. The sample weighted and record this weight as weight of W3 (dry soil + tare). The sample then return to the oven and dry for several hours, and determine the weight of (dry soil +tare). These steps were repeated until there is no difference between any two consecutive measurements of the weight of (dry soil+tare).

The moisture content in dry weight basis may be calculated using the relation (Equation 3):

$$MC\% = \frac{W2 - W3}{W3 - W1} \times 100 \qquad \text{(Eqn. 3)}$$

where:
W1 = Weight of tare (g)
W2 = Weight of moist soil + tare (g)
W3 = Weight of dried soil + tare (g)

3.3.2.4. Total Carbon, Organic carbon and Carbonic carbon analysis

Total Carbon as well as organic carbon and carbonate carbon were analyzed in the Institute of Land and Environment department at SLU. These investigations were done with the flow of LECO methods.
The instrument was prepared by following the procedures outlined in the operator's instruction manual (i.e. perform maintenance, check gas supplies, and perform leak checks). Blank samples were analyzed until the instrument is stable, then analyze three to five empty 528-203 combustion boats. 0.5 g was enter as the weight. A blank was set using result from these empty boats. About 0.5 g of standard material was weight into a 528-203 combustion boat and it was analyze three to five times, then drift correct using these values (note: Using 0.5 g sample size reduces maintenance frequency). The sample was mixed well and 0.5 g sample weighted into a 528-203 Combustion Boat, and analyze. A standard also analyzed at the end of the set to verify calibration.

3.3.2.5. Extracion with HNO_3

The chemistry of the samples sediments was established by oxalate and nitric acid extractions. A total extraction with nitric acid (HNO_3) was performed to establish the content of As in the sediments. HNO_3 extraction releases elements associated with the non-silicate minerals (Kumar, 2005).

Figure 11: *Digestion of soil samples and filtration analyses of arsenic.*

2 g of dried sediment samples were taken in 50 ml conical flasks with 15 ml of 7 M HNO_3. The solutions were first boiled, with small glass balls assuring a good circulation, for approximately 5 hours and were thereafter left overnight to reach ambient temperature. The solutions were filtered through OOK paper and diluted 5 times with deionized water and make it volume 50 ml (Figure 11) and taken into a 50 ml plastic bottle. Then the filtered samples transferred into Stockholm university to run in ICP-OES for determination of total As and as well as another cations.

3.3.2.6 Selective extraction

The selective extraction with oxalate solution releases elements in the reducible phase i.e. present as oxides, particularly poorly crystalline/amorphous oxides and hydroxides (Kumar, 2005). This extraction was made in order to establish the content of Fe(III)- oxyhydroxides. 2 g of dried sediment were placed in 250 mL polyethylene bottles with 50 mL 0.2 M oxalate solution. These were positioned in a vertically rotating shaker for 4 hours. The samples were centrifuged and diluted 10 times.
The solid Fe(III) oxyhydroxide concentration was calculated according to the relation (Equation 4)

$$HFO_{Solid} = Fe_{oxalate} \times \frac{M_{HFO}}{M_{Fe}} \times \frac{L}{S} \qquad \text{(Eqn. 4)}$$

where
- HFOsolid is the concentration of Fe(III) oxyhydroxides in the sediment (mg/kg)
- Feoxalate is the concentration of Fe from the oxalate extraction (mg/L)
- MHFO is the molar weight of Fe(III) oxyhydroxides: 88.85 g/mol
- MFe is the molar weight of Fe: 55.85 g/mol
- L/S is the liquid/solid ratio (L/kg)

3.3.3. Analysis of Rice grain samples

The rice grain samples (rice grain without husk and with husk) were digested with concentrated nitric acid. 2 g of dried sediment samples were taken in 50 ml conical flasks with 15 ml of 7 M HNO3. The solutions were first boiled, with small glass balls assuring a good circulation, for approximately 5 hours and were thereafter left overnight to reach ambient temperature. The solutions were filtered through 00K paper and diluted 5 times with deionized water and make it volume 50 ml and taken into a 50 ml plastic bottle. Then the filtered samples transferred into Stockholm university to run in ICPMS for determination of total As and as well as another cations.

4. Result and Discussion

4.1. Hydrochemical characteristics of irrigation water

The field measured parameters and the laboratory analyses are presented in detail in Appendix D-1 – D-3.

4.1.1. Water pH

The pH values from the 10 irrigation wells are grouped according to the union of Matlab thana and presented in Figure 12with minimum, maximum and median values. The pH values of 10 study union are ranged from 5.7 to 6.7. The pH values of the Kadergaon unions' irrigation water are generally higher than the other union irrigation wells water. On the other hand, Matlab Pourasova irrigation wells water contained lower level of pH. According to Ahmed et al. (2004) groundwater of the BDP that contains high As levels have a neutral to slightly basic pH. Likewise, Jonsson and Lundell (2004) observed similar pH values in their research which was ranged from 6.04 to 6.95. Meanwhile, Bivén and Häller (2007) also found similar pH values of their studies in Matlab Upazila. They observed that Matlab Upazila tube wells water pH level varies from 6.3 to 7.

4.1.2. Water Eh

The redox potential ranged from +267 to +284 mV. The shallowest irrigation wells of Matlab Pourasova contain the lowest values, which indicate reducing conditions in the upper layers. On the other hand the highest values of Khadergaon union in the red sediment indicate oxidized conditions. The minimum, maximum and median values for the different areas irrigation wells water types are presented in Figure 13. From Jonsson and Lundell (2004) research work it was observed that The Eh values differ from +105 to +387Mv in different types of sediments of their studies. The relationship between the different sediments are still of interest though.

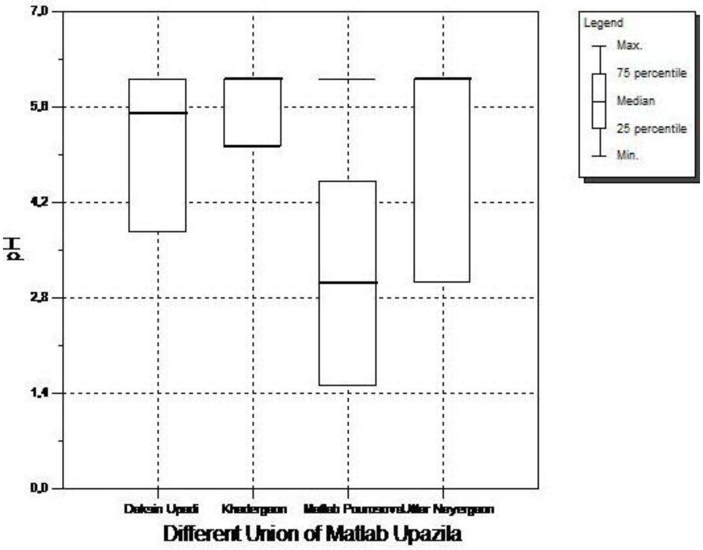

Figure 12: *Variation in the measured pH values in the irrigation water samples of different union of Matlab upazila*

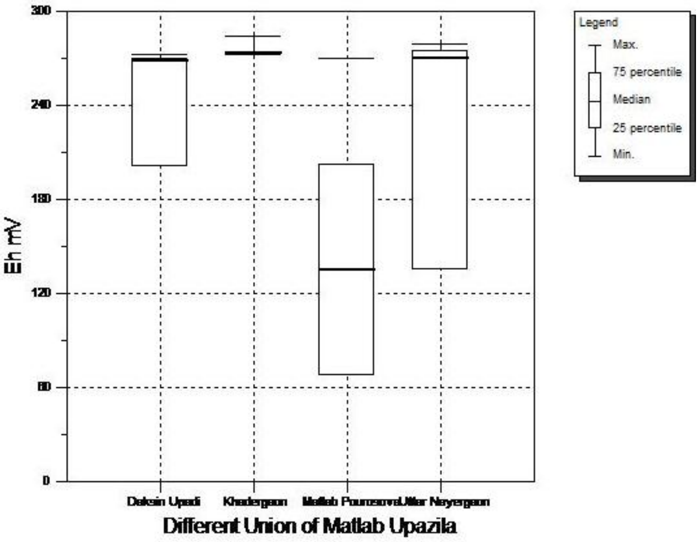

Figure 13: *Variation in the measured Eh values in the irrigation water samples of different union of Matlab Upazila.*

4.1.3. Conductivity

The conductivity values range between 640 and 1820 µS/cm (Figure 14). The values are generally high, with median values above 800µS/cm for all study area. The highest values are identified in khadergaon union and the lowest values in Matlab pourasova. Jonsson and Lundell (2004) observed conductivity values between 448 and 2800 µS/cm which is similar with current study.

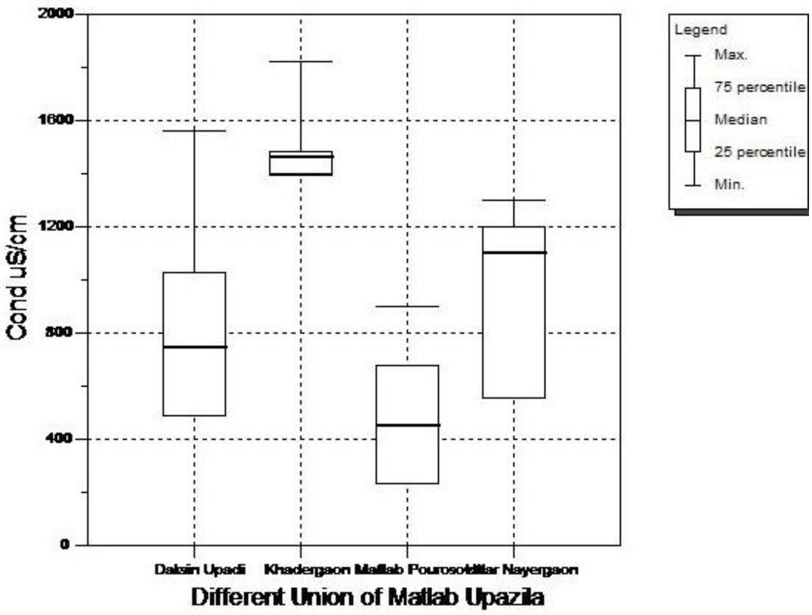

Figure 14: *Variation in the measured conductivity values in the irrigation water samples of different union of Matlab Upazila.*

4.1.4. Alkalinity

The alkalinity of different union of Matlab upazila was, in general high. From this study it was observed that the highest alkalinity was found in the water from Daksin Upadi union irrigation wells. On the other hand the lowest Alkalinity found in the Daksin Nayergaon union irrigation wells (Figure 15). The reason for high alkalinity might be the presence of higher organic matter or redox reaction. During sulphate reduction, HCO_3 is produced and thus increase the alkalinity.

4.1.5. Total As

The ten selected irrigation wells were tested for As at site by using an arsenator. The values ranged from 0 to 100 µg/L. According to the field measurement by arsenator, 10% irrigation wells did not contain any As and rest 90% had levels equal to or above the WHO irrigation water guideline of 20 µg/L.

The concentration of As measured in the laboratory was higher than the one measured in the field with the Arsenator. From the laboatory analysis the As values ranged 6 to 513 µg/L. Gilatoli deep irrigation wells contained the lowest concentration (6 µg/L) of As and on the other hand, Daksin Baregaon shallow wells containted the highest concentration (513 µg/L) of As. Figure 16 shown the max., min., and 25 and 75 percentile values for the four different unions.

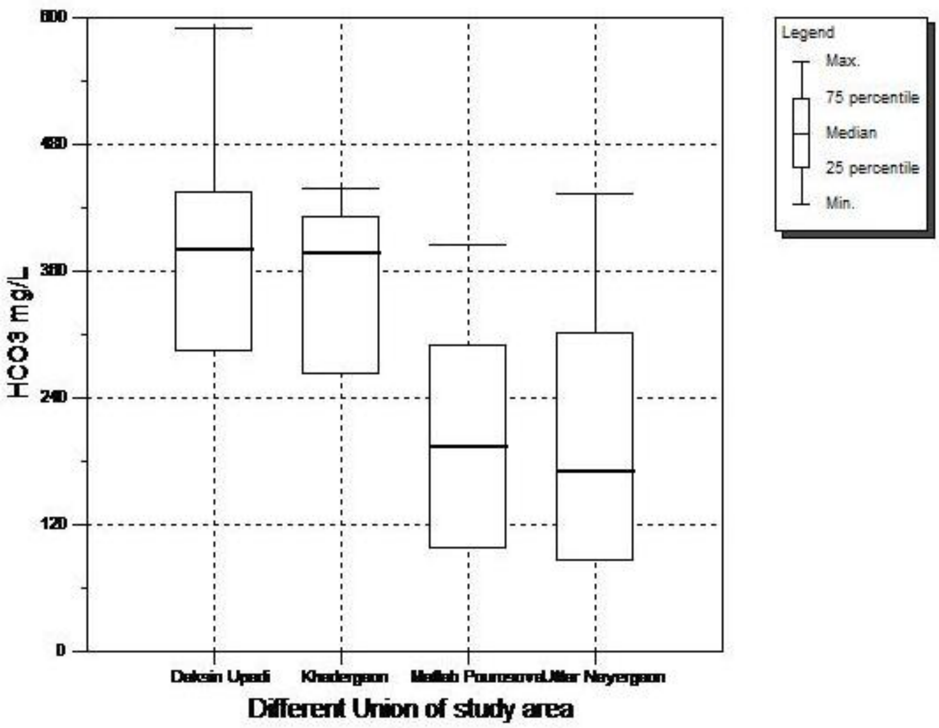

Figure 15: *Variation in the measured alkalinity (here shown as HCO_3) values in the irrigation water samples of different union of Matlab upazila*

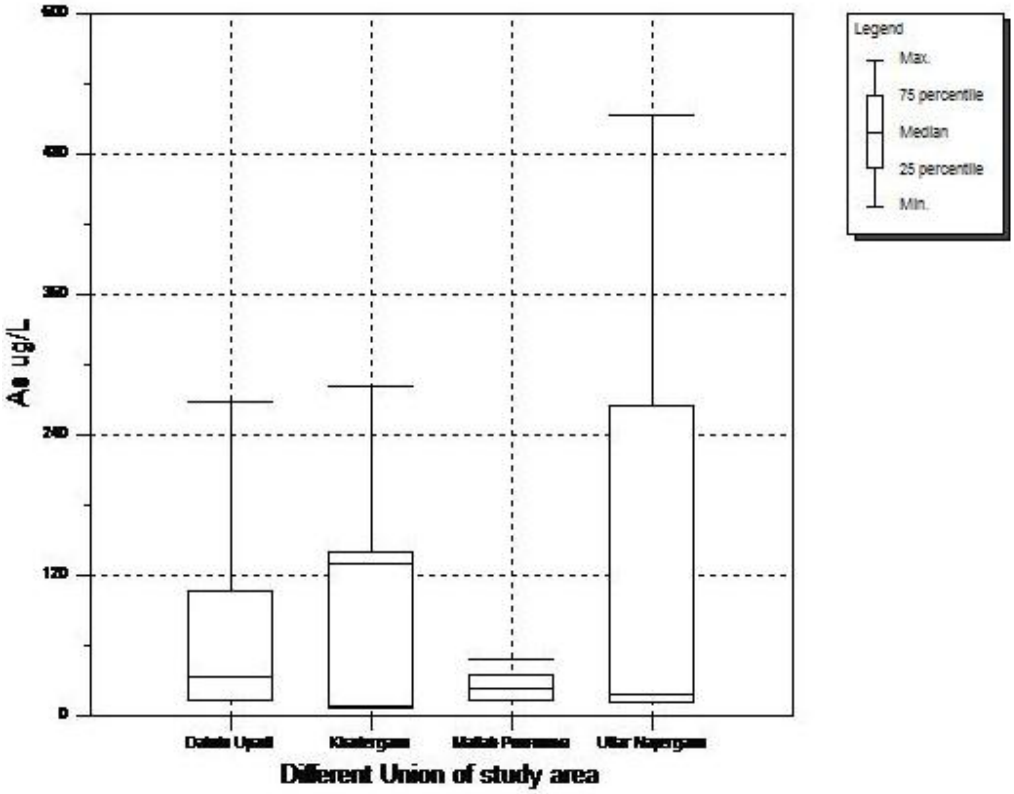

Figure 16: *Variation in the measured total As values in the irrigation water samples of different union of Matlab upazila*

4.1.6. Depth versus As concentration

Figure 17 shows the total field and lab measured concentration of As against the depth of irrigation wells. Here one can generally see that the shallow irrigation wells contained higher concentration than the deeper irrigation wells. From the laboratory analysis it is observed that the highest As concentration found against the depth of 36 m. But the lowest As concentration observed against the depth of 61 m in the against of 115 or 110 m depth. It's happened may be due to the installation sediments color.

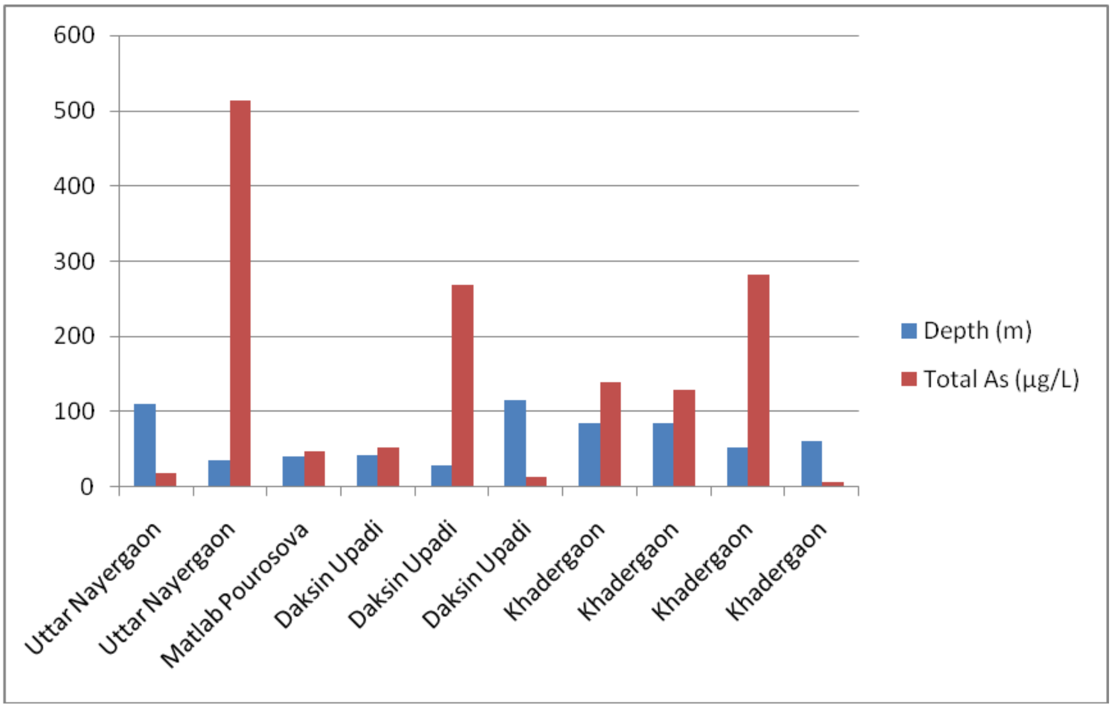

Figure 17: *As concentration against the installation depth of irrigation wells*

4.1.7. Arsenic in Soils

According to this study it is observed that the As concentration of different union of Matlab upazila varies from 1.85 to 5.02 mg/kg. From the box plots (Figure 18) for As shows that Uttar Nayergaon union agriculture land contained the lowest amount of As concentration and the Daksin Nayergaon had the highest concentration of As.

4.1.8. As in rice grain:

Concentrations of As in rice grain (with husk) from the As contaminated field were varied from 0.01 to 0.15 mg/kg. The highest concentration of As 0.15 mg/kg was recorded in Uttar upadi union which rich field was irrigated by shallow irrigation wells. On the other hand, the rice grains (without husk) of study area were contained below detection limit to 0.02 mg/kg of As. The total As of rice grain in different union of Matlab is shown in Figure 18 by boxer plots. Huq et al. (2006) observed that irrigation water contained 0.136 to 0.55 mg/L of As and considering this values he estimated that total loading of As in irrigated soils for a *boro* rice that requires 1,000 mm of irrigation-water per season ranged from 1.36 to 5.5 kg/ha/year. On the other hand, Panaullah (2004) observed that rice grain contained 0.8-1.0 mg/kg of As in few site, but in general he observed that As concentration ranged from 0.2 – 0.4 mg/kg in rice grain.

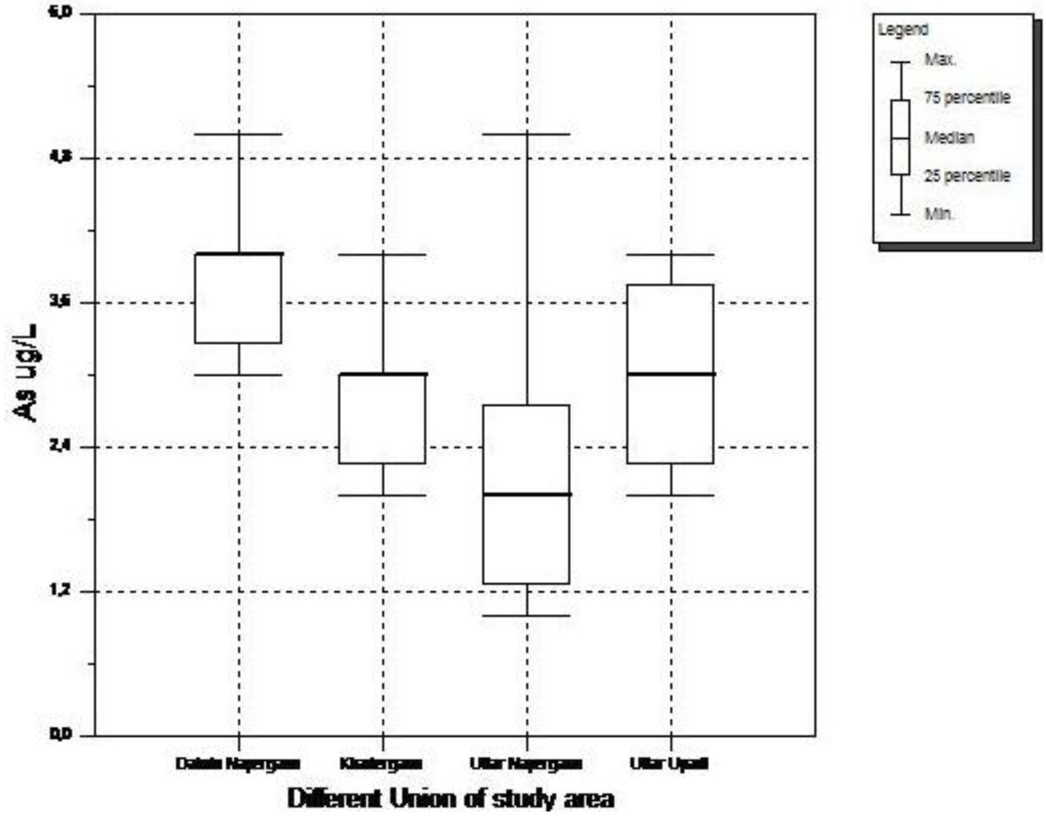

Figure 18: *Variation in the measured As values in the soil samples of different union of Matlab Upazila*

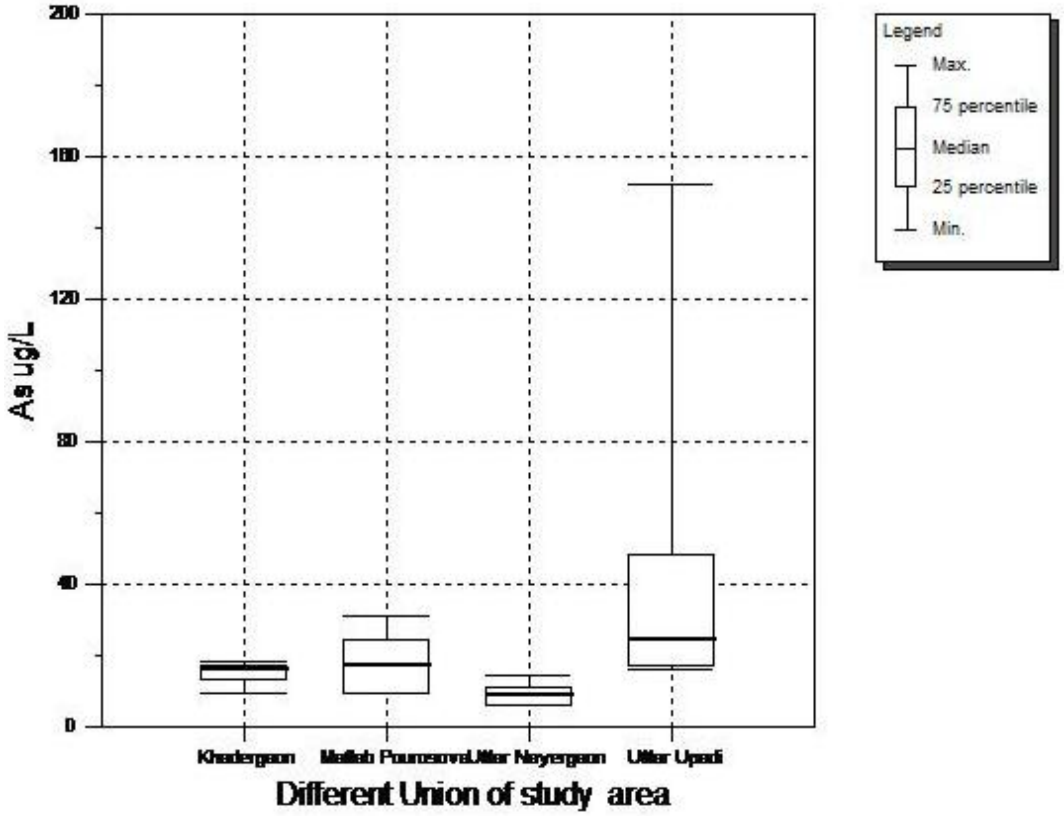

Figure 19: *Variation in the measured As values in the rice grain samples of different union of Matlab Upazila*

4.1.9. Water-soil-crop route for transfer of arsenic to human body:

Several researchers were focused on As exposure through drinking water to human body. Like this As also enter human body through irrigation wells water to irrigated soil and from irrigated water to cultivated crops. Ali (2003) estimated by using 1996 irrigation data that each year 1kg of As release into irrigated land from the groundwater and thus As moved into rice grain through soil. This investigation shows in Figure 20, that 0.006 to 0.513 mg/L of As loaded from the groundwater by pumping and 1.85 to 5.02 mg/kg of As accumulated into rice field after irrigation. Due to anthropogenic activity, As contents in rice field may be higher than the pumping water. From the As contaminated these investigated field rice grain accumulated 0.01 to 0.15 mg/kg of As.

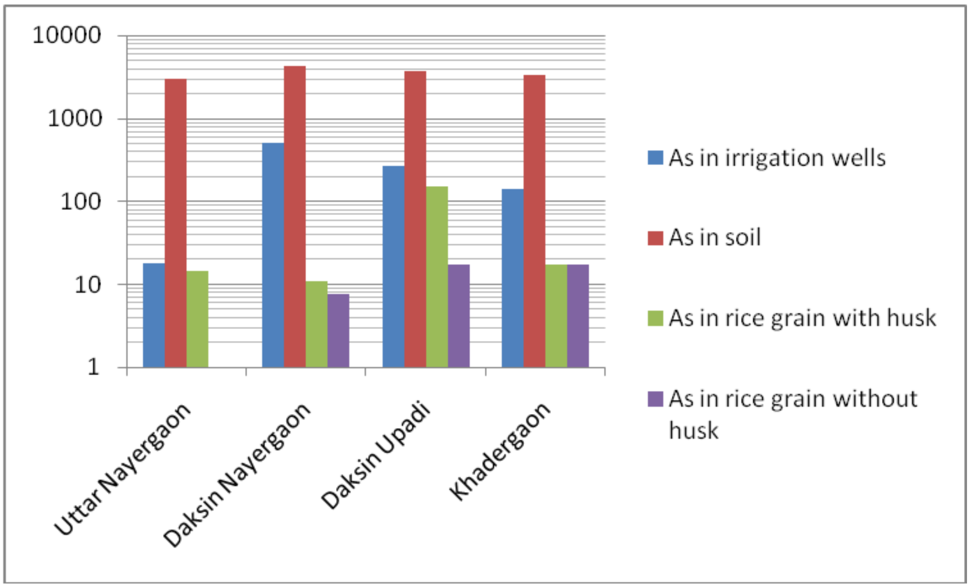

Figure 20: Arsenic concentration of water, soil and rice grain in study area

4.2. Discussion

It is clear from the present study and some other previous research that As deposits in soil from the As contaminated groundwater and then plant uptake As from this As contaminated irrigated soil. From the field survey by FFQ it was identify that the Bangladeshi rural people exposed to As from a variety of environmental sources. Among them food constitutes the largest source of As intake.

From the field survey it was observed that most of the villagers are involved in agrarian manual labor. Daily water consumption by an adult ranged between 4 to 8 L. According to the AsMat field study the As concentration of most Matlab tube wells water contained more than 0.05 mg/L. Thereby, an adult is expected to intake 0.2 to 0.4 mg of As/day from drinking water. Farmer and Johnson (1990) also observed that most of As affected Bangladeshi rural people daily consumed 4 to 6 L water and then considering 50 µg/L of acceptable limit for drinking water, an adult is expected to intake 0.2 to 0.3 mg of As/day from drinking water.

According to the FFQ of this study it was found that the average daily rice consumption by an adult of this area was between 450 to 1020 g raw rice grains. In the present study, the average As concentrations in rice grain (without husk) were 0.02 mg/kg. With the consideration of this value, an adult of study area is expected 0.01 to 0.16 mg/kg of As daily intake with rice. On the other hand, Duxbury et al. (2003) reported that the average daily rice consumption by an adult of this area is between 400 and 650 g raw rice grain and Rahman et.al. (2006) observed that As concentrations in rice grain were 0.57 and 0.42 mg/ kg dry weight for glasshouse and field sample, respectively. With the combination of this two reports, Rahman et al. (2006), estimated that, the daily intake of As from rice grain containing 0.57 mg/kg dry weight would be between 0.20 and 0.35mg (according to the glasshouse data) and between 0.164 and 0.266mg (according to the field data). Bae et al.(2002) found from their research that cooked rice contained higher As concentration from the raw rice. Rahman et al. (2006) described that this happened due to rice cooked by the As contaminated water and the gruel was not discarded after cooking. This was because the As in water was absorbed by cooked rice. Ackerman et al. (2005) supported of this statement. They observed that 89–105% absorption of As by rice from total volume of water [1:1–4:1 (water: rice)] used in cooking for two different contaminated drinking water. Moreover, Duxbury et al. (2003) argued that most of the As in drinking water is dissolved as toxic inorganic forms, while the species of As in raw and cooked rice are poorly characterized. Schoof et al. (1999) also stated that between 30% and 85% of As in rice is inorganic. These reports suggest that intake of As from rice and its potential to human exposure is very important. It should not be ignored.

Rice is the staple food of Bangladesh and constitute the principal exposure risk for the population in Bangladesh. Arsenic is incorporated in rice through bioaccumulation from soils irrigated with As contaminated water (Meharg and Rahman, 2002). The increased As level in pumping water act as worsen outlook for Bangladesh's water safety crisis (Harvey et al., 2002). Meharg and Rahman (2002), sampled soils at 70 sites throughout Bangladesh and rice from seven different regions where there were As-tainted irrigation pumps and this study found high levels of As in soils. So, people of Bangladeshi affected by As throughout the irrigation water-soil-crops interaction.

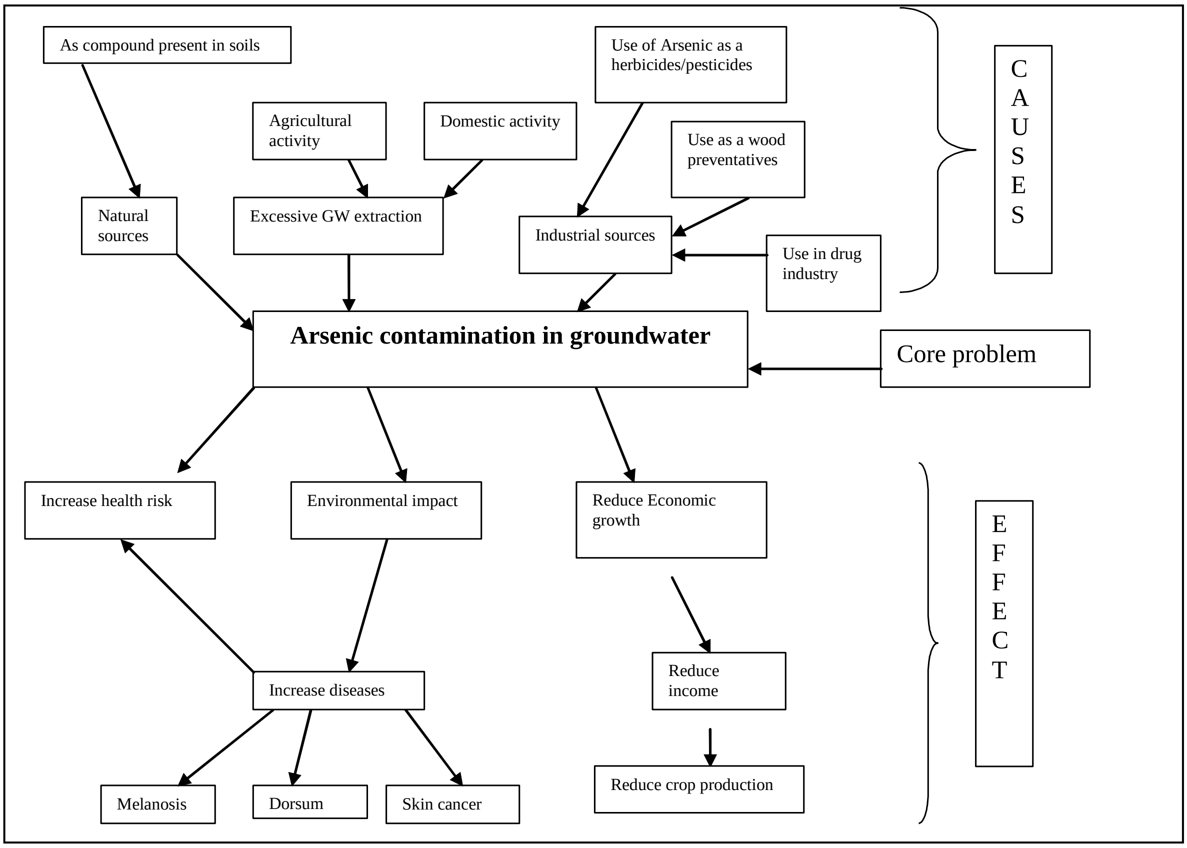

Figure 21: *Problem tree: the possible causes and effect of arsenic contamination in groundwater*

It is thus observed that As enter in food chain and the risk of arsenicosis to human do not go hand in hand. People living with same household and use the same sources water but they are not equally affected by arsenicosis. Moreover, the manifestation of arsenicosis also differs from one region to another region in the country (Haq et al., 2006). He also observed that the possibility of As accumulation in soils through irrigation water and its subsequent entry into the food chain through various food materials cannot be overlooked. With this view in mind and principle of IWRM, As problematic situation are analyzed on the basis of soft system methodology. From this study it is observed that As in groundwater is the core problem of food safety issue to human and as well as environmental pollution issues. The possible causes and effect of As problem in Bangladesh are conceptualized in problem tree (Figure 21).

Developing and industries countries face more or less similar consideration to mitigate the As contamination in groundwater. Developing countries like Bangladesh faced some additional constraints like financing, technical and administrative problems. In both cases, needs to follow multi-disciplinary activities in a sustainable way. With the consequence of problem tree, this research work developed an objective tree (Figure 22). Objective tree described the multi-disciplinary factors of process to develop the problematic situation.

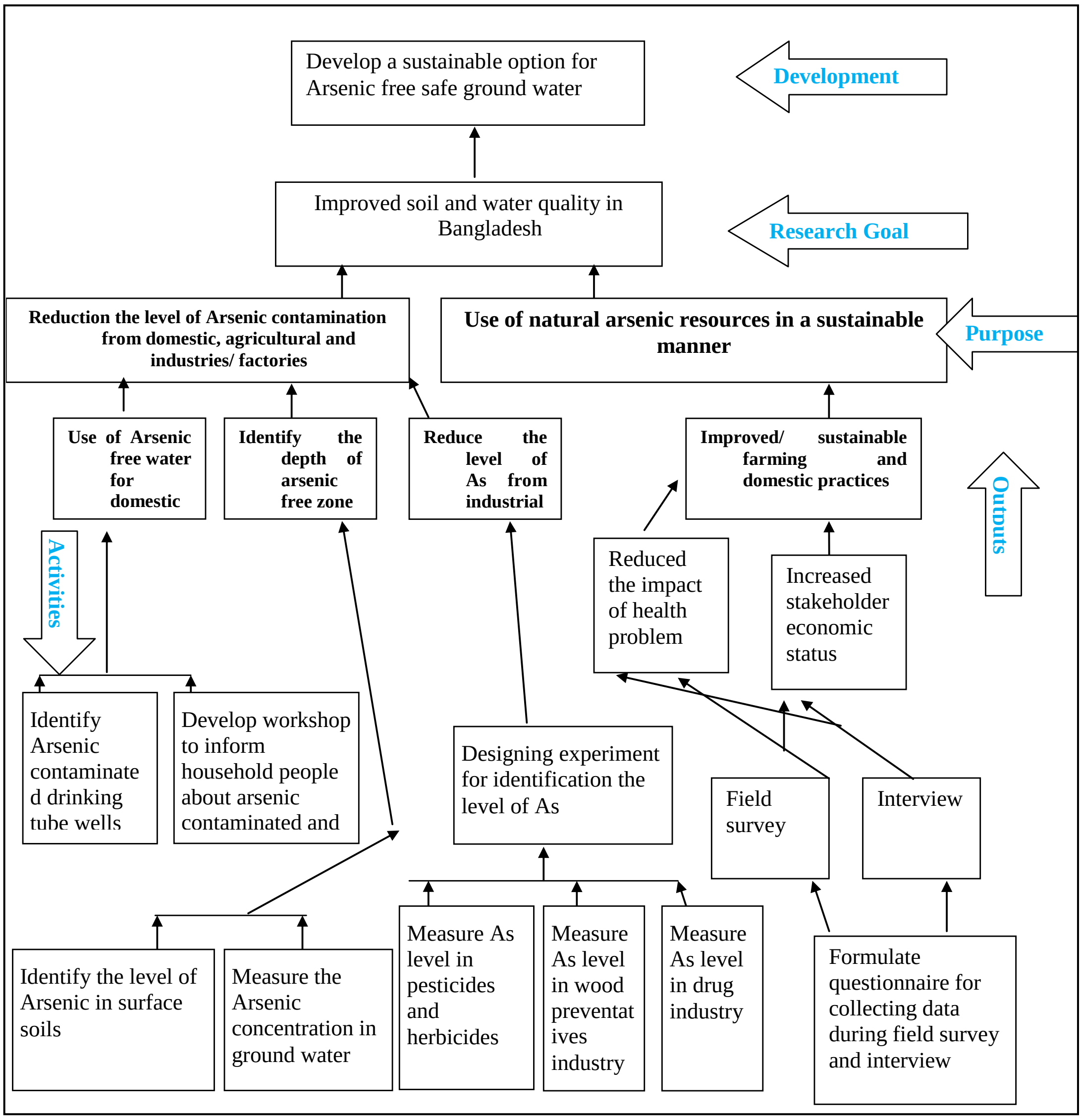

Figure 22 *Objective tree for the the multi-disciplinary process of arsenic mitigation.*

5. Feasibility option of As mitigation on IWRM aspect

Arsenic contamination in irrigation water is one of the major problems to food safety worldwide especially for human health in developing countries. A new report from the University of Calcutta said that the number of people at risk of As poisoning from drinking water from sunken wells may be considerably higher than previously thought. A population of almost 330 million people are ancipated be at risk in India and Bangladesh compared to 150 million as believed earlier (Chakraborti et al., 2002). The input of As contaminated irrigation water should be avoided or at least it can be minimize by the practice of natural water resources management. There are various options to mitigate of As contamination from soil, crop and water. One of the main important mitigation options is, reduce the use of irrigation water in the region of As contaminated which will reduce As input and extraction of groundwater resources. Another alternative option is to practice less water demanding cropping pattern or use the select/breed rice cultivars which are tolerant to As and have a limited uptake of As.

According to Alaerts et al. (2001), the feasible option depends on a variety of factors such as: 1) the existing basic water supply system: As treatment by centralized piped system in urban area and in rural area one consisting tube wells used by a community; 2) considering the feasibility of As removal on the basis of amount and percentage of As contaminated water; 3) the opportunity of technical and managerial support to install and maintain the treatment units; and 4) financial support and willingness of government and local community to operation and maintenance of the equipment. Feasibility of As mitigation needs to thoroughly check of the capability and willingness of households and the quality of alternative sources. As removal of As from water involved cost and operational complexity of the technologies, it is preferable to choose an alternative water source of good quality in the third world countries. In Bangladesh, there are several alternative options instead of As contaminated groundwater such as surface water, harvested rain water, or As free groundwater. Farmers can use these alternative sources water in their agriculture which can be reduced the As into the food chain.

On the other hand, Saifuddin and Karim (2001) point out several options to remediation of As in groundwater on the basis of cost effectiveness for the developing country like Bangladesh. The notable mitigation options are –

1) Use of alternative sources water such as pond sand filters, infiltration galleries, or Rainey wells, and in some places even rainwater harvesting can be adopted to alleviate the As disaster.
2) Purification of surface water by filtration and chlorination or by ultraviolet disinfection and solar radiation. This water can be use for drinking or other domestic purposes.
3) Extraction and distribution of As free water from deep aquifers.
4) To ensure the safe and As free water need to develop a long lasting efficient water supply system for the whole country.
5) An efficient sewage and waste disposal system also need to be developed with the water supply system to prevent the contamination of soil and water.

Considering above discussion this study design a set of As mitigation strategy which is outline in below.

Short term mitigation option:

1) Raising the rural people awareness about the As contamination and food safety issues.
2) Cheap, efficient and easy groundwater treatment technologies applied to protect the As contaminated regions people as an interim or midterm solution.

3) Improvement of diet and nutrition status so that they can survive under-nourishment due to As crisis.
4) Involvement of civil society, NGO's and other aid agencies into the designing, planning and implemented stages.
5) Coordination between different intra-governmental bodies.
6) Building trust among the different stakeholders through transparency and transfer of information.

Long term mitigation option:

1) Integrated water resource management on regional or national level should be follow on terms of improving the situation
2) Coordination, management and dissemination of information should be well organized
3) Alternative livelihood approach should be applied who are directly affected by As poisoning.
4) Given the high priority on the food safety and nutritional status of diet.
5) Scientific research should be conducted for reduce uncertainty and complexity
6) More understanding is required to quantify the impact of As contaminated irrigation water on the food chain for sustainable agriculture.

6. Conclusion

In summary, from this research work and also with the basis of other previous study it can be concluded that As in groundwater is the greatest risk for the Bangladeshi rural peoples and this issue makes the livelihood in an uncertainty and complexity situation to the sustainable development of agriculture at the national scale. Arsenic from the groundwater enters the food chain through water-soil-crop route. The continuous release of As by irrigation water and other anthropogenic activities such as use of arsenals herbicides and pesticides raise the level of As in soil. The raising As concentrations in soil increase the threat for crop production and for the sustainable agriculture. It affects the soil properties by becoming toxic for plant and other organisms. As a result crop production decrease and its impact to the income and nutritional status of As affected region peoples. Till now, the risk of As contamination in groundwater which is used for agricultural purposes have not received well attention. The knowledge about the As in food chain is not developed in the rural communities. To develop the knowledge about the food chain and to minimize the As withdraw from the groundwater we need to coordinate among the all governance bodies including the NGO's, different aid agencies and local stakeholders. Proper watershed management and villager participation are needed to ensure this As mitigation process.

7. Recommendations

Arsenic in food chain is consider as a crisis situation on terms of food safety, water supply, health emergencies, disaster relief, etc. and to faced this serious issues we need to a more comprehensive study in the future.

For future, following topics are interested to investigate in depth analysis of As poisoning in food chain.

1) According to the other previous study it is observed that 'water-soil-crop' is not only the source of As in food chain, there have also other route of As accumulation in human body such as 'plant-human', 'plant-animal-human' pathway. To assessment of this fact we

need to an intensive study on terms of food poisoning in human body through these other routes.

2) This study feels in-depth investigation to understanding the level of As in irrigation water, soil and crops.
3) It also requires determining the behaviour of As in soil, uptake and toxicity in crops in the contaminated agro-ecosystem.
4) This study refers to identify the influence of agricultural practices including irrigation water management on As and determine the standards level of As for irrigation water, soil and crops.
5) Influence of anthropogenic activities such as use of arsenals herbicides or pesticides and their interaction with soils and thereby transmission of As from soil to crops needs to determines.
6) A more intensive study needs to assess the level of As concentrations in the irrigation wells during a certain period of time interval.
7) A comprehensive research plan need to developed for determine the risk assessment to the As poisoning.

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9. Appendices

Appendix A: Location and owners of the irrigation wells

Sample ID	Village	Union	Longitude (E)	Latitude (N)	Owner
Mubarakdi shallow	Mubarakdi	Matlob Pourosova	90°41'14.4″	23°18'49.1″	Mujib Gazi
Bakra shallow	Bakra	Daksin Upadi	90°43'55.5″	23°16'42.1″	Md. Monir Hossain
East Bakra shallow	East Bakra	Daksin Upadi	90°44'08.6″	23°16'43.9″	Anower Hossain
Gobindapur deep	Gobindopur	Daksin Upadi	90°43'03.8″	23°17'19.9″	Md. Delower Hossain Khan
Nagdah deep	Middle Nagdha	Khadergaon	90°45'27.0″	23°20'59.0″	Md. Noyan Bokul
Nagdah deep	Middle Nagdha	Khadergaon	90°45'34.7″	23°20'57.4″	Mrs. Kohinur
Gilatoli shallow	Gilatoli	Khadergaon	90°45'34.7″	23°21'15.4″	Siraz Talukdar
Gilatoli deep	Gilatoli	Khadergaon	90°45'29.5″	23°21'26.0″	Delower Member
Kalihasi shallow	Kalihashi	Daksin Nayergaon	90°46'35.3″	23°23'46.8″	Md. Osman Goni
Luck deep	Luck	Uttar Nayergaon	90°47'07.2″	23°23'54.1″	Abdul Hai

Appendix B: Age of the irrigation wells, sediment colour, depth and cropping pattern of wells

Sample ID	Age of wells (yr)	Sediment Colour (Install depth)	Depth (m)	Well diameter (m)	Operation hour (hr/day)	Operational power	Area coverage (ha)	Cultivated Crops
Mubarakdi shallow	4	Grey	40	0.11	5	Diesel	2	Paddy, Mustard oil
Bakra shallow	5	Dark grey	42	0.10		Diesel	6	Paddy, tomato, potato
East Bakra shallow	5	Off white	29	0.10	12	Diesel	8	Paddy, Mustard oil, Potato, Tomato
Gobindapur deep	22	Grey	115	0.20	20	Electrified	40	Paddy, Mustard oil, Potato, cauliflower, Tomato
Nagdah deep	10	Dark Grey	85	0.10	20-22	Diesel	6.075	Paddy, Chilli, Tomato, Onion, Wheat
Nagdah deep	7	Grey	85	0.10	10-12	Diesel	4.86	Paddy, Onion, Potato, Chilli, Wheat
Gilatoli shallow	13	Yellow/light brown	52	0.10	18-20	Diesel	6.075	Paddy, Maize, Wheat, Mustard oil
Gilatoli deep	8-9	Yellow	61	0.10	20-22	Diesel	16.20	Paddy, Maize, Wheat
Kalihasi shallow	4	Grey	37	0.10	10-12	Diesel	3.24	Paddy, Potato, Mustard oil
Luck deep	20-22	Reddish grey	110	0.20	12	Electrified	70	Paddy, Potato, Tomato

Appendix C: Information Deep Irrigation Well of Matlab South

Well No.	Union	Block	Village	Name of Caretaker	Depth (m)	Status	Well Diameter (m)	Area Coverage (ha)	Time of operation (h)
1	Dakshin Upadi	Gobindapur	Gobindapur	Delwar Hossain Khan		Operational	0.20	40	7
2	Dakshin Upadi	Karbanda	Karbanda	Mawlana Tajul Islam		Operational	0.15	24	10
3	Dakshin Upadi	Ghoradhari	Madhya Tingra	Nurul Islam Bakaul		Operational	0.20	39	12
4	Dakshin Upadi	Ghoradhari	Dakshin Purba Tingra	Manik Chandra Sarker		Operational	0.20	42	12
5	Dakshin Upadi	Ghoradhari	Uttar Ghorabari	Fazlul Haque Prodhania/ M. Rafiqul Islam		Operational	0.20	154	12
6	Khadergaon	Narayanpur	Gilatoli	Shahidullah Bokaul		Operational	0.20	41	8
7	Narayanpur	Baroigaon	Badhantoli	Fazlul Haque Mollah		Operational	0.20	45	8
8	Narayanpur	Kalikapur	Doulatpur	Ali Hossain		Operational	0.10 or 0.15	30	3
9	Narayanpur	Kasimpur	Chapatia	Anwar Hossain	110	Operational	0.20	27	15
10	Narayanpur	Kasimpur	Monigaon	Prof. Mustafa Khalil	110	Operational	0.20	25	12
11	Narayanpur	Kasimpur	Puron	Abdur Razzak	110	Operational	0.20	32	12
12	Uttar Nayergaon	Adhara	Lak	Abdul High		Operational	0.10	70	12
13	Uttar Upadi	Naogaon	Naogaon	Shafiqul Islam/ Majid Alam		Operational	0.20	70	14
14	Uttar Upadi	Bahari	Bahari	Solayman Prodhania		Operational	0.10 or 0.15	20	14

Appendix D: Hydrochemical characteristics of the irrigation well waters

D-1: Field Parameter measured on-site for the irrigation water wellsr

Sample ID	Sampling date	Depth	pH	Eh (mV)	Conductivity µS/cm
Mubarakdi	04/03/09	Shallow	6.3	270	900
Bakra	04/03/09	Shallow	6.3	272	850
East Bakra	04/03/09	Shallow	6.6	267	640
Gobindapur	03/03/09	Deep	5.7	269	1560
Nagdah	03/03/09	Deep	6.3	274	1480
Nagdah	03/03/09	Deep	6.4	273	1390
Gilatoli	03/03/09	Shallow	6.1	272	1460
Gilatoli	03/03/09	Deep	5.9	284	1820
Kalihasi	02/03/09	Shallow	6.5	270	1300
Luck	02/03/09	Deep	6.7	279	1100

D-2: Major ions in irrigation water

Sample ID	Depth	HCO3 mg/L	Na mg/L	K mg/L	Mg mg/L	Ca mg/L
Mubarakdi	Shallow	385.9	228.5	6.77	40.2	48.7
Bakra	Shallow	589.4	252.9	8.63	41.2	65.6
East Bakra	Shallow	382.2	37.3	6.47	30.6	59.1
Gobindapur	Deep	377.6	227.8	5.75	29.3	49.6
Nagdah	Deep		297.8	11.7	38.0	47.7
Nagdah	Deep	349.2	32.4	11.8	29.7	42.1
Gilatoli	Shallow	438.1	71.1	7.59	29.1	44.1
Gilatoli	Deep	403.6	148.6	6.63	36.7	61.3
Kalihasi	Shallow	433.6	68.3	8.59	39.2	91.6
Luck	Deep	170.6	60.4	5.97	33.5	89.7

D-3: Analyses of As, Fe and Mn in the irrigation wells

Sample ID	Depth	As (field) µg/L	Total As (lab) µg/L	As (III) µg/L	As (V) µg/L	Fe µg/L	Mn µg/L
Mubarakdi	Shallow	87	347.9	263.7	84.2	4099.4	44.3
Bakra	Shallow	100	153.4	125.2	28.2	51.9	101.6
East Bakra	Shallow	100	268.4	35.5	232.9	13329.8	357.3
Gobindapur	Deep	100	14.4	13.6	0.84	6739.47	34.8
Nagdah	Deep	45	139.9	137.8	2.21	88.0871	141.5
Nagdah	Deep	90	130.0	95.6	34.4	4587.345	200.7
Gilatoli	Shallow	85	281.5	255.4	26.1	3393.385	91.8
Gilatoli	Deep	95	6.15	6.01	0.14	3737.26	180.3
Kalihasi	Shallow	85	512.9	470.9	42.05	7973.11	175.1
Luck	Deep	0	218.1	196.2	21.9	18.671	299.3

Appendix E: Trace element distribution in irrigation wells (See Appendix D for the well depths)

E-1: Trace element distribution in irrigation wells

Sample ID	Al µg/L	Ba µg/L	Cd µg/L	Co µg/L	Cr µg/L	Cu µg/L
Mubarakdi	12.3	104.4	<0.9	<0.9	1.3	<0.3
Bakra	6.1	72.3	<0.9	<0.9	<0.5	<0.3
East Bakra	23.1	196.4	2.4	<0.9	1.5	0.4
Gobindapur	11.2	100.9	<0.9	<0.9	0.9	<0.3
Nagdah	5.8	21	1.5	<0.9	<0.5	<0.3
Nagdah	13.4	110.9	<0.9	<0.9	1.8	<0.3
Gilatoli	14.2	53.9	2.6	<0.9	1.9	0.6
Gilatoli	9.2	92.4	<0.9	0.9	1.4	0.4
Kalihasi	32.9	177.5	4.9	<0.9	1.4	<0.3
Luck	14.9	49.8	<0.9	<0.9	<0.5	<0.3

E-2: Trace element distribution in irrigation wells

Sample ID	Li µg/L	Mo µg/L	Ni µg/L	P µg/L	Pb µg/L	S µg/L
Mubarakdi	9.3	<1.9	<2.5	1547.9	<2.1	492.3
Bakra	14.8	<1.9	<2.5	23.5	<2.1	283.4
East Bakra	5.1	<1.9	2.8	1757.6	<2.1	667.5
Gobindapur	16.9	<1.9	<2.5	1000.9	<2.1	370.5
Nagdah	8.7	2.4	<2.5	263.1	<2.1	253.9
Nagdah	7.3	<1.9	<2.5	1997.7	<2.1	469.5
Gilatoli	4.9	<1.9	<2.5	2855.1	<2.1	797.7
Gilatoli	15.8	<1.9	<2.5	21.4	<2.1	373.5
Kalihasi	5.1	2.7	3.1	1985.5	<2.1	688.1
Luck	5.1	<1.9	<2.5	22.3	<2.1	604.4

E-3: Trace element distribution in irrigation wells

Sample ID	Si mg/L	Sr mg/L	Ti µg/L	V µg/L	Zn µg/L	Zr µg/L
Mubarakdi	7.1	0.5	0.5	<1.1	<1.1	<0.3
Bakra	8.4	0.4	<0.1	<1.1	<1.1	<0.3
East Bakra	9.1	0.3	1.1	<1.1	<1.1	0.4
Gobindapur	9.3	0.4	0.7	<1.1	<1.1	<0.3
Nagdah	8.2	0.3	<0.1	<1.1	<1.1	<0.3
Nagdah	7.1	0.2	0.7	<1.1	<1.1	<0.3
Gilatoli	8.9	0.2	0.7	<1.1	<1.1	<0.3
Gilatoli	9.9	0.4	0.2	<1.1	<1.1	<0.3
Kalihasi	8.1	0.4	1.8	<1.1	<1.1	<0.3
Luck	8.9	0.3	0.3	<1.1	<1.1	0.4

Appendix F: Munsell color information for the rice field soils

Sample ID.	Depth (cm)	Location (union, village)	Munsell color code	Munsell color description
Luck A1	5.1-10.2	Uttar Nayergaon, Luck	2.5YR 3/1	dark reddish grey
Luck A2	35.6-40.6	Uttar Nayergaon, Luck	2.5YR 5/1	reddish grey
Luck A3	71.1-76.2	Uttar Nayergaon, Luck	5YR 6/4	light reddish brown
Luck B1	5.1-10.2	Uttar Nayergaon, Luck	5YR 2.5/2	dark reddish brown
Luck B2	35.6-40.6	Uttar Nayergaon, Luck	5YR 5/3	reddish brown
Luck B3	71.1-76.2	Uttar Nayergaon, Luck	5YR 4/4	reddish brown
Luck C1	5.1-10.2	Uttar Nayergaon, Luck	7.5YR 3/1	very dark grey
Luck C2	35.6-40.6	Uttar Nayergaon, Luck	7.5YR 4/1	dark grey
Luck C3	71.1-76.2	Uttar Nayergaon, Luck	7.5YR 4/2	brown
Kalihashi A1	5.1-10.2	Daksin Nayergaon, Kalihasi	10YR 3/2	very dark greyish brown
Kalihashi A2	35.6-40.6	Daksin Nayergaon, Kalihashi	10YR 4/2	dark greyish brown
Kalihashi A3	71.1-76.2	Daksin Nayergaon, Kalihashi	10YR 5/3	brown
Kalihashi B1	5.1-10.2	Daksin Nayergaon, Kalihashi	10R 4/1	dark reddish grey
Kalihashi B2	35.6-40.6	Daksin Nayergaon, Kalihashi	2.5YR 5/1	reddish grey
Kalihashi B3	71.1-76.2	Daksin Nayergaon, Kalihashi	7.5YR 5/3	brown
Kalihashi C1	5.1-10.2	Daksin Nayergaon, Kalihashi	5YR 4/1	dark grey
Kalihashi C2	35.6-40.6	Daksin Nayergaon, Kalihashi	7.5YR 5/1	grey
Kalihashi C3	71.1-76.2	Daksin Nayergaon, Kalihashi	7.5YR 7/1	light grey
Bakra A1	5.1-10.2	Uttar Upadi, East Bakra	7.5YR 3/1,	very dark grey
Bakra A2	35.6-40.6	Uttar Upadi, East Bakra	7.5YR 3/1	very dark grey
Bakra A3	71.1-76.2	Uttar Upadi, East Bakra	7.5YR 4/2	brown
Bakra B1	5.1-10.2	Uttar Upadi, East Bakra	2.5YR 4/1	dark reddish grey
Bakra B2	35.6-40.6	Uttar Upadi, East Bakra	5YR 5/1	grey
Bakra B3	71.1-76.2	Uttar Upadi, East Bakra	5YR 6/1	grey
Bakra C1	5.1-10.2	Uttar Upadi, East Bakra	2.5YR 2.5/1	reddish black
Bakra C2	35.6-40.6	Uttar Upadi, East Bakra	2.5YR 5/1	reddish grey
Bakra C3	71.1-76.2	Uttar Upadi, East Bakra	5YR 3/2n	dark reddish brown
Nagdah A1	5.1-10.2	Khadergaon, Nagdha	7.5YR 3/1	very dark grey
Nagdah A2	35.6-40.6	Khadergaon, Nagdha	7.5YR 4/1	dark grey
Nagdah A3	71.1-76.2	Khadergaon, Nagdha	7.5YR 6/1	grey
Nagdah B1	5.1-10.2	Khadergaon, Nagdha	7.5YR 3/1	very dark grey
Nagdah B2	35.6-40.6	Khadergaon, Nagdha	5YR 4/1	dark grey
Nagdah B3	71.1-76.2	Khadergaon, Nagdha	2.5YR 5/1	reddish grey
Nagdah C1	5.1-10.2	Khadergaon, Nagdha	2.5YR 4/1	dark reddish grey
Nagdah C2	35.6-40.6	Khadergaon, Nagdha	10YR 3/1	very dark grey
Nagdah C3	71.1-76.2	Khadergaon, Nagdha	10YR 5/1	grey

Appendix G : Chemical characteristics of the irrigated soils.

G-1: Major element distribution in irrigated soils

SampleID	Na mg/kg	K mg/kg	Mg mg/kg	Ca mg/kg
Luck A1	321.9	1665.9	4568.9	2687.7
Luck A2	459.2	2259.9	6554.8	2371.1
Luck A3	346.6	1918.9	6638.3	2728.6
Luck B1	309.4	1576.1	4337.7	2370.7
Luck B2	338.6	1972.3	6006.8	2190.9
Luck B3	453.9	2074.6	7478.9	2767.7
Luck C1	338.8	1545.8	3977.3	3202.4
Luck C2	329.1	1492.7	4022.2	3023.3
Luck C3	471.8	1839.3	5705.2	2824.9
Kalihashi A2	292.2	1632.8	4341.8	2373.5
Kalihashi A3	509.4	2610.8	7412.1	2835.4
Kalihashi B1	469.5	2015.3	7390.6	3260.2
Kalihashi B2	471.1	2185.1	5444.8	2923.1
Kalihashi B3	618.9	2935.3	7996.2	3033.1
Kalihashi C1	562.7	2504.3	7816.9	3544.8
Kalihashi C2	481.8	2174.6	5540.5	3192.8
Kalihashi C3	656.2	2956.2	8302.9	3121.5
Kalihashi A2	595.6	2557.4	8233.7	3742.4
Bakra A1	514.5	1976.9	7649.5	4234.2
Bakra A2	546.8	2298.3	8932.7	4002.4
Bakra A3	559.4	2610.9	9299.4	4104.7
Bakra B1	509.9	2024.2	8155.1	4214.8
Bakra B2	511.6	2172.1	8435.7	4271.9
Bakra B3	536.7	2547.5	9205.4	4073.4
Bakra C1	538.1	2074.7	8277.9	4353.1
Bakra C2	551.9	2445.1	9265.4	3969.7
Bakra C3	557.7	2704.7	9801.2	4005.4
Nagdah A1	665.9	2165.3	7756.7	3935.6
Nagdah A2	694.9	2493.5	8307.3	3853.5
Nagdah A3	604.6	2124.5	7350.5	3899.1
Nagdah B1	752.1	2260.3	7953.9	4918.7
Nagdah B2	628.6	2320.9	8537.7	3952.7
Nagdah B3	622.9	2358.3	8321.4	3979.3
Nagdah C1	665.2	2134.9	7997.7	3943.6
Nagdah C2	631.6	2238.6	8270.4	3891.2
Nagdah C3	585.3	2260.3	7948.2	3785.2

G-2: Soil moisture, pH, Organic C, Arsenic, Fe and Mn distribution in irrigated soils

SampleID	Soil Moisture %	pH	Tot-C %	Carb.-C %	Org-C %	As mg/kg	Fe mg/kg	Mn mg/kg
Luck A1	26.5	6.04	0.6	0.04	0.59	2.3	10729	132
Luck A2	31.8	7.15	0.3	0.04	0.26	3.4	13721	5800
Luck A3	33.8	7.08	0.1	0.03	0.14	4.9	13752	393
Luck B1	19.9	7.33	0.3	0.03	0.32	1.8	10569	1199
Luck B2	26.9	7.31	0.2	0.03	0.25	2.7	12559	1563
Luck B3	17.7	7.31	0.1	0.03	0.15	5.1	13870	418
Luck C1	24.6	6.94	0.8	0.03	0.80	2.1	9785	273
Luck C2	27.7	7.30	0.3	0.05	0.24	1.8	9887	1307
Luck C3	34.4	7.18	0.3	0.04	0.27	2.5	12189	2359
Kalihashi A2	18.7	7.03	0.3	0.04	0.35	3.1	10719	1895
Kalihashi A3	13.5	7.66	0.3	0.03	0.29	4.1	14318	380
Kalihashi B1	28.3	7.92	0.1	0.03	0.15	4.3	13537	3981
Kalihashi B2	25.2	6.95	0.4	0.04	0.38	4.2	12360	2391
Kalihashi B3	26.1	7.65	0.3	0.05	0.26	4.1	14391	401
Kalihashi C1	25.1	8.06	0.1	0.03	0.14	4.5	13419	7386
Kalihashi C2	24.1	6.92	0.7	0.04	0.69	5.0	12073	238
Kalihashi C3	22.4	7.79	0.3	0.04	0.30	3.8	14441	5625
Kalihashi A2	27.6	7.81	0.1	0.04	0.14	4.8	13967	435
Bakra A1	33.3	8.23	1.2	0.04	1.21	3.8	12543	3416
Bakra A2	33.3	8.02	0.3	0.04	0.32	2.8	13046	2840
Bakra A3	27.6	8.00	0.1	0.04	0.14	3.3	12984	545
Bakra B1	30.8	7.85	0.3	0.04	0.28	4.3	12858	348
Bakra B2	31.3	7.96	0.1	0.05	0.10	3.3	12592	2737
Bakra B3	29.9	7.91	0.2	0.04	0.18	3.8	13067	518
Bakra C1	21.2	7.64	1.1	0.05	1.01	2.5	11795	2457
Bakra C2	31.1	7.81	0.2	0.10	0.12	4.5	13605	363
Bakra C3	17.4	7.83	0.1	0.05	0.14	4.4	13535	6853
Nagdah A1	38.1	7.85	0.6	0.05	0.6	2.6	12551	2897
Nagdah A2	34.6	8.01	0.4	0.09	0.34	3.4	13592	336
Nagdah A3	32.8	8.03	0.2	0.04	0.19	3.2	12285	5650
Nagdah B1	26.8	7.29	1.5	0.07	1.49	3.5	12756	3369
Nagdah B2	27.7	7.90	0.4	0.05	0.35	3.2	13281	387
Nagdah B3	31.4	7.85	0.1	0.05	0.11	3.2	12770	434
Nagdah C1	28.1	7.64	1.1	0.05	1.12	4.2	12896	3209
Nagdah C2	28.1	7.89	0.8	0.04	0.76	2.5	12533	2904
Nagdah C3	36.1	7.92	0.2	0.04	0.21	3.7	12780	3568

G-3: Trace element distribution in irrigated soils

SampleID	Al mg/kg	Ba mg/kg	Be mg/kg	Cd mg/kg	Co mg/kg	Cr mg/kg	Cu mg/kg
Luck A1	21609	65.5	0.5	-	7.1	27.9	11.1
Luck A2	34033	86.5	0.9	0.03	1.3	40.0	16.6
Luck A3	28029	61.7	0.7	0.03	1.0	36.0	14.3
Luck B1	21313	52.4	0.5	-	6.8	27.4	9.0
Luck B2	28663	57.8	0.7	-	8.2	34	13.5
Luck B3	29794	66.4	0.8	0.02	11.4	38.0	15.7
Luck C1	18491	57.8	0.4	-	6.1	24.6	11.0
Luck C2	19612	54.3	0.5	-	6.1	25	92.6
Luck C3	26247	67.1	0.7	-	9.0	33.1	12.6
Kalihashi A1	22751	53.4	0.5	-	7.3	28.4	9.8
Kalihashi A2	36697	77.1	0.1	0.02	12.0	43.3	17.7
Kalihashi A3	28093	71.5	0.7	0.03	10.7	35.8	14.5
Kalihashi B1	28716	63.9	0.7	0.03	8.8	35.2	12.4
Kalihashi B2	39237	84.7	1.0	0.02	11.5	46.3	19.0
Kalihashi B3	31763	88.0	0.8	0.03	11.6	39.3	16.0
Kalihashi C1	28553	70.0	0.7	0.03	9.1	35.6	13.1
Kalihashi C2	40561	96.4	1.1	0.09	13.7	47.3	19.6
Kalihashi C3	31694	64.9	0.8	0.02	10.9	39.9	16.7
Bakra A1	23516	65.1	0.5	0.02	9.3	32.5	16.9
Bakra A2	26413	69.1	0.6	0.02	10.4	36.7	20.5
Bakra A3	26646	75.7	0.6	0.03	10.7	37.3	22.3
Bakra B1	23532	60.8	0.5	0.03	9.6	33.5	17.9
Bakra B2	22564	46.2	0.5	0.02	9.0	32.3	18.0
Bakra B3	25519	89.0	0.6	0.03	10.6	36.2	21.5
Bakra C1	26231	75.0	0.6	-	9.1	35	20.2
Bakra C2	26117	68.0	0.6	0.04	10.9	36	21.8
Bakra C3	28022	92.0	0.6	0.03	11.1	39.1	24.3
Nagdah A1	23757	54.0	0.5	-	9.8	34.0	18.3
Nagdah A2	25670	53.0	0.6	0.03	10.9	36.2	19.3
Nagdah A3	21344	60.0	0.5	-	9.6	31	15.8
Nagdah B1	24830	61.0	0.6	0.02	10.0	34.5	19.7
Nagdah B2	24582	57.0	0.5	0.02	10.6	34	19.3
Nagdah B3	21718	45.0	0.5	-	10.5	31.2	15.2
Nagdah C1	24116	58.0	0.6	0.03	10.1	34.2	19.0
Nagdah C2	24975	54.4	0.7	-	10.1	35.2	21.2
Nagdah C3	26864	46.8	0.5	-	9.9	32.2	17.0

G-3: Trace element distribution in irrigated soils (continued)

SampleID	Li mg/kg	Ni mg/kg	P mg/kg	Pb mg/kg	Rb mg/kg	S mg/kg
Luck A1	20.9	18.9	464.1	6.1	59.4	64.4
Luck A2	43.3	33.3	139.9	9.0	91.0	22.8
Luck A3	36	29.6	320.7	7.2	79	16.3
Luck B1	23.9	18.8	961.1	5.4	57.9	20.7
Luck B2	36	27.9	137.6	7.0	74.9	16.1
Luck B3	39.5	31.3	328.9	7.9	85.6	16.5
Luck C1	18.4	16.1	592.7	5.0	54.5	67.7
Luck C2	21.5	17.1	102.2	5.0	54.4	24.0
Luck C3	31.1	23.9	130.9	6.5	75	20.4
Kalihashi A1	25.9	20.6	167.9	5.7	63	27.9
Kalihashi A2	46.6	35.7	164.6	9.4	113.2	28.4
Kalihashi A3	36.9	29.1	331.6	7.3	84	25.4
Kalihashi B1	33.1	25.1	226.9	7.0	88.9	43
Kalihashi B2	47.1	36.1	215.5	9.6	124.3	30.6
Kalihashi B3	41.1	31.6	343.7	7.7	100	21.4
Kalihashi C1	32	24.7	521	7.2	90.9	68.8
Kalihashi C2	48.4	37.6	195.6	1.0	130.4	32
Kalihashi C3	42.0	31.0	350.7	7.4	108.7	20.0
Bakra A1	30.7	24.7	372.6	6.0	76.4	100.5
Bakra A2	36	28.5	303.6	6.5	94.0	29.8
Bakra A3	37.3	29.4	349.5	6.8	109.0	17.9
Bakra B1	31	25.6	369.0	5.8	77.5	37
Bakra B2	31.4	25	389.5	5.6	96	18.6
Bakra B3	35.8	28	363.3	7.0	104.9	26.1
Bakra C1	35.0	26.3	316	6.0	76.1	57.9
Bakra C2	36.2	28.9	357.9	6.9	96	26.9
Bakra C3	39.2	30	364.9	7.5	113.1	21.6
Nagdah A1	33.4	26.9	293.4	6.5	101.5	54.2
Nagdah A2	36.7	29.4	296.4	7.2	110.8	56.8
Nagdah A3	31.2	25.3	356.3	5.9	92.9	21.6
Nagdah B1	35	27	384.4	7.3	101.1	140
Nagdah B2	35.4	28	325.4	6.7	109.7	31.7
Nagdah B3	33.3	26.8	355.1	5.9	104.9	160.8
Nagdah C1	34.4	277.5	360.2	6.8	99.2	106.9
Nagdah C2	35	28	274.9	7.1	106.1	45
Nagdah C3	33.0	26.7	332.6	6.1	103.3	22.3

G-3: Trace element distribution in irrigated soils (continued)

SampleID	Si mg/kg	Sn mg/kg	Sr mg/kg	Ti mg/kg	V mg/kg	Zn mg/kg	Zr mg/kg
Luck A1	23.6	0.3	22.5	36.2	21.0	34.4	1.8
Luck A2	48.4	0.3	21.3	316.7	37.2	50.2	2.7
Luck A3	27.4	0.5	21.0	414.8	34.4	46	2.5
Luck B1	18.2	0.2	20.1	296.5	23.9	32.9	1.8
Luck B2	34.0	0.2	19.1	299.7	30.9	43.7	2.3
Luck B3	24.1	0.3	22.6	434.7	36.4	50	2.6
Luck C1	18.5	0.2	24.6	599.1	24.8	35	1.6
Luck C2	45.5	0.4	22.7	339.7	22.8	30.5	1.7
Luck C3	16.0	0.4	23.1	359.5	29.3	41.8	2.1
Kalihashi A1	33.8	0.1	19.3	297.9	25.5	33	1.8
Kalihashi A2	24.4	0.4	24.0	344.1	40.7	56.2	2.9
Kalihashi A3	27.1	0.3	23.4	425	34.7	47	2.4
Kalihashi B1	35.1	0.2	23.8	347.5	32.0	41.1	2.3
Kalihashi B2	41.4	0.3	26.2	368.5	43.8	58.8	3.1
Kalihashi B3	37.9	0.3	27.2	414.6	37.8	50.8	2.5
Kalihashi C1	55.7	0.5	24.6	499.2	34.5	44.3	2.3
Kalihashi C2	37.8	0.4	26.4	377.0	45.0	60.4	3.2
Kalihashi C3	36.1	0.3	27.6	430	38.0	52.0	2.5
Bakra A1	27.9	0.2	25.5	682	33.1	44.1	1.9
Bakra A2	70.7	0.4	26.2	432	31.6	48.5	2.0
Bakra A3	48.1	0.3	27.2	457.0	32.0	50.6	1.9
Bakra B1	27.5	0.2	26.6	520.1	31.4	44.0	1.9
Bakra B2	29.5	-	26.3	564.8	29.9	44.1	1.8
Bakra B3	31.3	0.3	27.1	445.8	31.1	49.2	2.0
Bakra C1	18.0	0.2	27.0	824.6	34.1	48.3	2.0
Bakra C2	20.0	0.2	27.1	402.3	31.8	54.4	2.1
Bakra C3	22.8	0.3	28.6	422.4	34.9	53.8	2.1
Nagdah A1	19.2	0.2	25.9	423.5	30.3	44.5	2.0
Nagdah A2	19.3	0.2	26.0	375.4	31.3	50.5	2.2
Nagdah A3	14.7	-	25.0	552.7	30.5	43	1.8
Nagdah B1	19.9	-	30.0	539.5	34.7	51.7	2.1
Nagdah B2	17.0	0.2	26.6	460.4	29.0	48.2	2.0
Nagdah B3	14.3	-	25.6	322.6	20.4	52	1.7
Nagdah C1	17.9	0.3	27.1	589.8	31.6	47.5	2.0
Nagdah C2	17.5	0.3	25.3	619.3	32.6	47.4	2.0
Nagdah C3	14.5	0.3	25.2	461.5	25.0	45.4	1.9

Appendix H: Rice grain sampling information

SampleID/ Sampled well	Owner	Well Depth m	Latitude (Degree)	Longitude (Degree)	Geology
Mubarakdi shallow	Mujib Gazi	40	23.3136	90.6873	Alluvial silt
Mubarakdi shallow	Md. Mujib Gazi	40	23.3136	90.6873	Alluvial silt
Bakra shallow	Md. Monir Hossain Bokaul	42	23.2784	90.7321	Alluvial silt
East Bakra shallow	Md. Anower	29	23.2789	90.7357	Alluvial silt
Bakra shallow	Md. Monir Hossain Bokaul	42	23.2784	90.7321	Alluvial silt
East Bakra shallow	Md. Anower	29	23.2789	90.7357	Alluvial silt
Gobindapur deep	Md. Delower Hossain	115	23.2889	90.7177	Alluvial silt
Gobindapur deep	Md. Delower Hossain	115	23.2889	90.7177	Alluvial silt
Nagdah deep	Md. Noyan Bokaul	85	23.3497	90.7575	Alluvial silt
Nagdah deep	Mrs. Quahinur	85	23.3493	90.7596	Alluvial silt
Nagdah deep	Md. Noyan Bokaul	85	23.3497	90.7575	Alluvial silt
Nagdah deep	Mrs. Quahinur	85	23.3493	90.7596	Alluvial silt
Luck deep	Abdul Hai	110	23.3980	90.7850	Alluvial silt
Kalihasi shallow	Osman Gani	36	23.3963	90.7765	Alluvial silt
Kalihasi shallow	Md. Osman Gani	36	23.3963	90.7765	Alluvial silt
Gilatoli shallow	Siraz Talukdar	52	23.3543	90.7596	Alluvial silt
Gilatoli shallow	Siraz Talukdar	52	23.3543	90.7596	Alluvial silt
Gilatoli deep	Delowar Prodhanya	61	23.3572	90.7582	Alluvial silt
Gilatoli deep	Delowar Prodhanya	61	23.3572	90.7582	Alluvial silt
Luck deep	Abdul Hai	110	23.3980	90.7850	Alluvial silt

Appendix I-1: Chemical analysis of the rice grains

SampleID/ Sampled well	Al mg/kg	As mg/kg	Be mg/kg	B mg/kg	Ba mg/kg	Ca mg/kg	Cd mg/kg	Co mg/kg
Mubarakdi shallow	0.2	0.017	-	0.21	0.01	3118	-	0.001
Mubarakdi shallow	0.6	0.031	-	0.26	0.04	6480	-	0.005
Kalihasi shallow	0.2	0.007		0.17	0.03	3031	0.002	-
Kalihasi shallow	0.4	0.010	-	0.38	0.06	5037	-	0.005
Bakra shallow	0.3	0.016	-	0.27	0.01	2567	0.004	0.002
East Bakra shallow	0.2	0.017	-	0.19	0.01	2936	0.001	-
Bakra shallow	0.3	0.069	0.017	0.20	0.04	6837	0.009	0.002
East Bakra shallow	4.6	0.152	0.027	0.32	0.11	6899	0.008	0.007
Gobindapur deep	0.5	0.024	-	0.28	0.02	3202	0.003	-
Gobindapur deep	1.1	0.027	-	0.21	0.06	6201	0.002	0.006
Nagdah deep	0.3	0.016	-	0.17	0.01	2667	0.008	0.002
Nagdah deep	0.3	0.009	-	0.10	0.01	3743	-	0.002
Nagdah deep	1.9	0.017	-	0.32	0.06	5525	0.01	0.007
Nagdah deep	0.5	0.018	-	0.29	0.02	5067	-	0.002
Gilatoli shallow	0.1	0.016	-	0.14	0.08	2215	-	0.002
Gilatoli deep	0.3	-	-	0.19	0.02	3090	0.004	-
Gilatoli shallow	0.5	0.018	-	0.19	0.01	4891	-	0.004
Gilatoli deep	0.6	0.14	-	0.18	0.04	5592	-	0.003
Luck deep	0.2	-	-	0.21	0.02	2913	0.003	0.002
Luck deep	0.4	0.015	-	0.18	0.05	5044	0.003	0.004

Appendix I-2: Chemical analysis of the rice grains (continued)

SampleID/ Sampled well	**Cr** mg/kg	**Cu** mg/kg	**Fe** mg/kg	**K** mg/kg	**Li** mg/kg	**Mg** mg/kg	**Mn** mg/kg
Mubarakdi shallow	0.010	0.10	0.49	37.7	0.006	22.3	0.40
Mubarakdi shallow	0.502	0.19	1.6	44.4	0.007	20.0	1.2
Kalihasi shallow	0.234	0.14	0.65	32.8	0.007	18.7	0.32
Kalihasi shallow	0.017	0.10	2.6	38.8	0.006	17.9	0.49
Bakra shallow	0.017	0.12	0.62	36.7	0.007	23.8	0.49
East Bakra swhallo	0.012	0.12	0.53	39.5	0.007	22.4	0.43
Bakra shallow	0.337	0.16	1.6	60.3	0.008	39.8	0.9
East Bakra swhallo	0.010	0.13	4.6	59.2	0.008	33.9	1.0
Gobindapur deep	0.016	0.08	0.94	38.8	0.006	22.5	0.54
Gobindapur deep	0.013	0.12	3.0	43.8	0.007	22.6	1.2
Nagdah deep	0.025	0.18	0.59	31.2	0.006	17.0	0.33
Nagdah deep	0.039	0.31	0.52	28.7	0.008	15.6	0.25
Nagdah deep	0.227	0.16	3.8	37.4	0.007	16.8	0.8
Nagdah deep	0.367	0.16	2.5	34.4	0.008	14.6	0.5
Gilatoli shallow	0.020	0.10	0.37	36.4	0.007	22.4	0.28
Gilatoli deep	351,70	0.11	0.64	31.7	0.006	18.7	0.32
Gilatoli shallow	0.445	0.14	1.7	40.2	0.008	19.6	0.6
Gilatoli deep	0.372	0.14	1.9	36.8	0.008	17.5	0.6
Luck deep	0.009	0.11	0.45	35.1	0.006	18.7	0.17
Luck deep	0.011	0.11	2.7	39.7	0.007	17.0	0.28

Appendix I-3: Chemical analysis of the rice grains (continued)

SampleID/ Sampled well	**Mo** mg/kg	**Na** mg/kg	**Ni** mg/kg	**P** mg/kg	**Pb** mg/kg	**S** mg/kg	**Si** mg/kg
Mubarakdi shallow	0.019	2.4	0.01	-	0.009	20.4	2.0
Mubarakdi shallow	0.018	2.9	0.11	-	-	17.4	2.0
Kalihasi shallow	0.013	2.5	0.02	-	0.007	21.0	2.2
Kalihasi shallow	0.016	2.7	0.20	-	-	18.1	1.8
Bakra shallow	0.016	2.4	0.01	-	0.009	22.1	1.7
East Bakra swhallo	0.012	2.3	0.01	1.9	0.003	18.0	2.2
Bakra shallow	0.014	3.9	0.02	5.5	0.223	21.0	1.6
East Bakra shallow	0.010	3.9	0.03	1.5	0.466	17.2	1.3
Gobindapur deep	0.011	2.9	0.01	-	0.009	18.5	1.8
Gobindapur deep	0.017	3.4	0.16	-	0.005	16.7	1.8
Nagdah deep	0.013	2.4	0.01	-	-	20.6	2.2
Nagdah deep	0.006	2.6	0.03	-	0.004	20.0	2.0
Nagdah deep	0.017	3.5	0.23	-	0.013	18.0	1.9
Nagdah deep	0.011	2.5	0.16	-	0.007	18.2	1.7
Gilatoli shallow	0.017	2.3	0.02	-	0.007	22.7	2.0
Gilatoli deep	0.009	2.9	0.02	-	0.008	20.4	1.8
Gilatoli shallow	0.017	2.7	0.11	-	0.007	19.3	2.0
Gilatoli deep	0.014	3.3	0.17	-	0.038	19.2	1.9
Luck deep	0.014	2.3	0.01	-	-	19.3	1.5
Luck deep	0.017	2.8	0.16	-	0.003	17.7	1.9

Appendix I-4: Chemical analysis of the rice grains (continued)

SampleID/ Sampled well	**Sr** mg/kg	**Ti** mg/kg	**V** mg/kg	**Zn** mg/kg
Mubarakdi shallow	0.010	1.1	0.078	0.38
Mubarakdi shallow	0.022	0.3	0.022	0.43
Kalihasi shallow	0.009	1.5	0.097	0.52
Kalihasi shallow	0.019	0.2	0.017	0.43
Bakra shallow	0.009	1.1	0.062	0.51
East Bakra swhallo	0.010	0.9	0.061	0.40
Bakra shallow	0.025	0.5	0.113	0.73
East Bakra swhallo	0.029	0.2	0.109	0.85
Gobindapur deep	0.014	2.4	0.149	0.58
Gobindapur deep	0.032	0.1	0.009	0.43
Nagdah deep	0.010	1.8	0.110	0.57
Nagdah deep	0.010	0.07	0.024	0.38
Nagdah deep	0.024	0.1	0.015	0.39
Nagdah deep	0.016	0.1	0.006	0.41
Gilatoli shallow	0.006	0.3	0.020	00.30
Gilatoli deep	0.009	1.1	0.094	0.49
Gilatoli shallow	0.014	0.1	0.009	0.25
Gilatoli deep	0.019	0.2	0.017	0.33
Luck deep	0.009	1.0	0.067	0.48
Luck deep	0.019	0.09	0.006	0.36

Appendix J : Field survey information

J-1: House hold survey 1

Risk assessment by surveying Bangladeshi family to estimate the daily intake of Arsenic

Arsenic food chain pathways through irrigation water – soil – crop – human body in the rural population of Bangladesh.

The Food Frequency Questionnaire (FFQ) is designed to assess habitual diet over the past year in the study population. The FFQ illustrates a complete set of questionnaire where not only gathered the information of dietary pattern but also collect the spatial characteristics of the landscape, socio-demographic information and also geographic location which indicates the As exposure to human body. This risk assessment survey fulfils the course requirement of master thesis which is conducted by Bashir Ahmed[1] during the session of January/2009 to June/2009.

The FFQ is designed in four sections:
(1) General household information,
(2) Household water and rice information,
(3) Individual dietary intake of other foods and,
(4) Rural people knowledge about Arsenic.

This survey is part of a master thesis which is funded by the project of sustainable Arsenic Mitigation (SAsMit) for risk assessment of sustainable development of agriculture.

1.1. Identification of Household

Name of family chief	Md.Mostofa	Age	36
Village	Dhanarpar	Mauza	
Union	Matlab Paurashava	Thana	Matlab Dhashin
Post		District	Chandpur
Person interviewed	Md.Mostofa	Date	08/07/09
Name of interviewer	Md.Ileash	Signature	

1.2. Spatial location of household:

GPS Coordinates	
X-Coordinate (longitude)	
Y-Coordinate (Latitude)	
Z-Coordinate (height above sea level)	
Date	

[1] Student of Mater program in Integrated Water Resource Management at SLU, Sweden.

1.3. Demographic, economic information of household members:

Person ID	Full Name	Gender (M/F)	Age (years)	Relationship to chief of Household	Occupation^A	Income (Tk/month)	Diagnosed with Arsenicosis?	
1	Md.Mostofa	M	36	own	3	8000	Not Tested	
2	Hosnawara	F	30	Wife	15	-	Not Tested	
3	Md.Rasel	M	17	Son	9	3000	Not Tested	
4	Md.Rasid	M	14	Son	3	2000	Not Tested	
5	Md.Masud	M	12	Son	16	-	Not Tested	
6								
7								
8								
9								
10								

[A] Use the following Occupation Codes for each household members:

1- Farm owner 2- Farm day worker 3- Other day worker 4- Irrigation well owner 5- Irrigation well worker 6- Store owner 7- Store worker 8- Driver 9- Ricshaw puller 10- teacher 11- Doctor 12- engineer 13- Lawyer 14- Student 15- House wife 16- Unemployed 17- Other (Please specify)

2.2. Household water, rice consumption and usage of cooking water information

2.2.1 Amount of water and rice consumed by each person:

Person ID	Name	Source of drinking water	Amount consumed (L/day)	Amount of rice (cooked) (g/plate)	No. of plate of rice (cooked) (plate/meal)	Rice consumed (times /day)	Amount of rice consumed (cooked) (g/day)	Source of rice (Market/ cultivated)
1	Md.Mostofa	TW	4	170	2	3	1020	Market
2	Hosnawara	TW	3	150	2	3	900	Market
3	Md.Rasel	TW	2	130	1	3	390	Market
4	Md.Rasid	TW	2	130	1	3	390	Market
5	Md.Masud	TW	2	120	1	3	360	Market
6								
7								
8								
9								
10								

2.2.2 Amount of water used in cooking:

Cooked food type	Amount Kg/day (dry weight)*	Source of Water	Amount used (L/Kg of food item)**	Total amount of water used (L)
Rice	3.6	pond	1	6
Other Food (Curry and Dal)	3	pond	2	5

Note: * Amount cooked per meal (morning + lunch + evening)
** How much water is used to cook 1Kg of rice?

3. Dietary Intake of Other Food (Weigh amount consume if possible)

3.1 Other grains intake: NA

List of grains food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				

3.2 Dairy food Intake:

List of dairy food intake	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Milk	500 ml	200ml	220ml	80ml	1	7	4	Market
Egg	4	2	-	2	1	7	4	Market
Fish	500 g	50 g	200 g	250 g	2	5	4	Market
Meet	1 kg	100g	500 g	400 g	2	1	4	Market

3.3. Fruits intake:

List of fruits intake	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Mango	5 pc	3	1	1	1	4	4	Market
Jack Fruit	2 kg	100 g	1 kg	900 g	1	2	2	Market
Banana	1 Dozen	4	5	3	3	7	4	Market

3.4. Pulse food intake:

List of pulse food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Dal Musori	150 g	30 g	80 g	40 g	2	7	4	Market
Pulse Anchar	200 g	25 g	75 g	100 g	2	5	4	Market

3.5. Vegetables intake:

List of grains food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Potato	500 g	300 g	270 g	200 g	3	7	4	Market
Kolmi Shak	1 kg	200 g	600 g	200 g	1	7	4	Market

4. General knowledge about Arsenic

A: Do you know anything about Arsenic?
Ans: No

B: What is the good or bad side of Arsenic?
Ans: No good side.

C: Can you tell us the relationship of Arsenic with your agricultural activities or your health or your income?
Ans: Its Relationship with our Health.

THANK YOU
for
Your cordial cooperation

J-2: House hold survey 2

Risk assessment by surveying Bangladeshi family to estimate the daily intake of Arsenic

Arsenic food chain pathways through irrigation water – soil – crop – human body in the rural population of Bangladesh.

The Food Frequency Questionnaire (FFQ) is designed to assess habitual diet over the past year in the study population. The FFQ illustrates a complete set of questionnaire where not only gathered the information of dietary pattern but also collect the spatial characteristics of the landscape, socio-demographic information and also geographic location which indicates the As exposure to human body. This risk assessment survey fulfils the course requirement of master thesis which is conducted by Bashir Ahmed[2] during the session of January/2009 to June/2009.

The FFQ is designed in four sections:
(1) General household information,
(2) Household water and rice information,
(3) Individual dietary intake of other foods and,
(4) Rural people knowledge about Arsenic.

This survey is part of a master thesis which is funded by the project of sustainable Arsenic Mitigation (SAsMit) for risk assessment of sustainable development of agriculture.

1.1. Identification of Household

Name of family chief	Md.Sujat Kha	Age	90
Village	Dhakirga	Mauza	Dhakirga
Union	Matlab Paurashava	Thana	Matlab Dhakin
Post	Bourdia	District	Chandpur
Person interviewed	Chan Banu	Date	09/07/09
Name of interviewer	Md.Ileash	Signature	

1.2. Spatial location of household:

GPS Coordinates	
X-Coordinate (longitude)	
Y-Coordinate (Latitude)	
Z-Coordinate (height above sea level)	
Date	

2 Student of Mater program in Integrated Water Resource Management at SLU, Sweden.

1.3. Demographic, economic information of household members:

Person ID	Full Name	Gender (M/F)	Age (years)	Relationship to chief of Household	Occupation[A]	Income (Tk/month)	Diagnosed with Arsenicosis?	
1	Md.Sujat Kha	M	90	Own	1	10000	Not	Tested
2	Chan Banu	F	55	Wife	15	-	Not	Tested
3	Md.Idris	M	23	Son	14	-	Not	Tested
4	Md. Muslim Kha	M	27	Son	17 (service)	-	Not	Tested
5	Safali	M	30	Daughter in law	15	-	Not	Tested
6	Hamid Kha	M	4	Grand son	14	-	Not	Tested
7								
8								
9								
10								

[A] Use the following Occupation Codes for each household members:
1- Farm owner 2- Farm day worker 3- Other day worker 4- Irrigation well owner 5- Irrigation well worker 6- Store owner 7- Store worker 8- Driver 9- Ricshaw puller 10- teacher 11- Doctor 12- engineer 13- Lawyer 14- Student 15- House wife 16- Unemployed 17- Other (Please specify)

2.2. Household water, rice consumption and usage of cooking water information

2.2.1 Amount of water and rice consumed by each person:

Person ID	Name	Source of drinking water	Amount consumed (L/day)	Amount of rice (cooked) (g/plate)	No. of plate of rice (cooked) (plate/meal)	Rice consumed (times/day)	Amount of rice consumed (cooked) (g/day)	Source of rice (Market/ cultivated)
1	Do	TW	4	150	2	2	600	Market
2	Do	TW	3	140	2	2	560	Market
3	Do	TW	4	150	2	2	600	Market
4	Do	TW	3	130	2	2	520	Market
5	Do	TW	2	130	2	2	520	Market
6	Do	TW	1	100	1	2	200	Market
7								
8								
9								
10								

2.2.2 Amount of water used in cooking:

Cooked food type	Amount Kg/day (dry weight)*	Source of Water	Amount used (L/Kg of food item)**	Total amount of water used (L)
Rice	3	Pond	2	6
Other Food (Curry and Dal)	2.5	pond	2	4

Note: * Amount cooked per meal (morning + lunch + evening)
** How much water is used to cook 1Kg of rice?

3. Dietary Intake of Other Food (Weigh amount consume if possible)

3.1 Other grains intake: NA

List of grains food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				

3.2 Dairy food Intake:

List of dairy food intake	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Milk	500 ml	200 ml	100ml	200ml	1	5	4	Market
Egg	3 pc	1pc	1pc	1pc	1	7	4	Market
Fish	1000g	50 g	600 g	350 g	1	3	4	Market
Meat	1 kg	100	500	400	1	1	4	Market

3.3. Fruits intake:

List of fruits intake	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Mango	1 kg	0	0.5kg	0.5kg	1	7	4	Market
Banana	1 Dozen	3p	5p	4p	1	5	4	Market
Apple	1kg	0	0.5kg	0.5kg	1	4	4	Market

3.4. Pulse food intake:

List of pulse food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Mushuri pulse	300g	0	150gm	150gm	2	6	4	Market
Mugh pulse	250g	0	125gm	125gm	2	3	4	Market

3.5. Vegetables intake:

List of grains food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Potato	1kg	200 gm	500gm	300gm	2	7	4	Market
Bagun	1kg	0	500gm	500gm	2	6	4	Market
Papa	500g	0	250gm	250gm	2	5	4	Market

4**. General knowledge about Arsenic**

A: Do you know anything about Arsenic?
Ans: So far I know that its come from TW water.

B: What is the good or bad side of Arsenic?
Ans: No good of Arsenic.

C: Can you tell us the relationship of Arsenic with your agricultural activities or your health or your income?

Ans: No Relationship.

THANK YOU
for
Your cordial cooperation

J-3: House hold survey 3

Risk assessment by surveying Bangladeshi family to estimate the daily intake of Arsenic

Arsenic food chain pathways through irrigation water – soil – crop – human body in the rural population of Bangladesh.

The Food Frequency Questionnaire (FFQ) is designed to assess habitual diet over the past year in the study population. The FFQ illustrates a complete set of questionnaire where not only gathered the information of dietary pattern but also collect the spatial characteristics of the landscape, socio-demographic information and also geographic location which indicates the As exposure to human body. This risk assessment survey fulfils the course requirement of master thesis which is conducted by Bashir Ahmed[3] during the session of January/2009 to June/2009.

The FFQ is designed in four sections:
(1) General household information,
(2) Household water and rice information,
(3) Individual dietary intake of other foods and,
(4) Rural people knowledge about Arsenic.

This survey is part of a master thesis which is funded by the project of sustainable Arsenic Mitigation (SAsMit) for risk assessment of sustainable development of agriculture.

1.1. Identification of Household

Name of family chief	Md. Omar Gazi	Age	39
Village	Dashpara	Mauza	Bhangarpar
Union	Matlab Paurashava	Thana	Matlab Dakshin
Post	Matlab	District	Chandpur
Person interviewed	Md. Omar Gazi	Date	09.07.2009
Name of interviewer	Ratnajit Saha	Signature	

1.2. Spatial location of household:

GPS Coordinates	
X-Coordinate (longitude)	
Y-Coordinate (Latitude)	
Z-Coordinate (height above sea level)	
Date	

3 Student of Mater program in Integrated Water Resource Management at SLU, Sweden.

1.3. Demographic, economic information of household members:

Person ID	Full Name	Gender (M/F)	Age (years)	Relationship to chief of Household	Occupation[A]	Income (Tk /month)	Diagnosed with Arsenicosis?	
1	Md. Omar Gazi	M	39	Self	17 (Drillar)	8000	Yes	No Dise.
2	Shahana Begum	F	32	Wife	15	0	Yes	No Dise.
3	Halima	F	14	Daughter	14	0	Yes	No Dise.
4	Sakil	M	9	Son	14	0	Yes	No Dise.
5	Sadia	F	2	Daughter	--	0	Yes	No Dise.
6								
7								
8								
9								
10								

[A] Use the following Occupation Codes for each household members:
1- Farm owner 2- Farm day worker 3- Other day worker 4- Irrigation well owner 5- Irrigation well worker 6- Store owner 7- Store worker 8- Driver 9- Ricshaw puller 10- teacher 11- Doctor 12- engineer 13- Lawyer 14- Student 15- House wife 16- Unemployed 17- Other (Please specify)

2.2. Household water, rice consumption and usage of cooking water information

2.2.1 Amount of water and rice consumed by each person:

Person ID	Name	Source of drinking water	Amount consumed (L/day)	Amount of rice (cooked) (g/plate)	No. of plate of rice (cooked) (plate/meal)	Rice consumed (times/day)	Amount of rice consumed (cooked) (g/day)	Source of rice (Market/ cultivated)
1	Md. Omar Gazi	TW	4	120	2.5	2	600	Market
2	Shahana Begum	TW	4	120	2	2	480	Market
3	Halima	TW	3	120	1	2	240	Market
4	Sakil	TW	3	100	1	2	200	Market
5	Sadia	TW	2					
6								
7								
8								
9								
10								

2.2.2 Amount of water used in cooking:

Cooked food type	Amount Kg/day (dry weight)*	Source of Water	Amount used (L/Kg of food item)**	Total amount of water used (L)
Rice	1.5	Canal & TW	1.5	3
Other Food (Curry and Dal)	2	Canal & TW	2.5	5

Note: * Amount cooked per meal (morning + lunch + evening)
** How much water is used to cook 1 kg of rice?

3. Dietary Intake of Other Food (Weigh amount consume if possible)

3.1 Other grains intake: NA

List of grains food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				

3.2 Dairy food Intake:

List of dairy food intake	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Milk	250 ml	250 ml	0	0	1	7	4	Market
Egg	5 p	3 p	1 p	1 p	1	2	4	Cultivated
Meat	1000 g	400 g	300g	300g	1	1	4	Cultivated

3.3. Fruits intake:

List of fruits intake	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Mango	4000gm	2000 gm	1000gm	1000gm	3	7	4 (2 month of year)	Cultivated
Banana	8 p	4 p	2 p	2 p	1	0	1	Market
Guava	1000 gm	500g	125g	125g	1	0	2	Market
Jack-fruit	4000g	2000 g	1000g	1000g	2	1	4	Market

3.4. Pulse food intake:

List of pulse food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Musur Pulse	125 gm				2	3	4	Market

3.5. Vegetables intake:

List of grains food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Potato	500gm	200 g	150g	150g	2	3	4	Market
Purbal	500 g	200 g	150 g	150g	2	2	4	Market
Calery			150g	150g	1	1	4	Market

Basil Green	500 g 500g 500g	200g 200g 200g	150g 150g	150g 150g	1 2	1 3	4 4	Market Market

4**. General knowledge about Arsenic**

A: Do you know anything about Arsenic?

Ans. Arsenic is a germ. As come from TW. As cause disease.

B: What is the good or bad side of Arsenic?

Ans. As has no good side. As has bad side.

C: Can you tell us the relationship of Arsenic with your agricultural activities or your health or your income?

Ans. As a driller, I have some relationship with As in my income and profession. That is with drawling As contaminated TW and install TW in As free safe aquifer.

THANK YOU
for
Your cordial cooperation

J-4: House hold survey 4

Risk assessment by surveying Bangladeshi family to estimate the daily intake of Arsenic

Arsenic food chain pathways through irrigation water – soil – crop – human body in the rural population of Bangladesh.

The Food Frequency Questionnaire (FFQ) is designed to assess habitual diet over the past year in the study population. The FFQ illustrates a complete set of questionnaire where not only gathered the information of dietary pattern but also collect the spatial characteristics of the landscape, socio-demographic information and also geographic location which indicates the As exposure to human body. This risk assessment survey fulfils the course requirement of master thesis which is conducted by Bashir Ahmed[4] during the session of January/2009 to June/2009.

The FFQ is designed in four sections:
(1) General household information,
(2) Household water and rice information,
(3) Individual dietary intake of other foods and,
(4) Rural people knowledge about Arsenic.

This survey is part of a master thesis which is funded by the project of sustainable Arsenic Mitigation (SAsMit) for risk assessment of sustainable development of agriculture.

1.1. Identification of Household

Name of family chief	Md. Leyakat Ali	Age	42
Village	Mobarakdi	Mauza	Mobarakdi
Union	Matlab Paurashava	Upazila	Matlab Dakshin
Post	Borodia	District	Chandpur
Person interviewed	Md. Leyakat Ali	Date	23.06.2009
Name of interviewer	Ratnajit Saha	Signature	

1.2. Spatial location of household:

GPS Coordinates	
X-Coordinate (Longitude)	90^0 41' 17.0"
Y-Coordinate (Latitude)	23^0 18' 46.5"
Z-Coordinate (height above sea level)	
Date	

[4] Student of Mater program in Integrated Water Resource Management at SLU, Sweden.

1.3. Demographic, economic information of household members:

Per son ID	Full Name	Gen der (M/ F)	Age (years)	Relations hip to chief of Househol d	Occupa tion[A]	Income (Tk/ month)	Diagnosed with Arsenicosis?	
1	Md. Md. Leyakat Ali	M	42	Self	6	6000	No	
2	Minara Begum	F	36	Wife	15	00	No	
3	Mahamud Hasan	M	12	Son	14	00	No	
4	Abul Hossain	M	9	Son	14	00	No	
5	Unme Hafsa	F	4	Daughter	--	00	No	
6								
7								
8								
9								
10								

[A] Use the following Occupation Codes for each household members:

1- Farm owner 2- Farm day worker 3- Other day worker 4- Irrigation well owner 5- Irrigation well worker 6- Store owner 7- Store worker 8- Driver 9- Ricshaw puller 10- teacher 11- Doctor 12- engineer 13- Lawyer 14- Student 15- House wife 16- Unemployed 17- Other (Please specify)

2.2. Household water, rice consumption and usage of cooking water information

2.2.1 Amount of water and rice consumed by each person:

Per son ID	Name	Source of drinking water	Amount consumed (L/day)	Amount of rice (cooked) (g/plate)	No. of plate of rice (cooked) (plate /meal)	Rice consu med (times /day)	Amount of rice consumed (cooked) (g/day)	Source of rice (Market/ cultivated)
1	Md. Md. Leyakat Ali	TW	7	150	1.5	2	450	
2	Minara Begum	TW	8	150	1.5	2	450	
3	Mahamud Hasan	TW	6	120	1	2	240	
4	Abul Hossain	TW	4	120	1	2	240	
5	Unme Hafsa	TW	2	100	1	2	200	
6								
7								
8								
9								

2.2.2 Amount of water used in cooking:

Cooked food type	Amount Kg/day (dry weight)*	Source of Water	Amount used (L/Kg of food item)**	Total amount of water used (L)
Rice	1.5	Pond	1.5	3
Other Food (Curry and Dal)	2	Pond	2.5	5

Note: * Amount cooked per meal (morning + lunch + evening)
** How much water is used to cook 1Kg of rice?

3. Dietary Intake of Other Food (Weigh amount consume if possible)

3.1 Other grains intake: NA

List of grains food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				

3.2 Dairy food Intake:

List of dairy food intake	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Milk	500 ml	200ml	225 ml	75 ml	1	7	4	Market
Egg	4 p	1 p	2 p	1 p	1	5	4	Market
Meet	1000 g	100g	600g	300 g	2	1	4	Market

3.3. Fruits intake:

List of fruits intake	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Mango	4000g	500 g	3000g	1500g	3	7	4 (2 month of year)	Cultivated
Jackfruit	2 kg	200 g	3000g	800g	3	2	4 (2 month of year)	Market
Banana	12 p	2 p	9 p	2 p	3	7	4	Market
Water Melon	1 p				2	3	4	Market

3.4. Pulse food intake:

List of pulse food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Mushur Pulse	150gm				2	7	4	Market
Anchor Pulse	250 gm				2	1	4	Market

3.5. Vegetables intake:

List of grains food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market / cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Potato	500gm		250g	250g	2	7	4	Market
Green Vegetables	1000gm	100g	500gm	400gm	2	7	4	Market

4**. General knowledge about Arsenic**

A: Do you know anything about Arsenic?

Ans. As is a disease of water, basically TW water.

B: What is the good or bad side of Arsenic?

Ans. No good side. As has all bad side. As create diseaes.

C: Can you tell us the relationship of Arsenic with your agricultural activities or your health or your income?

Ans. Still no relationship of As in my health and income.

THANK YOU
for
Your cordial cooperation

J-5: Household Survey 5

Risk assessment by surveying Bangladeshi family to estimate the daily intake of Arsenic

Arsenic food chain pathways through irrigation water – soil – crop – human body in the rural population of Bangladesh.

The Food Frequency Questionnaire (FFQ) is designed to assess habitual diet over the past year in the study population. The FFQ illustrates a complete set of questionnaire where not only gathered the information of dietary pattern but also collect the spatial characteristics of the landscape, socio-demographic information and also geographic location which indicates the As exposure to human body. This risk assessment survey fulfils the course requirement of master thesis which is conducted by Bashir Ahmed[5] during the session of January/2009 to June/2009.

The FFQ is designed in four sections:
(1) General household information,
(2) Household water and rice information,
(3) Individual dietary intake of other foods and,
(4) Rural people knowledge about Arsenic.

This survey is part of a master thesis which is funded by the project of sustainable Arsenic Mitigation (SAsMit) for risk assessment of sustainable development of agriculture.

1.1. Identification of Household

Name of family chief	Mohon Mia	Age	43
Village	Dashpara	Mauza	Bhangarpar
Union	Matlab Paurashava	Thana	Matlab Dakshin
Post	Matlab	District	Chandpur
Person interviewed	Mohifol Begum	Date	08.07.2009
Name of interviewer	Ratnajit Saha	Signature	

1.2. Spatial location of household:

GPS Coordinates	
X-Coordinate (longitude)	90^0 42' 48.2"
Y-Coordinate (Latitude)	23^0 20' 37.7"
Z-Coordinate (height above sea level)	
Date	

[5] Student of Mater program in Integrated Water Resource Management at SLU, Sweden.

1.3. Demographic, economic information of household members:

Person ID	Full Name	Gender (M/F)	Age (years)	Relationship to chief of Household	Occupation[A]	Income (Tk/month)	Diagnosed with Arsenicosis?	
1	Mohon Mia	M	43	Self	17 (Business)	50000	Not Tested	
2	Mohifol Begum	F	37	Wife	15		Not Tested	
3	Billal Hossain	M	15	Son	14		Not Tested	
4	Reshma Aktar	F	17	Daughter	15		Not Tested	
5	Fatema Aktar Mili	F	7	Daughter	14		Not Tested	
6	Faruk Hossain	M	17	Nephew	14		Not Tested	
7	Minhaz	M	1	Grandson				
8								
9								
10								

[A] Use the following Occupation Codes for each household members:

1- Farm owner 2- Farm day worker 3- Other day worker 4- Irrigation well owner 5- Irrigation well worker 6- Store owner 7- Store worker 8- Driver 9- Ricshaw puller 10- teacher 11- Doctor 12- engineer 13- Lawyer 14- Student 15- House wife 16- Unemployed 17- Other (Please specify)

2.2. Household water, rice consumption and usage of cooking water information

2.2.1 Amount of water and rice consumed by each person:

Person ID	Name	Source of drinking water	Amount consumed (L/day)	Amount of rice (cooked) (g/plate)	No. of plate of rice (cooked) (plate/meal)	Rice consumed (times/day)	Amount of rice consumed (cooked) (g/day)	Source of rice (Market/ cultivated)
1	Mohon Mia	TW	5	160	2	2	640	Cultivated
2	Mohifol Begum	TW	4	160	2	2	640	Cultivated
3	Billal Hossain	TW	1.5	150	1	2	300	Cultivated
4	Reshma Aktar	TW	3	160	2	2	640	Cultivated
5	Fatema Aktar Mili	TW	2.5	150	1	2	300	Cultivated
6	Faruk Hossain	TW	4	170	1	2	340	Cultivated
7	Minhaz	TW	2					

2.2.2 Amount of water used in cooking:

Cooked food type	Amount Kg/day (dry weight)*	Source of Water	Amount used (L/Kg of food item)**	Total amount of water used (L)
Rice	1.5	TW	1.5	3
Other Food (Curry and Dal)	3	TW	4	10

Note: * Amount cooked per meal (morning + lunch + evening)
** How much water is used to cook 1Kg of rice?

3. Dietary Intake of Other Food (Weigh amount consume if possible)

3.1 Other grains intake:

List of grains food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Mustard	50gm		25g	25g	2	2	4	Market

3.2 Dairy food Intake:

List of dairy food intake	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Milk	1500 ml	500ml	500ml	500ml	2	7	4	Market
Egg	8 p	1 p	3 p	3 p	1	7	4	Market
Meet	1500g	0	750g	750g	2	2	4	Market

3.3. Fruits intake:

List of fruits intake	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Mango	1000g		500g	500g	1	7	4	Market
Lichi	50 p		25 p	25p	1	2	4	Market
Banana	12 p	1 p	6 p	5 p	1	5	4	Market
Guava	1000 g		500g	500g	1	2	3	Market
Apple	1000g	50g	500 g	450g	1	2	2	Market

3.4. Pulse food intake:

List of pulse food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Musur Pulse	250gm		125g	125g	2	5	4	Market
Mugh Pulse	250g		125g	125g	2	2	4	Market

3.5. Vegetables intake:

List of grains food	Amount consumed (g/day)				No. of times consumed /day	No. of days consumed/week	No. of weeks consumed /month	Source (Market/ cultivated)
	No. of family member	No. of child	No. of Adult male member	No. of adult female member				
Potato	500g	0	250g	250g	3	7	4	Market
Purbal	250g	0	125g	125g	3	7	4	Market
Papa	500g	0	250g	250g	2	7	4	Market
Karella	250g	0	100g	150g	2	3	4	Market
Catery	500g	0	250g	250g	1	2	4	Market
Green Banana	2 p	0	1 p	1p	2	2	4	Market

4**. General knowledge about Arsenic**

A: Do you know anything about Arsenic?

Ans. Men died by arsenicosis. As comes from TW.

B: What is the good or bad side of Arsenic?

Ans. No good side. As is bad, because it causes diseases.

C: Can you tell us the relationship of Arsenic with your agricultural activities or your health or your income?

Ans. Still no relationship.