Int. J. Environ. Res., 5(3):627-638, Summer 2011
ISSN: 1735-6865

REVIEW

Impact of Arsenic Contaminated Irrigation Water in Food Chain: An Overview From Bangladesh

Ahsan, D. A.* and Del Valls, T. A.

UNESCO/UNITWIN/WiCop. Department of Physical-Chemistry. Faculty of Marine and Environmental Sciences. University of Cadiz, Campus Rio San Pedro, 11510 Porto Real, Cadiz, Spain

Received 2 June 2010; Revised 12 Nov. 2011; Accepted 22 Nov. 2011

ABSTRACT: Arsenic in ground water is a very serious environmental hazard of Bangladesh and West Bengal of India. The presence of high level of Arsenic (<50 µg/L) in groundwater of Bangladesh has been detected in 1980's. According to World Health Organization (WHO), the permissible limit of arsenic in drinking water is 10 µg/L. 80% of groundwater of the country has been contaminated with arsenic. Nearly 80 million Bangladeshi are now at risk from arsenic related several diseases including cancer. It has been assumed that arsenic is only present in ground water of Bangladesh but some recent studies showed that meantime arsenic had contaminated the agricultural soil as well. A high level of arsenic is also reported food grains and vegetables. The vision of this review is to give an overview of the latest findings of arsenic in agriculture soil and food crops of Bangladesh.

Key words: Arsenic, Ground Water, Food Chain, Bangladesh

INTRODUCTION

Arsenic is a common metaloid of the environment. It usually presents in a small amount in all rocks, soils, waters, air and biological tissues (Nriagu and Pacyna 1988; Matschullat 2000; Miteva *et al.*, 2005). Arsenic naturally occurs as sulfides and as complex sulfides of iron, nickel, and cobalt. It is estimated that the global As production is 75,000 to 100,000 tons annually, of which the United States produces about 21,000 tons and uses about 44,000 tons. Sweden is the world largest As producer and importer in the world market (NAS 1977; EPA 1980).Recently, As is using for the production of herbicides, incesticides, desiccants, wood preservatives, and growth stimulants for plants and animals (Ali 2003). Arsenic is one of the most toxic elements of the environment (Cullen and Reimer 1989; Dermatas *et al.*, 2004; Hudson-Edwards *et al.*, 2004). Arsenic can enter terrestrial and aquatic environments through natural geologic processes and anthropogenic activities as well. So, arsenic can also present in ground-water and soil.

Groundwater is the main source of drinking water in most of the countries (Table 1). It is estimated that approximately one third of the world's population use groundwater for drinking purpose (UNEP 2000). According to WHO guideline, the maximum consumable limit of As in drinking water is 10 µg/L. However, Bangladesh and many developing countries still use the 50 µg/L of As in drinking water as standard (Table 2).In the 1990s, several studies detected As in groundwater (due to anthropogenic and non-anthropogenic activities) in different countries e.g. USA, Argentina, Taiwan, China, Hungary, Vietnam, India and Bangladesh (Smedley and Kinniburgh 2002, Anawar *et al.*, 2003; Roychowdhury *et al.*, 2002).

Bangladesh is a developing country with nearly 140 million people. About 82% of the population lives in rural areas. More than 80% of the population depends on agriculture for their livelihood. Now-a-days, 90% of Bangladeshi depends on ground water for drinking purpose because much of surface water of Bangladesh is microbially unsafe to drink. Before1960's, people usually used surface water (e.g. pond, lake and river) for drinking and domestic purposes but severe microbial diseases specially cholera were very common at that time. To mitigate that problem, in 1970's, the government with the assistance of UNICEF, WHO and many NGOs, drilled several groundwater wells (BGS & DPHE, 2001). Besides domestic use, huge quantities of water from shallow aquifer are also using for irrigation during the dry season. Unfortunately, the vast area of Bangladesh's groundwater is naturally contaminated with arsenic (As) concentrations above the World Health Organization (WHO) drinking water guideline (0.01 mg/L) and even the Bangladeshi drinking water guideline (0.05 mg/L) (BGS and DPHE 2001; Smedley 2003; Anawara *et al.*, 2002). Groundwater in the

*Corresponding author E-mail: daahsan@yahoo.com

Table 1. Proportion of groundwater in drinking water supplies in selected countries

Country	Area (sq. mile)	Population	Proportion of groundwater
Denmark	16,639	5,450,661	98%
Hungary	35,919	9,981,334	95%
Portugal	35,672	10,605,870	80%
Switzerland	15,942	7,523,934	83%
UK	94,525	60,609,153	28%
Spain	194,896	40,397,842	21%
Netherlands	16,033	16,491,461	68%
Bangladesh	55,598	147,356,352	90%
Finland	130,558	5,231,372	57%
France	211,208	60,876,136	56%
Greece	50,942	10,688,058	50%
Italy	116,305	58,133,509	80%
Germany	137,846	82,422,299	72%
Norway	125,181	4,610,820	13%
Czech Republic	30,450	10,235,455	43%

Table 2. Limits for As in drinking water (µg/L)

Organization/Country	Concentration of As	References
WHO	10	Matschullat 2000
EU	10	
Netherlands	10	
Germany	10	
Bangladesh	50	BGS & DPHE 2001

majority of wells in 60 of the 64 districts, covering approximately 118,000 sq km (nearly 80% of the country), has concentrations of arsenic exceeding the World Health Organization's limit of 10 µg/L (Table 3). Only 30% of groundwater contains arsenic at levels below the Bangladesh drinking-water standard. Concentrations of arsenic exceeding 1,000 µg/L in shallow tube-wells were reported from 17 districts in Bangladesh Agricultural soil and food grains are also being contaminated with As.Nearly, 80 million people of Bangladesh are in great risk with As contaminated water and food stuff.

The aim of this review is to provide an overview of the latest findings of As contamination in food materials through arsenic-contaminated irrigation-water and the subsequent transfer of arsenic via water/soil to crops. These findings would likely help the researchers and policy makers to conduct more research on this issue and formulate proper agricultural strategies to produce As free food products and to reduce the arsenic causing disease risk in human being.

Chemistry of As

The atomic number of As is 33, which is situated in Group 15 (or VA) of the periodic Table. Arsenic may exists in four different oxidation states: (-III), (0), (III), and (V), however, oxidized As (III) and As(V) are the most widespread forms in nature. Arsenic ranks twentieth in abundance of elements in the earth's crust, fourteenth in seawater and is the twelfth most abundant element in the human body (Mandal and Suzuki 2002). The overall arsenic cycle is similar to the phosphate cycle.

The reduced trivalent form of arsenic As (III), called arsenite, is normally found in anaerobic or reducing groundwater and the oxidized pentavalent form As (V), called arsenate, is found in surface water and aerobic groundwater(Pongratz 1998; Smith *et al.*, 1998; Turpeinen *et al.*, 1999, 2002). In some groundwater, both forms have been found together in the same water source. Arsenate exists in four forms in aqueous solution based on pH; H_3AsO_4, $H_2AsO_4^-$, $HAsO_4^{2-}$ and AsO_4^{3-}. Similarly arsenite exists in five forms; $H_4AsO_3^+$, H_3AsO_3, $H_2AsO_3^-$, $HAsO_3^{2-}$ and AsO_3^{3-} (Jonsson and Lundell 2004). Arsenic is sensitive to mobilisation at pH values typically found in groundwater, i.e. pH 6.5-8.5, and under both oxidising and reducing conditions (Smedley and Kinniburgh 2002).

Arsenic in ground water of Bangladesh

Arsenic exists in the form of As^{5+} in surface waters, and As^{3+} in ground waters. The residence time of arsenic is 60,000 years in the ocean and 45 years in a freshwater lake (NRCC 1978). The baseline concentration of arsenic in an uncontaminated river is

Table 3. Arsenic concentration in natural surface water of different parts of the world

Location	Groundwater (mg/L)	River water (mg/L)	Lake water (mg/L)	References
Bangladesh	0.02-9.0	--	--	Bhattacharya et al. (2002)
Taiwan	0.01-1.82	--	--	Hossain (2006)
Norway	--	0.25 (<0.02-1.1)	--	Lenvik et al. (1978)
Belgium	--	0.75-3.8 up to 30	--	Andreae and Andreae (1989)
Maxico	0.5-3.7	--	--	Hossain (2006)
British Columbia	--	--	0.2-0.42	Azcue et al. (1994,1995)
Sweden	--	--	0.06-1.2	Reuther (1992)
Argentina	1.0-4.8	--	--	Bhattacharya et al. (2002)
China (Inner Mongolia)	0.5-18.60	--	--	Bhattacharya et al. (2002)
Cordoba,Argentina	--	0.07-1.14	--	Lerda and Prosperi (1996)
North chile	--	4.0-4.5	--	Sancha (1999)
Western USA	--	--	0.003-10.00	Benson and Spencer (1983)
Thailand (Ron Phibun)	--	0.04-5.83	--	Williams et al. (1996)

usually very low, with a range from 0.1 to 0.8 µg/L but normally does not exceed 2 µg /L (Seyler and Martin 1991). The main reasons responsible for the low concentration level of arsenic is the high affinity of arsenic to oxide minerals especially iron oxides/ hydroxides.In addition to geochemical factors, microbial agents can influence the oxidation state of As in water, and can mediate the methylation of inorganic As to form organic As compounds. Microorganisms can oxidize arsenite to arsenate; reduce arsenate to arsenite or even arsine (AsH_3). Bacteria and fungi can reduce arsenate to volatile methylarsines.

Arsenic contamination in the ground water of Bangle-delta (Bangladesh and West Bengal, India) region was first discovered in 1980's in the West Bengal of India. The scientists of West Bengal urged Bangladesh to test the level of As in Bangladesh as both the regions (Bangladesh and West Bengal, India) are situated in the Bengal-delta. In 1993, the Department of Public Health Engineering first identified the presence of arsenic in well-water in three districts in the northwest region of Bangladesh.However, the major concern about the As contamination in Bangladesh's groundwater raised in 1998 when the first national survey of arsenic contamination in Bangladesh was undertaken by the Department of Public Health Engineering of Bangladesh, British Geological Survey and Department for International Development (DFID), UK. That survey indicated that arsenic contamination was concentrated in the shallow aquifers of up to 150m (roughly 500 ft) depth, although the highest average contamination was found in the 15-30m (50-100ft) range. The very shallow aquifer of below 15m (50ft) seemed to be largely arsenic free, although subsequent studies have shown significant arsenic contamination in shallow dug wells. However, the surface water of Bangladesh is uncontaminated with As.

A number of hypotheses have been developed to explain the origin and basic cause of As calamity in Bangladesh (BGS and DPHE 2001). However, the Pyrite hypothesis and Oxy-hydroxide reduction hypothesis are the most renowned among those. According to Dudas (1984) pyrite is known as a carrier of arsenic and may contain up to 5,600 mg/kg. Several studies (Das *et al.*, 1984; Chatterjee *et al.*, 1995) in West Bengal suggest that extensive seasonal pumping of groundwater for irrigation is responsible for As contamination in groundwater Table. However, they did not showed any direct evidence to support the idea. Actually, this idea is based on the assumption that arsenic is present in the sulphide mineral pyrite and arsenopyrite. According to the theory, lowering of the water Table due to pumping introduces oxygen into the water Table, which causes the breakdown of pyrite and releases arsenic, iron and sulphate into the water. But the arsenic contaminated groundwater of Bangladesh typically shows very low concentrations of sulphate.

The Oxy-hydroxide reduction model came in 1997.According to this hypothesis As adsorbed on Fe-/Mn-oxides/ hydroxides is released into the groundwater due to a decrease of the redox state in the aquifer (Nickson *et al.*, 1998 and 2000; Smedley and Kinniburgh 2002; Bhattacharya *et al.*, 1997; Stuben *et al.*, 2003). Again there is no adequate model to explain how the low and diffuse As contents in the aquifer sediments generated the high As concentrations in the groundwater and there are only speculations on the factors triggering the redox decrease.

Soil arsenic in Bangladesh

The concentrations of As in non-contaminated soils range from 0.1 to 10 mg/Kg (Kabata-Pendias and Pendias 1992). However, the As content in some parts of Bangladesh soils are more than 30 mg/kg. Several soil analytical works have been done on As issue in Bangladesh (Ahsan *et al.*, 2008; Meragh and Rahman 2003; Hossain *et al.*, 2001; Huq *et al.*, 2003). The results of several studies on soil arsenic of different parts of Bangladesh are summarized in Table 4. In Srinagar thana, Bangladesh, arsenic concentration in the top soil layer (top 75 mm) of paddy field varied from about 7 to 27.5 mg/kg (Ali *et al.*, 2003) whereas at the Sonargaon area of Bangladesh arsenic concentration in the top soil layer of paddy field varied from about 3.2 to 19 mg/kg. Das *et al.*, (2004) reported that the mean arsenic concentration in soils of two up-zillas (Daudkandi and Begumganj) of Bangladesh was 15.676 ppm which was 1.5 times higher than the worldwide natural concentration of 10 ppm. However, arsenic contents in soil differ in different locations. Ahsan et al. (2008) reports high level of soil As (33.15 mg/kg) in Faridpur of Bangladesh and ground water of this region is also contain high level of As. On the other hand, in Dhamrai region (area with low As in groundwater) the level is soil As is 6.10 mg/kg which is lower than world limit (Ahsan *et al.*, 2008).

Table 4. Arsenic concentration of soil in different locations of Bangladesh

Location	As content (mg/kg)	References
Barisal	26.1	
Ramgati	16.8	Meragh and Rahman (2003)
Burichang	18.4	
Chandina	6.8	
Dhamrai	6.10	Ahsan et al.(2008)
Faridpur	33.15	
Mirsharai	6.5	
Pahartali	7.0	Meragh and Rahman (2003)
Rawjan	8.6	
Belabo	14.6	
Sirajdikhan	4.930	
Chandina	3.321	Huq et al. 2003
Sonargoan	9.915	
Ghatail	16.5	
Sonatala	13.4	
Kendua	9.0	Meragh and Rahman (2003)
Tarakanda	9.3	
Melandaha	9.6	
Dumuria	21	
Ishurdi	33.3	
Bhabanipur	1.783	
Kalapur	0.594	
Bhabanipur	1.783	Hossain et al. 2001
Sherpur	2.576	
Srimongal	1.981	
Khulna	5.13	
Meherpur	4.68	Uddin,1998
Pabna	7.60	
Polashbari	7.6	
Pirgacha	12.4	Meragh and Rahman (2003)
Bhabanipur	24.3	
Atwari	8.1	
Khulna	5.13	
Meherpur	4.68	
Pabna	7.60	
Laksam	2.68	Uddin 1998
Gazipur	3.13	
Rajshahi	3.80	
Comilla	5.64	Das et al.2004
Chapainabganj	56.68	Alam& Sattar 2000

Factors affecting As mobility in soil

The mobility of As in water and soil depends on several factors like pH, redox conditions, biological activity and adsorption-desorption process (Ali 2003; Goh and Lim 2005).So, the presence of high concentrations of As in soil is not only dependent on the concentration of As in soils but also on the aforesaid factors. Moreover, organic content, soil fractions and oxides of Al, Fe and Mn also affect the amount of As in soil. Several studies have reported the mobilization and attenuation of As in the fine and coarse soil fractions (Lombi *et al.*, 2000; Bhattacharya *et al.*, 2002; Cai *et al.*, 2002; Sadiq 1997). Sediments with finer texture usually contain more arsenic than sediments with coarser texture (Khan 2003). According to Lombi et al. (2000), the coarse textured soils are likely to yield a higher fraction of readily mobile As, while As in the fine textured soils is relatively immobile, but can be released upon changes in the subsurface geochemical environment. Climate and geomorphic characteristics of an area, such as rainfall, surface runoff, rate of infiltration, and the groundwater level and its fluctuations, also affect the mobility and redistribution of arsenic (Bhattacharya *et al.*, 2002).

Redox potential is also the most important factors controlling As speciation (Smedley and Kinniburgh 2002). The term redox represents a large number of chemical reactions involving electron transfer. When a substance is oxidised, it transfers electrons to another substance, which is then reduced. The point at which a given reaction can take place is determined by the electrical potential difference or redox potential (Eh) (SEPA, 1999).

This redox sequence is of extreme importance on arsenic speciation, not only because it is an indication of redox level that the arsenic resides on but also because it influences the behaviours of the important bulk elements (iron and sulphur), which have very strong binding affinity to arsenic and are principally responsible for the enhanced contamination of arsenic in the environment. Redox processes can be mediated by microorganisms, especially bacteria which serve as catalysts in speeding up the reactions. Mobility of As in natural system also largely depends on adsorption and desorption processes. Both arsenate and arsenite adsorb to surfaces of many different solids including iron, aluminium and manganese oxides, as well as clay minerals. Arsenate is much more strongly adsorbed than arsenite because of its greater negative charge at the same pH (Ali and Ahmed, 2003).

Fe-oxides/hydroxides represent the major sink for As adsorption in soils, whereas the importance of Al- and Ca-bound fractions are variable (Ali and Ahmed, 2003; Chen, *et al.*, 2002, Akins and Lewis, 1976; Wasay *et al.*, 2000; Manning and Goldberg, 1997). Fixation of As with iron oxide surfaces is an important reaction in the subsurface soil because iron oxides are widespread in the environment as coatings on other solids, and because arsenate adsorbs strongly to iron oxide surfaces in acidic and near-neutral pH conditions.Soil organic matter has no contribute in significant quantities to As sorption in soils, especially in the presence of effective sorbents such as hydrous Fe oxides (Livesey and Huang, 1981; Wenzel *et al.*, 2002). However, a few researches have been designed on As adsorption by organic matter (Fitz and Wenzel, 2002).

Transmission of As in agricultural soil through irrigating water

The immediate and long-term impact of using As contaminated water for irrigating paddy soils is a burning concern as arsenic can transfer from water to soil and several studies have proven this phenomenon. Boro (dry season) rice requires approximately 1000 mm of irrigation water per season. Meharg and Rahman (2003) predicted that soil arsenic levels could be raised by 1 µg/g per annum due to irrigation with As contaminated water. Alam and Sattar (2000) showed that arsenic contained in soils was positively correlated with arsenic content in water. The study of Ahsan et al. (2008) reported that As rich irrigation water can enrich the As level in agricultural soil up to five time than the normal soil. In the unaffected areas, where irrigation water contained little As (< 1 µg/L), As concentrations of rice field soils ranged from 1.5 to 3.0 mg/kg whereas the agricultural soil contains arsenic up to 436 µg/L where irrigated with As rich ground (Saha and Ali, 2007). Some recent studies (Dittmar *et al.*, 2007) show that input of As into rice field soils decreases significantly with increasing distance from the irrigation water inlet. However, there is a tendency of soil build-up of As in some cases where As-contaminated ground water is used for irrigation (Table 5).

Arsenic in food materials

Arsenic is not an essential element both for plant and animal. Food crops such as vegetables and cereals can become a path by which As may enter the food chain, because they can reflect the levels of As that exist in the environment in which they are cultivated (soil and irrigation water). So, the accumulation of As in rice field soil and its introduction into the food chain through uptake by the rice plant is of major concern. The accumulation of arsenic in plants occurs primarily through the root system and the highest arsenic concentrations have been reported in plant roots and tubers (Anastasia and Kender, 1973; Marin *et al.*, 2003). Therefore, tuber crops are expected to have higher arsenic contents than that of other crops when those are grown in arsenic contaminated soil.

Table 5. Arsenic in water and corresponding As in soils in some parts of Bangladesh

Location	Water As (mg/L)	Soil As (mg/kg)	References
Chapainawabganj Sadar	0.01-0.056	1.27-31.84	
Kustia Sadar	0.01-0.07	7.01-24.20	
Bera	0.01-0.056	16.56-22.29	Alam and Sattar 2000
Ishurdi	0.01-0.41	1.27-24.20	
Sarishabari	0.025-0.071	3.18-10.83	
Gopalganj Sadar	0.015-0.079	0.26-7.03	
Mukshidpur	0.012-0.05	0.30-8.62	
Monirampur	0. 024-0.076	0.69-4.96	
Pirghacha	0.013-0.066	1.2-8.1	Farid et al. 2003
Rajarhat	0.01-0.049	0.20-5.5	
Chapi Nawabganj Sadar	0.05-0.079	1.9-7.4	
Charghat	0.015-0.068	0.20-40.08	
Sharsha	0.041	13.670	
Sirjdikhan	0.544	10.655	
Alamdanga	0.058	10.675	
Meherepur	0.016	28.220	Huq et al. 2003
Laksham	0.145	10.791	
Sonargaon	0.860	14.00	
Bancharampur	0.092	17.147	
Nagarkanda	0.064	26.559	

Arsenic in rice

Rice is the staple food for Bangladeshi people. There are two seasons for rice culture; aman and boro. Aman culture period is in rainy season when no irrigation is required but the boro cultivation phase (in dry season) is completely depended on irrigation. About 86% of total groundwater withdrawn in Bangladesh is utilized in agricultural sector especially in rice cultivation in dry season. A total of 925,152 shallow and 24,718 deep tube-wells were used for irrigation during the 2004 dry season (BADC 2005) and groundwater irrigation covered about 75% of the total irrigated area. Boro cultivation and irrigation have together increased since 1970. Saha (2007) estimated that nearly 1000 metric tons of As is cycled with irrigation water during the dry season of each year as boro rice needs huge amount of water.

It is expected that surface soil of agricultural land accumulates arsenic from contaminated water due to its high affinity with metal oxides/hydroxides in soil. Some studies (Alam and Sattar, 2000; Meharg and Rahman, 2003) have reported elevated concentrations of As in rice field soils irrigated with As contaminated groundwater. The study of (Williams *et al.*, 2006) showed that rice obtained from districts with contaminated waters (>50 µg/L) were clearly more elevated with As than rice from less contaminated or uncontaminated (<50 µg/L) districts and boro season rice contained more As than aman season rice (Table 6).

Duxbury et al. (2002) found that arsenic concentrations in rice could varied from 10 - 420 µg/kg in dry condition. On the other hand, the studies of Das et al. (2004) and Abedin et al. (2002) showed that no samples of rice grain had arsenic concentrations more than the recommended limit of 1.0 mg/kg in three different regions of Bangladesh. However, arsenic accumulation of rice grain depends on the variety of rice (Table 7). A high level of As in rice grain (ranging between 1.75 and 1.83 mg/Kg) of Nawabgonj and Naogoan (high level of As in paddy soil) has been reported by Meragh and Rahman (2003). So, the order of magnitude of As concentration in rice grain related with the magnitude of As concentration in soil and variety of rice species. It is also important to point out that the results of Meragh and Rahman (2003) also higher than the results of other researches of the world as well. As for instance, the field trials by Xie and Huang (1998) on Chinese arsenic polluted paddy soils showed that rice could accumulate up to 0.725 mg/kg dry wt arsenic when grown on soils containing 68 mg/kg arsenic. In Taiwan, the field survey showed that rice grain grown on paddy soils containing 6.9-7.5 mg/kg of arsenic had an arsenic concentration of 0.2 mg/kg dry weight (Schoof *et al.*, 1999).

It appears that arsenic present in irrigation water and soil results in higher level of arsenic in rice plant root, leaf and stem (Ali, 2003). A very recent study of Liu et al. (2005) on the distribution of As in rice plant showed that the order of As accumulation in rice plant was in the order root > leaf > grain and they detected the level of As up to 248±65 mg /kg in root tissue where as 1.25±0.23 mg /kg was detected in the grain. The root, shoot and leaf tissue of rice plant contain mainly inorganic As III and As V while the rice grain contain

Table 6. Arsenic level in ground water and rice grain in different districts of Bangladesh (Williams et al. 2006)

District	Aman season rice (µg/g;dry wt)		Boro season rice (µg/g;dry wt)		As in groundwater (µg/L)
	Min-max	Mean	Min-max	Mean	
Barisal	0.10-0.32	0.16 ± 0.01	0.17-0.44	0.25 ± 0.06	92
Bogra	0.10-0.22	0.14± 0.02	0.13-0.17	0.15± 0.02	18
Brahmanbaria	0.15-0.31	0.22± 0.04	0.21-0.31	0.26± 0.03	101
Chandpur	0.13-0.40	0.22± 0.02	0.04-0.91	0.28± 0.09	366
Chuadanga	0.10-0.48	0.24± 0.05	0.15-0.81	0.32± 0.03	79
Dhaka	0.09-0.15	0.11± 0.02	0.12-0.23	0.18± 0.03	41
Dinajpur	0.06-0.11	0.08± 0.01	0.13-0.17	0.15± 0.01	3
Fardipur			0.44-0.58	0.51± 0.07	140
Khulna	0.04-0.32	0.12± 0.01	0.14-0.20	0.17± 0.02	35
Kushtia	0.07-0.28	0.19± 0.06	0.12-0.23	0.18± 0.01	104
Meherpur	0.06-0.42	0.18± 0.02	0.15-0.84	0.29± 0.04	116
Mymenshing	0.04-0.18	0.11± 0.01	0.21-0.36	0.26± 0.05	25
Nator	0.08-0.18	0.12± 0.01	0.11-0.20	0.17± 0.02	45
Satkhira	0.08-0.92	0.36± 0.04	0.19-0.62	0.38± 0.03	133
Sherpur	0.07-0.13	0.12± 0.01	0.13-0.23	0.17± 0.02	22

Table 7. Arsenic content of irrigation water, soil, different parts of rice plants in Bangladesh (Alam and Rahman 2003)

As in water (ppb)	As in soil (mg/kg)	Rice variety	As in rice grain (mg/kg)
156	7.52	BR-14	0.00
364	2.07	BR-14	0.00
277	12.0	BR-14	0.00
199	3.76	BR-28	0.00
131	3.98	BR-28	0.032
188	3.30	BR-28	0.00
255	2.42	BR-28	0.063
62	2.01	BR-29	0.016
208	3.63	BR-29	0.00
278	9.93	IR-50	0.00
105	3.37	Purbachi	0.022
222	2.24	Purbachi	0.026
177	3.02	Purbachi	0.094

predominantly DMA (85 to 94%) and As III (Liu *et al.*, 2005). Tsutsumi et al. (1980) reported 149 mg of As/ kg dry weight in rice straw when soil arsenic concentration was 313 mg /kg. Abedin et al. (2002) conducted a study in greenhouse and found 25 mg of As /kg dry weight in rice straw when the plant was irrigated with As rich water (2mg /L).

So, it can be predicted that As contaminated irrigation water could easily increase the As level in rice grain, straw and other part of rice plant. Arsenic contents in boro rice could be 1.3 times higher than for aman rice (Table 6). However, accumulation of As by rice largely depends on redox potential in plant and soil phosphate concentration, rhizosphere iron plaque formation, microbial activity, and rice variety (Meragh, 2004). The precise mechanisms controlling the translocation of As to grain is yet to be determined.

Soil As is also responsible for the reduction of rice production. Arsenic concentration in irrigation water (0.1 to 2.0 mg/L) and soil (5 to 50 mg/kg) could result in lower yield of a local rice variety. Rice production is reported to decrease by 10% at a concentration of 25 mg/kg As in soil (Xiong *et al.*, 1987). Abedin et al. (2002) reported the reduced yield of a local variety of rice (BR-11) irrigated with elevated As (0.2 to 8.0 mg/ L) bearing water.

Arsenic in vegetables

Several greenhouse studies show that an increment in As in cultivated soils leads to an increment in the levels of As in edible vegetables (Burlo *et al.*, 1999; Carbonell-Barrachina *et al.*, 1999). In Bangladesh, a few studies have been carried out to analyse the amount of As in different types of vegetables. Farid et al. (2003) conducted a study on level of arsenic in different types of vegetables cultivated with As free and As contaminated ground-water in Bangladesh and the results of that study is presented in Table 8. They found that the level of arsenic was higher in vegetables which were irrigated with arsenic contaminated water.

Ali et al. (2003) conducted a research on As concentration in different vegetables which were irrigated with low level of As rich pond water. They found the highest accumulation of arsenic in the root of potato plants (up to 2.9 mg/kg) whereas As concentration in the edible parts varied from 0.12 to 0.85 mg/kg. Study results of Ali et al. (2003) also showed that As concentration in edible parts of lalshak (spinach) ranged from < 0.39 to 0.96 mg/kg; for datashak (spinach) it ranged from 0.56 to 1.06 mg/kg, for cabbage 0.38 to 1.6 mg/kg and for cauliflower 0.35 mg/kg. Das et al. (2004) also conducted a research on vegetables cultivated with As rich ground water in Bangladesh. Their result revealed that the mean arsenic concentrations in potatoes (*Solanum tuberosum*) and pointed gourd/potals (*Trichosanthes dioeca*) were 0.598 and 0.10 ppm FW, respectively and were higher than the values for those grown on uncontaminated soils, as reported in literature (Nriagu, 1994). Significant levels of arsenic in arum/kachu (*Colocasia antiquorum*) and water spinach/kalmi sak (*Ipomoea reptans*) were found (range: 0.11-3.49 ppm FW) and (range: 0.09-2.03 ppm FW) respectively. Arsenic concentrations in balsam apple/korola (*Momordica charantia*), ladies finger/derosh (*Hibiscus esculentus*), and jute (*Corchorus capsularis*) leaves were not significant. High level of arsenic was found in sajnay danta (*Amaranthus lividus*) stem (1.41 ppm FW).Study of Alam et al. (2003) found mean As concentrations (mg/kg) were in snake gourd (0.489), ghotkol (0.446), taro (0.440), green papaya (0.389), elephant foot (0.338) and Bottle ground leaf (0.306), respectively. So, tuber crops are expected to have higher arsenic contents than that of other crops when those are grown in arsenic contaminated soil as root system is the main parts of accumulate As in plants.

Arsenic in fish

A very limited studies have been carried out in Bangladesh to find out the As concentration in fish in Bangladesh. Das et al. (2004) analyzed arsenic content in catfish (*Heteropenuestis fossilis*) (0.021-0.043 ppm) from an uncontaminated canal of Bangladesh and did not found no significant level of arsenic in the fish tissues. Lata fish (*Ophicephalus punctatus*) did not contain unacceptable levels of arsenic from three different regions of Bangladesh.

Discussion

Bangladesh is an agricultural country. Rice, fish and vegetables are the main food stuffs of the people. The present review indicates that As is gradually interring into the food chain through As contaminated irrigated water and soil. To mitigate the huge food demand, groundwater is using for irrigation for paddy culture and horticulture during the dry season. The water demand of rice is very high. The volume of water used for irrigation of Boro rice in the Indo-Gangetic Plain is in the range between 1000 and 1800 mm/year (Huq *et al.*, 2003). Norra et al.(2005) reported As content in the soils of the agricultural areas irrigated with As bearing groundwater, up to five times higher than the background values of the reference site. Although, As concentration of rice field soils increases significantly at the end of the irrigation season, it decreases subsequently during the wet season, possibly as a result of remobilization of As due to reductive dissolution of As bearing iron oxyhydroxides. The remobilized As may be leached into deeper soil layers and/or transported away from the field with the flood/rain water. However, data on accumulation of arsenic on irrigated agricultural soil over time is not available. Also, there appears to be a

Table 8. Arsenic content in vegetables of Bangladesh (Farid et al. 2003)

Crop	Location	Arsenic content (ppm)			
		Contaminated		Uncontaminated	
		Range	Mean	Range	Mean
Tomato	Nawabgonj	0.016-0.049	0.030	0.001-0.025	0.011
	Monirampur	0.013-0.021	0.017	0.001-0.014	0.007
Potato	Pirgacha	0.042-0.107	0.068	0.024-0.068	0.041
	Rajarhat	0.00-0.080	0.024	0.00-0.055	0.021
Brinjal	Nawabgonj	0.042-0.063	0.049	0.028-0.063	0.045
Cabbage	Muksedpur	0.031-0.042	0.037	0.00-0.059	0.030
Okra	Charghat	0.034-0.046	0.040	0.016-0.046	0.031
Amaranth	Nawabgonj	0.093-0.201	0.161	0.099-0.109	0.103
	Pirgacha	0.182-0.79	0.935	0.060-0.370	0.241
Spinach	Monirampur	0.132-0.606	0.321	0.072-0.240	0.163

lack of information on desorption kinetics of arsenic from soil, which is needed for better understanding of the long-term retention of arsenic on soil. More studies should be carried out to better understand the processes leading to the depletion of As in rice field soil during the wet season and desorption kinetics process of arsenic from soil.

Rice plants and vegetables are also accumulating As from contaminated soil. The high As contents measured in the root are due to an Fe-rich mineral plaque which coats the root. Though several studies indicated that the concentration of arsenic in edible parts of most plants is generally low but long term ingestion of As contaminated rice and vegetables could be dangerous for human health. The average daily rice consumption by an adult in Bangladesh is between 400 and 650 g raw rice grain (Duxbury *et al.*, 2002). Schoof et al. (1999) reported that between 30% and 85% of arsenic in rice is inorganic. So, intake of arsenic from rice and its potential impact on human exposure should not be neglected. Use of contaminated groundwater for drinking and cooking may enhance the overall situation. As a result, several researches are also essential for the clarification of As intake through cooked rice, cereal and solid food stuffs prepared by arsenic contaminated water. It is also necessary to invent arsenic tolerant rice varieties which will not accumulate As. Variation in arsenic tolerance and iron plaque formation could be the starting points for breeding rice for arsenic affected soils (Meharg 2004). Involvement of high yield variety of rice which need very low amount of water would be one of the good solutions.

Arsenic could also be accumulated by freshwater fish, marine fish and birds. Sea fish and shell fish may contain significant amount of As in their muscle and liver tissue. Lima et al. (1984) found significant level of As (> 0.1 mg/Kg ww) in muscle of different sea fish and shell fish like dogfish, rays, sole etc. However, no research has been conducted in Bangladesh to find out the As status in marine fish and shell fish and other organisms. More over, in Bangladesh people like to take dried sea fish but As concentration becomes higher (up to 5 times from fresh fish concentration) in dry condition (Lima et al. 1984). Unfortunately, a very few research has conducted to ascertain the effect of As in aquatic biota, fish and bird in Bangladesh.

Cattle are one of the primary consumers of terrestrial ecosystem. In Bangladesh, cattle generally feed on rice straw and husk as there is a severe scarcity of grassing land due to high population. Cattle also drink As contaminated water and the people even cannot imagine to provide the arsenic free water to the cattle as arsenic free drinking water is not very easy to get even for human consumption in some part of the country. It has been mentioned that high level of As was determined in the rice husk by several studies. Rice straw is not consumed as human diet but rice straw trash is commonly fed to cattle. Though, there is no direct report of arsenic accumulation in cattle body from rice straw or husk, the consequence of exposure to this toxic element in organs such as the liver and kidneys of this animal is well reported (WHO, 2001). Moreover, there is no available data on the level As in milk and cattle meet. So, there is no clear information whether the cattle have been infected by As and cattle meet and milk transferring As to human body. Further research in this area is needed to quantify the importance of As transportation to human being through soil-plant-animal-human pathway.

Accumulation of As from one tropic level to other tropic level depends not only on the total As concentration but also largely depends on the bioavailability. So, one area with high As concentration may not be dangerous in comparison to another area with lowest As concentration. However, a very few research has been designed to find out the bioavailability of As from soil and water to food chain in Bangladesh. More over no study yet to conduct to determine the ecological risk of As and other metals in Bangladesh. It should be considered that a very little is known about the chemical forms of arsenic (e.g., inorganic and organic) in crop/vegetable/fish, which in turn is needed for estimating its toxicity. More researches are essential to ascertain the chemical forms of arsenic (e.g., inorganic and organic) in crop/vegetable and the bioavailability of As in crop and vegetables. Studies with the larger samples are needed to demonstrate the extent of arsenic contamination of food in Bangladesh. So, immediate researches are essential to ascertain the impact of As and other metals in over all food chain and ecosystem of Bangladesh.

There is no system in Bangladesh to check the level of As in food grain as the country is poor and with deficit in food. From this review, it could be perceived that arsenic contaminated drinking water is not the only source of As accumulation in human body. Human being can also uptake As from contaminated rice, vegetables, milk and meet hence ‘‘plant–human’’ and ‘‘plant–animal–human’’ could be other potential food chain pathways of arsenic accumulation in human body (Fig.1). This study also wants to point out that the people who live in As contaminated regions are not only at risk but also other people (who live in non-contaminated zones) are in danger as they are also consuming arsenic contaminated food stuffs.

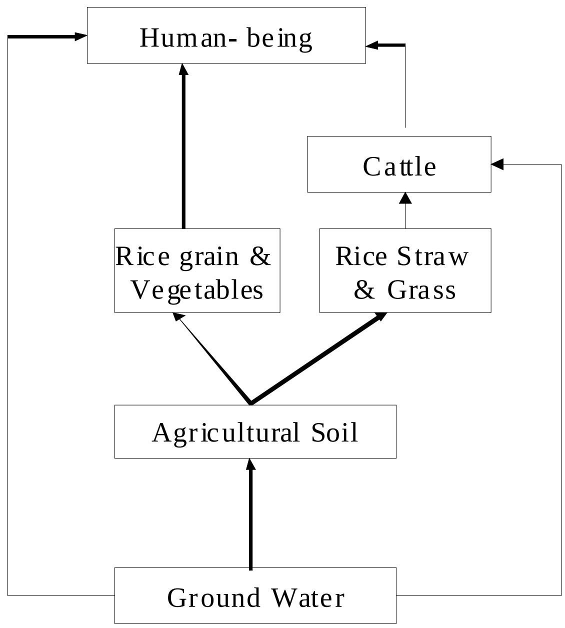

Fig.1. possible routes of As exposure to human-being in Bangladesh

REFERENCES

Abedin, M. J., Malcolm, S., Andy, A., Cotter-Howells, J. (2002). Arsenic Accumulation and Metabolism in Rice (Oryza sativa). Environ. Sci. Technol., **36**, 962 -968.

Ahsan, D. A., Del Valls, A. C. and Blasco, J. (2008). Distribution of Arsenic and Trace Metals in the Floodplain Agricultural Soil of Bangladesh. Bull. Environ. Contam. Toxico., **82 (1)**, 11-15.

Akins, M. B. and Lewis, R. J. (1976). Chemical distribution and gaseous evolution of arsenic-74 added to soils as DSMA-74As. Soil Sci, Am. J. **40**, 655- 658.

Ali, M. (2003). Review of Drilling and Tubewell Technology for Groundwater Irrigation. The University Press Limited, Dhaka, Bangladesh.

Ali, M. A. and Ahmed, M. F. (2003). Environmental Chemistry of Arsenic. In: Ahmed MF (ed) Arsenic contamination: Bangladesh Perspective. ITN-Bangladesh, Dhaka.

Ali, M. A., Badruzzaman, A. B. M., Jalil, M. A., Hossain, M. D., Ahmed, M. F., Masud, A. A., Kamruzzaman, M. and Rahman, M.A. (2003). Arsenic in plant-soil environment in Bangladesh. In: Ahmed MF, Ali MA, Adeel Z (eds) Fate of frsenic in the environment. Proceedings of the international symposium on fate of arsenic in the environment, ITN Centre, BUET, Dhaka

Alam, M. B. and Sattar, M. A. (2000). Assessment of arsenic contamination in soils and waters in some areas of Bangladesh. Water Sci. Technology, **42,** 185-193.

Alam, M. G. M., Snow, E. T. and Tanaka, A. (2003). Arsenic and heavy metal contamination of vegetables grown in Samta village, Bangladesh. Sci. Total Environ. **308**, 83-96.

Alam, A. and Rahman, A. (2003). Accumulation of arsenic in rice plant from arsenic contaminated irrigation water and effect on nutrient content. In: Ahmed MF, Ali MA, Adeel Z (eds) Fate of frsenic in the environment. Proceedings of the international symposium on fate of arsenic in the environment, ITN Centre, BUET, Dhaka

Anawar, H. M., Akai, J., Komaki, K., Terao, H., Yoshioka, T., Ishizuka T., Safiullah, S., Kato, K. (2003). Geochemical occurrence of arsenic in groundwater of Bangladesh: sources and mobilization processes. J. Geochem. Explor, **77**, 109-131.

Anastasia, F. B. and Kender, W. J. (1973). The influence of soil arsenic on the growth of low-berry bush. Environ. Qual., **2**, 335–337.

Andreae MO, Andreae TW (1989) Dissolved arsenic species in the Schelde estuary and watershed, Belgium. Estuar Coast Shelf Sci 29: 421-433.

Azcue, J. M., Murdoch, A., Rosa, F. and Hall, G. E. M. (1994). The effects of abandoned gold mine tailing on the arsenic concentrations in water and sediments of Jack of Clubs Lake, BC. Environ. Technol., **15**, 669-678.

Azcue, J. M., Murdoch, A., Rosa, F., Hall, G. E. M., Jackson, T. A. and Reynoldson, T. (1995). Trace element in water, sediments, pore water, and biota polluted by tailings from an abandoned gold mine in British Columbia, Canada. J. Geo-chem. Explor, **52**, 25-34.

BADC, (2003). Bangladesh Agricultural Development Corporation, (2003). Survey report on irrigation equipment and irrigated area in boro/2003 season. Survey and monitoring project for development of minor irrigation; BADC: Sech Bhaban, Dhaka, Bangladesh.

Benson, L.V. and Spencer, R. J. (1983). A hydro chemical Reconnaissance Study of the Walker River Basin, California and Nevada. USGS United States Geological Survey, Open File Report no 83-740.

Bhattacharya, P., Chatterjee, D. and Jacks, G. (1997). Occurrence of arsenic contaminated groundwater in alluvial aquifers from Delta Plains, Eastern India: Options for safe drinking water supply. Int. J. Water Res. Manage., 13,79-92.

Bhattacharya, P., Jacks, G., Frisbie, S. H., Smith, E., Naidu, R. and Sarkar, B. (2002). Arsenic in the environment: a global perspective. In : Sarker B (ed) Handbook of heavy metals in the environment , Marcel Dekker Inc, New York, pp. 147-215.

BGS and DPHE, (2001). Arsenic contamination of groundwater in Bangladesh. BGS Technical Report WC/00/ **19,** British Geological Survey,UK.

Burlo, F., Guijarro, I., Carbonell-Barrachina, A. A., Valero, D. and Martínez-Sánchez, F. (1999). Arsenic species: effects on and accumulation by tomato plants. J. Agric. Food Chem., **47**, 1247-1253

Cai, Y., Cabrera, J.C., Georgiadis, M. and Jayachandran, K. (2002). Assessment of arsenic mobility in the soils of some golf courses in South Florida. Sci, Total Environ., **291**, 123-134.

Carbonell-Barrachina, A.A., Burlo, F., Valero, D., Lopez, E., Martinez-Romero, D. , Martinez-Sanchez, F. (1999). Arsenic toxicity and accumulation in turnip as affected by arsenical chemical speciation. J. Agric. Food Chem., **47**, 2288-2294.

Chatterjee, A., Das, D., Mandal, B. K., Chowdhury, T. R., Samanta, G. and Chakraborti, D. (1995). Arsenic in groundwater of six districts of West Bengal: the biggest arsenic calamity in the world. Part 1. Arsenic species in drinking water and urine of affected people. Analyst, **120**, 640-650.

Chen, M., Ma, L. and Harris, W. G. (2002). Arsenic concentrations in Florida surface soils: influence of soil type and properties. Soil. Sci. Soc. Am. J., **66**, 632-640.

Cullen, W.R. and Reimer, K. J. (1989). Arsenic speciation in the environment. Chem. Rev., **89**, 713-764.

Das, H. K., Mitra, A. K., Sengupta, P. K., Hossain, A., Islam, F. and Rabbani, G. H. (2004). Arsenic concentrations in rice, vegetables and fish in Bangladesh: a preliminary study. Environ. Int., **30**, 383-387.

Dermatas, D. ,Moon, D.H. ,Menounou, N., Meng, X. and Hires, R. (2004). An evaluation of arsenic release from monolithic solids using a modified semi-dynamic leaching test. J. Hazardous Materials, **116**. 25-38.

Dittmar, J., Voegelin, A.,Roberts, L. C., Hug, S. J., Saha, G. C., Ali, M. A., Badruzzaman, B. M. and Kretzschmar, R. (2007). Spatial distribution and temporal variability of arsenic in irrigated rice fields in Bangladesh. 2. Paddy soil. Environ. Sci. Technol., **41**, 5967–5972.

Dudas, M. J. (1984). Enriched levels of arsenic in post-active acid sulfate soils in Alberta. Soil Sci. Soc. Am. J., **48**, 1451-1452.

Duxbury, J. M., Mayer, A. B., Lauren, J. G. and Hassan, N. (2002). Arsenic content of rice in Bangladesh and impacts on rice productivity. Proceedings of 4th annual conference on arsenic contamination in groundwater in Bangladesh, Dhaka, Bangladesh.

EPA, (1980). Ambient water quality criteria for arsenic. US Environ Protection Agency Rep 440/5-80-021, 205.

Farid, A. T. M., Roy, K. C., Hossain, K. M. and Sen, R. (2003). A study of arsenic contaminated irrigation water and its carried over effect on vegetable. In: Ahmed MF, Ali MA, Adeel Z (eds) Fate of arsenic in the environment. Proceedings of the international symposium on fate of arsenic in the environment, ITN Centre, BUET, Dhaka.

Fitz, W. J. and Wenzel, W. W. (2002). Arsenic transformations in the soil rhizosphere-plant system: fundamentals and potential application to phytoremediation. J. Biotechnology, **99**, 259-278.

Goh, K. H. and Lim, T. T. (2005). Arsenic fractionation in a fine soil fraction and influence of various anions on its mobility in the subsurface environment. Appl. Geochemistry, **20**, 229-239.

Hossain, M. F. (2006). Arsenic contamination in Bangladesh—an overview. Agri. Ecosystem Environ., **113**, 1-16.

Hossain, M. M. ,Sattar, M. A., Hashem, M. A. and Islam, M. R. (2001). Arsenic status at different depths in some soil of Bangladesh. J. Biological Sci., **1**, 1116-1119.

Hudson-Edwards, K. A. , Houghton, S. L. and Osborn, A. (2004). Extraction and analysis of arsenic in soils and sediments. Trends Analy. Chem., **23**, 745-752.

Huq, S. M. I., Rahman, A., Sultana, N. and Naidu, R. (2003). Extent and severity of arsenic contamination in soils of Bangladesh. In: Ahmed MF, Ali MA, Adeel Z (eds) Fate of arsenic in the environment. Proceedings of the international symposium on fate of arsenic in the environment, ITN Centre, BUET, Dhaka.

Jonsson, L. and Lundell, L. (2004). Targeting safe aquifers in regions with arsenic-rich groundwater in Bangladesh case-study in Matlab Upazila. Ms Thesis, Department of Earth Sciences, Uppsala University Uppsala, Sweden.

Kabata-Pendias, A. , Pendias, H. (1992). Trace elements ion soils and plants. 2nd edn. CRC Press, Boca Raton, USA.

Khan, A. A. (2003). The aspects of Arsenic in Groundwater in Reference to the Bengal Delta. In: Ahmed M. F. (ed) Arsenic Contamination: Bangladesh Perspective. ITN-Bangladesh, Dhaka.

Lenvik, K., Steinnes, E. and Pappas, A. C. (1978) Contents of some heavy metals in Norwegian rivers. Nord Hydrol, **9**, 197-206.

Lerda, D. E. and Prosperi, C. H. (1996). Water mutagenicity and toxicology in Rio Tercero, Cordoba, Argentina. Water Res., **30**, 819-824.

Lima A. R., Curtis, Hammermeister D. E., Markee T. P., Northcott C. E. and Brooke L. T. (1984). Acute and chronic toxicities of arsenic (III) to fathead minnows, flagfish, daphnids, and an amphipod. Arch Environ Contam Toxicol., **13**, 595-601.

Livesey, N. T. and Huang, P. M. (1981). Adsorption of Arsenate by soils and its relation to selected chemical properties and anions. Soil Sci., **131**, 88-94.

Liu, W. J., Zhu, Y. G. and Smith, F. A. (2005). Effects of iron and manganese plaques on arsenic uptake by rice seedlings (Oryza sativa) Grown in solution culture supplied with arsenate and arsenite. Plant and Soil, **277**, 127-138.

Lombi, E., Sletten, R. S. and Wenzel, W. W. (2000). Sequentially extracted arsenic from different size fractions of contaminated soils. Water Air Soil Pollut., **124**, 319-332.

Matschullat, J. (2000). Arsenic in the geosphere – A review. Sci. Total Environ., **249**, 297-312.

Mandal, B. K. and Suzuki, K. T. (2002). Arsenic round the world: A review. Talanta, **58**, 201-235.

Manning, B. A. and Goldberg, S. (1997). Arsenic (III) and arsenic (V) adsorption on three California soils. Soil Sci., **162**, 886-895.

Marin, A. R., Masscheleyn, P. H. and Patrick, Jr. (2003). Soil redox-pH stability of arsenic species and its influence on arsenic uptake by rice. Plant Soil, **152**, 245–253.

Meharg, A. A. (2004). Arsenic in rice – understanding a new disaster for South-East Asia. Trends in Plant Science, **9**, 415-417.

Meharg, A. A. and Rahman, M. (2003). Arsenic contamination of Bangladesh paddy field soils: Implications for rice contribution to arsenic consumption. Environ. Sci. Technol., **37**, 229-234.

NAS, (1977). Arsenic. Natl. Acad. Sci., Washington, DC, pp 332.

Nickson, R. T., McArthur, J. M., Burgess, W., Ahmed, M., Ravenscroft, P. and Rahman, M. (1998). Arsenic poisoning of groundwater in Bangladesh. Nature, **395**, 338.

Nickson, R. T., McArthur, J. M., Ravenscroft, P., Burgess, W. and Ahmed, K. M. (2000). Mechanism of arsenic release to groundwater, Bangladesh and West Bengal. Appl, Geochem., **15**, 403–413.

Norra, S., Berner, Z. A., Agarwala, P., Wagner, F., Chandrasekharam, D. and Stuben, D. (2005). Impact of irrigation with As rich groundwater on soil and crops: A geochemical case study in West Bengal Delta Plain, India. Appl. Geochemistry, **20**, 1890–1906.

NRCC, (1978). Effects of arsenic in the Canadian environment. Natl. Res. Coun. Canada Publ. no. NRCC, 15391, pp 349.

Nriagu, J. O. and Pacyna, J. M. (1988). Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature, **133**, 134-139.

Pongratz, R. (1998). Arsenic speciation in environmental samples of contaminated soil. Sci. Total Environ., **224**, 133-140.

Reuther, R. (1992). Geo-chemical mobility of arsenic in a flow-through water-sediment system. Environ. Technol., **13**, 813-823.

Roychowdhury, T., Uchino T., Tokunaga, H. and Ando, M. (2002). Survey of arsenic in food composites from arsenic affected area of West Bengal, India. Food Chem. Toxicol., **40**, 1611–1621.

Sadiq, M. (1997). Arsenic chemistry in soils: an overview of thermodynamic predictions and field observations. Water Air Soil Pollut., **93**, 117-136.

Saha, G. C. and Ali, M. A. (2007). Dynamics of arsenic in agricultural soils irrigated with arsenic contaminated groundwater in Bangladesh. Sci, Total Environ., **379**, 180–189.

Sancha, A. M. (1999). Full- scale application of coagulation processes for arsenic removal in Chile: a successful case study. In: Chappell WR, Abernathy CO, Calderon RL (eds.) Arsenic exposure and health effects. Elservier Amsterdam, 87-96.

Schoof, R. A., Yost, L. J., Eickhoff, J., Crecelius, E. A., Cragin, D. W., Meacher, D. M. and Menzel, D. M. (1999). A market basket survey of inorganic arsenic in food. Food Chem. Toxicol., **37**, 839–846.

Seyler, P. and Martin, J. M. (1991). Arsenic and selenium in a pristine river-estuarine system: the Krka, Yugoslavia. Mar. Chem., **2**, 277-294.

Smedley, P. L. and Kinniburgh, D. G. (2002). A review of the source, behaviour and distribution of arsenic in natural waters. Appl. Geochemistry, **17**, 517-568.

Smedley, P. L. (2003). Arsenic in groundwater – South and East Asia. In: Welch AH, Stollenwerck KG (eds). Arsenic in Groundwater.Geochemistry and Occurrence. Dordrecht, 179–210.

Smith, E., Naidu R. and Alston, A. M. (1998). Arsenic in the soil environment: A review. Adv Agronomy, **64**, 149-195.

Stuben, D., Berner, Z., Chandrasekharam, D. and Karmakar, J. (2003). Arsenic enrichment in groundwater of West Bengal, India: geochemical evidence for mobilization of As under reducing conditions. Appl, Geochem., **18**, 1417–1434.

SEPA, (1999). Swedish Environmental Protection Agency Bedomningsgrunder for miljokvalitet: Grundvatten. Naturvardsverket rapport 4915, Naturvardsverket forlag, Uppsala.

Tsutsumi, M. (1980). Intensification of arsenic toxicity to paddy rice by hydrogen sulphide and ferrous iron I. Induction of bronzing and iron accumulation in rice by arsenic. Soil Sci, Plant Nutr., **26**, 561–569.

Turpeinen, R. R., Panstar-Kallio, M., Haggblom, M. and Kairesalo, T. (2002). Role of microbes in controlling the speciation of arsenic and production of arsines in contaminated soils. Sci. Total Environ., **285**, 133-145.

Turpeinen, R. R., Panstar-Kallio, M., Haggblom, M. and Kairesalo, T. (1999). Influence of microbes on the mobilization, toxicity and biomethylation of arsenic in soil. Sci. Total Environ., **236**, 173-180.

Uddin, M. K. (1998). Arsenic contamination of irrigated sols, groundwater and its transfer into crops in some areas of Bangladesh. MSc. Thesis. Department of Soil, Water and Environment, University of Dhaka, Dhaka 1000, Bangladesh.

UNEP, (2000). United Nations Environment Program, Global Environment Outlook 2000. Earthscan , UK.

Wasay, S. A., Parker, W., Van Geel, P. J., Barrington, S. and Tokunaga, S. (2000). Arsenic pollution of a loam soil: retention form and decontamination. J. Soil Contamin, **1**, 51-64.

Wenzel, W. W., Brandstetter, A., Wutte, H., Lombi, E., Prohaska, T., Stingeder, G., Adriano, D. C. (2002). Arsenic in field-collected soil solutions and extracts of contaminated soils and its implication to soil standards. J. Plant Nutr. Soil Sci., **165**, 221-228.

WHO, (2001). Arsenic and arsenic compounds, second ed. IPCS Environmental Health Criteria Document 244. International Program on Chemical Safety, WHO, Geneva.

Williams P. N., Islam M. R., Adomokao, E. E., Raab, A., Hossain, S. A., Zhu, Y. G., Feldman, J. And Mehrag, A. A. (2006). Increase in rice grain arsenic for regions of Bangladesh irrigating paddies with elevated arsenic in groundwaters. Environ. Sci. Technol., **40**, 4903-4908.

Xie, Z. M., Huang, C. Y. (1998). Control of arsenic toxicity in rice plants grown on an arsenic-polluted paddy soil. Soil Sci. Plant Anal., **29**, 2471–2477.

Xiong, X. Z., Li P. J.,Wang, Y.S., Ten, H., Wang, L. P. and Song, S. H. (1987). Environmental capacity of arsenic in soil and mathematical model. Huanjing Kexue, **8**, 8-14.