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Arsenic Contamination in Irrigation Water for Rice Production in Bangladesh: A Review

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ABSTRACT

About 150 million people are exposed to Arsenic contamination in the World with the largest percentage coming from Asia especially Bangladesh and West Bengal, India. Also, an estimated 30 million people drink water from Arsenic-contaminated Shallow Tube Wells (STWs) and approximately 900,000 STWs are used in irrigating 2.4 million out of 4 million ha under irrigation in Bangladesh, mainly paddy fields. This has led to the accumulation of As in paddy soils and potentially have adverse effects on rice yield and quality. The present study reviews the damaging effects of As-contaminated irrigation water in rice production especially in South and South East Asia. The study highlights the causes of arsenic contamination in irrigation water, health and dietary hazards of rice consumers and its derivatives. The study suggested remedial measures from aerobic rice production to Phytoremediation for mitigating Arsenic contamination in food especially, As-free rice production and sustainable livelihoods.

Key words: Arsenic toxicity, contamination, rice, irrigation, groundwater

INTRODUCTION

Arsenic (As) pollution in groundwater has been reported in over 70 countries and population of about 150 million people worldwide with heavy concentration discovered in 10 countries in south and south-east Asia namely, Bangladesh, Cambodia, China, India, Laos, Myanmar, Nepal, Pakistan, Taiwan and Vietnam with over 110 million people living in these areas have serious health hazards due to their dependence on As-contaminated water for drinking and irrigation purposes (Stroud *et al.*, 2011; Brammer and Ravenscroft, 2009). Fendorf *et al.* (2010) also added that groundwater in these regions contained microbial pathogens than surface water and more often contained appreciable hazardous amounts of arsenic, a known carcinogen. The most severe effects have been found in Bengal Delta region in Bangladesh and West Bengal, India where the groundwater has been widely developed to supply drinking and irrigation water (Duxbury and Panaullah, 2007). An estimated 30 million people drink water from Arsenic-contaminated Shallow Tube Wells (STWs) and approximately 900,000 STWs are used in irrigating 2.4 million out of 4 million ha under irrigation in Bangladesh, mainly paddy fields. Also, about 95% of the groundwater extracted is used for irrigation (Duxbury and Panaullah, 2007). Reports indicated that the problem originated from the arsenic-rich bedrock of the Brahmaputra river basin that filters drinking water pumped to the surface through millions of tube wells (FAO, 2006). In addition to drinking water health risks, it was also reported that high concentration of arsenic enters the food chain via absorption by crops from roots to straw and grain contaminated from irrigated water. It was also estimated that water pumping from shallow aquifers for irrigation adds one million kilogram of arsenic per year to the arable soil in Bangladesh, mainly in the paddy fields (FAO, 2007). Since rice is a staple food in Bangladesh which is consumed in large quantities, despite lower yield when compared with other rice-producing countries in Asia (Salam and Kato-Noguchi, 2010), its contamination with arsenic could potentially aggravate As-polluted drinking water. This if not checked poses potential risk from dietary exposures and on the long run reduces rice yield. Rouhi (2005) reported that Arsenic in U.S. rice is predominantly organic (58% by composition) and by contrast small when compared with arsenic in rice from Europe, Bangladesh and India which is primarily inorganic (64, 80 and 81%, respectively). Inorganic arsenic is known to be far more toxic than organic species. Young-Son (2010) and Suriyan *et al.* (2005) remarked that apart from Arsenic contamination which retard growth, temperature-induced salt-tress slowed down the germination rate, especially of red rice and also inhibits its development.

Rice constitutes one of the most important staple foods of over half of the world's population. Globally, it ranks third after wheat and maize in terms of production (Bandyopadhay and Roy, 1992). It is a member of genus *Oryza* in the grass family (Gramineae) consisting of 22 species in the genus of which only two are cultivated: *O. sativa* and *O. glaberrima* (Bounphanousay *et al.*, 2008). It is one of the most important cereal crops, with over 170 million ha under cultivation globally and grown in wide range of climatic zones (Singh *et al.*, 2011). At the current growth of population, rice requirement increases dramatically and many nations are facing second-generation challenge of producing more rice at less cost in a deteriorating environment, hence it is challenging task to ensuring food and nutritional security (Tiwari *et al.*, 2011). Future global rice production could be increased by efforts to increase rice production area or increase yield or combination of both (Mitra *et al.*, 2005). Bangladesh is ranked among the top ten leading producing countries globally (The country is ranked 4th after China, India and Indonesia going by recent statistics) (Akinbile *et al.*, 2011). It has been reported by several researchers that rice grown in Bangladesh, the world's hot spot for arsenic poisoning, contains about 80% inorganic arsenic and people there eat 450 g daily (Potera, 2007). In Bangladesh more than 80% of the districts have arsenic levels exceeding the World Health Organization guideline value for arsenic contamination in drinking water (10 $\mu g\ L^{-1}$) (Smith *et al.*, 2006). Although Ahuja (2009) reported that Arsenic in rice varied widely, he however gave more frightening information about Bangladesh rice that it contained more than As(III) but with traces of DMAA and As(V) and that more than 80% of the recovered As were in inorganic form. It was also reported that more than 85% of Arsenic in rice is bioavailable, compared to only about 28% of arsenic in leafy vegetables such as arum (kochu), gourd leaf, *Amaranthus* and *Ipomea* (kalmi) which has been found to act as arsenic accumulators in recent study Ahuja (2009).In other words, rice is a more efficient As accumulator than any other cereal crop (Stroud *et al.*, 2011). Midrar-ul-Haq *et al.* (2005) reported that among many other factors responsible for heavy metal such as Arsenic contamination in soils are long term usage of sewage or effluents for irrigation purposes which in turn will have adverse effects on plants, animals and human health. Bangladesh was referenced mostly in this study due to the availability of results of recent studies on the subject matter. The study, therefore examined the implications of Arsenic-contaminated irrigation water on rice production, soil and the probable remedial strategies to reduce as concentration with minimal effects on rice yields.

ARSENIC AND ITS OCCURRENCE

Arsenic is a crystal-shape metalloid element which is brittle in nature and grayish white in color. As is a naturally-occurring poisonous chemical element and always occurs as compounds with

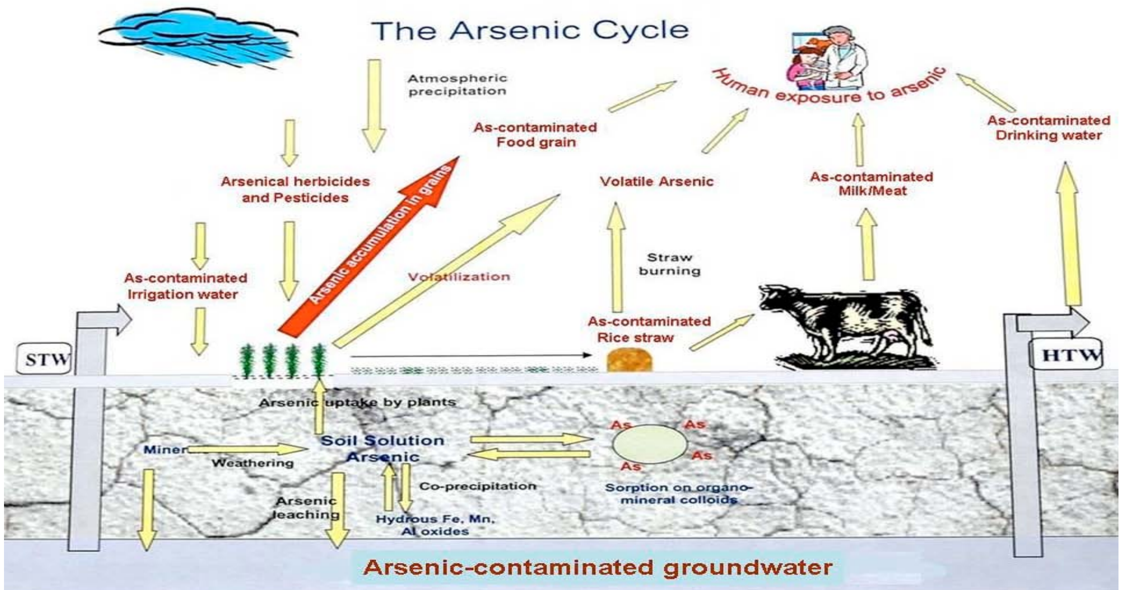

Fig. 1: The arsenic cycle in soil-water-plant interfaces (adopted from DPHE, 2000)

others. It is widely distributed in the soil profile as component of minerals and found in nominal amounts in all organisms. As can be found as a compound of oxygen, chlorine, sulfur, carbon, hydrogen, lead, mercury, gold and iron. There are as many as 150 species of arsenic-bearing minerals that exist on the earth. However, only few of them are considered as arsenic ore, because the amount of arsenic is higher in these compounds and also they are more available. These compounds are: realgar or arsenic disulphide (AsS), orpiment or arsenic trisulphide (As_2S_3) and arsenopyrite or ferrous arsenic sulphide (FeAsS). Arsenopyrite has been primarily identified as the main source of arsenic pollution in Bangladesh. The arsenic cycle in soil-water-plant interfaces is presented in Fig. 1.

Arsenic contamination has been reported from many parts of the world but in terms of severity of the problem, Bangladesh tops the list, followed by India and China Nordstrom (2002). Arsenic is considered to be a dangerous environmental pollution and a serious health hazard. Some of the arsenic-polluted countries with affected population and the cause of the pollution are shown in Table 1.

Chemically, arsenic compounds are of two types-inorganic and organic. Inorganic arsenic is more toxic (≈10 times) than organic. Inorganic arsenic has again two natural ionic forms-trivalent and pentavalent. The trivalent arsenic (Arsenite, As(III)) is more mobile and toxic (40-60 times) than the pentavalent arsenic (Arsenate, As (V)). As(III) has higher ability to form complex with coenzymes in human and animals. Usually, two types of inorganic arsenic compounds (arsenite-H_2AsO_3 and arsenate-H_2AsO_4) and two types of organic arsenic compounds (methyl arsenic acid-$CH_3AsO_3H_2$ and dimethyl arsenic acid-$(CH_3)_2AsO_2H$) exist in water. Inorganic Arsenite and Arsenate are commonly found in Bangladesh groundwater (Chappell *et al.*, 1999). Exposure to such high levels of acute arsenic poisoning is very unlikely. However, long-term exposure to very low arsenic concentrations in drinking water is also a health hazard (UN, 2001; WHO, 2001; Ahmed, 2003; UNICEF, 2006).

Table 1: Some arsenic-polluted countries with population affected and cause of pollution

Country	Year	Population affected by arsenic	Maximum range of pollution (mg L^{-1})	Main cause of pollution
Argentina	1938-1981	20,000	0.1-2.0	Natural soil pollution
Mexico	1963-1983	200,000	0.1-0.5	Oxidation of arsenic bearing minerals
Chile	1957-1969	130,000*	0.8-1.3	Rive cutting through arsenic bearing formation
USA	1972-1982	3,000,000*	0.045-0.092	Oxidation of pyrite, Reduction of ferric oxide, etc.
Taiwan	1961-1985	100,000	>0.05	Oxidation of pyrite
Mongolia	1962-1989	1,774	>0.05	Over-irrigation
Thailand	1987-1998	18,000*	0.05-5.0	A tin mine
Philippines	1992-1995	39	-	Geothermal power plant
China	1953-1993	1,546	-	Use of coal as fuel
Japan	1945-1995	217	-	Metal and coal mine
India	1978-1998	200,000	0.05-3.7	Over-exploitation of groundwater (pyrite oxidation)
Bangladesh	1993-2005	30,000,000*	0.052-4.727	Over-exploitation of groundwater (pyrite oxidation) or arsenic released under reducing condition

*Population at risk, actual affected is unknown, -: Data not available, Source: Haque *et al*. (2007)

ARSENIC CONTAMINATION AND EXTENT OF DAMAGE IN BANGLADESH

The Department of Public Health Engineering (DPHE) of Bangladesh first detected Arsenic in groundwater in 1993 and the issue came to limelight at the beginning of 1995 (Nickson *et al*., 1998). After that, many government and non-government organizations started working on the problem. Among them, Dhaka Community Hospital (DCH); School of Environmental Studies (SES) of Jadavpur University, India; British Geological Survey (BGS); UNICEF; World Vision; Water Partnership Program (WPP) and DANIDA (official Danish aid agency) are worthy of mention here. For every organization, the first job was to identify the arsenic-contaminated wells. High levels of arsenic in well water are causing widespread poisoning in Bangladesh. In a typical aquifer in southern Bangladesh, chemical data imply that arsenic mobilization is associated with recent inflow of carbon (Harvey *et al*., 2002). According to WHO, the safe limit of arsenic in drinking water is 0.01 mg L^{-1} however, the maximum permissible limit for Bangladesh and India at 0.05 mg L^{-1}. Sophisticated laboratory facilities are required to accurately detect arsenic in groundwater, but the facilities are very limited in terms of resources and costs in Bangladesh. Therefore, most organizations used field-kit method for As-detection. Field-kit can identify the presence of arsenic with concentration level >0.05 mg L^{-1}. It is a Yes-No type field instrument and cannot detect arsenic with reliability if the concentration is <0.2 mg L^{-1}. Erickson (2003) suggested that field kits used to measure As in the regions' groundwater are unreliable and that many wells in Bangladesh have been labeled incorrectly. To assess the magnitude of As contamination, the World Bank, UNICEF, WHO and several other international aid agencies made a joint decision 1997 to test all hand pumped tubewells using colorimetric field kits. After that more than million of wells were tested in Bangladesh and labeled with red (>0.05 mg L^{-1}) and green (<0.05 mg L^{-1}) color respectively. However, Rahman *et al*. (2002) questioned about accuracy and precision of the above methods of test and found that 45% of wells were mislabeled with the observation of a technique called flow injection hydride generation atomic absorption spectroscopy (FI-HG-AAS). Moreover, As-contamination level changed with time and it was found to become higher in which previously indicated as low level (Erickson, 2003). Population exposed to As poisoning through drinking water is about 36 million. It is suspected that over 0.2 million people are suffering from arsenic-related diseases, ranging from melanosis to skin cancer and gangrene. So far, about 38,000 As-patients are

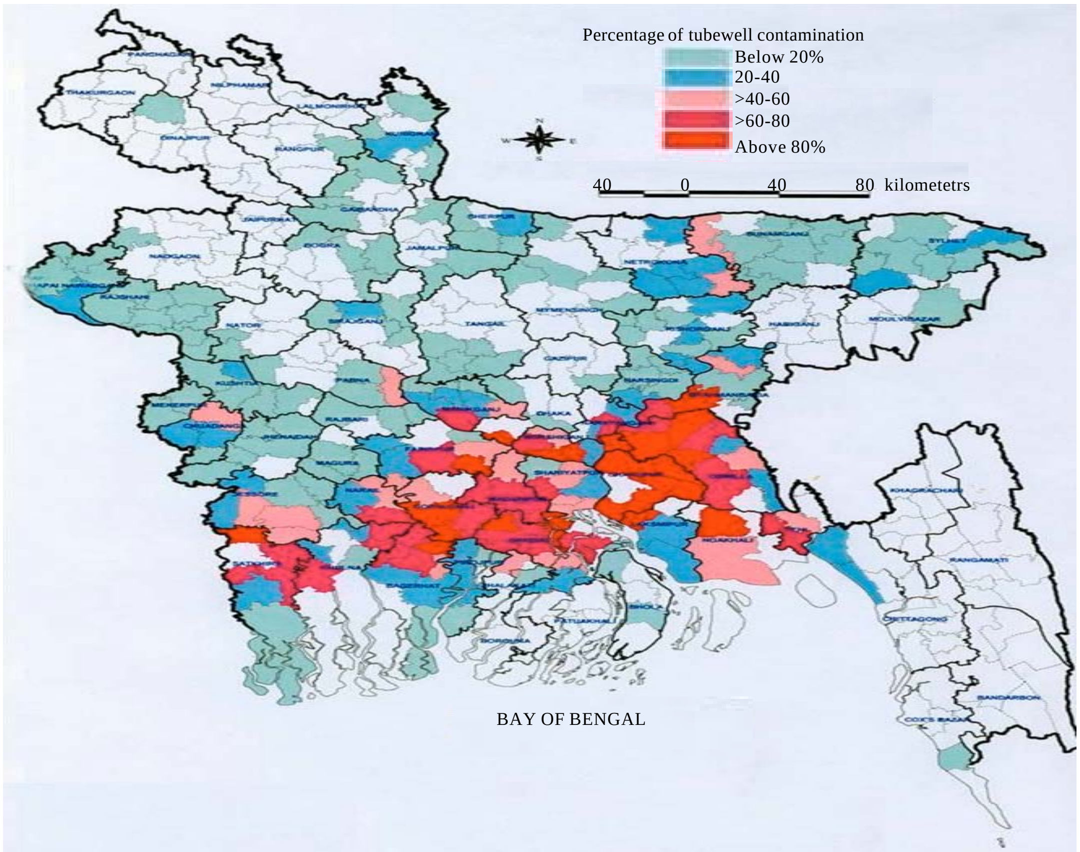

Fig. 2: Arsenic contamination in Bangladesh (adopted from BGS, 2000) and culled from Haque *et al*. (2007)

clearly identified and it is predicted that 0.20-0.27 million people will die of cancer from drinking As-contaminated water and foods in Bangladesh alone (Meharg and Rahman, 2002).

Bangladesh is a small South Asian country (area 147,570 km^2) with a very high population (140 million) located between 20°34' and 26°38' North latitude and 88°01' and 92°41' East longitude. Except for the hilly regions in the north-east and south-east, some areas of high lands in the north and northwestern part, the country consists of low, flat and fertile land (Azad *et al*., 2005). To feed huge population from limited cultivable land (8.3 million hectares), it has to adopt intensive irrigated agricultural products. Therefore, it has about 1,129,000 Shallow Tubewells (STW) and 27,000 Deep Tubewells (DTW), lifting groundwater for irrigation purpose. Using all these pumps, about 13,000 Million Cubic Meters (MCM) of water is pumped every year from the underground water sources. Over 90% of all groundwater extraction is used in irrigation purpose (Bangladesh Bureau of Statistics, 2004).

More than 60% of the country is contaminated with arsenic, with more contamination in southern districts (Fig. 2). Concentrations of As exceeding 1.0 mg L^{-1} of water in shallow tubewells were reported from 17 districts in Bangladesh. The badly-affected districts are Chandpur, Comilla, Noakhali, Feni, Munshiganj, Brahmanbaria, Faridpur, Madaripur, Laksmipur, Gopalganj,

Table 2: Percent of arsenic-contaminated tubewells in 61 districts, affected area and population under the contamination (BGS, 2000; Fazal *et al*., 2001)

Wells contaminated (%)	No. of districts	Percent area (%)	Percent population (%)
<1	9	15.85	17.00
1~25	30	42.81	46.39
26~50	18	27.25	29.42
> 50	4	5.36	6.27

Shariatpur, Narayanganj, Sariatpur, Madaripur, Narail, Satkhira and Chapi-Nawabganj (Table 2). High levels of As have also been found in isolated 'hot-spots' in the South-Western, North-Western, North-Eastern and North-Central region of the country (Huq *et al*., 2006). The Ganges, Megna and Atri rivers floodplains, the tidal regions and coastal plains are the physiographic regions vulnerable to arsenic contamination. In general, where iron (Fe) concentration is higher, As-concentration is also found to be higher. Historically, surface (river or pond) and dug well water has been used as drinking water in Bangladesh. Due to water related diseases, resulting from bacterial contamination of water caused severe infant and child mortality. To overcome this problem through drinking safe water, UNICEF had started installing Hand Tubewells (HTW) across the country since 1970s and 1980s. Presently, Bangladesh has about 8.6 million Hand Tubewells (HTW), supplying drinking water from groundwater sources to >95% of 140 million people. The supply of pure drinking water has been one of the few success stories in the public health care. This helped reduce the water-borne diseases, while in mid 1990s; detection of arsenic in groundwater became a new issue to the nation. In 2006, UNICEF reported that 4.7 million (55%) of the 8.6 million wells in Bangladesh had been tested for arsenic of which 1.4 million (30% of those tested) had been showing them to be unsafe for drinking water: defined in this case as >0.05 mg L^{-1}. Although many people have switched to using arsenic free water where arsenic had been identified (51%), while no action had yet been taken by 34% of the peoples in contaminated areas in Bangladesh (UNICEF, 2006). In 2000, a WHO report (Smith *et al*., 2000) described the situation in Bangladesh as: "the largest mass poisoning of a population in history ... beyond the accidents at Bhopal, India, in 1984 and Chernobyl, Ukraine, in 1986."

RICE PRODUCTION IN BANGLADESH

Bangladesh is the World's 4th largest producer of rice with an annual production of over 47 million tonnes (Akinbile *et al*., 2011). Since Arsenic-polluted water is being used majorly for its production, the effect on yield reduction is tremendous due to As intake by the rice crop. Meharg *et al*. (2009) reported that about 80% inorganic arsenic contamination in rice was reported in Bangladesh which is far more toxic than organic species. This was in sharp contrast to 58% Arsenic in U.S. rice, 64% in rice from Europe and 81% contamination in rice from India. However, basmati rice imported from India and Pakistan and jasmine rice from Thailand were found to contain the least arsenic (Meharg *et al*., 2009). It has been widely reported that by Islam *et al*. (2005), Delowar *et al*. (2005) and Bhattacharya *et al*. 2009 that rice accumulates up to 2.0 mg kg^{-1} which is much above the permissible limit of 1.0 mg kg^{-1}, according to the WHO recommendation. Meharg and Rahman (2002) concluded that the average contribution to total arsenic intake from drinking water was 13%, whereas from cooked rice, it was 56%, thus making it clear that rice contributed most to the daily arsenic intake.

Arsenic has been detected in different food items. Long-term use of arsenic-contaminated groundwater to irrigate crops, especially paddy rice (*Oryza sativa,* L.), has resulted in elevated soil

Fig. 3: Effect of arsenic-contaminated irrigation water on rice growth stages and yield with different level of arsenic concentration (Personal collection from M. Harun-ur-Rashid, BARI)

Table 3: Effect of arsenic-contaminated irrigation water on the agronomic parameters of rice (adopted from Abedin *et al*., 2002)

As conc. ($mg L^{-1}$)	Plant height (cm)	Tiller No.	Root weight ($g pot^{-1}$)	Straw weight ($g pot^{-1}$)	Grain No.	Grain weight ($g pot^{-1}$)	1000 grain weight (g)
0	107	5.7	2.36	17.1	166	3.23	19.49
1	97	7.0	2.04	17.6	128	2.49	19.48
2	99	5.7	1.99	15.5	106	1.94	18.30
4	91	6.3	1.87	15.2	80	1.44	18.04
8	87	4.7	1.69	12.1	68	1.25	18.50

arsenic levels in Bangladesh. A green house (pot) study result presented in Table 3 which showed that use of arsenic-contaminated irrigation water decreased seed germination and rice yield, reduced plant height and affected development of root growth Fig. 3 (Abedin *et al*., 2002).

The study results also revealed that the arsenic concentration in rice plant parts increased with the increase of As concentration in irrigation water (Fig. 4). However, the remarkable shielding of rice grains from the build-up of As in soil and soil water of paddies irrigated with groundwater is consistent in different studies. The health risks due to ingestion of As contained in rice therefore appear to be dwarfed in countries such as Bangladesh (Van Geen *et al*., 2006). Moreover, several studies observe that rice (*Oryza sativa,* L.) in different growth stages accumulates As in different levels but at maturing stage uptakes highest amount significantly than at other stages (Fig. 4) (Wang *et al*., 2006). Percent of rice seed germination over control decreased significantly with the increasing concentrations of arsenite (As-III) and arsenate (AS-V) and found that arsenite was more toxic than arsenate for rice seed germination (Abedin *et al*., 2002). The impact of using contaminated irrigation water from shallow tubewells indicted the entry of As into human food chain, animal food chain, effect on soil quality particularly microbiological functioning and nutrients uptake for production (Hossain, 2006).

IRRIGATION WATER POLLUTION BY ARSENIC CONTAMINATION

Contamination of shallow groundwater aquifers with Arsenic has been reported in over 20 countries around the world (Nordstrom, 2002) but is most serious in the Bengal Delta region of

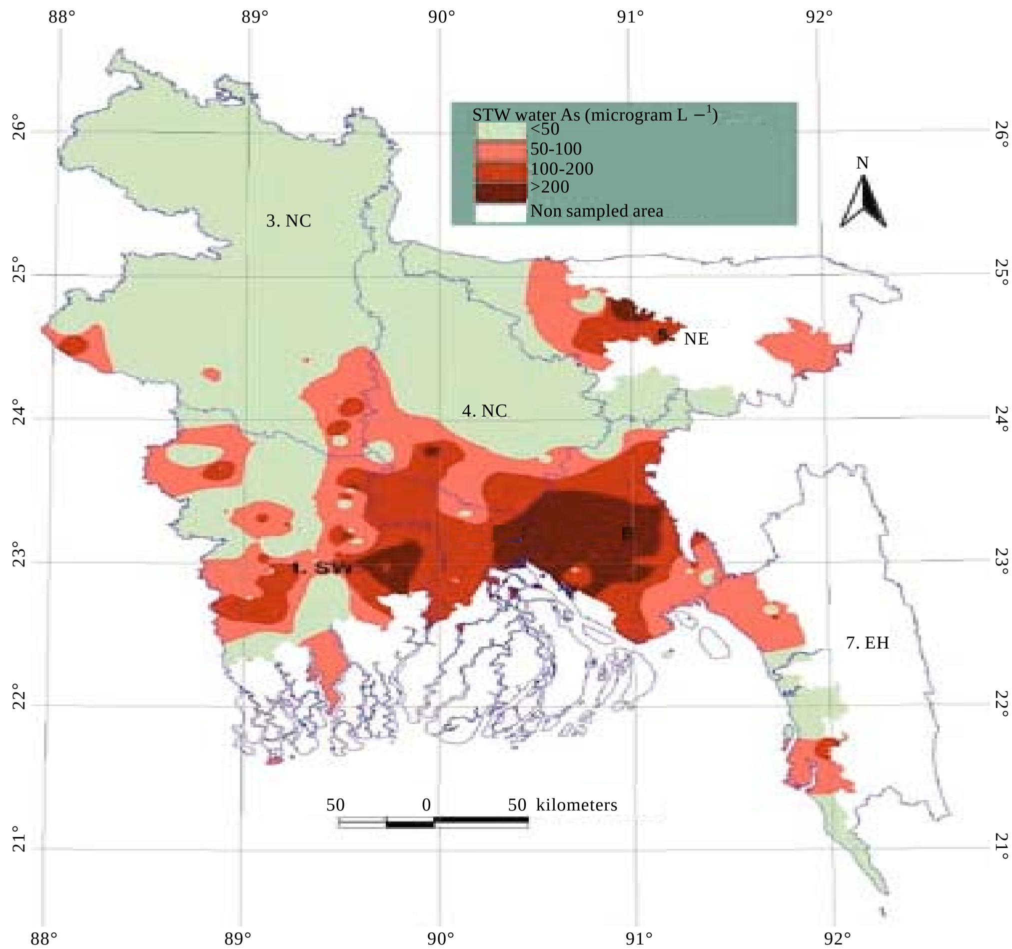

Fig. 4: Kriged map of irrigation water As content in shallow tubewells

Bangladesh and West Bengal, India where the groundwater has been widely developed to supply drinking and irrigation water (Ali *et al*., 2003). The highest irrigation water As levels were found in the south central and south east regions of Bangladesh. Figure 4 showed the map for As in irrigation water in the country (Duxbury and Panaullah, 2007). Groundwater in nine out of eighteen districts of West Bengal has been contaminated with Nadia district as the most affected in terms of arsenic concentration and area of coverage (Bhattacharya *et al*., 2009). Dahal *et al*. (2008) also established the significant presence of As-contaminated irrigation water on alkaline soils and As uptake in agricultural plants at field level in Nepal. He concluded his study by giving the mean arsenic content of edible plant material (dry weight) in the order of onion leaves (0.55 mg As kg^{-1}>onion bulb (0.45 mg As kg^{-1}>cauliflower (0.33 mg As kg^{-1}>rice (0.18 mg As kg^{-1}>brinjal (0.09 mg As kg^{-1}>potato (<0.01 mg As kg^{-1} indicating that in Nepal, onion leaves had highest and rice (fourth in order of concentration) As uptake.

From the map, Boro season (a term used to describe winter dry-season, flood irrigated rice in Bangladesh and vicinity) rice is exposed to As from both soil and irrigation water, while monsoon T. Aman rice (a term used to describe summer monsoon, rain-fed, flooded, transplanted rice) is exposed to the natural soil arsenic in addition to any build up of As over time due to the use of contaminated irrigation water. With these reported cases of arsenic contamination of rice fields, the transfer of arsenic both from the contaminated soil and irrigation water has a very high possibility (Bhattacharya *et al*., 2009). Several researchers (Khan *et al*., 2010; Panaullah *et al*., 2009; Islam *et al*., 2005) had reported the gradual transfer of Arsenic in irrigation water from contaminated shallow tube-wells to the soils, where it was potentially available for uptake by plants. It was reported by Roberts *et al*. (2007) that over 1000 tons of As is transferred to arable land each year from irrigation with As contaminated groundwater in Bangladesh. However, As accumulation in irrigated paddy soils and its transfer into rice can vary depending on the soil type, crop, background-As concentration, As concentration of irrigation water, distance from pumping source, depth and duration of flooding (Khan *et al*., 2010). Long term use of arsenic contaminated groundwater for irrigation purposes may result in further increase in arsenic concentration in agricultural soil and eventually led to hyper-accumulation in crops, including rice (Bhattacharya *et al*., 2009; Nahar, 2009). Although, Harvey *et al*. (2002) identified that irrigation pumping was sufficient to have drawn water to the depth where dissolved arsenic is at a maximum, (Stokstad, 2002) reported that pumping for irrigation might be at least partly to blame for the poisoned water, although the finding is controversial. He suggested the need for deeper drinking-water wells beyond pollution levels in As-contaminated regions. Also, Van Geen *et al*. (2003) believed that increased irrigation over the past 25 years is unlikely to have caused widespread arsenic mobilization in Bangladesh groundwater, thereby supporting Stokstad (2002) views.

Also, Khan *et al*. (2009) concluded in his study that increasing As-contaminated irrigation water on rice crop resulted in increase in soil As-status of all the soils. This was demonstrated by Islam *et al*. (2005) who concluded that a 0.10 mg As L^{-1} in irrigation water to *Boro* rice would result in a corresponding increase of 0.50 mg kg^{-1} $year^{-1}$ of As in the rice field. Similarly, Meharg and Rahman (2002) reported that if the field is irrigated with 0.1 mg As L^{-1} water, soil As will increase by 1 mg kg^{-1} per year. Garnier *et al*. (2010) further reported that between 0.2-0.4 mg kg^{-1} As is deposited in paddy rice irrigated with As-contaminated groundwater. The implications of the high retention of As applied in irrigation in the soil surface is reflected on the systematic yield reduction and soil nutrient depletion over the years. In the study conducted recently by Bangladesh Consortium for Arsenic Management in Agriculture and the Environment (BCAMAE), it was established that reduced groundwater was rapidly oxidized after discharge from the well causing precipitation of amorphous Fe and Mn oxides (Fig. 5) with concomitant adsorption and co-operation of As and P (Duxbury and Panaullah, 2007). The rapid re-oxidation of water coupled with the largely field to field water distribution method used in the command area raised soil As levels considerably. Zhao *et al*. (2010) also reported that rice plants take up arsenate through the phosphate transporters and arsenite and undissociated methylated As-species through the nodulin 26-like intrinsic (NIP) aquaporin channels. Arsenate is readily reduced to arsenite in planta which is detoxified by complexation with thiol-rich peptides such as phytochelatins and/or vacuolar sequestration. These views were corroborated by Roberts *et al*. (2010) from the study of floodwater for rice irrigation in Bangladesh. Safiuddin and Karim (2001) remarked that the groundwater in Bangladesh had declined progressively over the years due to the excessive extraction of water for irrigation and other uses, lack of water management structures and inadequate recharge of the aquifers. This, according to the researchers led to the creation of aeration zone in clayey and peaty sediments containing aresnopyrite. The oxidation of arsenopyrite was responsible for groundwater

Fig. 5: Irrigation water discharging from pump into concrete channel, showing orange Fe oxide deposition as water oxides (Source: Duxbury and Panaullah, 2007)

arsenic contamination in Bangladesh, thereby leading to pollution of irrigation water. Yield reduction therefore in rice as a result of long term use of As-contaminated irrigation water. Most of the studies on As-contaminated water for irrigation will result in the accumulation of As in soil which has long-term implications to agricultural productivity, agricultural sustainability and food quality.

TOXICITY IMPLICATIONS OF RICE PRODUCED FROM AS-CONTAMINATED IRRIGATION WATER

Several studies previously carried out, including mass balance exercise, indicated that the As added through irrigation water was almost quantitatively retained in the soil (Rahman *et al*., 2008; Panaullah *et al*., 2009) which is in sharp contrast with reports of Dittmar *et al*. (2007) and Huq *et al*. (2006) which suggested that soil-As concentration increased with groundwater irrigation in the winter (*Boro*) season but declined during summer monsoon. However, the long-term use of STW has left its chemical imprint on the soil, indicating that irrigation with As-contaminated irrigation was has led to loading of As (Fe, Mn and P) to the soil (Panaullah *et al*., 2009). This is contrary to the views of Van Geen *et al*. (2006) who suggested 'modest if any' impact of the As content of irrigation water on rice crop. Lu *et al*. (2009) reported that further addition of arsenic from irrigation water only leads to gradual increase in grain arsenic concentration. This view was supported by Rahman *et al*. (2007), Rahman *et al*. (2009) from their research findings on arsenic uptake by rice. Rahman *et al*. (2008) also reported that average rice consumption between 400 and 650 g day^{-1} by typical adults in the arsenic-affected areas of Bangladesh and therefore arsenic intake through rice stood at 0.20-0.35 mg day^{-1}. Also, with a daily consumption of 4 L drinking water, (Rahman *et al*., 2008) remarked that arsenic intake through drinking water stood at 0.2 mg day^{-1}. The WHO (2006) in its situation assessment report had consistently maintained that

Fig. 6(a-f): Arsenic affected diseases in human body (a) Melanosis-palm (b) Melanosis-body (c) Keratosis-sole (d) Keratosis-palm (e) Gangrene-foot-toe and (f) Gangrene-head (culled from Haque *et al*., 2007)

the maximum permissible arsenic level in water of 0.01 mg L^{-1} was only provisional in view of scientific uncertainties and that due to the toxicity nature, 1 of 100 people who consumed As-infected rice for a long period may eventually die from arsenic related cancers. The world body also opined that drinking of As-contaminated water exceeding 0.05 mg L^{-1} for a similarly long period may result in death. All these clearly demonstrate the toxicity nature of As if ingested by humans in any form whether in drinking water or food already contaminated by it. Sengupta *et al*. (2006) in his study reported varying degrees of As concentrations in raw and cooked rice using different methods. A similar study was conducted by Smith *et al*. (2006) on As responses to cooking using freshwater and As-contaminated water. Despite heavy reduction of Arsenic in the two studies by about 57%, it still underlined the fact that the remaining As in the rice poses considerable health risk to the consumers. Continuous consumption of As-infected rice leads to all manner of skin diseases and cancer in liver, lung, bladder, kidney and skin while consumption of rice straw by cattle could potentially increase arsenic levels in meat and/or milk by which there is a further risk arsenic entrance into human bodies (Bhattacharya *et al*., 2009). Chronic arsenic exposure causes a characteristic pattern of dermal effects that might start with melanosis (pigmentation) to keratosis and hyperkeratosis while it was also observed that drinking water with more than 300 µg L^{-1} arsenic for several years may cause arsenical skin lesions (Fig. 6) (Ahamed *et al*., 2006). Panaullah *et al*. (2009) further stressed the detrimental impact on animal health and quality of animal products due to rice straw consumption grown by As-contaminated irrigation water. According to the findings of (Rahman *et al*., 2008), the rice plant grown in 60 mg of As kg^{-1} soil, arsenic concentrations in rice straw would be 20.6±0.52 at panicle initiation stage and 23.7±0.44 at maturity stage, whereas it was 1.6±0.20 mg kg^{-1} in husk. Manure, used as fertilizer to other crops including rice and also used as a kitchen fuel, provides additional route for human exposure to Arsenic ingestion (Pal *et al.*, 2007). Other crops grown in fields irrigated with As-contaminated groundwater can contain significantly higher levels of As than rice (Das *et al.*, 2004) but no independent research to our knowledge has been conducted to establish a direct relationship between the elevated levels of As content of irrigation water to these other crops. The significant consequence of continued build-up of As in soil and rice crop from irrigation water is reduction in crop yields (Van Geen *et al.*, 2006). Also, increased exposure of children to As-contaminated fields, especially playing with sand and other form of direct contacts with sand during dry season have considerable impact on their mental development, brain impairment was reported by Wasserman *et al.* (2004). Rahman *et al.* (2008) therefore put forward a hypothesis to elucidate the food chain pathways through which arsenic may enter into human body.

STRATEGIES FOR RICE REMEDIATION IN ARSENIC CONTAMINATED IRRIGATION WATER

Having identified the negative implications of As contaminated irrigation water on rice production, especially in Asia, several management strategies have been suggested to reduce the impacts, sustain rice production increase and ensure sustainable livelihoods in Arsenic endemic areas. Practical measures are needed to mitigate the problem of excessive As accumulation in paddy rice. Zhao *et al.* (2010) proposed a range of mitigation methods, from agronomic measures and plant breeding to genetic modification, necessary to reduce As uptake by food crops. Mitigation of the resulting health crisis in South and Southeast Asia requires an understanding of the transport of arsenic and key reactants such as organic carbon that could trigger release in zones with presently low groundwater arsenic levels (Fendorf *et al.*, 2010). Carbonell-Barrachina *et al.* (2009) remarked that while workable solutions to remove As from water and breeding rice cultivars with low As accumulation are being sought, simple recommendations for processing and cooking foods will help to reduce As intake. Part of the recommendations included cooking using high volumes of As-free water may be a cheap way of reducing As exposure in rural populations. As part of strategies and technologies for remediation and disposal of arsenic from rice fields especially in S and SE Asia, Visoottiviseth and Ahmed (2008) suggested bioremediation and Phytoremediation as more suitable options in developing countries where sunlight is plentiful. In such countries, plant biodiversity may allow identification of plants suitable for bioremediation and in addition to removing arsenic from irrigation water; Phytoremediation could also provide economic benefit to the people who apply these methods.

Khan *et al.* (2010) concluded his findings by saying that continued long-term irrigation with As- contaminated water represents potential risk food security and sustainable rice production as well as to grain quality, not only in Bangladesh but to other countries in central south and south East Asia. Some of mitigation strategies for lowering As-contamination in rice included, practicing Alternate Wetting and Drying (AWD) to reduce contaminated water application to rice (Potera, 2007). Application of less quantity of water reduces drastically the quantity of Arsenic intake. Roberts *et al.* (2011) suggested that intermittent irrigation, also known as AWD, currently advocated in Bangladesh for water-saving purposes, may be a promising means of reducing As input to paddy soils and rice plant exposure to As. This is undergoing experimentation using the System of Rice Intensification (SRI) at Cornell University, USA before being transferred to farmers groups in the Rajshai-Natore area. However, preliminary results showed that the method has increased rice yields, reduced water use by 30-40%, improved fertilizer N efficiency and had lowered seed, tillage and labour costs. Li *et al.* (2009) proposed two potential mitigation methods, management of the water regime and Silicon fertilization for reducing As accumulation in rice. From his study, Silicon fertilization decreased the total As concentration in straw and grain by 78 and 16%, respectively and also significantly influenced As speciation in rice grain and husk by enhancing methylation. Li *et al.* (2009) concluded that water management, Si fertilization and selection of rice cultivars are effective measures that could be used to reduce As accumulation in rice. Garnier *et al.* (2010) suggested changes in agricultural practices such as in aerobic cultivation (Duxbury and Panaullah, 2007) or breeding (Meharg and Rahman, 2002) of rice plants which absorb less arsenic currently explored to lower As content of rice grown in the region are therefore relevant to human health today and will become increasingly so in the future. Xu *et al.* (2008) reported from his study that growing of rice aerobically could dramatically decrease As transfer from soil to grain. The development of arsenic tolerant rice varieties will thrive in As contaminated water and soil, reduce arsenic intake and minimize the unpleasant health risks and implications on consumers. The International Rice Research Institute (IRRI) is working on development of 'aerobic' rice varieties to be experimented in the Indo-Gangetic regions of Pakistan, India, Nepal and Bangladesh (Duxbury and Panaullah, 2007). These researchers also suggested the growing of rice in an aerobic environment where As is adsorbed on oxidized Fe surfaces and is unavailable to rice. Duxbury and Panaullah (2007) also opined that Arsenic may be present as arsenate where uptake is suppressed by phosphate Abedin *et al.* (2002) instead of arsenite usually present in flooded soils. It has also been suggested that switching from As-contaminated shallow groundwater to non-contaminated surface or deep groundwater will avoid further build up of soil Arsenic thereby reducing its intake in rice plants and vegetables (Farid *et al.*, 2003). However, this option is limited and requires large irrigation development projects. Akter and Alli (2011) also suggested that the proposed remedial measure would be successful if sound planning and management programmes are undertaken jointly by the government, non-governmental organizations and other stakeholders in order to reach at the sustainable solution for mitigating arsenic and its associated problems.

CONCLUSIONS

The potential future impact of As contaminated irrigation water on global food security is cause for growing concern. Irrigation with As-rich groundwater poses serious threats to sustainable agriculture, especially rice production and human health in many countries of S and SE Asia. The potential impact is especially severe in West Bengal, India where As-contaminated groundwater is widely used for rice production irrigation and in Nepal Terai, where groundwater sources are being developed for irrigation. This is particularly worrisome since rice production needed to be increased at an annual rate of 4 to 4.5% in Bangladesh to address poverty and keep with expected population growth (Meharg and Rahman, 2002). Dittmar *et al.* (2010) estimated that, under unchanged irrigation practice, especially in Bangladesh, average grain As concentrations will increase from currently ~0.15 to 0.25-0.58 mg As kg^{-1} by the year 2050. This will translate to a 1.5-3.8 times higher As intake by the local population via rice, possibly exceeding the provisional tolerable As intake value defined by FAO/WHO. The extent and urgency of those threats urgently need to be assessed in affected countries so that appropriate countermeasures can be tested and introduced (Ravenscroft *et al.*, 2009).

Stroud *et al.* (2011) established from his study, the effect of irrigation water on As concentrations in standing water and spatial soil As concentrations within a paddy field and As concentrations in pore water reflected in soil total As concentrations. Increasing recognition of the implications of As in irrigation water and action to reduce its impacts will have profound consequences for water resources development and management (Ravenscroft *et al.*, 2009). Surveys are needed to identify tubewell sites where soils and rice grain are already As-contaminated or appear likely to become seriously contaminated within the next 5-10 years and appropriate remediation strategies put in place to alleviate the concentration. In the case of human contamination as a result of consumption of As-infected animals and drinking water, Ahamed *et al.* (2006) suggested early screening which will expedite remedial measures and thus mitigate suffering. The mitigation strategy needs to be location specific, depending on the availability of arsenic-safe options. Other alternative safe water options such as surface water, dug-wells and rainwater harvesting may also be explored, with measures against bacterial and other chemical contaminants. Also, awareness generation about the arsenic problem and adequate supply of arsenic-safe water to the affected population is required (Ahamed *et al.*, 2006). Soil, crop and irrigation-water management strategies are urgently needed to minimize the potential detrimental consequences of As contamination. One of the management strategies is bioremediation as suggested in the findings of Harvey *et al.* (2002). The results of the study showed that field injection of molasses, nitrate and low-arsenic water show that organic carbon or its degradation products may quickly mobilize arsenic, oxidants may lower arsenic concentrations and sorption of arsenic is limited by saturation of aquifer materials. Harvey *et al.* (2003) further reported that pumping transports carbon, perhaps from nearby sediment and mixes young and old carbon at the surface which is involved in arsenic mobilization. Also, Hoque *et al.* (2011) suggested the programmes of testing and monitoring groundwater as being essential, especially in these As-infected environments. There are several As-contaminated rivers deltas in Southeast Asian countries such as Irrawaddy (Myanmar), Red (Vietnam) and Mekong (Cambodia) which has not been developed for irrigation; it would be a good policy not to do so (Panaullah *et al.*, 2009). The need to address management practices to minimize As hazards in rice production is also inevitable (Khan *et al.*, 2009). Finally, it is essential to recognize that agricultural mitigation of As-polluted soils cannot be divorced from sound and efficient water resources management.

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