Arsenic in rice and vegetables: Human body loading, perception and mitigation strategy

By

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Statement of Originality

I, ROKONUZZAMAN, Md, hereby declare that I am the sole author of the dissertation and the material presented in this dissertation is my original work except those indicated in the acknowledgement. I further declare that I have followed the University's policies and regulations on Academic Honesty, Copyright and Plagiarism in writing the dissertation and no material in this dissertation has been submitted for a degree in this or other universities.

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Abstract

Arsenic (As) elevated groundwater irrigation and its bioaccumulation in rice and vegetables is a significant health concern worldwide. Global ninety percent of rice-producing Asian countries largely depend on As contaminated groundwater irrigation for rice and vegetable production. Researchers are endeavoring to invent As mitigating strategies to combat this terrible hazard; all their striving have ensued without adequate grassroots information about farmers' perception of the As accumulation scenario in their crops. Again, tracing As intake, particularly from rice and vegetables by biomarker analysis, has also been poorly addressed. At the same time to combat the problem, the best combination of irrigation management and suitable rice variety altering As content in grains must be ensured. This study aims to assese farmers' perception, investigate the human exposure to arsenic due to rice and vegetable consumption, and suggest As mitigating strategy in the naturally As affected area.

Results reveal that 25 percent of farmers have a good perception. In contrast, the rest have poor to moderate perception, particularly about the effect of contaminated groundwater irrigation on rice & vegetables and mitigation measures. The correlation coefficient demonstrates ten out of sixteen characteristics have significant positive association with perception at a 1% significance level. Farmers' knowledge (74.6%), direct participation in farming (8.2%), information sources (4.5%), participant education (0.7%), and organizational participation (0.8%) together explain 88 percent variances in perception. Path analysis depicts that direct participation in farming presents the highest positive total effect (0.855) and direct effect (0.503), whereas information sources show the highest positive indirect effect (0.624).

Keeping the study of farmers' perception, current health risk status was assessed. For the health risk assessment, 100 farmers were purposively selected who met certain criteria and

donated their scalp hair, and provided their field soil, irrigation water, vegetables, and rice samples. Data on sociodemographic characteristics and food consumption were collected in-person through administering questionnaires. The mean As content in soils, irrigation water, vegetables, rice, and scalp hairs exceeded the permissible limit, while As content was significant at 5%, 0.1%, 1%, 0.1%, and 0.1% probability levels, respectively, in all five study locations. Arsenic levels in scalp hair showed a significant positive correlation ($p \leq 0.01$) with that in rice and vegetables. The bioconcentration factor (BCF) is less than one and significant at a 1% level of probability. The RfD limit for As is larger than the average daily intake (ADI). The hazard quotient (HQ) of grains and vegetables is greater than 1. According to the maximum incremental lifetime cancer risk (ILCR), there is a threshold risk of 1.6 per 1000 individuals and a considerable risk of 2.8 per 100 people, respectively. The PCA analysis revealed that the first principle component (PC1), which is dominated by As in irrigation water, grain, and vegetables, explains 91.1 percent of the overall variance. While rice and vegetables As exhibit larger variety in similarity on the dendrogram, it has been discovered that vegetables As contributes more to human body loading than grain As.

However to suggest an As mitigating strategy in rice, a field trial was conducted. The field trial results revealed that As content in different portions of the paddy plant was significantly different ($P<0.001$) with irrigation practices and rice varieties. AWD irrigation with TSG accumulated lower As in rice grains than CF-AsW for both varieties. Data showed that AWD-TSG practice led to 61.37% and 60.34% grain As reduction for BRRI dhan28 and BRRI dhan29, respectively, compared with CF-AsW. For Principle Component Analysis (PCA), the first principle component (PC1) explained 91.7% of the variability and irrigation water As, soil total and available As, straw As, root As, and husk As were the dominating

parameters. With significant (P< 0.05) variation in yields between the genotypes, AWD increased grain yield by 29.25% in BRRI dhan29 Compared with CF. However, translocation factor (TF) and bioconcentration factor (BCF) for both varieties were less than one for all the treatments. To combat the As accumulation problem, the best combination of irrigation management, i.e., AWD-TSG with BRRI dhan29, could be adopted as an As–safe practice for rice cultivation without compromising yields.

Keywords: Arsenic, Rice and Vegetables, Perception, Scalp Hair, Health Risk Assessment, Alternate Wetting and Drying (AWD), Temporarily Stored Groundwater (TSG)

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CHAPTER 1

GENERAL INTRODUCTION

1.1 General background

Arsenic (As)'s position in the human body is 12th out of 98 naturally-occurring elements (Mandal & Suzuki, 2002). Arsenic is also released into the groundwater, both natural, primarily from the dissolution of As-enriched minerals, and anthropogenic, from pesticides, mining, coal combustion, etc., means (Bundschuh et al., 2011; Singh et al., 2015). The worldwide consideration is basically centered on the appearance of As over the safe limit, particularly in groundwater, as a significant portion of the worldwide populace depends on groundwater for drinking and irrigation needs (Akinbile & Haque, 2012; Sarkar & Paul, 2016). Drinking As-contaminated groundwater is the prime pathway for the human to get exposed to the As but for the populace not subjected to a raised level of arsenic through drinking water, ingestion of crops produced in As-polluted crop fields or flooded with As-polluted groundwater speaks to be the remarkable sources of As ingestion for people, which causes hazardous threats to millions of individuals in vast zones of the world. Rice is generally consumed by almost fifty percent of the global populace. It is regarded as the staple food of most Asian nations where groundwater is still the primary irrigation source, which ultimately causes significant As intake by those populations (Mondal & Polya, 2008; Islam et al., 2016). Approximate 90% of the total rice production in the world is produced in Asia (Arunakumara et al., 2013). For the latest example, the gross production of global rice in 2017 was recorded as much as 735 million metric tons, whereas only Asian countries contributed almost 680 million metric tons (FAO, 2018).

Moreover, rice is usually traded to different places or even different countries from its production places which compelled us to consider As hazards as not a regional problem (Meharg et al., 2009). Additionally, there caused historical changes in global food-taking behavior in the recent 50 years, largely due to the migration of Asian people to Western countries, which promoted rice consumption to a significant level (Islam et al., 2016). In addition to rice, vegetables were narrated to contain elevated levels of As in regions with higher As in soil or irrigated with As-rich groundwater (Bhattacharya et al., 2012; Rehman et al., 2016), and Asian countries also contribute 50% to global vegetable export values (FAO/WITS, 2017).

In Bangladesh, rice is the primary crop during the three main growing seasons known as Rabi (November–February), Kharif-1 (March–June), and Kharif-2 (July–October). Three varieties of rice are grown: Boro in Rabi, Aus in Kharif I, and Aman in Kharif II season. Both Aus and Aman rice are grown throughout the monsoon season (May to October), and they are commonly partially irrigated. The dry season is the most fruitful, risk-free, and diverse cropping season in the nation due to the risk of floods and other natural catastrophes, such as cyclones during the monsoon. As a result, Boro rice, which today accounts for 55–60% of the nation's total paddy cultivation, is the dominant irrigated crop during the dry season (Mainuddin et al., 2019). According to Mainuddin et al. (2019), the total area irrigated increased dramatically as the number of shallow tubewells (STWs) and deep tubewells (DTWs) for groundwater extraction climbed from 1.52 Mha in 1983 (18 percent of the gross arable land) to 5.5 Mha in 2015 (64 percent of the national cultivable land). During the same time period, the number of STW climbed from 93 thousand to 1.52 million, while the number of DTW increased from 14 thousand to 36.7 thousand. According to the BBS (Bangladesh Bureau of Statistics, 2017) just 21% (1.25 Mha) of the region is now being irrigated by surface water, with the majority (4.2 Mha) being done so by groundwater.

Following reports of widespread water supply contamination in the neighboring districts of India and of numerous persons suffering from ailments associated to arsenic that had been treated medically in India, arsenic was first detected in groundwater in the west of

Bangladesh in 1993 (Rahman et al., 2003); however, Bangladesh government or any aid agencies were informed from 1994. The issue was not recognized until the international conference that took place in February of that year in Dhaka, Bangladesh (Jadavpur University and Dhaka Community Hospital, 1998). Although international aid organizations encouraged the development of hand tubewells in Bangladesh, they did not conduct any tests to determine whether or not the wells contained As. Arsenic contamination in groundwater and its consequences on human health in the Gangetic plain of West Bengal were first identified in 1983. By 1988, there were five articles on the subject in national journals, and one appeared in the WHO Bulletin (Mazumder et al., 1998). In the 1980s and early 1990s, the BGS dug tubewells in Bangladesh, but they did not do any arsenic testing on the groundwater there. When the BGS returned to Bangladesh in 1992 to evaluate the quality of the water that people were drinking, however, they did not test the water for As as they had done previously. In this particular scenario, peasants from Bangladesh filed a lawsuit in a British court (Clarke, 2001), claiming that BGS was to blame for the arsenic poisoning that they had been experiencing. In the year 1996, the Geology Department of Rajshahi University in Bangladesh delivered 600 water samples to the SOES laboratory. These samples had been collected from a few bordering districts in Bangladesh that were located in close proximity to regions in West Bengal, India. Arsenic was detected in many of the smples collected. In addition, the World Health Organization (WHO) in Bangladesh dispatched two doctors from the NIPSOM (NationalInstitute of Preventive and Social Medicine) to the SOES (School of Environmental Studies) for training in order to become familiar with the indications and symptoms of arsenicosis. These doctors' names are Dr. Sk. Abdul Hadi and Dr. Sk. Akhter Ahmed. They visited some As-affected areas in West Bengal with the Director, the SOES, and a dermatologist named Dr. K.C. Saha as part of their training so that they could learn how to recognize arsenical skin lesions. After that, SOES and NIPSOM worked together in

Bangladesh for three months between August and October 1996. During that time, they covered 17 districts and evaluated 750 water samples, as well as approximately 300 samples of hair, nails, and a few skin scales for the presence of As. There was a significant amount of As identified in each of the samples (Das, 1995). Inorganic forms of As, such as arsenite, As(III), and arsenate, As(V), were more toxic than organic forms of As, such as monomethyl arsenic acid, MMA(V), and dimethyl arsinicacid, DMA(V) (Williams et al., 2005). The most common form of As found in rice and vegetables in Bangladesh was iAs. According to the findings of Smith et al. (2006), the average iAs found in Bangladeshi vegetables was 96%, while Norton et al. (2009) detected 63 to 96% iAs in rice of Bangladesh.

Arsenic is a potent natural pollutant and human cancer-inducing agent (the carcinogen) (Joseph et al., 2015a; Islam et al., 2016), and thus, As entering into the food chain postures a noteworthy health risk, particularly a extend of cancers (NRC, 2001; WHO, 2004). Therefore, As entering the food chain poses significant health risks, including several cancers, restrictive lung disease, ischemic heart disease, diabetes mellitus, premature births, etc. (Mazumder et al., 2000; NRC, 2001; Srivastava et al., 2001; WHO, 2004). Therefore this catastrophe has been declared "the largest poisoning of a population in history" (Smith et al., 2000). Researchers commonly analyze human biological samples such as blood, nails, hair, urine, feces, skin scales, etc., to determine the As level in the human body in different countries (Bencko, 1995; Dongarrà et al., 2012). "Hair analysis is not generally useful for evaluating recent exposures or those occurring more than one year ago" (Harkins & Susten, 2003, p. 577). Another critical point is that, although fish is another important source of human exposure to As, fish As does not incorporate in human hairs (Mandal et al., 2003; Kales & Christiani, 2005; Pullella & Kotsopoulos,2020). Therefore, hair analysis is highly suitable if the researchers desire to determine As exposure within a brief period due to rice and vegetable consumption avoiding the confusion of past exposure. It is often claimed that "the lack of community participation has aggravated the arsenic catastrophe in the Ganga River Basin and put millions of lives in danger" (Chakraborti et al., 2018, p. 15). Generally, there is still a narrow emphasis on farmers' perceptions of such calamity management strategies (Withanachchi et al., 2018). On the other hand, although some As mitigation strategies exist in the field, utilization of mitigation technologies by the farmers in their practical fields has remained a challenge (Singh et al., 2015; Pearson et al., 2018). This possibly ensues because of the lack of suitability of those existing strategies (Singh et al., 2015), or farmers are not assuming the risk of arsenic in crops.

1.2 Statement of the problem

In 2002-03, a study was conducted in the United Kingdom to measure total arsenic levels in different foodstuffs comprising some vegetables, fish, and rice imported from Bangladesh since As contaminated groundwater is usually irrigated for crop production. The mean (54.5 µg/kg) and range (5–540 µg/kg) of the total As were higher than those imported from West Bengal, India, which were still higher than the proposed Bangladesh standard for rice concerning the equivalence with As level in drinking water as mentioned by Williams et al. (2006), "the Bangladesh national As standard for drinking waters, 50 µg/L, is equivalent to the predicted intake of rice at a grain level of 0.42 µg As/g" (p. 4907). Since it is the superfluous source of As in the food of the UK population, sincere attention was suggested to further investigation (Al Rmalli et al., 2005). Later on, Middleton et al. (2016) found a significant concentration of As in the hair and toenails of the UK people, which is claimed to be due to prolonged exposure to it. Using a cancer rate model, internal cancer rates for rice samples produced in Bangladesh (22 per 10,000 people), India (7 per 10,000 people), Italy (1 per 10,000 people), China (15 per 10,000 people), and the US (1 per 10,000 people)-the higher rice consumer nations (Booth, 2009).

Bangladesh is the world's hot spot for As poisoning in groundwater (Rahman & Hasegawa, 2011). In Bangladesh, out of 64 districts, groundwater is contaminated with As in 61 (BGS 1999) and almost all of which exceed 0.05 mg/L concentration (Bangladesh standard for arsenic in drinking water) (Rajmohan & Prathapar, 2014). To feed a gigantic populace from limited arable land (8.3 million hectares), Bangladesh adopted intensive groundwater irrigation management for about 79% of the entire agricultural fields (Qureshi et al., 2014). It is estimated that deep tubewells (total number 35,322), shallow tubewells (1,523,322 total number), and low lift pumps (170,570 total number) are in operation in the fields of Bangladesh (Qureshi et al., 2014) to draw over 13,000 Million Cubic Meters (MCM) groundwater for irrigation (Bangladesh Bureau of Statistics, 2004; Duxbury & Panaullah, 2007; Akinbile & Haque, 2012). Using all these pumps, an estimated amount of 900-1360 tons of As is incorporated into the cultivated fields of Bangladesh every year because of irrigating with As-polluted water (Ali, 2003). Eventually, this caused elevated As level in food crops such as rice grains and vegetables (Meharg & Rahman, 2003; Islam et al., 2007; Hossain et al., 2008; Biswas et al., 2012; Islam et al., 2016). Therefore, further consideration must be put on the As ingestion of rice & vegetables (Khan et al., 2010; Akinbile & Haque, 2012; Saha & Zaman, 2013).

Although people are drinking As free water in the As rich areas (Huq et al., 2006; Chakraborti et al., 2018) as "the government and other agencies have installed various arsenic-safe sources of water including deep tubewells, purified surface water, and arsenic removal plants (ARP) in arsenic-affected areas of Bangladesh" (Chakraborti et al., 2018, p. 9), some of them are yet suffering from arsenic caused health hazards in Bangladesh (Chakraborti et al., 2004; Sidhu et al., 2012; Joseph et al., 2015b). Maximum research based on As catastrophe is confined to assessing As concentration in crops, groundwater, or soils. Researchers have made minute reflections regarding the As transfer and analysis of As from the field soils to cereals & vegetables and finally to the human body as the soil-plant-animal/human continuum is the predominant channel of As intake (Sarwar et al., 2010; Massaquoi et al., 2015). Furthermore, in his thesis, Al-Rmalli (2012) explored "Arsenic and Other Trace Elements in Bangladeshi Foods and Non-Foods and Their Relationship to Human Health." However, scientists have paid little concern about As transfer from irrigation water-soil-crops-human body pathway in Bangladesh.

On the other hand, since "the lack of community's participation has aggravated the arsenic catastrophe in the Ganga River Basin (which includes Bangladesh) and put millions of lives in danger" (Chakraborti et al., 2018, p. 15), most of the perception research based on the crop growers is mainly confined to the use of untreated coal mine water, sludge, chemicals, fertilizers and pesticides, and related hazards. Whereas government, nongovernment organizations (NGOs), and bilateral and multilateral agencies are warring (against) this critical issue regarding crops contamination with As, all of their endeavors to date have continued without having much grassroots data, especially concerning the perception of the crop growers about using As-contaminated groundwater irrigation. Moreover, since most of the adopted arsenic mitigating innovations have some downsides and their by-products have been reported to be the potential source for additional As contamination (Singh et al., 2015), mitigation measures with changing water management without drawbacks is still in demand (Singh et al., 2015; Pravalprukskul et al., 2018).

Khan et al. (2009) suggested that "future arsenic risk assessment research should use an interdisciplinary approach" (p.161). Therefore the combination of three aspects, such as

1. revealing farmers' perception of the harmful effect of As-contaminated groundwater irrigation in rice and vegetable production;

2. investigating irrigation water-soil-crops-farmers body transfer pathway in a naturally As endemic area; and

3. suggesting an As mitigation practice with temporarily stored groundwater for rice cultivation will be the main focus of this study where researchers have paid extremely little attention in each of the three sections, and there is no such interdisciplinary approach for arsenic research yet, particularly in Bangladesh as per our knowledge.

1.3 Aims of this study:

This study investigates the potential human exposure to As due to ingestion of Bangladeshi rice and vegetables, assesses farmers' perception of the harmful effect of As-contaminated groundwater irrigation, and suggests arsenic mitigating irrigation practices to reduce As contamination in the food chain in a naturally arsenic affected area.

1.4 Objectives:

1. To assess farmers' perception of the harmful effect of As-contaminated groundwater irrigation for crop production and reconnoiter the relationship between the perception and their socioeconomic characteristics;

2. To investigate the level of arsenic in irrigation water, soil, rice & vegetables, and farmer's hair collected from naturally As-affected areas of Bangladesh and conduct a human health risk assessment due to the contaminated rice and vegetable ingestion; and

3. To suggest an As reducing irrigation practice for rice production through field trial.

1.5 Research questions

To fulfill the research gaps mentioned above, the answer to the following research questions will be explored in this research:

RQ 1. What are farmers' perceptions of the harmful effect of As-contaminated groundwater irrigation in rice and vegetable production, and is there any relationship between farmers' perception and their socioeconomic characteristics?

RQ 2. What are the concentration levels of arsenic in irrigation water, soil, rice & vegetables, and farmer's hair and its potential health risk? and

RQ 3. What is the impact of Alternate Wetting and Drying (AWD) with temporarily stored groundwater (TSG) to reduce As content in rice?

1.6 Significance and contributions of this study

The findings of this research will contribute in 3 ways. It will firstly contribute to the knowledge base regarding a better understanding of the arsenic transfer pathway to the human (farmers) body. Since the farmers play a dual role as they are "both the producers and consumers of food crops" (Xianxia & Yunxi, 2018), assessing the irrigation water, soil, and crops from their farm and subsequently collecting and analyzing their scalp hair with socio-demographic and food consumption data will produce a genuine understanding of the As transfer pathway to the human body. Secondly, it will also provide a better understanding of the farmers' perception of the harmful effect of As-contaminated groundwater irrigation for crop production. Lastly, it will yield new insight into the arsenic mitigation strategy with an irrigation practice. Overall, this interdisciplinary approach will contribute to reducing As in the food chain and will aid a new direction in current As-based research in health education programs in an advanced way and in minimizing the hazard of occurring arsenic-related diseases due to ingestion of As-rich crops and in identifying the scope for further emphasizing of research engaging farming community. It is envisioned that the information that will be learned from the situation of the naturally As contaminated area will be an essential reference for the naturally As affected zones worldwide.

1.7 The Conceptual framework of the study

This study comprised three distinct parts conducted in a naturally As contaminated region. The first part determines the rice and vegetables growers' perception of the risk of As contaminated groundwater irrigation for their crops grown. Several socio-economic factors are investigated to influence farmers' perceptions. The second part demonstrates the As transfer pathway from the cultivated rice and vegetables to the human body through human scalp hair analysis. Apart from the As content analyzed in the consumed rice, vegetables, and scalp hairs, it also analyses the As content in environmental media such as irrigation water and soils. Finally, part three suggests an As mitigating irrigation practice for rice cultivation comprised of two rice cultivars, five treatments with four replications. The general discussion section elaborates on each section's outputs and coincides with the impacts. Figure 1 depicts the conceptual framework of the study.

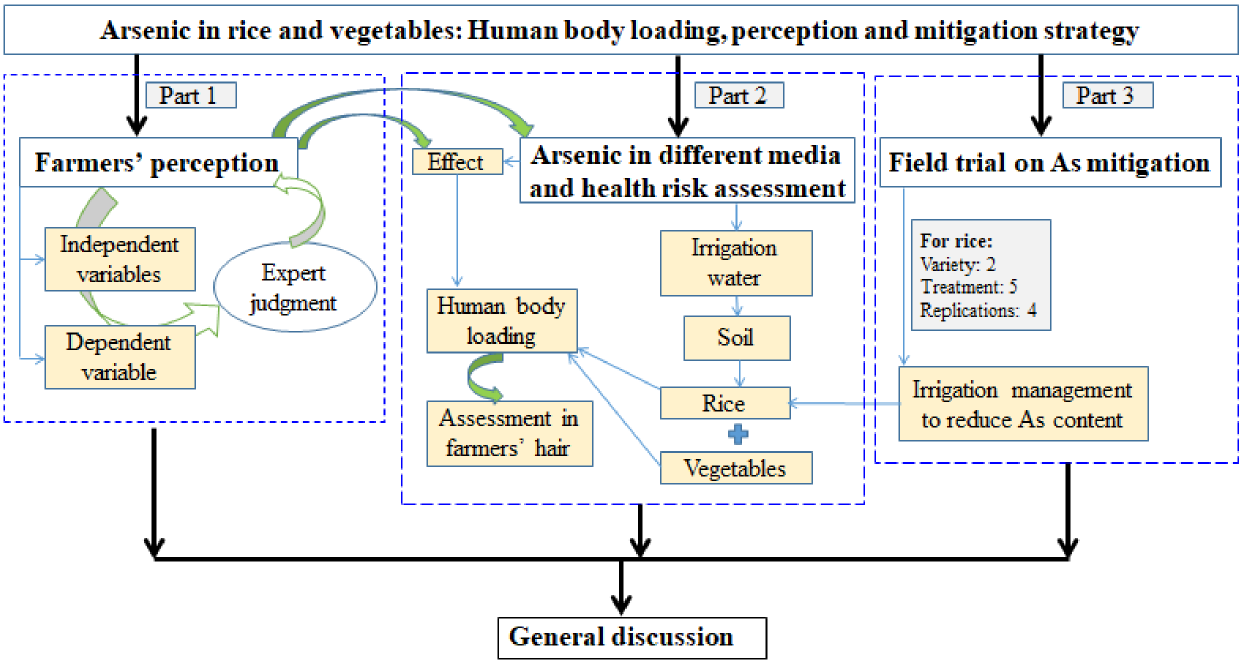


Figure 1: Conceptual framework of the study

CHAPTER 2

LITERATURE REVIEW

ARSENIC ACCUMULATION IN RICE: SOURCES, HUMAN HEALTH IMPACT AND PROBABLE MITIGATION APPROACHES

Rokonuzzaman, M., Li, W. C., Man, Y. B., Tsang ,Y. F., & Ye, Z. H. (2022). Arsenic Accumulation in Rice: Sources, Human Health Impact and Probable Mitigation Approaches. *Rice Science, 29*(4), 309-327.

2.1 Literature Review for Part 1

Based on their backgrounds, farmers' differences in perceptions lead to diversified economic behaviors, decision-making processes, and reactions to risk situations (Bergfjord, 2013; Ahsan, 2014; Duong et al., 2019). The background includes the personal, social, psychological, and economic characteristics of the farmers, which affect perceptions in complex and integrated ways (Dosman et al., 2001; Duong et al., 2019) and largely determine their perceptions of any phenomenon or risk (De Young, 1990; Whitford, 1993; Krewski et al., 1995; Sjöberg, 2000; Dosman et al., 2001; Botterill & Mazur, 2004; Duong et al., 2019).

2.1.1 Personal characteristics

The participants' age influences how food safety is viewed; the more the respondents are older, the more they perceive the risk of any situation (Dosman et al., 2001). Similarly, Lin (1995) reported that the age of respondents is positively correlated with their perception of food safety. Owusu et al. (2011) revealed that age significantly influences farmers' perceptions through a vegetable study in Ghana. However, the findings of Hamilton (1985a) and Van Liere & Dunlap (1980) differed from the abovementioned results. On the other hand, Friedler et al. (2006) revealed no correlation between the age of the respondents and their perception. Farmers' level of education is another crucial determinant of their perception. Pal (2009) revealed that farmers' education positively correlates with their perception. Kabir & Rainis (2012) and Adeola (2012) also found that education significantly affects farmers' perceptions in Bangladesh and Nigeria. While conducting a study in Tamil Nadu, India, about the farmers' perception of contaminated water irrigation, Rekha & Ambujam (2010) revealed a significant positive correlation between farmers' perception and educational status. Similar results were also reported by Islam (2000), Sayeed (2003), Uddin (2004), Sharmin (2005), and Owusu et al. (2011). Individuals with higher education levels usually perceive risks well and understand mitigation necessities in a very advanced way (Dosman et al., 2001). Krewski et al. (1994) stated that college-educated participants understand risk more deeply than high school students. Therefore, highly educated people are much better reflective of the "hazard" than those with low-level education (Dosman et al., 2001). Some other studies support this, mentioning that education level is the potential factor positively related to enhancing farmers' perception (Hossain et al., 2000; Larsen et al., 2002; Rahman, 2003; Ibitayo, 2006; Rahaman et al., 2018). In contrast to the above, Slovic (1997), Dosman et al. (2001), and Afique (2006) found a negative relationship between farmers' education and their perception. Nevertheless, Hamilton (1985), in his study, did not find a significant relationship where Kashem & Mikuni (1998) and Friedler et al. (2006) explored no relationship between the education of farmers and their perception. On the other hand, Slovic (1997) revealed a negative relationship between peoples' level of education and perception. However, Owusu et al. (2011) study in Ghana with vegetables revealed that age and education significantly influence farmers' perceptions. According to Krewski et al. (1995), there were sizable effects of age and education on respondents' perceptions that need to be better understood. However, Friedler et al. (2006) revealed no relationship between education and age with perception. Family size is also considered to influence the perception of health and environmental hazards (Dosman et al., 2001); wherefrom their study, Davidson & Freudenburg (1996) opined that family members usually influence the main meal planners' perception of risk. The findings of Rokonuzzaman (2016) support this result. In contrast, Alam's (2001) and Kabir (2002) study revealed that farmers' family size negatively correlated with perception. However, Sayeed (2003), Uddin (2004, Sharmin (2005), Islam (2005), Afique (2006), and Majlish (2007 reported a non-significant correlation between farmers' family size and their perception. The farmers' information sources can play an important role in building positive or negative perceptions of any phenomenon. Rezaei et al. (2017) claimed a significant relationship between farmers' exposure to the information sources and media and their perception. Different types and sources of information define farmers' perceptions where well-informed farmers feel less risk the health issues (Zuo & Chern, 1996). Through the study in Tamil Nadu, India, about the farmers' perception of contaminated water irrigation, Rekha & Ambujam (2010) revealed a significant positive correlation between farmers' perception and their mass media exposure. Krewski et al. (1994) revealed that respondents chose print media such as magazines and newspapers as the primary source, and TV & radio were chosen as second sources to collect food safety-related information. According to Lin (1995), respondents capture information from print media as more reliable and perceive less risk compared to the other type of sources. This may be because print media provide the latest information on food safety-related issues (Dosman et al., 2001). Alternatively, the potential factor positively related to enhancing farmers' perception is contact with extension personnel (Rahaman et al., 2018). In their study, Sarker (1999), Kabir (2002), and Sayeed (2003) also found a significant positive correlation. A similar finding was reported by Sharmin (2005). However, Fardous (2002) and Islam (2005) observed a non-significant relationship. Direct participation in farming had a significant positive relationship with farmers' perceptions (Rokonuzzaman, 2016). On the other hand, Islam (2000) did not find any relationship between farmers' direct participation in farming and their perception.

2.1.2 Economic characteristics

From their study result, Uddin (2004), Islam (2005), Karim et al. (2008), and Rokonuzzaman (2016) claimed a significant positive relationship between farmers' annual income and their perception. The study of Islam (2000) and Rekha & Ambujam (2010) also revealed a significant positive correlation between farmers' perception and annual income. In contrast, Dosman et al. (2001) revealed a negative relationship between the respondents' income and perceptions. However, Friedler et al. (2006) claimed no relationship between farmers' income and perception. While studying the effect of farm size on farmers' perception, Sayeed (2003), Uddin (2004), and Rekha & Ambujam (2010) revealed a significant positive relationship between farmers' farm size and their perception of sustainable agriculture. On the other hand, Fardous (2002), Islam (2005), Sharmin (2005), Afique (2006), Pal (2009), and Adeola (2012) revealed that household size had a non-significant influence on the farmers' perception. Hossain (2000), Hossain (1999), and Majydyan (1996) found similar findings in their respective studies. In respect to credit use, Kumar & Popat (2010) revealed that economic motivation, as well as credit offerings to the farmers, had a significant positive association with their perception. The potential factor positively related to enhancing farmers' perception is agricultural credit use (Hossain et al., 2000; Rahman, 2003; Ibitayo, 2006; Rahaman et al., 2018). Owusu et al. (2011) study in Ghana with vegetables revealed that farm size and credit use significantly influence farmers' perceptions. On the other hand, Islam (2000) did not find any correlation between farmers' credit use and perception. Regarding the relationship between farmers' ownership of farm power and machinery and their perception, Mottaleb et al. (2019) led a study based on the water markets in Bangladesh. Their findings demonstrate that irrigation pump ownership largely determines farmers' risk perception. However, they concluded that since the irrigation system in Bangladesh is mainly based on pumping underground water, pump ownership significantly influences the structure and choice of irrigation practices.

2.1.3 Social characteristics

Out of the factors affecting farmers' perception, organizational participation, i.e., membership in social organizations, develops networking among the villagers. Owusu et al. (2011) study in Ghana with vegetable farmers revealed that membership in farmer's organizations significantly influences farmers' perceptions. Keshavarz & Karami (2008) reported that social organization membership positively influences farmers' perceptions. Membership in formal or informal organizations helps the farmers get benefits and social support (Fuller-Iglesias et al., 2009). Segnestam (2009) argued that organizational participation helps disseminate innovations and develop mutual trust among the farmers, which eventually shapes farmers' perceptions. Chintawar (1997), Hossain (1999), Fardous (2002), Alam (2001), and Uddin (2004) exhibited a significant positive relationship between the organizational participation of the farmers and their perception. In contrast, Kashem & Mikuni (1998) found no relationship between the participation in the social organization by the Bangladeshi farmers and their perception; however, they found a significant negative relationship among Japanese farmers on the same variables. Concerning cosmopoliteness, Alam (2001) found that the cosmopoliteness of the farmers had a significant positive relationship with their perception. Hamid (1995) found a significant correlation between cosmopoliteness and farmers' adoption of the recommended dose of plant protection measures in vegetable cultivation. In contrast, Islam (2005) explored the non-significant relationship between farmers' cosmopoliteness and their perception. A similar finding was reported by Sharmin (2005). However, Hossain (2002) could not find any relationship between farmers' cosmopoliteness and their perception. Islam (2000) revealed a significant positive relationship between farmers' opinionatedness and perception in his study.

2.1.4 Psychological characteristics

While conducting a study in Tamil Nadu, India, about the farmers' perception of contaminated water irrigation, Rekha & Ambujam (2010) revealed a significant positive correlation between farmers' perception and innovativeness. Uddin (2004) studied farmers' perception of sustainable agriculture perspective. The finding showed a substantial significant positive correlation between farmers' innovativeness and perception. Similarly, Chintwar (1997), Sarker (1999), Islam (2000), Kabir (2002), Karim et al. (2008), Rokonuzzaman (2016), and Londhe et al. (2018) support the finding. On the other hand, Sayeed (2003) argued that a non-significant relationship exists between farmers' innovativeness and perception. However, Hossain (1999) and Alom (2001) reported that the farmers' innovativeness had no relationship with their perception. Londhe et al. (2018) revealed that farmers' risk orientation had a positively significant relationship and perception in their study. Islam (2000) and Rekha & Ambujam (2010) revealed a significant positive relationship between farmers' perception and risk orientation in Bangladesh and Tamil Nadu, India. In contrast, Charel et al. (2018) claimed risk orientation had a negative and non-significant relationship with farmers' perception. In their survey in Gujarat province in India, Kumar & Popat (2010) revealed that knowledge, a psychological characteristic of the farmer, had a significant positive association with their perception. Islam (2000), Fardous (2002), Uddin (2004), Majlish (2007), Karim et al. (2008), and Islam (2017) also found that the relationship between knowledge and perception was positively significant. Adeola (2012) and Kabir & Rainis (2012) also reported that farming knowledge significantly affected the farmers' perception.

While government, non-government organizations, and bilateral and multilateral aiding agencies are battling against the terrible problem concerning crops contaminated with As, mostly their endeavors to date being progressed without having much grassroots level information, especially for the perception of the crop growers about using As-contaminated groundwater irrigation. Therefore it is essential to investigate the farmers' perception regarding using As-contaminated groundwater irrigation and identify the correlates of that perception. Earlier studies have also shown that personal, economic, social, and psychological characteristics influence perception and displayed crucial influences on perception and risk management strategies (De Young, 1990; Whitford, 1993; Krewski et al., 1995; Sjöberg, 2000; Dosman et al., 2001; Botterill & Mazur, 2004; Duong et al., 2019). Previous studies recommended that endeavors are more fruitful when they are arranged to explore the perception of the target groups and influencing variables. So, time demands to understand better farmers' perceptions and influencing factors, and more empirical work should be done from this perspective (Duong et al., 2019).

2.2 Literature Review for part 2 and part 3

2.2.1 Sources, geochemistry and distribution of arsenic – A brief overview

The earth's crust contains significant amounts of the hazardous metalloid, As. Orpiment (As_2S_3), realgar (AsS), and Arsenical pyrite (FeAsS) are significant As-containing minerals in the environment (Smedley & Kinniburgh, 2001; Khosravi et al., 2019; Natasha et al., 2021). Arsenic is released into the environment not only from natural sources but also from anthropogenic activities such as the use of As-based pesticides and herbicides in agriculture, wood preservatives, mining and smelting, and coal combustion processes (Khosravi et al., 2019). Agricultural soils have become contaminated with As as a result of geogenic sources, including weathering of the parent material and alluvial sediments. For instance, the weathering of As-containing minerals like claudetite (As_2O_3) and bearsite (Be_2 (AsO_4) (OH). $4H_2O$) has been linked to the increased As content in rice fields in Manipur, India (50 to 90 mg/kg) (Chandrashekhar et al., 2016). Globally, and especially in South and Southeast Asia, the primary causes of As contamination of rice in paddy soils are the degradation of As minerals (such as FeAsS) and the accompanying secondary As-bearing Fe oxide minerals. Arsenic is present in a variety of natural reservoirs, including soil, oceans, rocks, the atmosphere, and biota, although more than 99 percent of As is found in rocks and minerals (Francesconi & Kuehnelt, 2001). Arsenic levels can reach up to 100 mg/kg in peat and clay-rich sediments, but are often found below 10 mg/kg in sandy strata (Hussain et al., 2019). According to several studies (Naidu et al., 2006; von Brömssen et al., 2007; Bhattacharya et al., 2007; Naidu & Bhattacharya, 2009; Muñoz et al., 2016; Suriyagoda et al., 2018), the oxidation and reduction of As-rich Fe oxide minerals that were deposited from the Himalayas in the Bangal Delta, Ganges-Brahmaputra, and Indus-Basin is the cause of As in countries like India (West Bengal), China Due to mineral dissolution, alluvial sediments containing as are frequently linked to as migration into groundwater under decreased circumstances.

Notably, these reactions regulate the presence of As in groundwater, which is influenced by a number of biotic and abiotic factors, such as the distribution of peat deposits and dissolved organic carbon (DOC) (Shahid et al., 2017), groundwater movement, pH, bicarbonate, Fe/Mn oxides, and microbial species (Sracek et al., 2004; Hossain et al., 2014). Arsenic concentrations can rise and as high as hundreds of micrograms per liter under anaerobic conditions like in paddy soils. The majority of farmers in Bangladesh, Pakistan, and India are forced to rely on As contaminated groundwater for rice production due to poor infrastructure and lack of availability of surface water (Brammer, 2009; Ravenscroft et al., 2009; Islam et al., 2012). As a result, over time, soil that receives irrigation water from pumps that is contaminated with As also becomes contaminated. In Bangladesh, Pakistan, and China, for instance, paddy soil concentrations between 0.68 and 72 mg/kg have been found. Recharging aquifers beneath unconsolidated sediments with rains or floodwater causes Fe(oxy)hydroxides reduction and thus releasing As into groundwater (Shakoor et al., 2018). As a result, inorganic As discharge is caused by both natural enrichment and anthropogenic perturbation of groundwater resources (Hu et al., 2013; Kumarathilaka et al., 2018; Nakaya et al., 2018). In the upper soil layer (0–20 cm, or the rhizoplane of rice plants), As from irrigation water accumulates primarily (Suriyagoda et al., 2018). During the rice plant's growth cycle (3 to 4 months), paddy soils are submerged for a longer period of time and may experience a number of physical and chemical processes mediated by redox (Upadhyay et al., 2019a; Yu et al., 2017a).

Arsenic released from natural and anthropogenic origins is the fundamental source of atmosphere, pedosphere, biosphere, or hydrosphere environment contamination, where natural source includes the dissolution of rock and rock-forming minerals and anthropogenic sources are the application of various phosphate fertilizers and pesticides, wood preservatives, wastages from mining and industrial activities, and coal combustion (Smedley & Kinniburgh, 2002, Mondal et al., 2006; Garelick et al., 2009; Bundschuh et al., 2011; Singh et al., 2015). Bengal Delta Plain has similar geologic features as that of the Terai area of Nepal, where As mobilization in below surface water of the Terai area is associated with microbial activities, geochemical changes, and organic matter oxidation (Thakur et al., 2010). Enrichment of As in groundwater is associated with organic matter degradation and Fe-oxyhydroxides reduction, which displays the similar phenomena of Terai region of Nepal with that of Bangladesh (Ahmed et al., 2004). Although researchers claim that As exists in alluvium aquifers under reduced conditions, particularly in Bangladesh and West Bengal of India, it is not typical all over the world since As remains in oxidized forms in the major parts of the earth (Mukherjee & Bhattacharya, 2001; Anawar et al., 2002; Ahmed et al., 2004).

The principal mechanism and sources of As pollution in Bangladesh's groundwater are still a contentious topic of debate due to the fact that the contamination process cannot be explained by a single mechanism alone (Islam et al., 2010). Pyrite oxidation and iron oxyhydroxide reduction are the two hypotheses for the origins of As contamination of groundwater in Bangladesh that have received the greatest attention and investigation from researchers (Nickson et al., 1998; Ahmed & Ahmed, 2014; Saha & Rahman, 2020; Adeloju et al., 2021). Because of the presence of (i) suitable As bearing source material (i.e., rocks, minerals, soils, and sediments); (ii) efficient mobilization and/or transport processes (i.e., oxidation of As bearing sulphides); and (iii) the lack of rapid As removal processes, high levels of As can be found in groundwater (Polya & Middleton, 2017). Formerly, it was believed that deep wells may offer a supply of clean water due to low As concentrations in the deeper aquifer (Harvey et al., 2002). However, recently, it has become apparent that extensive pumping from a deeper aquifer allows As- and carbon-rich groundwater to seep into the overlaying aquifer, which causes gradual As contamination in the deeper aquifer (Mozumder et al., 2020). It has been hypothesized that the majority of Bangladesh's groundwater aquifers have been contaminated due to the leaching of As-rich sediments that originated in the Himalayas and were transported to Bangladesh by the Ganges-Brahmaputra-Meghna river system (Ahmad et al., 2018).

In Bangladesh, the As level of groundwater is significantly higher than that of surface water, and the vast majority of As contamination may be identified in shallow tubewells that were erected at a depth of 15–50 meters or less (Ahmad et al., 2018). In spite of this, the presence of As pollution in tubewells located at greater depths has been discovered in certain regions of Bangladesh. In tubewells deeper than 150 meters, which are referred to as "deep tubewells," As contamination does not typically occur frequently. At first, it was thought that the Gangetic delta plain (which is shallow depth) was the source of the As contamination in the tubewell water of Bangladesh. However, actually As contamination was detected in almost all of the sedimentary areas of Bangladesh (even in deeper depth) (Ahmad et al., 2018). Recent research conducted by Mozumder and colleagues has shown that extensive pumping from a deeper aquifer that is devoid of As can lower the pressure of that aquifer, which in turn makes it possible for As- and carbon-rich groundwater to seep into an overlaying aquifer. As a direct consequence of this, As pollution of the deeper aquifer will eventually emerge over the course of time (Mozumder et al., 2020).

Besides, industrial wastewater (Wang & Mulligan, 2006), jute retting (Farooq et al., 2012), mining (Lee et al., 2008), and leaching loss of Wood preservatives (Townsend et al., 2005) are some other reported sources for As enrichment in groundwater. Drinking of groundwater (Morales et al., 2000) and consumption of cereals & vegetables (Alam et al., 2003; Williams et al., 2006) and fish (Mondal & Polya, 2008) cultivated with contaminated groundwater are significant sources of human exposure to As. While reviewing works about human As exposure, Khan et al. (2009a) emphasized that although fish contains a higher level of As and is a significant source of human exposure, it does not pose a potential threat to humans because the form of As is organic and non-toxic.

2.2.2 Arsenic in groundwater

Irrigation-based farming is the biggest utilizer of groundwater (Foster et al., 2012, 2018) where it accounts for almost 70% of total withdrawn freshwater worldwide (WWAP, 2015) and contributes to assuring food security for billions of populaces which usually get challenged due to the lack of the availability of surface water (Qureshi et al., 2015; Dey et al., 2017). But it is a matter of concern that groundwater As contamination has been reported in more than 70 nations worldwide; where elevated As level has been recorded in 10 Asian countries surpassing the WHO proposed limit for drinking (10 µg/L), and irrigation (20 µg/L) and the UNFAO proposed limit for irrigation (100 µg/L) water; ultimately putting at least 110 million populaces in Asia at risk of As induced diseases(Brammer & Ravenscroft, 2009; Chakraborti et al., 2010; Stroud et al., 2011). Arsenic concentration in groundwater from the natural source and permissible limit of As concentrations for irrigation water in different countries has been presented in Table 1 and Table 2, respectively. Irrigation with groundwater containing an elevated level of As is a significant source of soil accumulation. According to Bhattacharya et al. (2007) and Bhattacharya et al. (2012), As concentration in soil is significantly correlated with that in the below surface water used for irrigation, and soil

As concentration can be as higher as 83 mg/kg, where groundwater contains a higher level of As.

In most South and South East Asian countries, As contamination in groundwater is now widely acknowledged. Rice is the primary cereal crop grown in these regions, particularly in Bangladesh and West Bengal (India), which irrigate their rice fields with groundwater during the dry season. Rice is a staple food in both countries, and evidently, As-contaminated irrigation water is contributing a large quantity of As to the topsoil as well as to the rice, which poses a serious threat to the sustainable production of rice in these two countries (Meharg & Rahman, 2003; Brammer & Ravenscroft, 2009; Khan et al., 2009; Dittmar et al., 2010; Khan et al., 2010). Irrigation of paddy rice grown in these regions with As-elevated groundwater is expected to impose a similar impact since the agroecological and hydrogeological circumstances of the countries that make up South and Southeast Asia are largely comparable. Because of its increasing deposition in the topsoil from irrigation water and its subsequent uptake in rice grain, paddy rice is considered to be one of the major and potential exposure sources of As for humans (Meharg & Rahman, 2003; Mondal & Polya, 2008; Rahman et al., 2008a; Pillai et al., 2010; Singh et al., 2010; Tuli et al., 2010; Dittmar et al., 2010). Rice farming may be especially vulnerable to the negative effects of irrigation with As-elevated groundwater, both in terms of yield and grain contamination. Rice is the crop most vulnerable to As toxicity, which could be one of two primary reasons why this is the case. A large amount of underground water containing high levels of As has been irrigated for rice cultivation in most parts of South and Southeast Asia during the dry season (Brammer & Ravenscroft, 2009). As a result of the decline in rainfall that has been observed in this region, even during the monsoon season, it is anticipated that the reliance on groundwater for rice cultivation will increase over the next few years (Brammer & Ravenscroft, 2009). This will be necessary to boost crop production and satisfy the requirements of an expanding population. Because of this approach, there will be a greater accumulation of As in the topsoil. According to Roberts et al. (2007), the use of As-rich groundwater for irrigation in Bangladesh has resulted in a considerable rise in the amount of As found in the country's topsoil over the past 15 years. Arsenic concentrations were found to be unchanged at the beginning of two consecutive irrigation seasons, suggesting that the As added during the first irrigation season was washed away by floodwater during the monsoon season. Other studies showed that As concentrations remained unchanged at the beginning of both irrigation seasons (Dittmar et al., 2007). Therefore, the rate of As deposition from contaminated irrigation water would be higher in the soil of flat terrain compared to the soil of flood land if this were the case. A further significant worry about As deposition in paddy soil is whether or not all of the As supplied by the tubewells reaches the fields and is deposited there consistently. A further significant issue of concern is how As in irrigation water and soil leads to its uptake of As by rice plants and rice grain. In a review on As in a South and Southeast Asian viewpoint, Brammer & Ravenscroft (2009) underlined the difficulties at hand. They suggested that groundwater in the majority of As-affected regions in South and Southeast Asia is high in iron (Gurung et al., 2005; Postma et al., 2007). Iron gets oxidized when it is exposed to air, and it subsequently precipitates in the rhizosphere as iron-hydroxides. There is a strong affinity for binding between arsenate and these precipitated iron-hydroxides. Therefore, the As concentration in the soil will decrease with an increase in the distance between the location and the well-head (Dittmar et al., 2007; Roberts et al., 2007). However, because iron is such an essential nutrient, iron precipitation reduces its bioavailability and uptake, resulting in iron chlorosis in rice plants. In these environments, farmers will employ iron fertilizers to boost iron bioavailability and uptake to prevent iron chlorosis from occurring (Álvarez -Fernandez et al., 2005; Hasegawa et al., 2010; Hasegawa et al., 2011). the application of iron fertilizer may boost both iron and As bioavailability and uptake in rice plants because As is adsorbed on precipitated iron-hydroxides in the rhizosphere soil (Hasegawa et al., 2011; Rahman et al., 2008b). In addition to iron fertilizer, rhizospheric microbes solubilize ferric iron in the rhizosphere by exuding siderophores to the root-plaque interface (Crowley et al., 1991; Bar-Ness et al., 1992; Crowley et al., 1992; Kraemer, 2004). This may also render both iron and As bioavailability and uptake in the rice plant. Rice is a strategy II plant, and its roots secrete phytosiderophores into the rhizosphere soil when exposed to an iron-deficient environment. This helps boost the plant's iron bioavailability and uptake (Romheld & Marschner, 1986; Ishimaru et al., 2006). In this scenario, there is also the potential for increased bioavailability of As to the rice plant and its uptake. The conditions under which rice is grown also make As uptake in rice plants more likely. Rice is produced in flooded, anaerobic circumstances, in which As primarily exits in the form of dissolved As(III), and the rice plant quickly absorbs As from the soil solution (Xu et al., 2008).

Table 1:

Groundwater arsenic concentration in different countries in the world (Natural source)

Country and Region	**As concentration (µg/L)**	**References**
Bangladesh (Chandpur)	<10– >1318	Chakraborti et al. (2010)
China (Shanxi, Inner Mongolia, and Xinjiang)	50–4440	World Bank Policy Report (2005)
Cambodia (Mekong River floodplain)	1–1340	Buschmann et al. (2007)
India (West Bengal)	3 – 3700	Mandal et al. (1996)
Taiwan	0.15 – 3590	Smedley & Kinniburgh (2002)
Argentina (Pampa, Cordoba)	11.4 –1660	Litter et al. (2019)
Nepal	8–2660	Shrestha et al. (2003)
Pakistan	<1-906	Nickson et al. (2005)
Chile	470–770	United Nations (2001)
Japan	1–293	Naidu et al. (2006)
Vietnam	<1 to 632	Agusa et al. (2014)

Thailand (Nakhon Si Thammarat Province)	1.25–5114	Williams et al. (1996)
Korea	23–178	Kim et al. (2012)
Mexico	8–624	Mahimairaja et al. (2005)
Argentina (Chaco-Pampean plain)	< 10–5300	Nicolli et al. (2012)
Hungary	1–174	Sancha et al. (2008)
Northern Greece	1500	Casentini et al. (2011)
Australia	1-5000	Naidu et al. (2006)
Romania (Western Romanian Plain)	0-176	Rowland et al. (2011)
Peru (Western Amazonia)	0.5–715	de Meyer et al. (2017)
Finland (South-west)	<5–2230	Parviainen et al. (2015)

Table 2:

Permissible arsenic concentrations for irrigation water in different countries

Country	**Limit (µg/L)**	**References**
Mexico	100	Bundschuh et al. (2012)
Columbia	10	Alonso et al. (2014)
Venezuela	50	Bundschuh et al. (2012)
Ecuador	100	Bundschuh et al. (2012)
Taiwan	50	Chou et al. (2016)
Peru	200	Bundschuh et al. (2012)
Bolivia	50	Bundschuh et al. (2012)
Chile	100	Bundschuh et al. (2012)
Brazil (fruits and vegetables that are consumed raw)	10	Bundschuh et al. (2012)
Brazil (trees, cereals and forages)	33	Bundschuh et al. (2012)
FAO	100	Chakraborti et al. (2018)
WHO	<10	WHO (2004); Arain et al. (2009)
Argentina	100	Bundschuh et al. (2012)

2.2.3 Arsenic in agricultural soils

If the total soil As concentration is lower than hazardous amounts, then a crop will absorb more arsenic than it would otherwise; this applies to all species of As, regardless of how bioavailable they are (Punshon et al., 2017). This is the case with traditional (aerobic) crops, which uses oxygen, as well as with anaerobic farming techniques, such as those used to cultivate rice (Adomako et al., 2009; Lu et al., 2009; Williams et al., 2007b). There is substantial variation between regions with regard to the total As concentration in the soil. There is a potential for extremely high levels of naturally occurring As to be present in soils that have grown on or downstream from As-rich bedrock. For instance, As concentrations in soils from the arsenopyrite belt (iron arsenic sulfide, FeAsS) in Styria, Austria, can reach as high as 4,000 mg/kg (Geiszinger et al., 2002). Around 568 different minerals have been identified as having high amounts of As in them (IMA, 2014). As a result of its ability to chemically replace other elements in mineral formations, such as phosphorus (V), silicate (IV), aluminum (III), iron (III), and titanium (IV), As can be found in a wide variety of rock-forming minerals. Large-scale regional maps for soil As concentrations in Europe (Lado et al., 2008) and the USA are available. According to the findings of studies conducted in Europe, the majority of soils have As concentrations ranging from 7.5 to 20 mg/kg, with the median value being 6 mg/kg (Lado et al., 2008). This forecast was derived through block regression-kriging, a method of spatial prediction that employs a very high resolution and regresses values of soil As against auxiliary parameters (block size of 5 km2). On a continental scale, large areas of soil with an average concentration of 30 mg/kg of As have been found in southern France, the northern part of the Iberian Peninsula, and south-west England. The latter two regions are areas of extensive natural mineralization linked to mining activities for base and precious metals. According to the United States Geological Survey (USGS), the mean soil As content across the contiguous United States is around 5 mg/kg, with the 5 percentile value being approximately 1.3 mg/kg and the 95 percentile value being approximately 13 mg/kg, respectively (Smith et al., 2014). The data highlight important regional patterns. For example, the As concentrations in the soil of New Hampshire are approximately 10 mg/kg, but the amounts in the soil of Florida are 3.5 mg/kg. The sampling density goal for the United States surface soils and stream sediments database is 1 sample for every 289 km^2, even though the current rate is just 1 sample for every 1600 km^2 (USGS, 2016). Comparatively, more recent reports include smaller regional studies with sample density of 2 km^2 (Young & Donald, 2013) and median total soil arsenic concentrations of 8.7 mg/kg, such as the Tellus database for Northern Ireland. These investigations were conducted in a different region. At this level of sampling density, it is possible to see fine-scale data for variables that have been shown to affect soil arsenic, such as the kind of bedrock, altitude, and organic matter. This provides the opportunity to create predictions regarding the bioavailability and mobility of arsenic.

The presence of As in soil or sediment is the result of a complex and fluid interaction between the factors that serve as inputs and those that act as outputs (Smedley & Kinniburgh, 2002). Because of bedrock weathering (chemical, biological, and mechanical) and depositional inputs, which are the principal natural sources of As to agricultural catchments, the primary sinks at the bottom of catchments are typically quite a distance from the sources (Saunders et al., 2005). Outputs can take the form of things like leaching into water bodies (both horizontally and vertically), biovolatilization, and soil erosion (Smedley & Kinniburgh, 2002; Mestrot et al., 2011). In arid regions, surface evaporation of water can lead to arsenic enrichment as a result of the intake of groundwater and the use of water for agricultural irrigation (Smedley & Kinniburgh, 2002; Lawgali & Meharg, 2011). A mining-impacted catchment area provides a notable example of a mass-balance for As fluxes within catchment regions (Melegy et al., 2011). In this catchment area, chemical weathering, followed by mechanical weathering, dominated As inputs, which were predominantly from arsenopyrite. In other words, chemical weathering was the dominant process. In a manner comparable to this, it is believed that weathering is responsible for 95 percent of the As in an area that previously included gold mines (Drahota et al., 2006). Arsenic precipitation inputs in a wooded catchment region were less than 6 g/ha/y, and organic soils were a net source of As while mineral soils (soils with less than 10 percent organic matter) were a sink. Arsenic precipitation inputs in a forested catchment area (Huang & Matzner, 2007). The most significant source of As in highly organic soil was deposition from the atmosphere (soils with more than 10 percent organic matter). This is in line with the As depositional inputs that were measured in the UK, which ranged from 1 to 10 g of As per hectare per year (CEH, 2008). According to regional scale maps, the amount of As that is deposited is greatest at higher elevations and in the west of the United Kingdom, which are the places that receive the cleanest air masses from the Atlantic. This demonstrates that the As originated in the ocean. Depositional maps and soil As maps have a very significant correlation in the maps of England and Northern Ireland (UKSO, 2016). These maps show that the highest As concentrations in peat soils are found at higher elevations and are associated with bedrock geological anomalies. At higher elevations, peat soils act as a sink for As; but, if the peat is mined or eroded, the soil can change into a source of the element. More research is being done on the topic of upland organic soils acting as sources and sinks of As. This topic could be relevant on a regional basis as a source of As to downstream sediments, and more research is being done on the subject (Mikutta & Rothwell, 2016).

It is generally accepted that the mechanical weathering that results from plate tectonics is the primary source of As in major catchment areas that have continental significance. One example of this would be the deltas that can be found to the south and east of the Himalayas. One theory proposes that the high levels of As found in Holocene aquifers, such as those found in Southeast Asia, as well as in the glacial tills of Europe and North America are the result of mechanical weathering brought on by Pleistocene tectonic uplift in the Himalayas. This theory is part of the so-called "mechanical weathering hypothesis" (Saunders et al., 2005). Mechanical weathering of bedrock exposes mineral surfaces that were previously inaccessible, and finer grinding increases the surface area available for chemical and microbiological weathering, which in turn enhances the solubilization of As (Smedley & Kinniburgh, 2002, Saunders et al., 2005, Mailloux et al., 2009). The process of weathering, which is caused by chemicals and bacteria, can take place either at the source of the material, nearby, or in sediment sinks. For instance, Mailloux et al. (2009) stated that bacteria that were isolated from aquifers in the Bay of Bengal have the potential to mobilize As from apatite. Arsenic loadings in soil will always be affected by both the As that is present in the bedrock and the degree to which that bedrock-derived material has been weathered along the path that leads from source to sink. The median amount of As was found to be at its lowest in soils that were underlain by basalt, while it was found to be at its highest in soils that were underlain by psammite, semipelite, or lithic arsenite. Interpretation of such fine-scale mapping can ultimately result in projections of soil As concentrations in areas where exact data are not available. When combined with an understanding of soil chemistry, this will make it much simpler to make predictions on which crops will have greater As contents (Williams et al., 2011).

Based on the weathering and geology, soil usually retains 5 to 15 mg/kg of As (Mandal & Suzuki, 2002) and does not exceed 15 mg/kg (Smith et al., 1998). However, the reported world average level of naturally occurring soil As is 10 mg/kg (Das et al., 2002). It is deemed that As toxicity is comparatively higher in sandy than clayey soils (Smith et al., 1998). Irrigating the crop fields with high As-polluted groundwater is highly responsible for elevating As concentration in soils (Bhattacharya et al., 2012). Huq et al. (2006) estimated the incorporation of 5.5 kg of As per ha every year due to irrigation with groundwater containing 0.55 mg/L As.

Therefore, soil and crop accumulation of As in many countries surpassed the background limit. For example, the soils of Bangladesh, Brazil, Chile, India, Mexico, Poland, Turkey, and the USA fall into this category, and the crops grown in those regions are highly susceptible to As contamination and subsequent health hazards. For example, in Bangladesh, an average of 61 µg As/L groundwater has been documented in the wells of some regions at <100 m depth (BGS-DPHE, 2001; Huhmann et al., 2017). By estimating the usual boro rice cultivation practices for 25 years in Bangladesh, Huhmann et al. (2017) reported that 10.2 mg of As has been accumulated per kg of top 15 cm soil since Green Revolution. Arsenic uptake by crops is determined by the concentration level of soil As (Bhattacharya et al., 2012). According to Sheppard (1992), crop cultivation in highly As-polluted soils has been claimed to be the primary cause of As accumulation by crops and reduction of plant growth. Some studies in different countries show the evidence. Panaullah et al. (2009) observed an average 16% loss in rice yield in the Bengal basin when rice cultivated in the agricultural fields was contaminated with 10 to 70 mg As/kg of topsoil. Arsenic in agricultural field soils from different As endemic regions have been presented in Table 3.

Table 3:

Arsenic in agricultural field soils

Country	As concentration (mg/kg)	References
Bangladesh	46–83	Ullah (1998); Meharg & Rahman (2003)
India (West Bengal)	7.56–21	Roychowdhury et al. (2005)
Pakistan	46.2	Arain et al. (2009)
Cambodia	180	Seyfferth et al. (2014)
China	1.9–36.0	Zhou et al. (2018)
Taiwan	12.7	Kar et al. (2013)
Vietnam	Upto35	Phuong et al. (2008)
Thailand	0.08–124	Zarcinas et al. (2004)
Turkey (Highly polluted area)	Up to 660	Gunduz et al. (2010)
Nepal	6.1–16.7	Dahal et al. (2008)
Indonesia	0.04-5.10	Rinklebe et al. (2016)
Colombia	148	Alonso et al. (2014)

Spain (Duero Cenozoic Basin)	23 (Mean)	Gómez et al. (2006)
Chile (Northern)	36.2–729	Cornejo-Ponce & Acarapi-Cartes (2011)
Chile (Esquiña)	Up to 489	Bundschuh et al. (2012)
Greece (Northern)	20–513	Casentini et al. (2011)
UK (Wellingborough)	39 to 113	Nathanail et al. (2004)
Mexico (highly polluted area)	2215–2675	Nriagu et al. (2007)
Portugal	<20-306	Pereira et al. (2004)
Cuba	33.6	Alfaro et al. (2015)
Australia	92.0	Hinwood et al. (2003)
Brazil (Southeastern)	200–860	Bundschuh et al. (2012)
USA (Tulare lake)	280 (Mean)	Nriagu et al. (2007)

When paddy is cultivated in As-rich soil, more significant quantities of As are absorbed and accumulate in rice grain, often surpassing the safe limit proposed by WHO (Zhou et al., 2018; Suriyagoda et al., 2018). While reviewing the global soil and rice As concentration pattern and trend, Suriyagoda et al. (2018) observed that As concentration in rice grain rises until soil As concentration reaches up to 60 mg As/kg of soil, followed by decreases. Most rice-producing nations could not propose the critical limit for soil As to produce safe rice except very few (Suriyagoda et al., 2018). Among those few countries, the limit is restricted to 25 mg As/kg soil except for China, Germany, UK, Greece, and Belgium had more than that. Since WHO (2016) announced 0.2 mg iAs/kg rice grain as the permissible limit, considering the generic association between inorganic As (iAs) and total As in rice grains, the permissible limit for total grain As should be 0.37 mg/kg and in line with the above the permissible soil As should be set at 5.5 mg/kg soil (dry weight (dry wt.) basis) (WHO, 2016; Suriyagoda et al., 2018). However, to assure the limit of As in cultivable land soils, farmers should utilize a soil testing field kit to decide the suitable crops for the soil (Huhmann et al., 2021). A recent focus has been put on the future projection of rice production with the coupling stresses of soil As and climate change. Muehe et al. (2019) projected through the greenhouse study that future climate stress will lead to a higher proportion of pore-water arsenite, causing 39% less yield than present with doubled iAs content in rice grains. Permissible limits of As for agriculture soil in different countries have been presented in Table 4.

Table 4:

Permissible limits of arsenic for agriculture soil in different countries

Country	Limit (mg/kg)	References
FAO	50	FAO (1992)
China	30	Massaquoi et al. (2015); Zhou et al. (2016)
Taiwan	5.65	Chang et al. (1999)
Vietnam	12	Phuong et al. (2008)
Argentina	20	Tarvainen et al. (2013)
Australia	10-20	Duxbury and Zavala (2005)
Germany	200	German Federal Soil Protection Act (1998)
Canada	20	Duxbury and Zavala (2005)
UK	10-20	Duxbury and Zavala (2005)
UK	50	Smith (1996)
Netherlands	10-20	Duxbury and Zavala (2005)
Southeastern USA & Greece	40	Dudka & Miller (1999)

Norway	20	Hansen and Danielsberg (2009)
Belgium	45	Soil Remediation Act (1995)
Germany (partially reducing conditions)	50	German Federal Soil Protection Act (1998)
New Jersey, USA	20	Tarvainen et al. (2013)
U.S. Environmental Protection Agency	24	USEPA (1996)
European Union	20	Rahman et al. (2007)
Global average	10	Rahman et al. (2013)
Japan	15	Japan (2016)
Thailand	3.9	Punshon et al. (2017)

2.2.4 Arsenic in rice and vegetables

2.2.4.1 Relationship between As in different parts of rice plants. Usually, grain As is higher than 0.37 mg/kg when grown in soil containing more than 5.5 mg/kg, but some opposites are also evident (Suriyagoda et al., 2018). The explanation for less As in rice grains grown in soils beyond the safe limit can be due to some unique mechanism of those varieties partition minimum As to grains. In addition to this, As translocation from paddy roots to grain takes several steps, which causes possible variations among genotypes and higher accumulation in roots occurring due to the reduction of As(V) to As (III) may minimize As translocation to aerial parts as well as grains (Zhao et al., 2009; Seyfferth et al., 2011; Islam et al., 2017; Suriyagoda et al., 2018). The accumulation of As in different parts of the rice plant takes place in the following manner: grain<husk<straw<root (Smith et al., 2008; Islam et al., 2016). Moreover, with rising soil As, plant As increase accordingly (Islam et al., 2016). However, researchers have demonstrated overwhelming deviation in grain-As levels globally (Islam et al., 2016).

While studying the correlation between As in irrigation water and soil, Kar et al., 2013 and Mukherjee et al., 2017 observed a positive relationship. Mukherjee et al. (2017) also reported that As in irrigation water is positively correlated with grain As. Soil-available As was also found significantly correlate with As content in the root (Bhattacharya et al., 2010a) and grains, but no such relationship was observed between As in grain and soil-total As (Panullah et al., 2009; Khan et al., 2010; Kar et al., 2013; Mukherjee et al., 2017) although it is claimed soil-available As to have a significant positive correlation with soil total As (Huang et al., 2006; Kar et al., 2013). In contrast, Hossain et al. (2008) explored a strong positive correlation between soil total and grain total As. According to Lu et al. (2009), grain As level usually increases with increasing soil total As and reaches a saturation plateau at >10 mg As/kg soil. Khan et al. (2010) found that with the increase in soil As, straw As enriched, but the grain As did not. Therefore they made the possible explanation that because of the As phytotoxicity in some of the land area in Bangladesh similar to their, As translocation to rice grains from the shoot is inhibited which further let them unable to predict the level of grain As having measured the soil As. However, Talukder et al. (2012) claimed straw As have a strong positive relationship with grain As both for boro (BRRI dhan29) and aman (BRRI dhan32) rice varieties. Similar findings were reported by Mei et al. (2009) and Wu et al. (2011).

Rice consumption has been found to be a significant exposure pathway for As ingestion in regions where As-rich groundwater is the primary irrigation source for crop production (Alam et al., 2003; Al Rmalli, 2012). Indeed rice intake is the most critical exposure pathway for communities that do not drink groundwater containing As >50 µg/L (Alam et al., 2003; Banerjee et al., 2013). Although the interest in this crop as a possible source of As toxicity is very latest, researchers grabbed this scope with profound interest due to its crucially essential uses worldwide.

2.2.4.2 Dietary consumption of As through rice. The research conducted regarding the As accumulation in agricultural crops has yielded similarly controversial results in terms of the severity, degree, and uptake processes involved (Senanayakea & Mukherji, 2014). Scholars have proposed, on the one hand, that increased As concentrations in soil (as a result of As-contaminated groundwater irrigation) lead to increased As concentrations in grain (Williams et al., 2006; Khan et al., 2009; Azad et al., 2009; Zhao et al., 2009; Rahaman et al., 2011; Rauf et al., 2011). For example, Farid et al. (2005) reported positive associations between As contents in grain and soil at 96 sampling points within a single tubewell site in Brahmanbaria, Bangladesh. This particular site was located in Bangladesh. On the other hand, a number of academics point to results that are less conclusive. For instance, Van Geen et al. (2006, p.769) argued that " Despite the accumulation of As in soil and in soil water attributable to irrigation with groundwater containing elevated As levels, there is no evidence of a proportional transfer to rice grains collected from the same sites." In a study that reached a similar conclusion, Stroud et al. (2011, p. 950) discovered that "concentrations of arsenic in rice grain varied by 2 and 7 fold within individual fields and were poorly linked with the soil arsenic concentration." Finally, Duxbury & Panaullah (2007, p. 6) provide additional evidence in support of these findings, concluding that their "overall experience with large numbers of samples from farmer fields is that neither arsenic in irrigation water nor in soil are good predictors of arsenic in rice grain." This finding is supported by the fact that the researchers found no relationship between the arsenic concentrations in the grain and the total arsenic content in the soil at any of the field sites.

Another line of inquiry that is similar to this one contends that the absence of a correlation between contaminated groundwater and the uptake of As by crops can be traced to changes in environmental factors, agricultural factors, soil factors, and plant factors (Williams et al., 2006; Hartley & Lepp, 2008; Hossain et al., 2008; Brammer, 2009; Bogdan & Schenk, 2009). It has been established that the soil's redox potential, total organic matter content, pH, manganese, calcium-carbonate, iron, phosphorus, and soil microbes, all have an effect on the quantity of As that is accessible for crop uptake (Mahimairaja et al., 2005; Brammer & Ravenscroft, 2009). When it comes to the cultivation of rice, the influence of a few of these soil qualities shifts dramatically during the year because soils go through aerobic and anaerobic cycles throughout the year. Because As in aerated soils is predominantly found in its oxidized form (arsenate, or AsV), this form of the element has the potential to be rapidly absorbed by iron hydroxides, rendering it largely unavailable to plant (Duxbury & Panaullah, 2007). Arsenic is mostly found in its reduced form, arsenite (AsIII), and is dissolved in the soil-pore water in anaerobic soil conditions, such as flooded paddy fields (Brammer & Ravenscroft, 2009, p. 650; Xu et al., 2008). As a result, it is more easily accessible to the roots and thus rice is more susceptible to As uptake than dry-land crops (wheat and barley), according to several studies (Williams et al., 2005; Brammer, 2009; Sarkar et al., 2012). According to the same line of reasoning, rice that is produced in environments that receive adequate ventilation may similarly be less susceptible to As contamination.

Not only does the uptake of As differ depending on the qualities of the soil and the plant species (Hartley & Lepp, 2008), but it also differs depending on the components of the plant. For instance, Norra et al. (2005, p. 1890) discovered that “rice and wheat grains are not contaminated by arsenic (about 0.3 and 0.7 mg/kg, respectively), but concentrations in rice roots were found to be more than 20 times higher than values measured at the uncontaminated reference site.” Abedin et al. (2002), Das et al. (2008), Hartley & Lepp (2008), and Pigna et al. (2010) discovered in descending order. These results are very fascinating because they reveal that grain uptake does not necessarily follow even when As is supplied to the soil through irrigation water and deposited in the plant roots. This is one of the reasons why these researches are so interesting. To put it another way, the concentration of As in grain cannot always be adequately explained by either exposure to contaminated water or arsenic levels in soils or roots.

Although warrantable anxiety concerning the elevated levels of As in drinking water kept a significant proportion of the global population at risk (Smedley & Kinniburgh, 2002; Ravenscroft et al., 2009), additionally, consumption of As-rich rice is the most significant dietary source of As to the people not exposed to the contaminated drinking water (Meacher et al., 2002; Yost et al., 2004; Meliker et al., 2006; Tsuji et al., 2007; EFSA, 2009; Meharg et al., 2009). In addition to carbohydrates, rice contains thiamin, copper, zinc, and magnesium vitamin B6, making it the staple food of fifty percent of the global population (Singh et al., 2015). As a foremost source of iAs accumulator, rice has been reported to contain up to 90% of total accumulated As. Rice accumulates almost ten times more As compared to other crops since reductive conditions prevail in rice fields (Williams et al., 2007a,b), and naturally, this problem is even more severe in the Asian rice-producing countries like Bangladesh, India, China, and also US (Williams et al., 2005, 2007a; Meharg et al., 2008). Generally, more than 90 % of global rice production comes from Asian countries (Arunakumara et al., 2013), and for example, in 2017, out of a globally total produced 735 million metric tons of rice, only Asian countries contributed almost 680 million metric tons (FAO, 2018). Arsenic concentration (mg/kg) in rice grain from some rice-producing countries has been presented in Table 5, and Permissible limits for total As in rice and rice-based foods are depicted in Table 6.

Because of daily rice consumption, As gets accumulated and poses severe threats to the human body (Shraim, 2017). Thus, rice consumption exemplifies a key route for As exposure in most nations, exclusively for populaces enjoying a rice diet up to 60% of their daily meal (Islam et al., 2016). The quantity of As taken daily by the people via rice consumption is largely determined by the volume of rice in their meals (Singh et al., 2015). According to FAO (2004), the average consumption rate of rice varies by almost 0.9 to 650 g/person/day in many countries, including Bangladesh, Laos, Vietnam, Myanmar, and Cambodia, where much little consumption rates have been reported in some European and African nations as compared to the Asian countries. FAO (2004) extended that 46 Asian, South American, and African countries consume rice weighing over 100 g/person/day. For a specific example, Asian adults consume 200 to 600 g of rice per person/day (Duxbury et al., 2003; Rahman et al., 2009; Zavala & Duxbury, 2008;

Table 5:

Rice (grain) arsenic concentration (mg/kg) in some rice producing countries

Country	Min	Max	Avg	Reference
Bangladesh (Chandpur)	0.04	0.91	0.28	Williams et al. (2006)
India (West Bengal)	0.19	0.78	0.451	Bhattacharya et al. (2010a)
China (market basket)	0.015	0.586	0.121	Zhu et al. (2008)
Brazil	0.059	0.782	0.212	Ciminelli et al. (2017)
Taiwan	0.050	0.200	0.120	Lin et al. (2015)
Hong Kong (market basket)	0.015	0.138	0.080	Zhu et al. (2008)
Thailand	0.140	0.150	0.145	Meharg et al. (2009); Adomako et al. (2011)
Thailand	0.118	0.343	0.239	Nookabkaew et al. (2013)
Turkey	-	-	0.202	Sofuoglu et al. (2014)
Italy	0.070	0.330	0.150	Islam et al. (2016)
Korea	0.24	0.72	0.410	Lee et al. (2008)
Nepal	0.060	0.330	0.180	Dahal et al. (2008)

Pakistan	0.073	0.088	0.082	Rahman et al. (2014)
Japan	0.070	0.420	0.190	Meharg et al. (2009)
Sri Lanka	0.012	0.540	0.122	Jayasumana et al. (2015)
Philippines	-	-	0.070	Williams et al. (2006)
France	0.090	0.560	0.280	Islam et al. (2016)
Vietnam	253.70	344.50	299.10	Nookabkaew et al. (2013)
Cambodia	0.100	0.370	0.201	Seyfferth et al. (2014); Phan et al. (2014)
Spain	0.050	0.820	0.200	Islam et al. (2016)
Egypt	0.02	0.08	0.050	Meharg et al. (2007)
Europe	0.13	0.20	0.15	Williams et al. (2005)
EU			0.19	Zavala & Duxbury (2008)
U.S.	0.210	0.250	0.230	Heitkemper et al. (2001); Williams et al. (2007b)
U.S.	0.11	0.66	-	Zavala & Duxbury (2008)
Lebanon	0.01	0.07	0.04	Adomako et al. (2011)
U.S. (California)	0.10	0.30	-	Zavala & Duxbury (2008)
Australia	0.188	0.438	0.270	Rahman et al. (2014); Islam et al. (2016)

Australia	0.09	0.33	0.22	Fransisca et al. (2015)
Argentine	0.87	0.316	0.180	Sigrist et al. (2016)
Philippines	0.00	0.25	0.07	Williams et al. (2006)
Venezuela	0.19	0.46	0.30	Schoof et al. (1998); Zavala & Duxbury (2008)
Ghana	0.15	-	-	Adomako et al. (2011)
Canada	0.020	0.110	0.065	Heitkemper et al. (2001); Williams et al. (2005)

Table 6:

Permissible limits for total arsenic in rice and rice-based foods

Country/Organization	Permissible As concentration (mg/kg)	References
WHO	0.37	WHO (2016); Suriyagoda et al. (2018)
FAO	1	Singh et al. (2015)
China (foods of South Asia)	0.15	Chakraborti et al. (2018)
European Union (EU)	No regulation	Hojsak et al. (2015)
US	No regulation	Hojsak et al. (2015)
Bangladesh	No regulation	Aziz et al. (2015)

Zhu et al., 2008; Garnier et al., 2010), where it is 32–232 g in Ghana (Adomako et al., 2011). Because of the differences in rice intake with As concentration level in rice, the possible daily intake rate of As for the adults is also significantly different where it is 69 µg in Cambodia (Phan et al., 2014), 100–350 µg in Bangladesh (Panaullah et al., 2008; Rahman et al., 2009) and 19.59 µg in India (Kumar et al., 2016). Many of these estimations are considerably higher than daily As ingestion from 2L drinking water at WHO standard (10 µg As/L). Moreover, As intake of Cambodians from daily rice consumption has been reported as 1.46 µg/kg body weight (Phan et al., 2014), whereas it is 0.184, 0.49, and 1.7 µg/kg body weight for the people of France, China and Bangladesh, respectively (Williams et al., 2005; Khan et al., 2009; Huang et al., 2013). Out of the total amount of As content in rice, inorganic As accounts for around 96.8% (Roychowdhury, 2008), whereas rice from Asian countries contains up to 99% (Rahman et al., 2014). However, 2.1 µg As/kg body weight/day has been recommended by FAO/WHO as a daily tolerable limit where it is 15 µg inorganic As/Kg body weight/ week (WHO, 1989; Kohlmeyer et al., 2003; Sanz et al., 2007; Roychowdhury, 2008).

2.2.4.3 Dietary consumption of As through vegetables. In Bangladesh, vegetables are a significant part of the diet together with rice. Vegetable consumption is estimated to be 238 g per person per day (BIRDEM, 2013). The type of vegetable and the soil conditions in which the crop is grown both determine the As content in those crops (Huq et al., 2006; Kurosawa et al., 2008). In Bangladesh, irrigation water is provided through wells that are contaminated with As, providing a different route for As to enter the soil and subsequently become available for plant absorption (Alam & Sattar, 2000; Meharg & Rahman, 2003; Polizzotto et al., 2015). Arsenic levels as high as 83 mg/kg have been recorded for soils irrigated with As-contaminated water in the Bengal basin (Roychowdhury et al., 2005). According to some research, there is a direct link between the amount of As in a crop and that in the soil where the crop is grown and the groundwater used for irrigation purpose (Farid et al., 2003; Kurosawa et al., 2008). Farid et al. (2003) reported on vegetable crops grown in paired plots, one of which was irrigated with As-free water and the other with As-contaminated water, in a field experiment in Bangladesh. Vegetable samples (edible parts) from both plots were analyzed, and the results showed that the samples from the plot irrigated with contaminated water had an increase in As concentration ranging from 9 to 288 percent compared to the samples from the control plot. Regarding the buildup of As in crops, spatial variation is also reported (Farid et al., 2003). The majority of the As that is accumulated in root vegetables—such as potatoes, radishes, carrots, turnips, etc.—is found in the root tuber. Because there is typically little transfer to the plant's upper levels (Huq et al., 2006). Thus, compared to the As content in the remaining plant tissues, seeds and fruits end up having relatively lower levels of As (Williams et al., 2006; Carbonell-Barrachina et al., 2009; Senanayake & Mukherji, 2014). Root crops' external root skin contains more As than the inside of the root, indicating that washing and peeling edible tubers like potatoes and carrots effectively lowers human exposure to As (Carbonell Barrachina et al., 2009; Norton et al., 2013). Vegetables with a root tuber and leaves tend to score higher on average than those with a fruit or flesh (Roychowdhury et al., 2002a; Farid et al., 2003). Approximately 2500 samples of vegetables (edible parts), rice, wheat, and grasses from both As-affected and non-affected areas of Bangladesh were reported on by Huq et al. (2006). Arsenci levels in vegetables and crops in their study were up to 158 mg/kg, showing a significant As accumulation in those crop.

Arsenic analysis in vegetables from the Jalangi and Domkal blocks in West Bengal, India, revealed mean As levels of 0.0209 mg/kg (0.00004–0.138 mg/kg) and 0.0212 mg/kg (0.00004–0.212 mg/kg), respectively (Roychowdhury et al., 2003). According to Williams et al. (2006), leafy vegetables accumulate more As (0.041–0.464 mg/kg) than non-leafy vegetables (0.011–0.145 mg/kg). The range of As in vegetables in Bangladesh has been shown to vary by location, with Jamalpur and Chandpur districts (0.070–3.990 mg/kg) and Comilla, Rajshahi, and Sathkhira districts (0.040–1.930 mg/kg) having the highest levels (Williams et al., 2006). On the other hand, Munshiganj and Monohordi in Bangladesh have a range of 0.019–2.334 mg/kg in cooked vegetables (Smith et al., 2006). Some Bangladesh-based investigations of As contents in vegetables have been presented in Table 7.

According to statistics on As in vegetables, the concentrations of As in some vegetables can be as high as rice on a dry wt. basis. The maximum permitted levels (MPL) of As in vegetables (fresh weight) varies significantly between countries. Regarding the legislation, the MPL value is 0.5 mg/kg in China (Liu et al., 2010), 1.0 mg/kg in the United Kingdom (MAFF, 1997), Ireland (FSA, 2000), and Singapore (AVA, 2006). Numerous countries, among them Bangladesh, lack legislation, and some researchers consider the maximum food safety value, 1 mg/kg, as the MPL of As for fresh vegetables in Bangladesh (Ahmad, 2000; Islam et al., 2012).

Table 7:

Arsenic content in vegetables in some arsenic contaminated regions of Bangladesh

Location	**Sampling source**	**Sample category**	**As concentration (mg/kg)**	**References**
Samta village in the Jessore district	Home garden	15	0.019 to 0.49	Alam et al. (2003)
Gopalgonj sadar, Muksedpur, Monirampur, Pirgachha, Rajarhat, Chapai Nawabgonj Sadar, Charghat	Experimental field	11	0.011 to 0.94	Farid et al. (2003)
Dhaka, Bangladesh	Market sourced vegetable	8	0.001 to 0.29	Anawar et al. (2012)
Fifteen districts (160 sites)	Field vegetable samples	22	0 to 4	Huq et al. (2006)
Chowgacha upazila under Jessore district	households and local Markets covering	18	Leafy vegetables = ~0.1 to 2; Non leafy vegetables = ~0.1 to 0.8	Tani et al. (2012)

Hajiganj and Kachua, Chandpur District and Sharishabari, Jamalpur District	Field vegetable samples	3	0.07 to 3.99	Das et al. (2004)
Matlab Upazila of Chandpur district	Household sourced vegetable	7	0.0013 to 0.023 mg/kg	Khan et al. (2010)
Five upazillas of Feni district of Bangladesh	Field vegetable samples	8	Up to 0.69	Karim et al. (2008)
Ruppur area of Pabna District of Bangladesh	Field vegetable samples	7	0.05 mg/kg	Jolly et al. (2013)
Shaheb Bazar, Rajshahi	Market sourced vegetable	9	0.12 mg/kg	Saha & Zaman (2013)
Chiladi and Basantapur villages, Noakhali	Home garden vegetables	11	Leafy vegetables = 0.041 to 0.46; Non leafy vegetables = 0.011 to 0.15,	Rahman et al. (2013)
Different markets in Bangladesh	Market sourced vegetable	15	Leafy vegetables = 0 to 0.2; Non leafy vegetables = 0 to 0.05	Islam (2013)
Dhaka and	Field and local	10	Industrial= 0.17 – 0.43	Haque et al.

Faridpur region	markets	Non-industrial= 0.08 – 0.23	(2021)

2.2.4.4. Human health risk due to As exposure and its presence in biological materials. This section discuss As consumption scenario from rice and vegetables ingestions, human health risk associated to this exposure and human biological samples used to trace the exposere.

2.2.4.4.1 Arsenic consumption scenario and limit. People in Bangladesh are exposed to As through contaminated food (i.e., rice and vegetables), in addition to their contaminated drinking water. The situation is made worse by the fact that As-contaminated groundwater is frequently used to cultivate rice and vegetables (Harvey et al., 2002; Meharg & Rahman, 2003; Das et al.,2004; Huq et al., 2006). According to Williams et al. (2005), the average concentration of As in Bangladeshi rice ranges from 0.1 to 0.95 µg/g, making it the source of As with the highest average concentration among all dietary sources. Arsenic toxicity from a rice diet, on the other hand, is very dependent, both on the concentration of As species in rice as well as their bioavailability (Laparra et al., 2005). According to the findings of Zhu et al. (2008), the hazardous iAs makes up around half of the overall amount of As found in rice, which can range anywhere from 10 percent to 90 percent. The absolute bioavailability of inorganic arsenite is the highest at 103.9 percent, followed by that of arsenate (92.5 percent), dimethylarsenate (DMA) (33.3 percent), and monomethylarsenate (MMA) (33.3 percent) (Juhasz et al., 2006). Therefore, inorganic forms of As represent a greater risk to human health than their organic counterparts impose. Drinking water contributed only 13 percent to overall As exposure, according to an epidemiological study conducted in As-affected districts of Bangladesh, while consumption of cooked rice contributed 56 percent (Ohno et al., 2007). Because rice absorbs almost double its weight in water during the cooking process, the As levels in cooked rice are likely to be higher if the cooking water contains As in it. Therefore, rice cooking procedure plays a key part in the arsenic exposure contribution (Rahman et al., 2006; Sengupta et al., 2006; Rahman et al., 2018). As discussed earlier in section 2.2.4.3, vegetable consumption significantly contributes As loading to the human body apart from rice and drinking water. For example, based on the average body weight of a Bangladeshi adult (45 kg) from Madaripur thana of Bangladesh, vegetables alone contribute 0.05 µg of As per kg bw daily (Chowdhury et al., 2003; Rahman et al., 2013).

Arsenic-riched food poses a health danger to the majority of the population in As-affected areas, as well as in non-affected areas, because food crops are often imported from As-affected parts of the world. This is the case even when non-affected places are not themselves harmed by As. Consumption of foods containing As has been identified as the principal means through which humans are exposed to this toxic element. Numerous reports of exploratory studies have found evidence of a higher amount of As in the foodstuffs of Bangladesh (Das et al., 2004; Misbahuddin et al., 2007; Rahman et al., 2013; Islam et al., 2014; Ahmed et al., 2016; Sandhi et al., 2017). According to the findings of study on total diets carried out by the Food and Drug Administration (FDA) of the United States, food is responsible for 93 percent of As exposure in the United States (Adams et al., 1994). In a similar vein, there is a possibility of being exposed to As in Bangladesh not only through consumption of rice and vegetables, but also through consumption of items derived from animals, such as milk, eggs, and meat (Ahmed et al., 2016). Arsenic concentrations were measured in a variety of commonly consumed items that were gathered from thirty distinct agroecological zones in Bangladesh by Ahmed et al. (2016). They demonstrated that cereals, vegetables, milk, and fish account for around 90 percent of an individual's daily As intake. In addition to this, they explored the dangers that As in the food posed to human health in both rural and urban settings. The previous provisional tolerable daily intake (PTDI) guideline established by the World Health Organization (WHO) was 2.1 g/kg-BW/day. The estimated daily dietary intakes (EDI) of As for exposed people living in rural areas (3.5 g/kg-BW/day) and urban areas (3.2 g/kg-BW/day) far surpassed this value (Ahmed et al., 2016).

The Daily intake (µg/day) of total As through foods also has been estimated in different countries. The majority of the nations were found to take As less than USEPA provided guideline value (220 µg As/person/day) from different food sources, where the exception is observed in the case of Japan, Thailand, Mexico, and Spain, having the highest intake of daily dietary As (shown in Table 8). The provisional tolerable daily intake (PTDI) of As (2.1 µg/kg/bw) has been withdrawn and is no longer valid according to a recent evaluation by the Joint FAO/WHO Expert Committee on Food Additives (JECFA), as the iAs lower limit of the benchmark dose for a 0.5 percent increased the incidence of lung cancer (BMDL0.5). Using a number of assumptions, the total dietary exposure to inorganic As through food and drinking water was estimated to be 3.0 µg/kg/bw/day (2-7 µg/kg/bw/day based on the range of projected total exposure) (Rahman et al., 2013). The PTWI (Provisional Tolerable Weekly Intake) of As is 15 µg iAs/week/kg body wt. as established by FAO/WHO (Díaz et al., 2004), where Roychowdhury et al. (2002a) estimated 11-11.8 (for an adult male), 9.4-15.3 (for adult female), and 12-13.9 (for children) µg iAs/week/kg body wt. in West Bengal, India.

A vascular problem that ultimately caused gangrene and necrosis has been reported by Larsen & Berg (2001) upon an intake of 10 to 50 µg iAs/day/kg body wt. The NOAEL (No Adverse Effect Level) for chronic exposure through oral intake was established at one µg iAs/day/kg body wt., while the LOAEL (Low Adverse Effect Level) for the same was established at 10-100 µg iAs/day/kg body wt. (Tsuji et al., 2015).

Table 8:

Worldwide variation of mean daily total arsenic intake through food

Country	Mean daily total As intake (μg person/day/)	References
Bangladesh	214 (males) 120 (females)	Watanabe et al. (2004)
Sweden	60.0 ± 0.04 (<50–180)	Jorhem et al. (1998)
Korea	38.5	Lee et al. (2006)
UK	65–67	MAFF (1999)
Japan	182 ± 114 (27.0–376)	Mohri et al. (1990)
Japan	160–280	Tsuda et al. (1995)
West Bengal, India	60.3–102	Roychowdhury et al. (2003)
Thailand	287 ± 97.7 (68.2–564)	Ruangwises & Saipan (2009)
Mexico	394	Del Razo et al. (2002)
Germany	6.90 ± 12.4 (0.60–98.0)	Wilhelm et al. (2003)
Spain	223.6	Llobet et al. (2003)
Spain	221.18	Delgado-Andrade et al. (2003)
USA	88	Gunderson (1995)
USA	3.2 (children, 1-6 years)	Yost et al. (2004)

2.2.4.4.2 Human health risk. Arsenic can induce numerous severe health hazards, including cancerous, dermal, gastrointestinal, cardiovascular, respiratory, neurological, endocrinological (diabetes mellitus), developmental, cutaneous, and reproductive disorders (Chakraborti et al., 2017; Sobel et al., 2020). While reviewing the relevant pieces of literature, Pullella & Kotsopoulos (2020) represented As a modifiable and potential risk factor for developing breast cancer. However, they could not reflect the direct association between breast cancers and As exposure. The development of red flag lesions in the skin in the indication of acute internal damage (Chakraborti et al., 2011). Unfortunately, scientists to date could not produce any medicine that can remedy chronic As toxicity (Chakraborti et al., 2018). According to Booth (2009), iAs exposure through rice consumption is responsible for internal and external cancers such as lung, liver, kidney, bladder, and skin and can also cause Diabetes. Oberoi et al. (2014) calculated slope factors for As-induced foodborne diseases where they reported that each year the ingestion of iAs through food consumption could contribute to an additional number of 9,129 to 119,176 bladder cancer cases where it is 11,844 to 121,442 for lung cancer and 10,729 to 110,015 for skin cancer cases globally. In their study in India, Kumar et al. (2016) observed that rice and vegetables are remarkable As contributors to the human body where the health risk index (HRI) was >1 for both the food items. Several researchers counted the "lifetime cancer risk" per 10,000 people due to rice consumption, and this rate is for Taiwan at 1.04 (Chen et al., 2016), the US at 1.30 (Meharg et al., 2009; Islam et al., 2016), and Bangladesh 22.10, China 15.20, India 6.90, and Italy 0.70 (Meharg et al., 2009).

In addition to a number of other negative human health implications, skin lesions, also known as arsenicosis, are one of the most prevalent effects of chronic As exposure in Bangladesh (Kapaj et al., 2006; Yunus et al., 2016). Arsenic exposure can have a negative impact on practically all of a person's physiological systems, but the renal system, reproductive system, neurological system, endocrine system, cardiovascular system, hematological system, hepatic system, and respiratory system are the ones that are most likely to be affected (Rahman et al., 2018; Shaji et al., 2021; Rahaman et al., 2021;). Arsenic exposure has been shown to have negative effects not only on the health of adults but also on the health of children. Maternal As exposure during pregnancy has been linked to an increased risk of infant mortality, stillbirth, spontaneous abortion, preterm birth, delayed child growth, low birth weight, a lower IQ, an unhealthy immune system, neurodevelopmental impairment, and neurotoxicity (Vahter, 2008). However, As toxicity is more common in persons who consume less protein (Ahmad et al., 2018), and people who are malnourished are more prone to developing skin lesions associated to As exposure (Kapaj et al., 2006).

The transfer of As may not be immediately recognized since its exposure symptoms may be dormant for a long time. According to Sampson et al. (2008), it usually takes 8 to 10 years from the consumption of As-contaminated diets with unsafe concentrations for the appearance of visual symptoms of As-induced diseases. However, exceptions were also reported in Cambodia on the appearance of symptoms in only three years past consumption of drinking water with tremendously elevated As concentration (3500 mg/L water) which is also associated with malnutrition and the socioeconomic status of the consumers (Sampson et al., 2008).

2.2.4.4.3 Presence of As in human biological materials. According to Mossop (1989), exposure to only 0.25 ppm iAs can generate poisoning symptoms in the human body. Just after ingestion, As is quickly metabolized and precipitously defaecated in the urine, mainly in the form of direct dietary exposure (Vahter, 2002; Davis et al., 2017). In their study, He & Zheng (2010) observed that 63% of total As ingested through rice consumption was excreted in the urine, whereas Devis et al. (2017) reported the quantity was 40% while using a five-day diet plan. Having absorbed in the body, the rest of the portion of As gets bonded with the hemoglobin's protein (Habib et al., 2002). Within 24 hours, As present in the blood gets accumulated in various body organs, including skin tissue, liver, spleen, bone, lung, kidney, muscle, etc. (Habib et al., 2002). Two to 4 weeks passed absorption, maximum As present in the body system concentrated in the skin, nails, and hairs and gradually excreted in this way (Human Health and Ecosystem Effects, 1994; Habib et al., 2002). Although human biological samples such as blood, urine, feces, liver, kidney, rectum, large intestine, spleen, skin scales, hair, nails, etc. are used to determine As levels in the human body in different countries (Bencko, 1995; Mazumder, 2000; Jayasumana et al., 2011; Dongarrà et al., 2012), hair and nails are commonly used to trace the for comparatively more extended exposure period (Devis et al., 2017). Moreover, due to some unique characteristics and advantages, scalp hair is preferred by most scientists as a biomarker even than nails (Hindmarsh et al., 1999; Wang et al., 2013; Huang et al., 2014; Luo et al., 2014; Skalny et al., 2015; Xie et al., 2017). Arsenic value in scalp hair and background limit of As for different human organs, tissues and systems are shown in Table 9.

Hair's mineral content is almost ten times higher than blood, which directs a high likelihood of As exposure detection (Wilson et al., 2007; Islam et al., 2011). Furthermore, although human nails and hairs have a similar affinity to As, hair has much more convenience than nails (Hindmarch et al., 1999). In addition to this, since hair can incorporate much As in it (Li et al., 2011; Wang et al., 2013), hair is thought to be a more suitable and also easily usable body biomarker that may reflect the exact body loading happened in numerous ways in most of the countries (Teresa et al., 1997; Sera et al., 2002; Chojnacka et al., 2010a, 2010b; Dongarrà et al., 2011; Wang et al., 2013; Huang et al., 2014; Luo et al., 2014; Skalny et al., 2015; Xie et al., 2017) as compared to nails (Rodushkin & Axelsson, 2000). Therefore, hair seems to be of superior value in assessing previous and current As exposure (Gellein et al., 2008; Dongarrà et al., 2012). Hair has therefore been identified as a suitable indicator to reflect time-specific

Table 9:

Arsenic concentration in human hair in different countries with exposure means and normal arsenic values for different human organs, tissues and system

Scalp hair As, Source of exposure and Instrument used to measure					Background value of As in body systema	
Country	Hair As (µg/g)/ Sample number	Source of exposure	Instrument used for analysis	References	Human organs, tissues and system	Normal As values (µg g^{-1})
India (West Bengal)	0.17–14.39/ 44	Drinking water and food.	ICP-MS	Samanta et al (2004)	Large intestine	0.02
India (West Bengal)	0.133-4.713/ 147	Drinking water, vegetables & cereals	ICP-MS	Uchino et al (2006)	Liver	0.03
India (West Bengal)	0.70-16.2/ Not specified	Drinking water	HPLC- ICP-MS	Mandal et al (2003)	Spleen	0.02
Chile	0.7-6.1/ Not specified	Drinking water	HPLC-HG-ICP-MS	Yanez et al (2005)	kidney	0.03
China (Southern)	0.5-62.8/ 73	Rice & vegetables (Industrial area)	HG-AFS	Liao et al (2005)	Lung	0.08
China (Southwest)	0.130-0.484/ 129	Antimony mines	HG-AFS	Liu et al (2011a)	Stomach	0.02
China (Southwest)	0.104–0.796/ 22	Non-mine area	HG-AFS	Liu et al (2011a)	Pancreas	0.05
China (Wuhan)	0.55-0.68/ Not specified	Fresh water	ETAAS	Jiang et al (2009)	Prostate	0.04
Bangladesh	3.4/ 160	Drinking water	X-ray Spectrometry	Habib et al (2002)	Teeth	0.05
Bangladesh (South western)	3.71/ 51	Drinking water	NAA technique	Rakib et al (2013)	Skin	0.08

Korea (community residing in Washington State)	0.5-<1/ 108	Mainly rice and also some other foods	ICP-MS	Cleland et al (2009)	Nail	0.28
Korea	0.05-0.20/ 655	Not specified	ICP-MS	Park et al (2007)	Hair	0.46
Sri Lanka	3.04-7.18/ Not specified	Not specified	-	Jayasumana et al (2011)	Heart	0.02
Vietnam	0.07–7.51/ 213	Drinking water	HG-AAS	Agusa et al (2014)	Brain	0.01
Vietnam (Hanoi)	0.088-2.77/ 59	Drinking water	HG-AAS	Agusa et al (2006)	Thyroid	0.04
Pakistan	0.12-1.21/ 48	Drinking water	HG-AAS	Bibi et al (2015)	Uterus	0.04
Philippines	1.5-2.8/ Not specified	Not specified	-	Philippine Congress (1993)	Ovary	0.05
Laos	0.01-9.8/ 228	Drinking water	ICP-MS	Chanpiwat et al (2014)	Blood	0.3 – 2 (μgL^{-1})
Iran	0.012-3.41/ 39	Drinking Water	Neutron Activation Analysis (NAA)	Mosaferi et al (2005)		
Cambodia (Kandal province)	0.06-30/ 68	Drinking water	ICP-MS	Sthiannopkao et al (2010)		
Cambodia (Kandal province)	0.10-7.95/ 40	Drinking water	ICP-MS	Gault et al (2008)		
Brazil	0.001-0.016/ 126	Not specified	ICP-MS	Carneiro et al (2011a)		
Brazil	0.60-0.64/ 167	Not specified	ICP-MS	Carneiro et al (2011b)		
Portugal	0.245-0.834/ Not specified	abandoned cupric pyrite mine	AAS	Pereira et al (2004)		
Australia	3.31-5.52/ 153	Drinking water and soil	AAS	Hinwood et al (2003)		
UK	0.116-0.141/	foods	ICP-MS & GF-AAS	Brima et al (2006)		

	36			
Japan	0.2/250	Drinking water and sea foods	X-ray Spectrometry	Habib et al (2002)
Italy	0.14-0.24/ 263	Not specified	ICP-AES	Senofonte et al (2000)
Italy	0.0003- 0.03/ 130	Not specified	ICP-MS	Dongarrà et al (2011)

[a]Culled from Jayasumana et al. (2011); Liebscher & Smith (1968); Mazumder (2000); and Vahter et al. (1995)

exposures to contaminants (Song & Li, 2014). Medical researchers analyze hairs to diagnose diseases and also to ascertain relationships between As content and diseases (Khalique et al., 2006; Unkiewicz-Winiarczyk et al., 2009); where to examine the poisoning caused by overdosed metal exposure, forensic scientists usually analyze human hairs (Kintz et al., 2002; Lugli et al., 2011).

Scalp hair is used because of its several advantages, such as (a) collection of hairs does not require venipuncture; (b) the durability of hair which enables the transport processes and more extended storage; (c) as compared to urine and blood, more As usually deposited and stored in scalp hair and (d) long term exposure (up to 1 year) can be assessed by hair analysis (Kruse-Jarres, 2000; Pereira et al., 2004; Wang et al., 2009; Skalny et al., 2015; Awasthi et al., 2016). In contrast, the major drawback is the variations occurring in the intra and inter-hair As content, analysis of single hair or hairs collected from one side would give less reliable result (Mazumder, 2000). Therefore, to ensure the accuracy of the result, hairs should be collected from different sides of the scalp, weighted at least 1g, and analyzed the whole (Hindmarsh, 2000; Mazumder, 2000).

There are several opinions about the typical background levels of As in human hair. According to Nriagu (1994), in a population living in an uncontaminated area, concentrations of about 0.075 μg As/g hair is typical. From another point of view, typically, hair contains As within the range of 0.08–0.250 μg/g as the background value (National Food Authority, 1993; Sanz et al., 2007), whereas Chatt & Sidney (1988) opined that the natural concentration of As in human hair ranges between 0.1 and 1.0 μg/g. According to Islam et al. (2011), As levels > 0.50 ppm in human hair represent more significant arsenicosis risks. However, 1 μg As/g hair has been established unanimously as the toxicity indicator (Chatt & Sidney, 1988; Arnold et al., 1990; National Food Authority, 1993; Habib et al., 2002; Audinot et al., 2004; Sanz et al., 2007) whereas nearly 45 μg/g is reported for As-related fatalities (Mazumder, 2000).

While growth rates of scalp hair are commonly quoted as 12 cm/year or about 1 cm/month, actual rates might vary between 0.6 and 3.6 cm/month (Harkey, 1993). Because of this inconsistency, hair analysis is not generally helpful in evaluating As exposures occurring more than one year ago (Harkins & Susten, 2003). Another critical point is that, since fish is another important source of human exposure to As, fish As is not deposited in the hair (Mandal et al., 2003; Kales & Christiani, 2005; Pullella & Kotsopoulos, 2020). Therefore, hair analysis is highly suitable for determining As exposure within a few months due to rice and vegetable consumption, avoiding past exposure confusion (Harkins & Susten, 2003).

2.2.5 Strategies to mitigate As accumulation in rice

Rice is more effective than other cereal crops in accumulating As (Williams et al., 2007b; Su et al., 2010). Treating As polluted groundwater and soil may be the most efficient way to mitigate As contamination in rice grains and consequently the health risks, and to do so, different approaches are used. (Singh et al., 2015). The adopted techniques include As removal by oxidation techniques, Phytoremediation, Coagulation–flocculation, Electrocoagulation (EC), Electro-chemical As remediation (ECAR), Adsorption, Ion exchange, Electrokinetics, Membrane technology, and advanced hybrid and integrated technologies (Singh et al., 2015). However, sludge is produced in all the technologies mentioned above containing a high level of As, which may be the secondary source of As contamination (Singh et al., 2015). Moreover, it is not even practical to treat the massive amount of groundwater for rice cultivation in the same method used for drinking water purification (Hossain et al., 2005; Brammer, 2009).

Researchers have proposed several agronomic measures to reduce As in irrigation water, soil accumulation, and rice uptake (Wichelns, 2016; Chou et al., 2016; Khalid et al., 2017). Since As mobility in wetlands is controlled by soil's redox potential, As mobility in paddy fields and its uptake and transfer to rice grain can be minimized by water management (Zhao et al., 2010). Alternate Wetting and Drying (AWD) is the most popular irrigation management practice adopted in many Asian rice-producing countries. For AWD, polymerized vinyl chloride (PVC) tubes (length = 30 cm & diameter = 10 cm) are usually inserted 15 cm below the soil surface to monitor the depth of water level (Yao et al., 2012; Yang et al., 2017). The below-ground 15 cm part contains numerous holes of 0.5 cm in diameter with 3 cm side by side (lateral) and 1 cm vertical intervals. (Chou et al., 2016; Yang et al., 2017). All PVC pipes are inserted upward and placed 15 cm above the soil surface to prevent water from entering. Within 15 days, rice seedlings get settled in the main field (Sarkar et al., 2012); therefore, the first AWD cycle should be deployed just after the settlement and continued until flowering (Price et al., 2013). After that, the continuous ponding will be maintained up to 5 cm above the surface in all the plots till 12 days before harvesting (Bouman et al., 2007; Sarkar et al., 2012). In AWD practice, the wetting/drying cycle involves flooding the main field directly with As contaminated groundwater and then letting it dry out up to 15 cm below the soil surface (Bouman et al., 2007; Price et al., 2013; Islam et al., 2017); after that, the field will again be re-flooded to a height of 5 cm above the soil surface (Chou et al., 2016; Islam et al., 2017) and then the next drying cycle will begin (Price et al., 2013; Islam et al., 2017).

Few field trials have been conducted with AWD as an As mitigation approach. A study by Das et al. (2016) with three treatments, AWD, non-flooded (NF), and flooded (CF) practices, explored insignificant differences in soil As and found a decrease in grain As in the order of NF< AWD< CF treatment, while yield contribution was reported in the increasing order of AWD> NF> CF. Compared with CF, AWD and NF treatments reduced tAs concentration in rice grain by 49.7 and 53.0 %, respectively. The translocation factor (shoots to roots ratio of As content) in NF and AWD was significantly lower than in the CF treatment. The enhanced phytoavailability of As in CF treatment might be due to the enhanced reductive mobilization of As in flooded conditions (Roberts et al., 2010). The study of Acharjee et al. (2021) and Chou et al. (2016) support this finding concerning As reduction in AWD practice compared with CF practice. In their study with three irrigation regimes viz. AWD, saturation (ST), and continuous flooding (CF), Acharjee et al. (2021) revealed a significant As reduction in rice in AWD compared with ST<CF, but they reported that soil to grain As transfer was high in AWD practice than the other two practices. Chou et al. (2016) investigated the effect of flooded (CF), aerobic (AR), and alternate wetting and drying (AWD) irrigation practices on As loading status of two rice varieties, Tainan 11 and Tainong 84, each in one season. Total grain As content reduced significantly in AR and AWD compared with CF, but AR and AWD did not differ significantly for both seasons. According to their observation, altered irrigation management imparts changes in the oxidation and reduction process in the rice field, which influence the release or absorption of As in the soil, thus controlling As uptake by rice plants. Again, they suggest an intimate association of As uptake and accumulation in rice roots with the massive transpiration to absorb available water from the root zone. Due to the insufficiency of required water, such occurrence was not observed with AWD or aerobic irrigation management.

Through the practice of single soil drying with "safe AWD," Carrijo et al. (2018) observed that grain As content did not decrease at ~0 soil water potential at 0–15 cm below the soil surface, but soil drying to −71 kPa or −154 kPa, marked as medium severity and high severity, respectively, reduced 41–61% of grain As. They suggested that since the grain As level reduction largely depends on soils reaching the unsaturated state, safe AWD allowed continuous saturation state and, therefore, could not perform well. Islam et al. (2019) claimed a similar result in a greenhouse study where they found AWD contributed to an As reduction of 25% for rice grains, 25.42% for husk, and 23.35% for straw relative to CF, i.e., incessant flooding. In a similar trend, Yang et al. (2019) reported a 43.3%–85.0% As reduction in brown rice compared with continuous flooding practices. Rahman et al. (2014) conducted a field trial in an As-contaminated zone of Faridpur, Bangladesh, to explore the impact of deficit irrigation grain As concentration and found that AWD practice contributed significant grain As reduction with higher grain yield compared to continuous flooding for BRRI dhan28, a boro rice variety of Bangladesh. However, soil As did not change significantly in AWD practice. In their field trial, Shah et al. (2016) observed that AWD practices with As-contaminated groundwater reduced the As content in rice straw and grains compared to continuous standing groundwater practices.

The two-year field trial of Linquist et al. (2015) in the US with several treatments revealed that AWD accounted for a yield decline (<1 to 13%), but the As content in rice grains decreased remarkably compared to that under continuous flooding practices. Yield reduction due to AWD practice was also reported in the studies of Bouman & Tuong (2001) and Towprayoon et al. (2005). In contrast, while practicing AWD with fertilizer management, Islam et al. (2020) observed that early AWD practices reduced grain As by 66% without sacrificing grain yield. This sustained yield with AWD management agrees well with the previous studies of Feng et al. (2013), Liu et al. (2013), and Qin et al. (2010). A similar trend is observed in the study of Islam et al. (2017), who reported that AWD practice with suitable rice variety reduced As by up to 17 to 35% in rice grains, with a contribution of grain yield increase from 7 to 38%. Again, some previous studies also have reported that AWD's success largely depends on the rice variety selected (Bueno et al., 2010; Luo, 2010).

Alternate wetting and drying practices are being adopted in some Asian countries, such as China, India, Vietnam, Bangladesh, Taiwan, and the Philippines (Bouman, 2007; Das et al., 2016; Singh et al., 2008; Tuong et al., 2005), but their full adoption and application by farmers in practice remain a challenge (Pearson et al., 2018). This might be because there is still a lack of validation of this practice under different scenarios (Moreno-Jiménez et al., 2014). AWD has been incorporated into the government policies of Bangladesh, Vietnam, and the Philippines (Lampayan et al., 2015), and a review of the AWD adoption scenario in Bangladesh (Pearson et al., 2018) noted that the availability and pricing of irrigation water were critical issues for adopting this promising practice. Recently, endeavoring to explore the reasons for such failure in Bangladesh, Pandey et al. (2020) observed that people in the community usually pay for irrigation water per unit area and not for the amount of water. Therefore, the prime cause of not adopting AWD was insufficient economic incentives provided to the farmers. In addition to the above, farmers faced several social and biophysical constraints with adopting such a promising practice (Pandey et al., 2020).

On the other hand, Lampayan et al. (2015) claimed that inadequate extension services, a dearth of institutional support, and information sources significantly hinder the adoption of AWD practice. In addition to the above, Alauddin et al. (2020) identified farmers' education, information sources, and age as significant factors in determining such adoption. However, to overcome these shortcomings, exploring the interaction and relationship between socioeconomic and agricultural systems is crucial, and interdisciplinary research involving social, economic, biological, and agronomic parameters requires time to address the critical issues along with challenges that facilitate the failure of AWD adoption (Pearson et al., 2018).

CHAPTER 3

ARSENIC ELEVATED GROUNDWATER IRRIGATION: FARMERS' PERCEPTION ON RICE AND VEGETABLES CONTAMINATION IN A NATURALLY ENDEMIC AREA

3.1 Introduction

Groundwater arsenic (As) exceeding the permissible limit set by the WHO (<10 μg/L) and FAO (100 μg/L) for irrigation and its application for rice and vegetable production posed a potential health concern worldwide (Akinbile & Haque, 2012; Chakraborti et al., 2018; Sarkar & Paul, 2016; WHO, 2004). Although more than a hundred countries currently produce rice globally, 14 Asian countries account for 90% of global rice production using groundwater as the significant irrigation source (Elert, 2014; Mondal & Polya, 2008; Yu et al., 2020). This problem is even more significant in the top five rice-producing countries such as China, India, Bangladesh, Vietnam, and Indonesia (Ginting et al., 2018; Meharg et al., 2008; Nookabkaew et al., 2013; Williams et al., 2007c). Like rice, Asian countries also contribute 50% of global vegetable export values (FAO/WITS, 2017). Therefore, these led to an elevated risk of As toxicity from dietary intakes of products to both the As endemic and non-endemic populations, regardless of where they live. Several research studies have already proved that the consumption of rice and vegetables cultivated with As elevated groundwater is a potential Contributor to the human body globally (Al Rmalli et al., 2005; Kumar et al., 2016; Roychowdhury et al., 2003; Williams et al., 2006).

The arsenic occurrence has been severe in the Meghna River basin, in the eastern and northern region of the active deltaic plain of the southern coast, and the old deltaic plain of southwestern Bangladesh; however, poisoning has been less severe in the southeastern and northwestern part of Bangladesh (Paul, 2004). Residents in high-risk locations were familiar with the causes and symptoms of As poisoning and ailments induced by drinking arsenic-contaminated groundwater (Akmam & Higano, 2002; Caldwell et al., 2003; Paul, 2004). Despite the fact that most of the people in the endemic area of Bangladesh opted for As safe drinking, still, As related ailments are prevailing there (Huq et al., 2006; Joseph et al., 2015b). Consumption of rice and vegetables grown with As elevated groundwater is supposed to cause this health concern (Kumar et al., 2016; Williams et al., 2006). To date, the majority of scientific interest has been devoted to determining the sources and causes of arsenic contamination and inventing cost-effective methods for removing arsenic from irrigation water (Das et al., 2008; Singh et al., 2015). While determining the source of the contamination and developing technologies to remediate arsenic from groundwater are critical in combatting the problem, research efforts should go far beyond these efforts to ensure the sustainability of the technologies engaging farmers' perspectives (Khan et al., 2009; Kumar & Popat, 2010; Paul, 2004; Pearson et al., 2018). Furthermore, all efforts to minimize arsenic pollution have been made without adequate grassroots knowledge bases regarding the prime stakeholders, i.e. the farmers' perception of As accumulation in rice and vegetables due to As contaminated groundwater irrigation. A recent scenario demonstrated that the farmers' cooperation even seriously affected the implementation of the "policy of remediation during fallow (PRF)" to tackle soil fertility deterioration due to heavy metal pollution by the government of China, which finally saw the light after the survey of farmers' perspectives and associated recommendations (Yu et al., 2020). Therefore an exhaustive approach for evaluating As perception is essential for establishing research priorities, ensuring development strategies, and designing pertinent stakeholder engagement to combat the As-induced concern.

This research aims to explore how rice and vegetable farmers in Bangladesh perceive As accumulation in their rice and vegetables, its subsequent health consequences, alleviation possibility with mitigation strategies, and investigate if there is an association between their socio-economic status and their level of perception. Results of this study should help identify specific areas and segments of socio-economic and demographic parameters where further steps need to be intensified for sustainable As mitigation and farmers' adoption of the same. The purpose of this study is not to investigate whether farmers had heard of As pollution problem in general, but to explore if they are knowledgeable and have the correct perception about crucial aspects of arsenic poisoning, such as the source of As in rice and vegetables, its symptoms, diseases caused by poisoning, and how to prevent and mitigate As poisoning.

3.2 Material and methods

3.2.1 Study area and sampling procedure

Due to severe groundwater contamination, Chandpur, a district in Bangladesh's southeast, is considered a well-known As endemic zone (Rahman, 2009). Approximately 80-90 percent of tubewells in this area have an As concentration greater than 50 µg/L. (Jakariya et al., 2007; Mishra et al., 2021). Chakraborti et al. (2010) found 675 samples with 100-299 µg/L As, 294 samples with 300-499 µg/L As, and five samples with >1000 µg/L As, with the maximum As discovered being 1318 µg/L, out of a total of 1165 examined groundwater samples. More than 90% of residents in this region rely on groundwater extraction for drinking water and irrigation (Jakariya et al., 2007; Rahman, 2009).

Five well-known and heavily As-contaminated sub-districts (Upazilas) in Chandpur were chosen as the study region, namely, Chandpur Sadar (Sadar) (23.2139°N 90.6361°E, total land area 308.78 km^2), Matlab north (23.3500°N 90.7083°E, total land area of 131.69 km^2), Kachua (23.3500°N 90.8917°E, total land area of 235.82 km^2), Hajiganj (23.2500°N 90.8500°E; total land area 189.90 km^2), and Faridganj (23.1250°N 90.7486°E, total land area 231.56 km^2). Figure 2 shows the study area. Forty (40) farmers from each of the locations (totaling 200) fulfilling specific criteria, such as actively participating in farming, irrigating groundwater for rice and vegetable cultivation, consuming rice and vegetables produced in their fields, and drinking As safe water purposively sampled in this study. Multistage purposive sampling has been applied to select study locations and the respondents. As Morse and Niehaus (2009) note, whether a quantitative or qualitative methodology is adopted, sampling procedures are designed to maximize efficiency and validity. Nonetheless, sampling must be compatible with the objectives and assumptions inherent to either approach. Choosing settings, groups, or individuals to represent a sample in two or more stages while ensuring that each step reflects participant purposive sampling is known as multistage purposive sampling. Therefore, multistage purposive sampling entails picking a sample in two or more phases. Unlike multi-stage purposeful random sampling and random purposeful sampling, however, all stages include purposive sampling. Multistage purposeful sampling is distinct from mixed purposeful sampling in that it is always sequential, whereas the latter generally comprises contemporaneous sampling in which one sample is not a subset of other samples (Onwuegbuzie & Leech, 2007). Purposive sampling has the advantage of allowing researchers to gain a better understanding of the study's research problem and study sites (Palinkas et al., 2015).

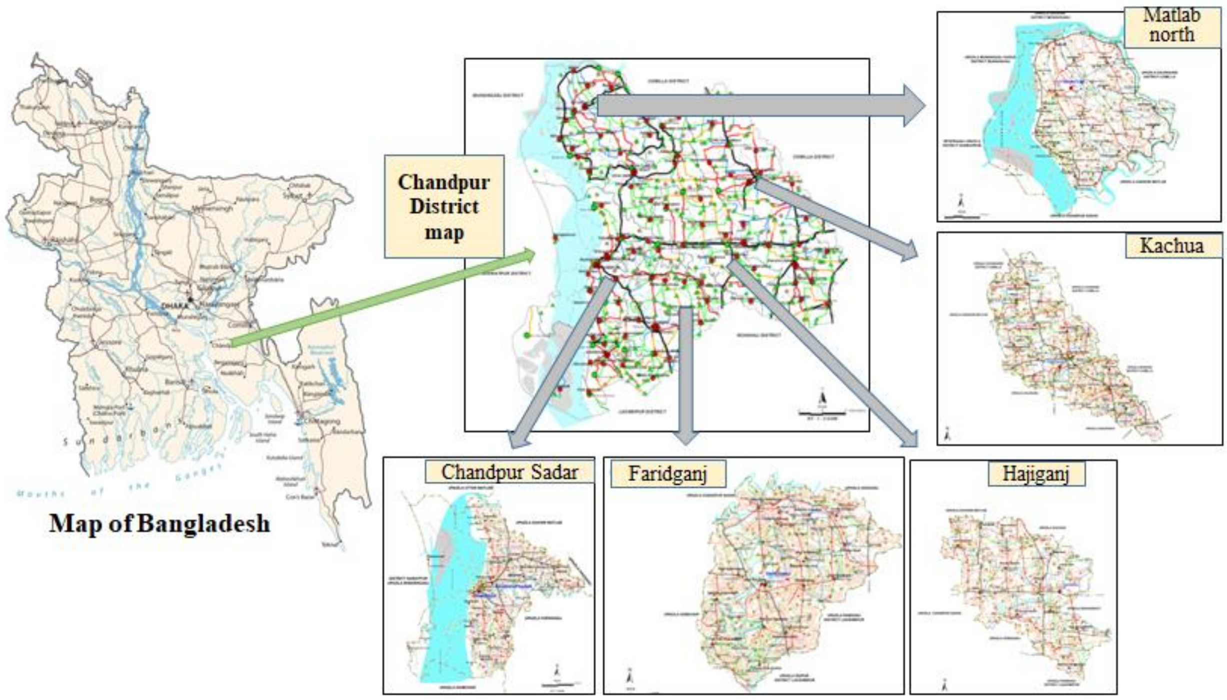


Figure 2: Study area

Furthermore, this entails locating and selecting individuals or groups who are remarkably experienced or knowledgeable about a topic of interest (Cresswell & Plano Clark 2011). In addition to experience and knowledge, Bernard (2002) and Spradley (1979) worth noting the significance of willingness, availability to participate, and the capability of experience and opinions communication in an articulate, reflective, and expressive manner.

In this present study, as a part of the multistage purposive sampling strategy, firstly, the Chandpur district was chosen on purpose because, according to the literature, it has a high level of As in its groundwater. During the second step, five of the sub-districts were selected purposively based on the literature and information from the Agriculture offices. In the third stage, forty farmers from each of the sub-districts were selected who met some specific criteria. These farmers were required to, among other things, produce rice and/or vegetables with groundwater irrigation, consume own field produced rice and vegetables, be willing to participate in the study voluntarily, and be willing to donate scalp hairs to determine As content for another associated study. The selection of the farmers was accomplished with the assistance of the Agriculture officer, the Sub Assistant Agriculture Officers, and the leaders of the local farmer communities. The data were collected administering an interview schedule that had been designed based on Focus Group Discussion (FGD) and Key Informant Interview (KII), and it was finalized following judge rating.

3.2.2 Analytical framework

3.2.2.1 Farmers' socioeconomic characteristics. A structured interview schedule was constructed and translated into the local language (Bengali), taking care not to lose any aspects of collecting the data (Kumar & Popat, 2010). The data were collected through face-to-face interviews from June 2019 to August 2020. In order to characterize the socioeconomic backgrounds of farmers, sixteen variables were assessed, such as age, education, family education, family size, farm size, annual income, knowledge, information sources, direct participation in farming, agricultural credit use, cosmopoliteness, opinionatedness, innovativeness, risk orientation, farm power and machinery (FPM), organizational participation.

The number of years from the farmer's birth to the interview was used to compute his age and was rounded to the nearest whole number. Regarding farmer's education, for passing class 1, a score of 1 was assigned; for passing SSC, a score of 10 was assigned; a score of 12 for passing HSC; 14 for Bachelor; and 16 for Master's degree completion. Family education of an individual was measured based on the methods suggested by Pareek & Trivedi (1964). In order to calculate the family education, the overall score on education was recorded and then divided by the 'effective family size.' The 'effective family size' was calculated by subtracting the number of children under the age of four from the total number of family members. The following formula was used to generate the Index of family education, which was used to quantify family education.

Index of Family Education = Total educational score/Effective family size

Family size was determined as the total number of individual farmers' family members. Direct participation in farming was measured by how a farmer performs agricultural work by himself rather than others. An individual farmer could get a score of 0 to 3 for each agricultural operation. The score of the respondents could range from 0 to 18, where 0 indicates 'no direct participation' and 18 'high direct participation' in farming. A 5-point scale checking any of the responses- most often, often, sometimes, rarely, and never with scores 4, 3,2,1, and 0 respectively were provided against each item to measure the degree to which the farmers used information sources. The responses were recorded by putting a tick mark in the appropriate column against each item. The total rank score for each item was obtained by multiplying the frequencies with the respective weights and adding them up. Farm size was computed using the following formula and expressed in hectare (ha).

Farm size = A+{1/2(B+C)+E+F}-D

Where A= land under own cultivation; B= land given to others on borga; C= land taken from others on borga; D= land given to others on the lease; E= land taken from others on the lease; F= homestead area.

Annual income refers to a farmer's and his family's total earnings from agriculture and other socially valid sources regularly over a year and is expressed in thousand (1000.00) taka. Agricultural credit use refers to the amount of money taken as agricultural credit and used in agricultural production. It was expressed in thousand takas. Social/Organizational participation, the degree to which the responding farmers were active in the formal organization as members or office-bearers and the regularity with which they attended meetings, was measured using a modified scale of Subramanium (1986). The scale had ten statements that indicated the respondent's involvement with organizations both within and outside his living community (Kumar & Popat, 2010). The score given for no membership = 0; membership in one organization = 1; and office-bearer in one organization = 2. Accordingly, attending meetings 'Never,' 'Occasionally,' and 'Regularly' received 1, 2, and 3 points. To obtain a respondent's final scores, the scores obtained as a member or office bearer were multiplied with the score received for attendance to meetings. The cosmopoliteness item was predicated on an individual's orientation outside of his social structure. A 6 item (4-point scale) statement was prepared for this purpose. Each participant was required to mention the number of times he visited each of the six distinct locations with the frequency of visit such as 'often,' 'occasionally,' 'rarely,' and 'never,' and weights assigned to these responses were 3, 2, 1, and 0, respectively. A respondent's cosmopoliteness score was calculated by adding the weights for his visits to the six types of places. Opinionatedness of a farmer was measured through a four items scale prepared for the study. A Score of 3, 2, 1, and 0 was assigned for high, medium, low, and no opinionatedness. A respondent's innovativeness was assessed based on the relative earliness in adopting new ideas (Rogers, 1995); here, 13 improved arsenic reducing agricultural practices. Scores were provided based on how long it took a farmer to adopt each technique, such as 5= within one year, 4 = within two years, 3 = within three years, 2 = within four years, and 1 = within five years, however, 0 = do not use. A farmer's innovativeness score was calculated by aggregating his scores for all 13 improved agricultural techniques. Risk orientation was assessed using a scale modified from Samantha's (1977) scale. The scale comprised ten statements, four positive and the rest negative, based on Edwards' (1957) screening guidelines. The replies of the respondents were recorded on a 5-point Likert scale (Likert, 1932) viz. 'strongly agree,' 'agree,' 'Undecided, 'disagree,' and 'strongly disagree' with scores 5, 4, 3, 2, and 1, respectively, for positive statements and 1, 2, 3, 4, and 5 respectively, for negative statements. For calculating the ownership score of farm power and machinery (FPM), seven items of farming and irrigation management tools were selected, and the score was assigned for the possession of each country plow = 1, hand sprayer = 2, rice weeder = 1, shallow tubewell (STW) (joint ownership) = 3, power tiller = 4, shallow tubewell (STW) (single ownership) = 4, and harvester=4. The number of tools was multiplied by the assigned score to obtain the final score. Farmers' knowledge was assessed based on the method used by Paul (2004) with slight modification. For each participant, a composite score was computed based on their responses to 11 questions about the source, symptoms, and As induced diseases, as well as potential preventive approaches and remedies to the arsenic accumulation problem in crops. These questions were distributed into six groups, and each group contained one to three questions. One focus group discussion (FGD) was held in each Upazila to establish the scores for anticipated answers consisting of farmer leaders, available rice and vegetable growers, and Agriculture officers. Various scores were allocated for each correct response and a zero for each incorrect answer based on the participants' recommendations.

3.2.2.2 Farmers' perception assessment. According to Hodgetts (1979), no two people will have the same perception of life, and no two people will see things in the same way. For recording farmers' perception, appropriate statements were prepared with the cooperation of researchers, farmer leaders, available rice and vegetable growers, and agriculture officer and validated with data from a field survey (Kumar & Popat, 2010). After subjecting these statements to judges' rating (Rekha & Ambujam, 2010), the interview schedule contained 43 statements under six groups and was administered to the respondents for expressing their perceptions on the use of As contaminated or safe water for rice and vegetable production. To avoid acquiescence, the propensity of participants to agree or disagree with statements irrespective of the item content, the interview schedule was constructed with both negative and positive statements. According to Schweizer et al. (2011), using negative and positive statements when replying to questions helps to avoid phrasing problems and responder personal bias. However, the statements were rated on a five-point Likert scale (Likert, 1932*)* where 'strongly agree,' 'agree,' 'undecided, 'disagree,' and 'strongly disagree' were scored with 1, 2, 3, 4, and 5, for negative statements and 5, 4, 3, 2, and 1 for positive statements, respectively.

3.2.3 Statistical analysis

Prior to analysis, data from the interview schedule was encoded, entered into a Microsoft Excel 2019 spreadsheet, and double-checked for mistakes. SPSS 26.0 was used to analyze the data. Cross-tabulation in Excel was used to calculate descriptive statistics such as percentages and frequencies (Kumar & Popat, 2010). Mean, median, and standard deviation (SD) had been used to categorize farmers into low, medium, and high groups (Kumar & Popat, 2010). For perception study, the low, medium, and high perceptions were regarded as poor, moderate and good perceptions (Muller et al., 2003). To determine the relationship between dependent and independent variables, the Pearson correlation coefficient (r) was used (Adam et al., 2015). Stepwise multiple regression analysis was used to investigate the socioeconomic parameters influencing perception in the research area (Udayakumara et al., 2010). Multiple regression analysis is a multivariate statistical analysis that can predict changes in the dependent variable in response to several independent variables (Hair et al., 1992). Path analysis was carried out to determine independent variables' influence and path effect on farmers' perception (Netuveli & Bartley, 2012).

3.3 Result and discussion

3.3.1 Farmers' socioeconomic characteristics

Farmers' socioeconomic characteristics have been summarized in figure 3 (a-p). Almost two-thirds of the participants were under middle-aged to old-aged group while 34 percent could be categorized into young age group in this study. The rural youth's paradigm shift is clearly articulated in terms other than agriculture (Rekha & Ambujam, 2010). Education is the process by which desired changes in human behavior takes place. It is primarily supposed that a higher level of education should influence farmers to be aware of and critically evaluate the consequences of As contaminated groundwater irrigation. Two-thirds of the respondents (66 percent) and slightly over fifty percent of their family members had primary and low to medium education, respectively, while 26 percent of participants passed secondary to above secondary classes. It could be seen that only 8 percent of respondents and 22 percent of the family members were illiterate. Less than half (42 percent) of participants had small families, while 31 percent had large families. On the other hand, The knowledge status of the respondents showed that no less than 50 percent of farmers lack adequate knowledge of As and its impact on rice and vegetable cultivation with contaminated groundwater, while 34% possess high knowledge. All the participants in the study area had basic knowledge regarding the groundwater contamination with As used for drinking water due to substantial awareness-building circulation from government and non-government organizations in the past decades. However, the knowledge differences were created with the advanced aspect regarding the crop contamination due to As elevated groundwater irrigation. The family size also influences the farmers' perception of groundwater irrigation. More than half (58 percent) of the farmers had small, 29 percent had medium, and only 4 percent possessed large (3.01-6.00 ha) farm holdings, which are the collective possession from own and others land in borga. Farmers with larger farms are predicted to be more eager to convert their land to irrigated fields to minimize their loss rather than keeping the land barren (Rekha & Ambujam, 2010). The result also revealed that the farm size largely determined the annual income of the participants. Nearly 60 percent of the respondents had very low to medium-income mainly derived from agriculture, particularly rice and vegetables. Of the rest, 19 percent had high, and 20 percent had very high annual income from some business in addition to agriculture.

Cosmopoliteness influences farmers' perception since it enables them to be introduced to the latest technologies by exploring neighboring localities, towns, and abroad. Nearly half (48 percent) of the participants had low cosmopoliteness, followed by 32 percent with high cosmopoliteness. Similar to the cosmopoliteness, distribution of the farmers based on the information sources exposure showed less than half (48 percent) of the participants had a low level of information sources exposure, followed by 52 percent had medium to a high level to get the latest agriculture information. The farmers' educational status would have influenced the exposure to information sources. In addition, the information technology revolution had a profound impact on the farming communities.

All the farmers in this study had active participation in the agricultural and farm management activities; however, they were categorized based on their extent of involvement. More direct participation in farming enhances the actual field-based knowledge and experience and increases farm productivity due to the close observation and management possibility. Over half (57 percent) of the participants had medium to high direct participation in farming in their crop production, and the rest required some support from others for cultivation activities. Opinionatedness allows a farmer to exercise leadership capacity for the fellow crop growers regarding several decision-making processes, including crop variety selection, irrigation management, and intercultural operations. Nearly 50% of participants had low opinionatedness, 27 percent had medium, and 24 percent had high opinionatedness to administer the leadership with some decision-making process. Regarding agricultural credit use, mostly half (49 percent) of the farmers did not use any credits; only 7 percent had low use, while 22 percent received medium and high credits for rice and vegetable production. Different banks, NGOs, cooperative organizations, and businessmen provide the credits. Although presumed as the financial support for the initial period, the higher interest finally captures them into the trap for most cases.

The distribution of farmers based on organizational participation depicts that approximately half (49 percent) of the participants had low organizational participation, just about one-third had high, and 18 percent had medium participation with different organizations. Organizational participation facilitates social networks to promote the information flow, which stimulates farmers' perceptions and decision-making on agricultural management (Bouma et al. 2008; Kilelu, 2004; Owusu et al., 2012). Innovativeness is the degree of readiness to adopt any innovation. Farmers' innovativeness in the adoption of As mitigation irrigation management in the study area was evaluated. It elucidates that almost half (49%) of the respondents have no innovativeness, followed by 26 percent have medium level, and 25

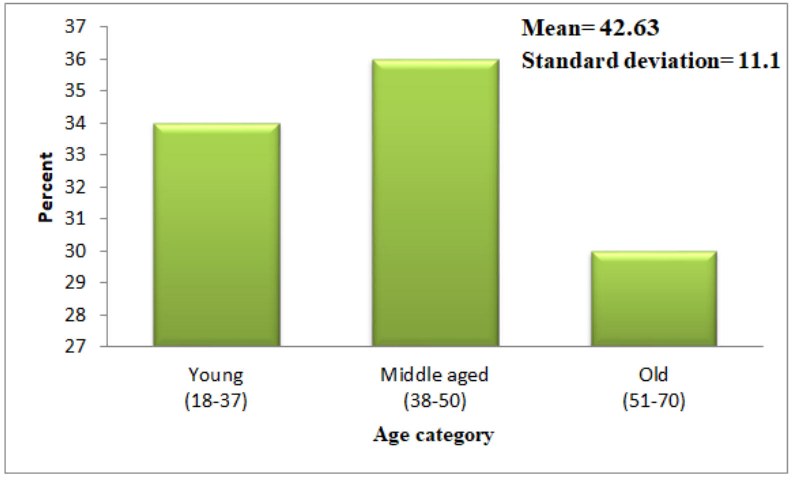


Figure 3a: Distribution of farmers based on their age

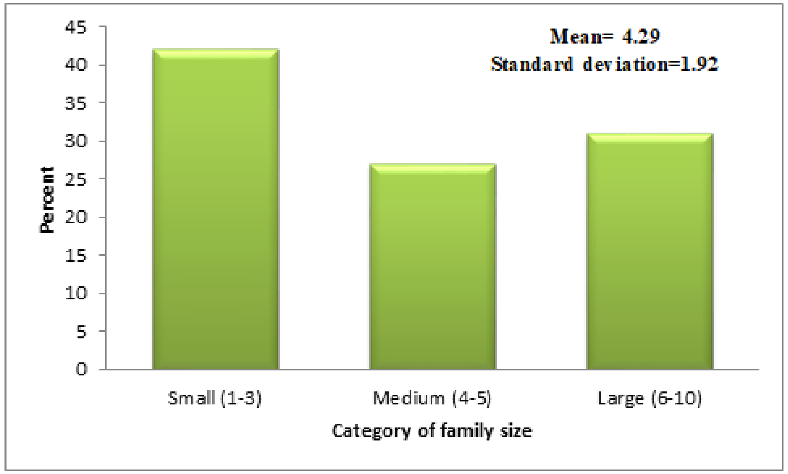


Figure 3b: Distribution of farmers based on their family size

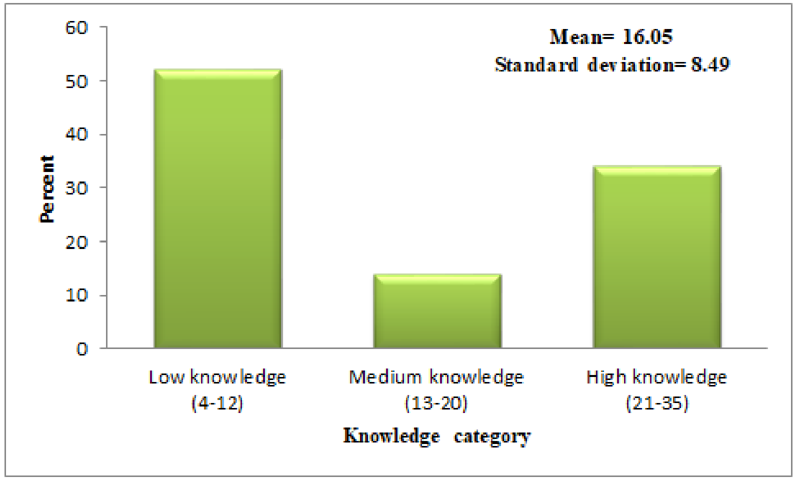


Figure 3c: Distribution of farmers based on their knowledge

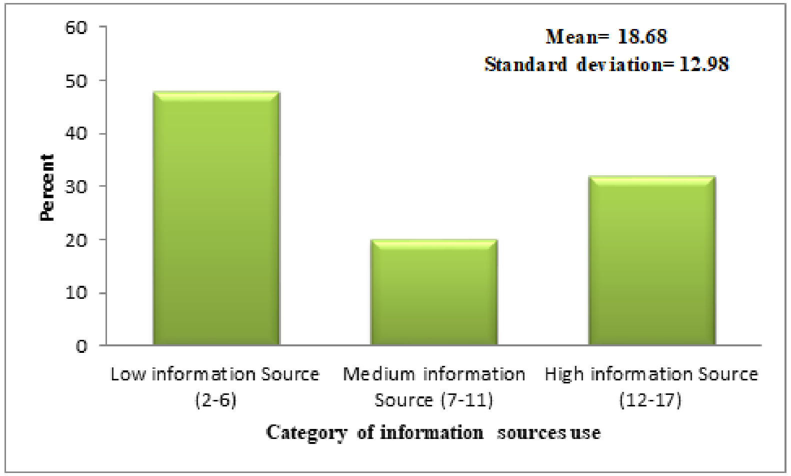


Figure 3d: Distribution of farmers based on their information sources use

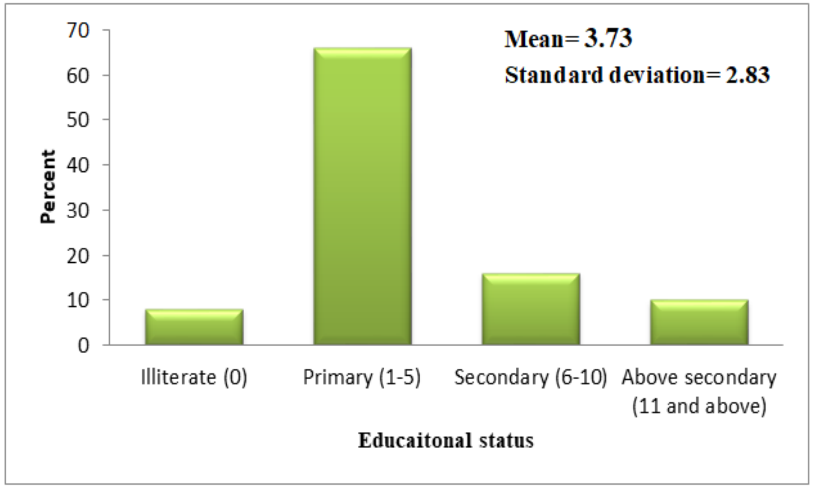


Figure 3e: Distribution of farmers based on their education

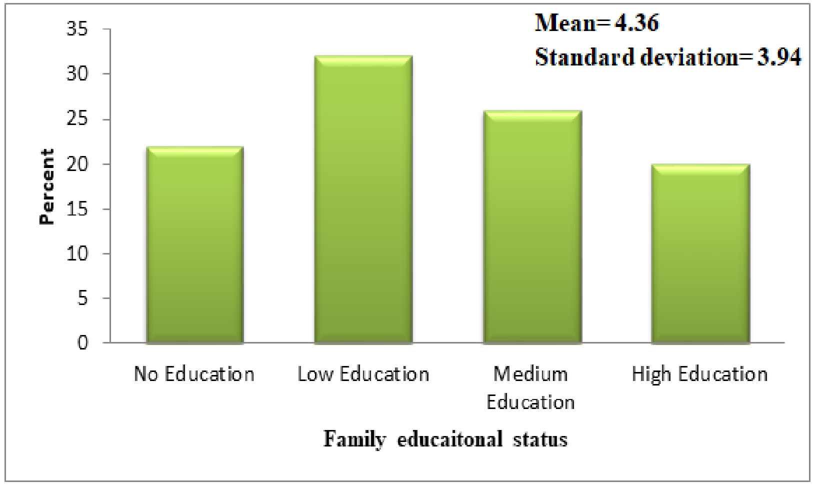


Figure 3f: Distribution of farmers based on family education

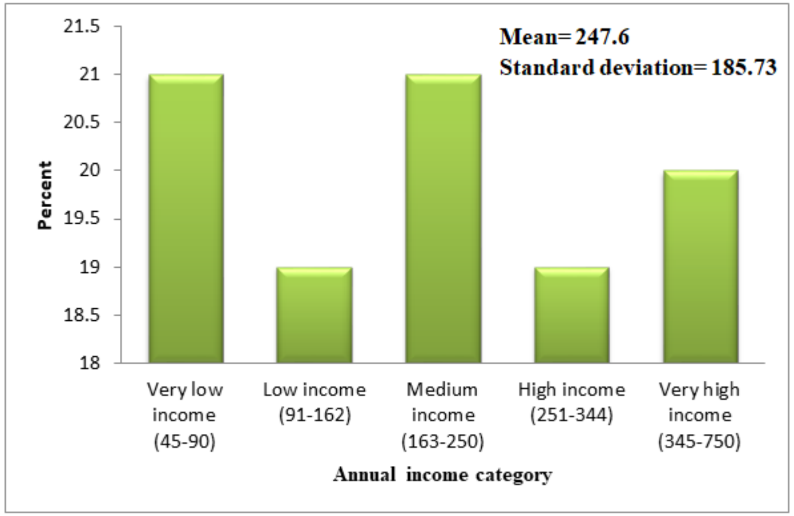


Figure 3g: Distribution of farmers based on their income

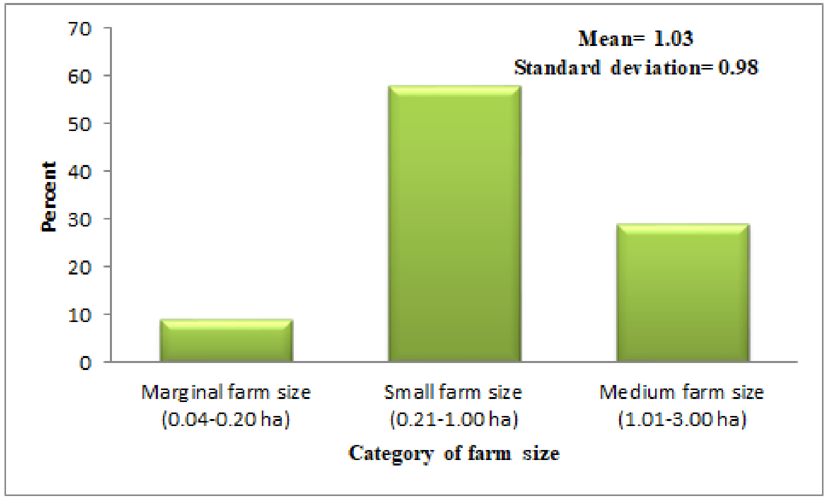


Figure 3h: Distribution of farmers based on their farm size

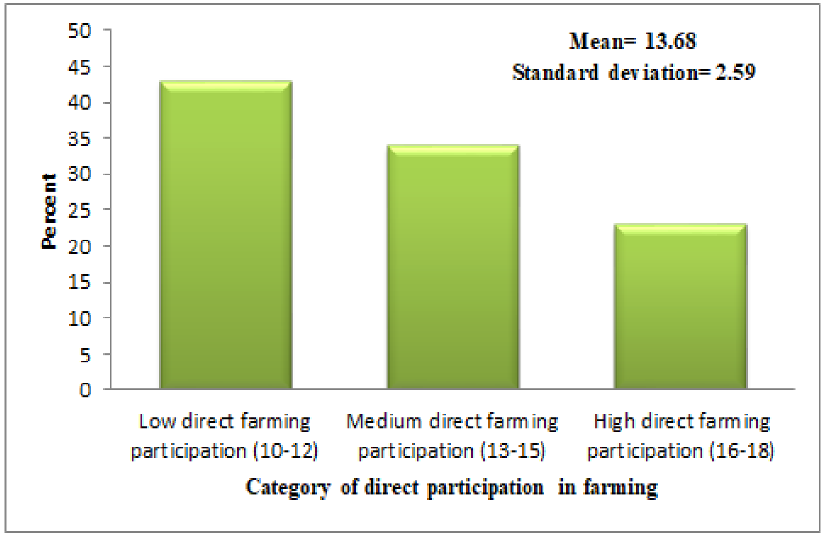


Figure 3i: Distribution of farmers based on farming participation

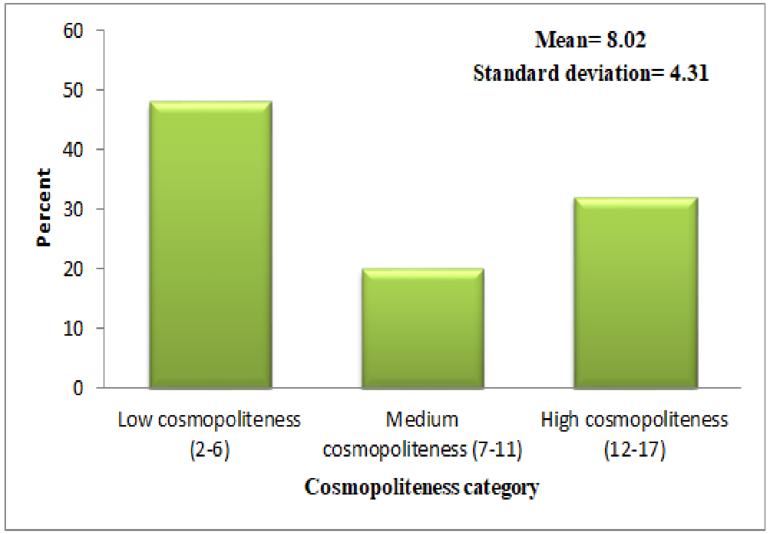


Figure 3j: Distribution of farmers based on cosmopoliteness

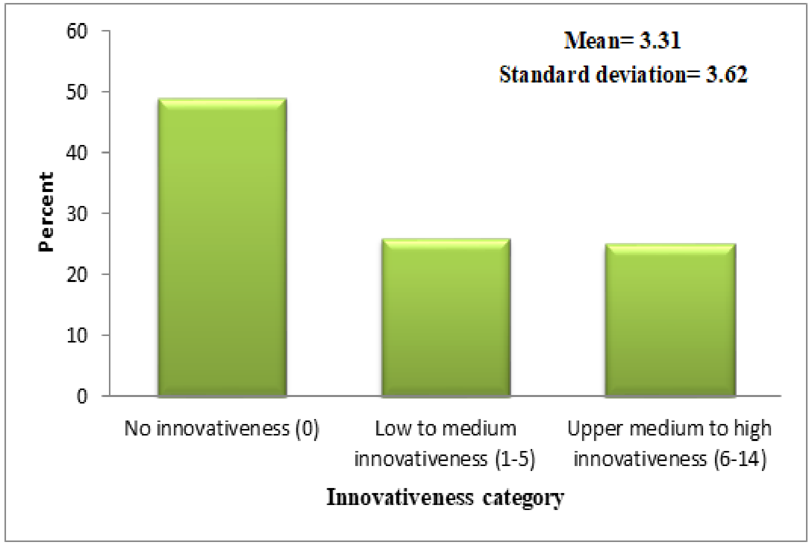


Figure 3k: Distribution of farmers based on innovativeness

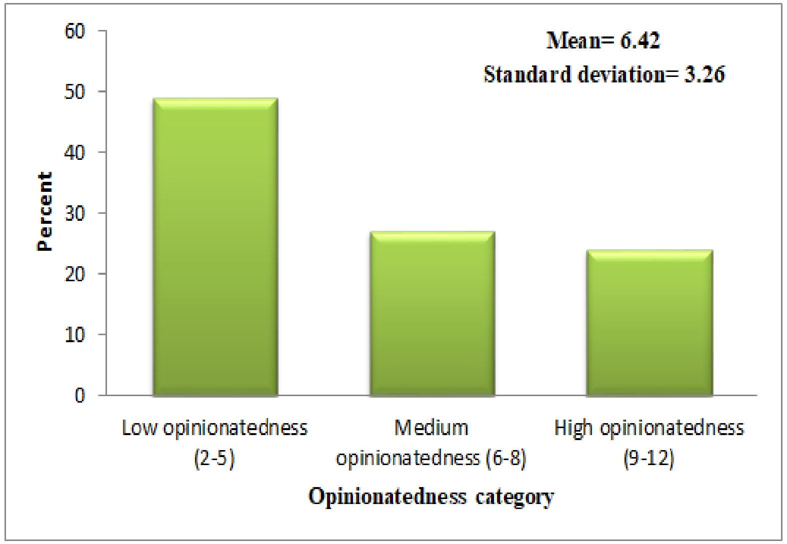


Figure 3l: Distribution of farmers based on opinionatedness

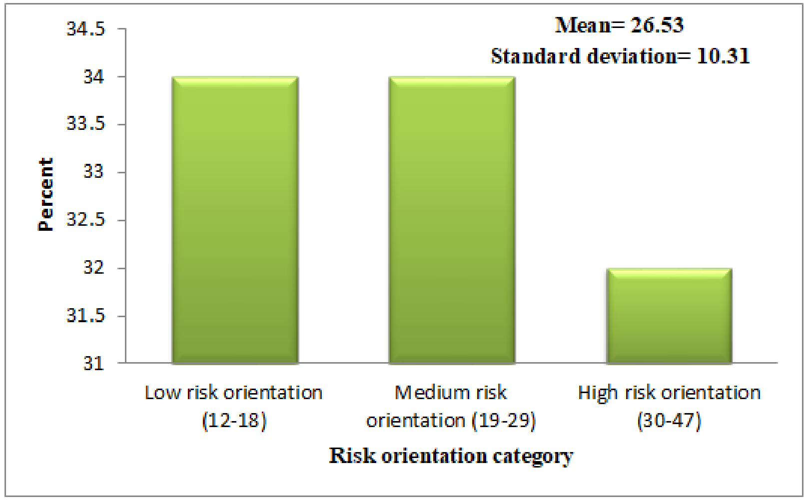


Figure 3m: Distribution of farmers based on risk orientation

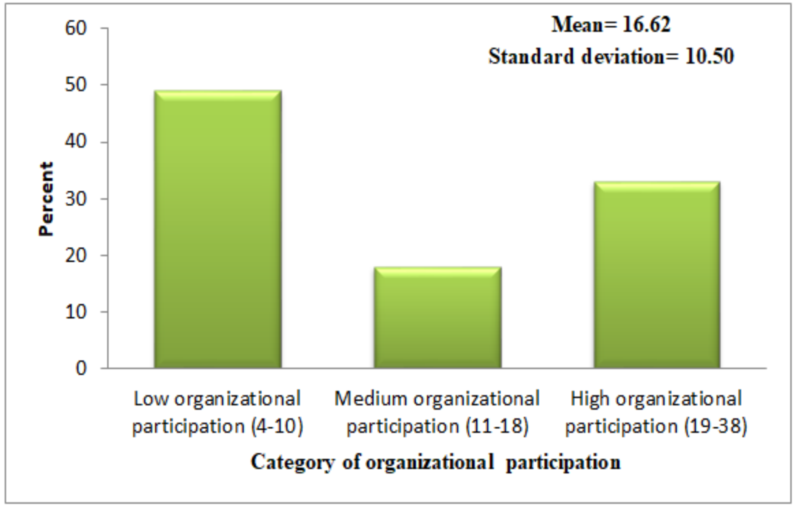


Figure 3n: Distribution of farmers based on organizational participation

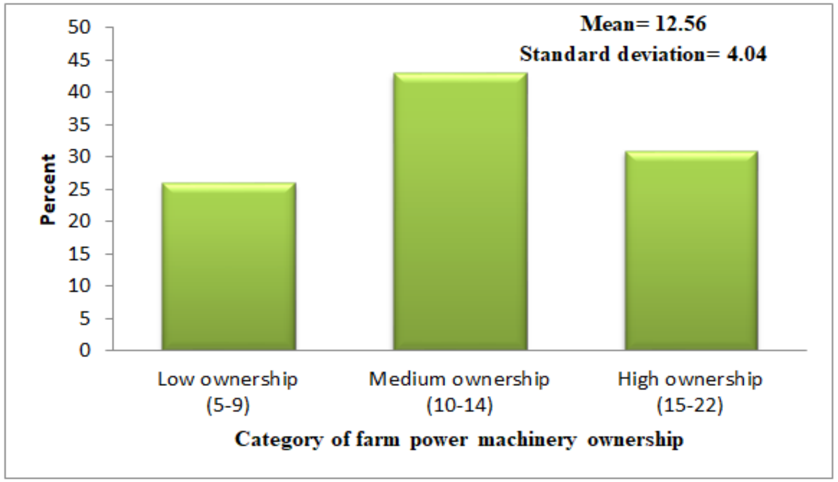


Figure 3O: Distribution of farmers based on machinery ownership

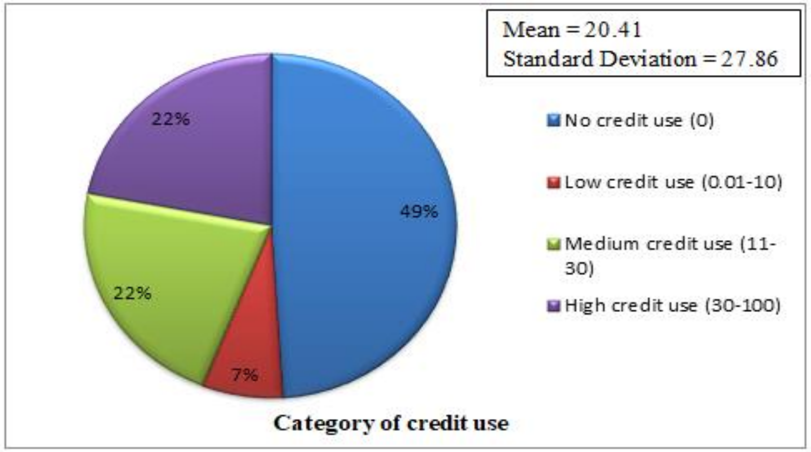


Figure 3P: Distribution of farmers based on credit use

Figure 3(a-p): Farmers' socioeconomic characteristics and their categorization (N=200) percent have high innovativeness. The ownership of agricultural machinery largely determines the freedom of production management, especially the irrigation practice with a specific strategy. The respondents mainly had similar agricultural machinery where 43% and 31% possessed a medium and higher number of irrigation management tools. Figure 3 also demonstrates that almost one-third of farmers had individual low, medium, and high-risk orientations. Those who had higher educational status, information sources used, and high organizational participation had a higher level of risk orientation (Rekha & Ambujam, 2010). In addition to the above, this study revealed that higher ownership of FPM also influences farmers' risk orientation. However, this psychological character influenced farmers' perception and the adoption of the As mitigating strategy.

3.3.2 Farmers' perception

According to McGraw-Hill (2004), perception is the process by which sensory stimuli are registered as meaningful experiences, while Epstein et al. (2018) understand perception as the process of transmission of stimulation through organized experiences. Perceptions are more sophisticated constructs made up of simple pieces connected by association and are therefore more susceptible to the influence of learning. Though the senses of taste, hearing, touch, and smell have all been investigated, the vision has garnered the most interest. Perception is the process of becoming aware of or comprehending sensory information in psychology, philosophy, and cognitive science (McGraw-Hill, 2004). Table 10 demonstrates that 25 percent of the farmers possess good perception in the study area regarding As contamination in rice and vegetables due to contaminated groundwater irrigation, drivers of irrigating As elevated groundwater, it's possible mitigation strategies and health impact. On the other hand, 36 percent of them have a moderate, and 39 percent have poor perception levels. After a comprehensive assessment of farmers' awareness regarding As in drinking water and foods, Mishra et al. (2021) reported that Bangladeshi farmers have comparatively

Table 10:

Farmers' perception on arsenic contaminated groundwater irrigation for rice and vegetables production

Category	Percent	Mean	Standard Deviation
Poor perception (129-136)	39		
Moderate perception (137-155)	36	146.6	14.16
Good perception (157-178)	25		
Total	100		

high awareness regarding As in drinking water rather than in the foods they consume. A total of 43 statements under seven groups were administered to get a detailed understanding of farmers' perceptions (figure 4 (a-g)). All the farmers responded to each of the statements from their learned experiences. A brief overview has been presented under seven subsections below.

3.3.2.1 Perception on As-contaminated or groundwater (AsW) or As free water (AsFW) use. Figure 4a represents nearly two-thirds (62 percent) of the respondents strongly agree, and one-fourth agrees that no AsW means no rice/vegetable cultivation. They opined that AsW is available throughout the year for crop cultivation in their locality while AsFW is seasonal. Apart from this, an overwhelming (89 percent) of respondents still debated not using the AsFW in their fields. This might be because although they are aware of the drinking water As contamination, the majority of them still lack proper knowledge regarding the possible crop contamination with As proper knowledge. On the other hand, only 19 percent of farmers believe in the possibility of rice and vegetable cultivation with AsFW. The explanation for such a stance is that they possess comparatively larger farm holdings with adequate irrigation management tools.

3.3.2.2 Drivers for irrigating AsW. According to figure 4b, **e**asy accessibility is the prime cause for AsW use, is unequivocally declared by all the participants in this study. Nearly 98 percent of the respondents claimed that they prefer irrigating their crop fields with some shareholders to reduce the production cost. This prevalent scenario of field irrigation practice threatens the choosy irrigation management in this study area. The scarcity of the AsFW (e.g., surface water), particularly during the winter season, compels them to go for groundwater irrigation. Another reason for using AsW is the saving purpose of the AsFW for household use, as reported by 26 percent of the respondents. Only 3 percent of the farmers are self-sufficient to irrigate with their own pump and manage irrigation as per their choice.

3.3.2.3 Effect of AsW irrigation on crop fields. While demonstrating the impact of AsW irrigation on crop fields from their experiences**,** two-thirds of the farmers remained undecided whether the AsW led to add additional As in their crop fields or not, although the rest one-third believed in As addition. Similarly, four-fifth of the farmers were undecided regarding the fertility loss of their crop fields with As incorporation due to groundwater irrigation. On the other hand, slightly over 50 percent of the participants observed their irrigation channel became red, 40 percent reported yield loss near the channel, and Land became hard.

3.3.2.4 Effect of AsW irrigation on rice & vegetables. Only 19 percent of the respondents believe in the As accumulation in rice & vegetables upon As contaminated groundwater application. The level of education, organizational participation, information source exposure, and cosmopoliteness enhanced their knowledge regarding this issue and influenced their perception. More than 95 percent of farmers were undecided about the other parameters such as the impact on tillering, influence on plants' height, uniformity of flowering, plant growth and grains maturity, grains filling percentage, or yield reduction. However, only 2-4 percent of participants agree with those advanced symptoms.

3.3.2.5 Impact of fertilizers and pesticides on As addition. Application of pesticides (Campos, 2002) and fertilizers, especially Phosphate fertilizer, (Jayasumana et al., 2015) may escalate As levels in the crop fields. Almost all the respondents were undecided since they did not get such information from any media or social networking.

3.3.2.6 Health impact. From their knowledge of groundwater As contamination and knowledge about the As related health impact from the drinking water exposure, 7 percent agreed, and 35 percent of the farmers highly agreed with the possible As transfer to the human body due to As elevated rice and vegetables consumption. However, more than fifty percent of the respondents remained undecided. Similarly, 45 percent of the participants perceive As may cause cancers, while 39 percent agreed on the development of skin lesions.

3.3.2.7 Farmers' practiced As mitigation strategy. Nearly one-third of farmers perceive that alternate wetting and drying (AWD) and surface water irrigation can reduce As accumulation in rice and vegetables. Seven percent of the participants believe that raised bed rice cultivation would limit As loading in rice grains. A very insignificant part (1-2 percent) of the participants perceive fertilizer management, such as supplementing with more urea, MoP, gypsum, zinc sulphate, cow dung, and intercultural operations such as mulching in vegetable fields or spreading Ash would limit As accumulation.

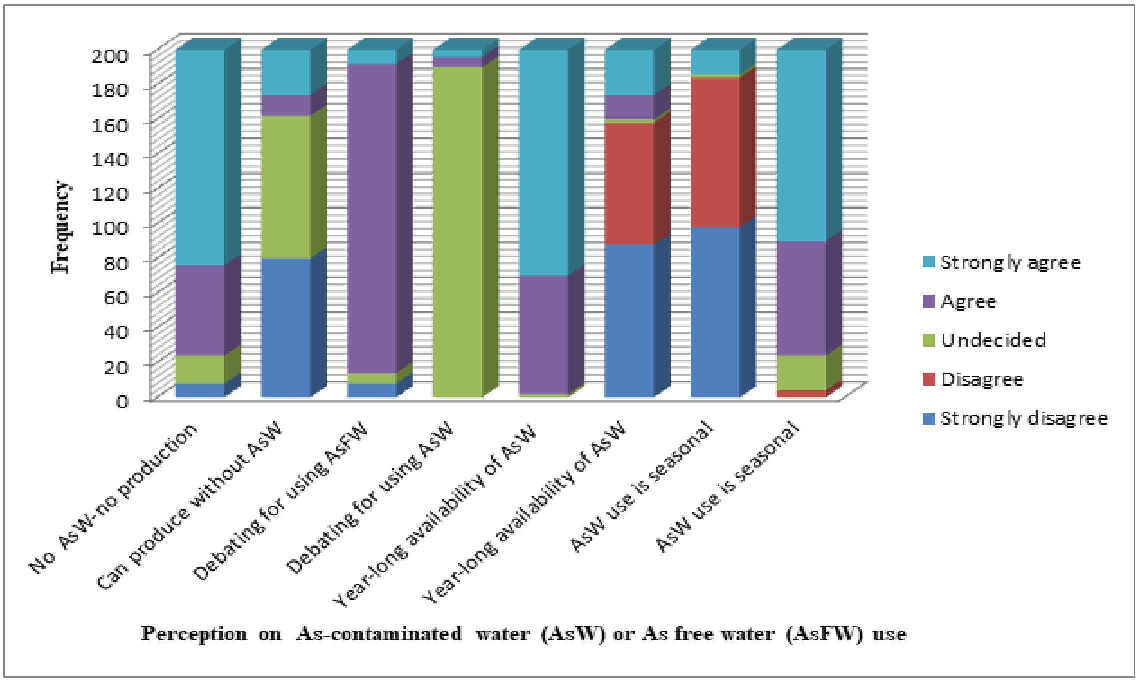


Figure 4a: Distribution of farmers based on their perception on As- contaminated water (AsW) or As free water use (AsFW)

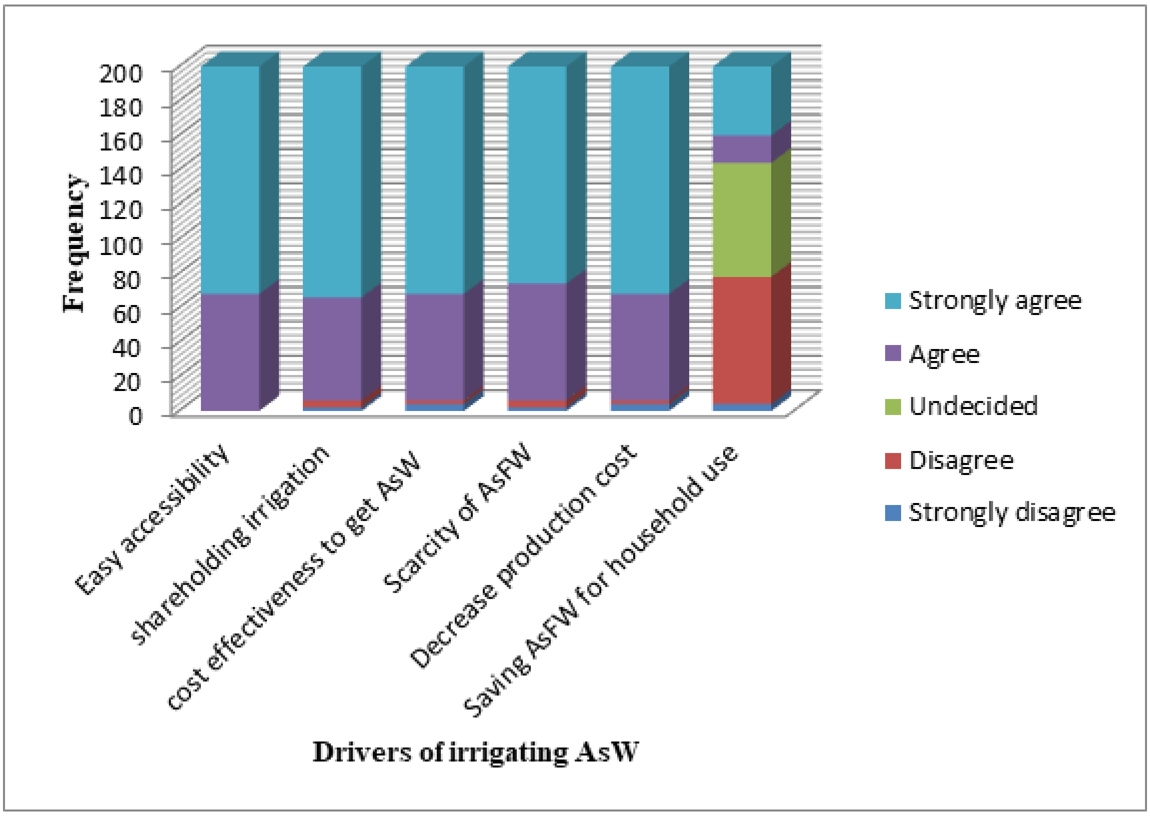


Figure 4b: Distribution of farmers based on their perception on drivers of irrigating AsW

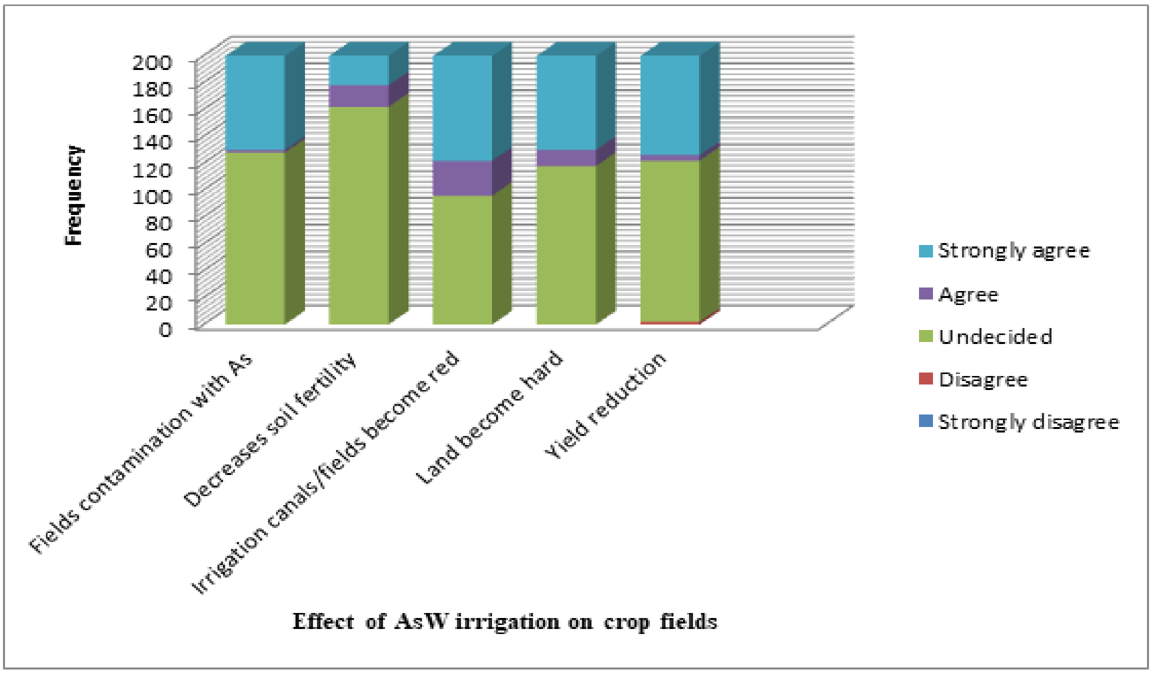


Figure 4c: Distribution of farmers based on their perception on effect of AsW irrigation on crop fields

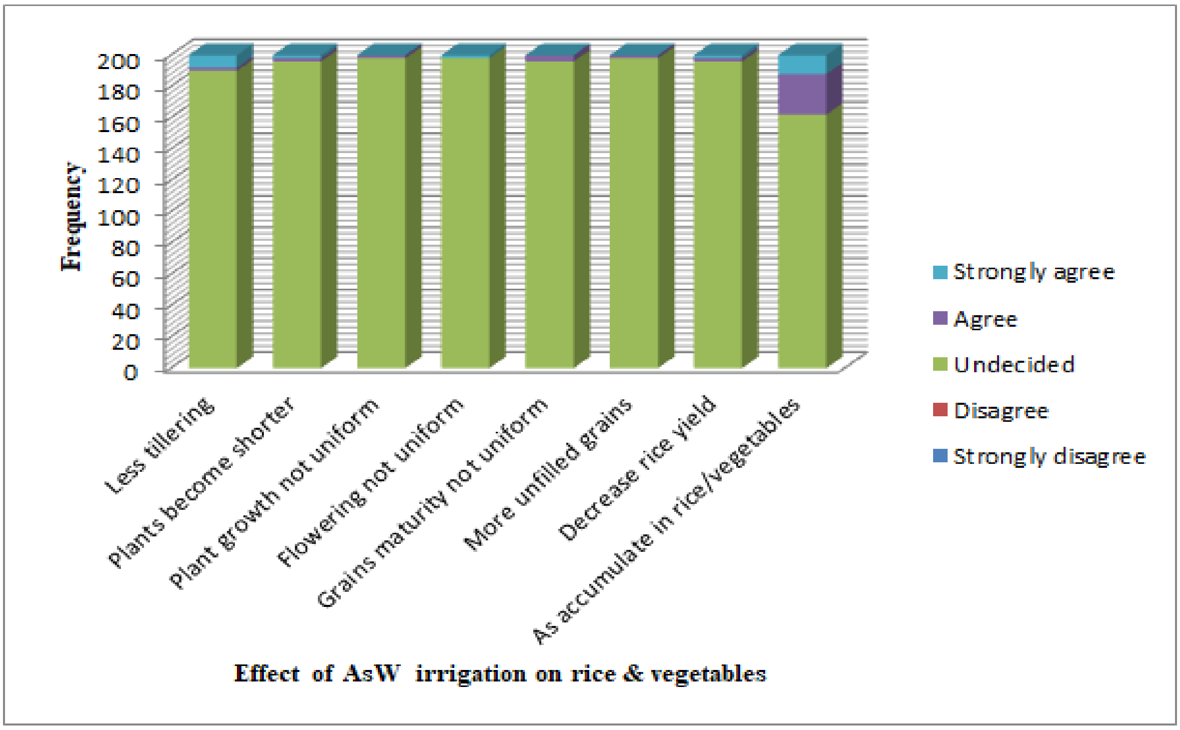


Figure 4d: Distribution of farmers based on their perception on effect of AsW Irrigation on rice & vegetables

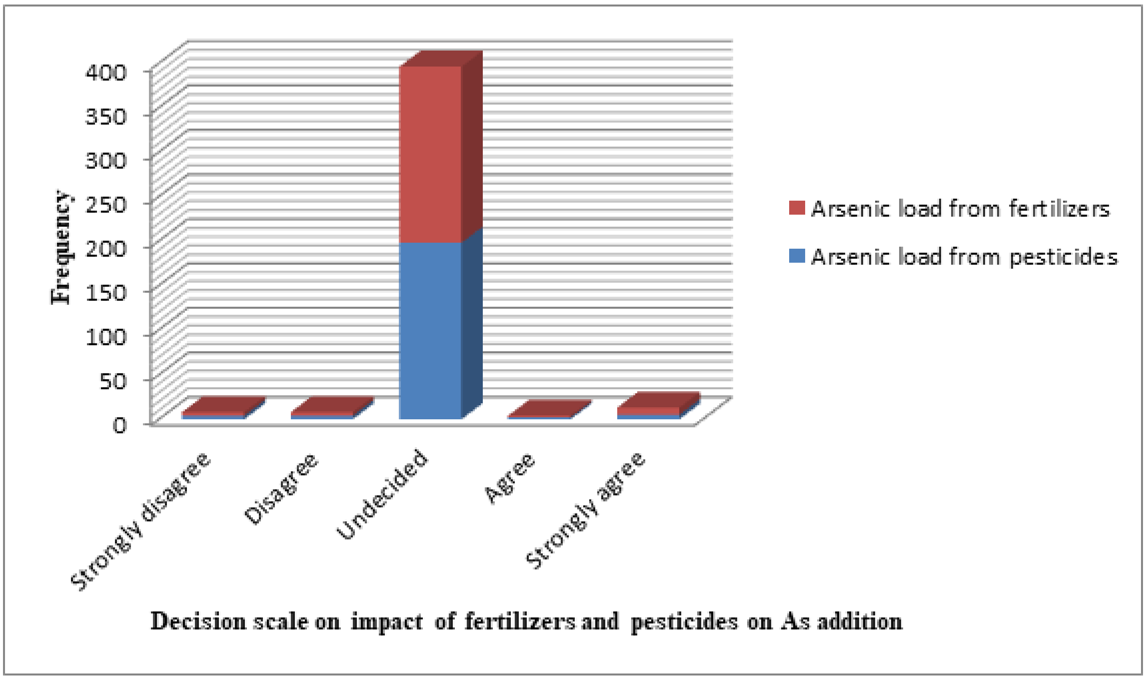


Figure 4e: Distribution of farmers based on their perception on impact of fertilizers and pesticides on As addition

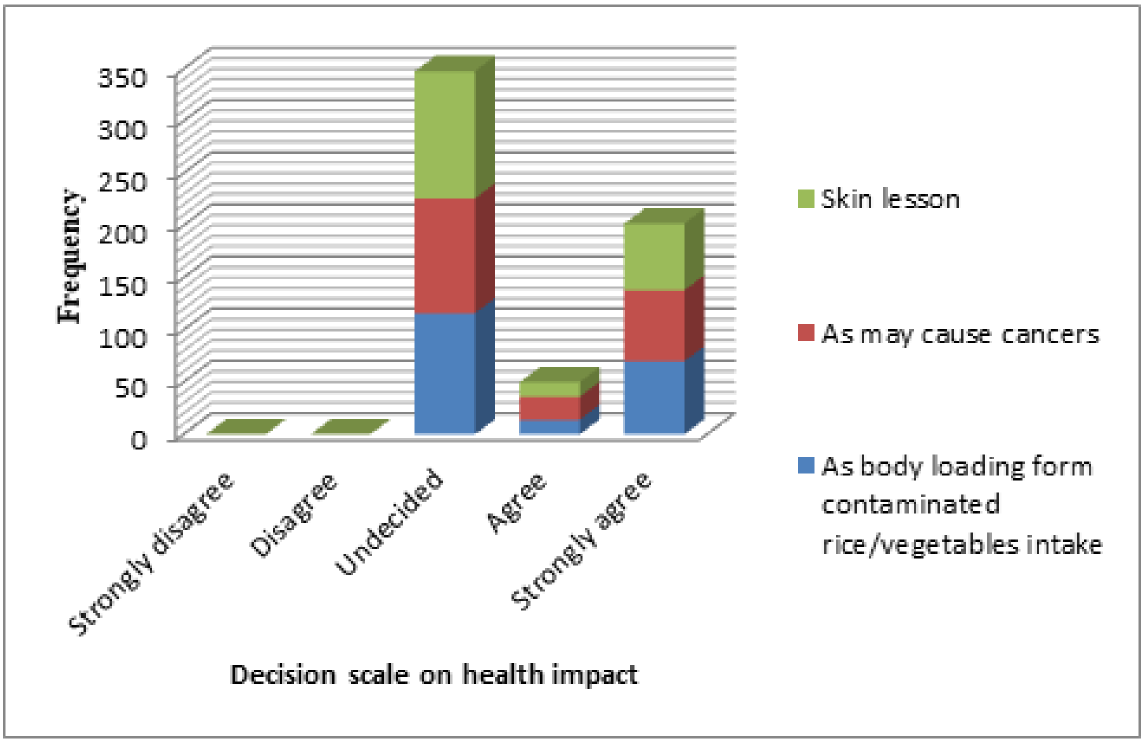


Figure 4f: Distribution of farmers based on their perception on Health impact

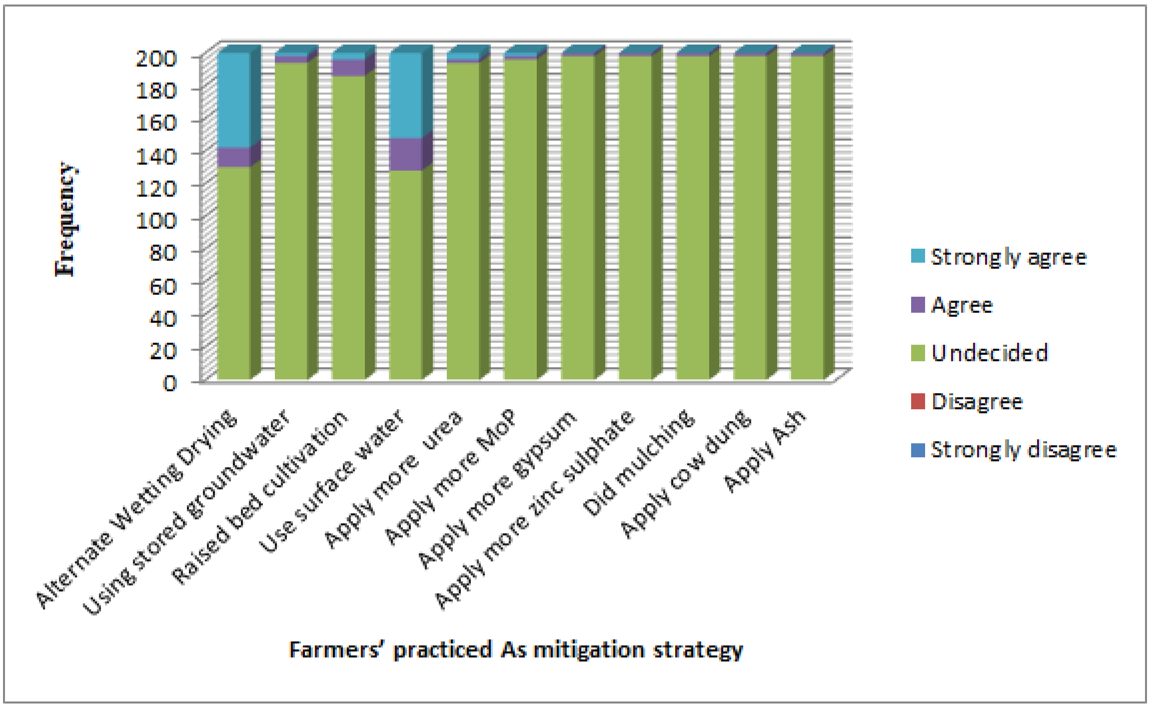


Figure 4g: Distribution of farmers based on their perception on practiced As mitigation strategy

Figure 4 (a-g): Farmers' perceptions under seven specific parameters

3.3.3 Correlations

Table 11 represents correlation coefficients between the dependent and independent variables, and Table 12 shows the correlation matrix representing the overall interaction between the variables. According to Table 11, among the socioeconomic characteristics, farmers' age, annual income, family education, family size, farm size, and agricultural credit use were non-significant. In contrast, farmers' age and family size were negatively correlated with their perception of As elevated groundwater irrigation for rice and vegetable production. The study of Alam (2001) and Kabir (2002) revealed a negative correlation of family size with perception, while Majlish (2007) reported a non-significant correlation. Afique (2006), Pal (2009), and Adeola (2012) revealed that farm size had no discernible effect on farmers' perceptions. Friedler et al. (2006) claimed no significant relationship of farmers' income and age with their perception. Islam (2000) observed no association between farmers' utilization of credit and their perception.

On the other hand, farmers' education, knowledge, information sources, direct participation in farming, cosmopoliteness, opinionatedness, innovativeness, risk orientation, farm power and machinery (FPM), and organizational participation were positively significant with perception at a 1% significance level (Table 11). Pal (2009) revealed that farmers' education positively correlates with their perception. Kabir & Rainis (2012) and Adeola (2012) also found that education significantly affects farmers' perceptions in Bangladesh and Nigeria. Individuals with higher education levels usually perceive risks and understand mitigation necessity in a very advanced way (Dosman et al., 2001). In their survey in Gujarat province in India, Kumar & Popat (2010) exposed that knowledge, a psychological characteristic of the farmer, had a significant positive association with their perception. The study of Adeola

(2012) reported similar findings in Nigeria. The farmers' information sources can play a crucial role in building positive or negative perceptions of any phenomenon.

Table 11:

Correlation coefficients (r) between farmers' perception and their socioeconomic parameters

Independent	**Dependent**	**Correlation co-efficient**
Age of the participant		-0.022NS
Farmers education		0.716**
Family education		0.038NS
Annual income		0.165NS
Family size		-0.045NS
Knowledge		0.865**
Information sources		0.735**
Farm size	Farmers' Perception	0.145NS
Direct participation farming		0.855**
Agricultural credit use		0.148NS
Cosmopoliteness		0.485**
Opinionatedness		0.512**
Innovativeness		0.488**
Risk orientation		0.613**
Farm power and machinery (FPM)		0.269**
Organizational participation		0.796**

** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed)

Rezaei et al. (2017) claimed a significant relationship between farmers' exposure to the information sources as well as media and their perception. Farmers engaged in farming activities helps determine their decision-making capacity in any circumstance (Larsen et al., 2002; Rahaman et al., 2018). Therefore, direct farming participation had a significant relationship with farmers' perceptions (Rokonuzzaman, 2016). Islam (2000) revealed a significant positive correlation between farmers' perception and annual income.

Regarding the association between farmers' ownership of FPM and their perception, through their study in the water markets in Bangladesh, Mottaleb et al. (2019) demonstrate that irrigation pump ownership largely determines farmers' perception. However, they concluded that since the irrigation system in Bangladesh is mainly based on pumping underground water, pump ownership significantly influences the structure and choice of irrigation practices. Regarding the relationship between organizational participation and perception, Keshavarz and Karami (2008) reported that membership in social organizations positively influences farmers' perceptions. Membership in formal or informal organizations helps the farmers get benefits and social support (Fuller-Iglesias et al., 2009). Segnestam (2009) argued that organizational participation helps disseminate innovations and develop mutual trust among the farmers, which eventually shapes farmers' perceptions. While studying cosmopoliteness, Alam (2001) noted a significant positive association between farmers' cosmopoliteness and their perception. According to Hamid (1995), there is a significant relationship between cosmopoliteness and farmers' use of the recommended level of plant protection practices. Farmers' opinionatedness and perception were found to have a significant positive association in the study of Islam (2000). Londhe et al. (2018) discovered a substantial positive relationship between perception and participants' risk orientation and innovativeness. The study of Rekha & Ambujam (2010) in Tamil Nadu, India, about the farmers' perception of contaminated water irrigation revealed a significant positive

Table 12:

Correlation matrix representing overall interaction between the variables

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16
X1	1															
X2	-.022	1														
X3	.716**	.009	1													
X4	.038	.380**	.304**	1												
X5	-.045	.878**	.009	.424**	1											
X6	.865**	-.121	.666**	.030	-.156	1										
X7	.735**	.061	.676**	.048	.085	.621**	1									
X8	.145	-.018	.179	-.037	-.014	.082**	.19	1								
X9	.855**	-.059	.554**	.045	-.101	.783**	.559**	.174	1							
X10	.148	.052	.243*	.211*	.13	.166	.149	.420**	.062	1						
X11	.485**	.038	.484**	.039	.032	.426**	.537**	.294**	.330**	.163	1					
X12	.512**	-.072	.542**	.115	-.052	.527**	.615**	.247*	.407**	.181	.476**	1				
X13	.488**	.011	.522**	.225*	.038	.395**	.565**	.199*	.308**	.125	.509**	.514**	1			
X14	.613**	.043	.670**	.125	.067	.606**	.700**	.042	.463**	.193	.527**	.567**	.473**	1		
X15	.269**	-.032	.228*	.084	-.037	.233*	.332**	.161	.235*	.259**	.107	.056	.230*	.231*	1	
X16	.796**	-.023	.550**	.000	-.062	.722**	.731**	.260**	.691**	.087	.570**	.562**	.435**	.557**	.196	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Listwise N=200

Participation Characters	Symbol	Participation Characters	Symbol		
Perception	X1	Knowledge	X6	Cosmopoliteness	X11
Participant age	X2	Information sources	X7	Opinionatedness	X12
Participant education	X3	Farm size	X8	Innovativeness	X13
Family education	X4	Direct participation in farming	X9	Risk orientation	X14
Family size	X5	Credit use (1000 BDT)	X10	Ownership of farm power and machinery (FPM)	X15
				Organizational participation	X16

correlation between farmers' perception and their educational status, information sources, annual income, farm size, risk orientation, and innovativeness.

3.3.4 Regression results

Stepwise multiple regression analysis was employed to identify the predictor variables (the independent variables) to explain farmers' perceptions (the dependent variable). Table 13 illustrates the findings of stepwise regression. The total variance explained by the five independent variables is 0.884 (R = .889, R^2 = 0. 884), as seen in this table. Of the total variance, participants' knowledge explained 74.6%, direct participation in farming 8.2%, information sources 4.5%, participant education 0.7%, and organizational participation 0.8%. The F value for participants' knowledge, direct participation in farming, and information sources are significant at 0.1% level, while for participants' education and organizational participation are significant at 5% level. This means that the five recognized predictor variables account for 88 percent of the variance in the dependent variables.

The positive influence of knowledge means a farmer having higher knowledge on As occurrence and health impact is likely to perceive As contamination in rice and vegetables irrigated with contaminated water and subsequent heath impact from the consumption. One-third of respondents in this study area have higher knowledge on crop contamination with As who like to be able to take quick and appropriate decisions on various aspects of using mitigating strategies for As safe rice production. According to Stoner & Freeman (1992), people with dissimilar knowledge backgrounds typically perceive the same event from different viewpoints. Kumar & Popat (2010) also revealed a close linkage between farmers' knowledge and perception. Farmers involved directly with the farming practices are instantly informed of the latest crop production incompatibilities, which enrich their perception of the circumstances (Rokonuzzaman, 2016).

Table 13:

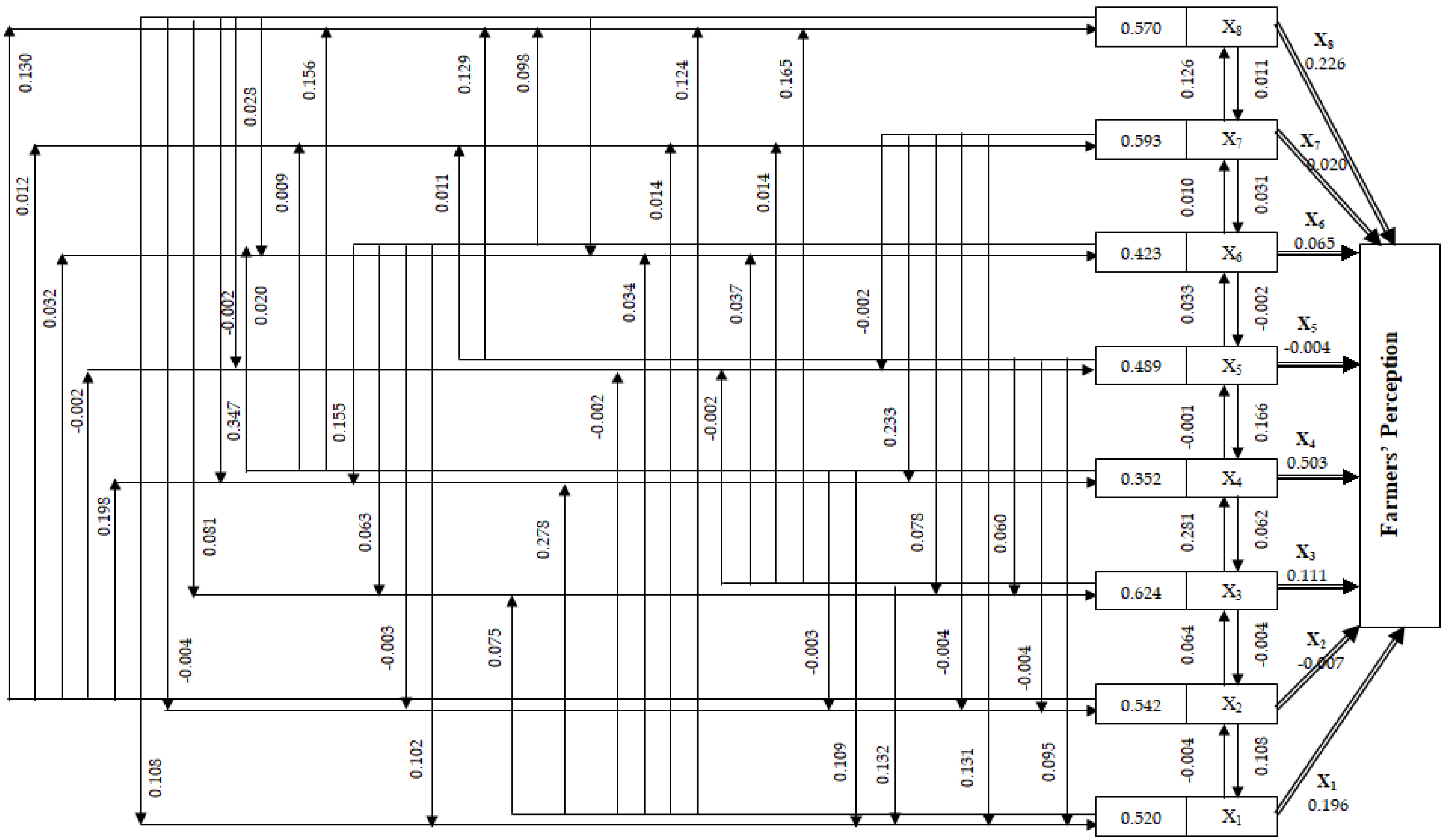
Regression of the estimated perception on the independent variables

Variables	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**R Square Change**	**F Change**	**Sig. F Change**
Participants knowledge	.865	.748	.746	7.140	.748	291.373	.000
Direct participation in farming	.911	.830	.826	5.899	.082	46.587	.000
Information sources	.935	.875	.871	5.089	.045	34.297	.000
Participant education	.939	.882	.877	4.973	.007	5.533	.021
Organizational participation	.943	.889	.884	4.832	.008	6.638	.012

On the other hand, out of the factors affecting farmers' perception, organizational participation and membership in social organizations develop networking among the villagers. The study of Owusu et al. (2012) in Ghana with vegetable farmers revealed that membership of farmer's organization significantly influences farmer's perception. Another factor that influenced respondents' risk perceptions was how they have been notified about food and health safety hazards (Dosman et al., 2001). Farmers get updated information through various print and electronic media, which broaden their understanding and boost their perception of food safety issues (Lin, 1995). The study of Rekha & Ambujam (2010) also reported farmers' educational status as a significant determinate to predict their perception of contaminated water irrigation since the increase in educational level, the farmers' perception increases. This result is comparable with with the findings of Kabir & Rainis (2012) and Lu et al. (2017). Farmers with a higher level of education avail potential knowledge about their farms and farm problems since they have accessibility to a broader multitude of information sources (Daberkow & McBride, 2003; Uddin et al., 2014). Only 26% of the participants had secondary to above secondary education that might influence information acquisition exuberance regarding As contamination in their cultivated rice and vegetables.

3.3.5 Path analysis

The path analysis decomposes the total effects into direct and indirect effects on selected independent variables. Direct participation in farming presents the highest positive total effect (0.855) and direct effect (0.503), whereas information sources show the highest positive indirect effect (0.624) (Figure 5). Table 14 demonstrates that organizational participation (0.796, 0.226) and participant education (0.716, 0.196) represent the second and third highest total and positive direct effect, respectively, both with positive impact. Risk orientation (0.593) and organizational participation (0.570) rank second and third in terms of positive



Legend : ⟶ Indirect effect ⟹ Direct effect

X_1 = Participant Education, X_2 = Knowledge, X_3 = Information sources, X_4 = Direct Participation in Farming,

X_5 = Cosmopoliteness, X_6 = Innovativeness, X_7 = Risk orientation, and X_8 = Organizational Participation

Figure 5: Direct and indirect effect of independent variables on farmers' perception (dependent variable) towards transformation

Table 14:

Decomposition of total effects into direct and indirect effect of independent variables on perception of farmers towards transformation (n = 200)

Independent variable	**Direct effect**	**Total indirect effect**	**Variable through which substantial indirect effects were channelized***	
			-0.004	Knowledge (X2)
			0.075	Information sources (X3)
			0.278	Direct participation in farming (X4)
Participant education (X_1)	0.196	0.520	-0.002	Cosmopoliteness (X5)
			0.034	Innovativeness (X6)
			0.014	Risk orientation (X7)
			0.124	Organizational participation (X8)
			0.108	Participant education (X_1)
			0.064	Information sources (X3)
Knowledge (X_2)	-0.007	0.542	0.198	Direct participation in farming (X4)
			-0.002	Cosmopoliteness (X5)

			0.032	Innovativeness (X6)
			0.012	Risk orientation (X7)
			0.130	Organizational participation (X8)
Information sources (X_3)	0.111	0.624	0.132	Participant education (X_1)
			-0.004	Knowledge (X2)
			0.281	Direct participation in farming (X4)
			-0.002	Cosmopoliteness (X5)
			0.037	Innovativeness (X6)
			0.014	Risk orientation (X7)
			0.165	Organizational participation (X8)
Direct participation in farming (X_4)	0.503	0.352	0.109	Participant education (X_1)
			-0.003	Knowledge (X2)
			0.062	Information sources (X3)
			-0.001	Cosmopoliteness (X5)
			0.020	Innovativeness (X6)
			0.009	Risk orientation (X7)

			0.156	Organizational participation (X8)
			0.095	Participant education (X_1)
			-0.004	Knowledge (X2)
			0.060	Information sources (X3)
Cosmopoliteness (X_5)	-0.004	0.489	0.166	Direct participation in farming (X4)
			0.033	Innovativeness (X6)
			0.011	Risk orientation (X7)
			0.129	Organizational participation (X8)
			0.102	Participant education (X_1)
			-0.003	Knowledge (X2)
			0.063	Information sources (X3)
Innovativeness (X_6)	0.065	0.423	0.155	Direct participation in farming (X4)
			-0.002	Cosmopoliteness (X5)
			0.010	Risk orientation (X7)
			0.098	Organizational participation (X8)
Risk orientation (X_7)	0.020	0.593	0.131	Participant education (X_1)

			-0.004	Knowledge (X2)
			0.078	Information sources (X3)
			0.233	Direct participation in farming (X4)
			-0.002	Cosmopoliteness (X5)
			0.031	Innovativeness (X6)
			0.126	Organizational participation (X8)
			0.108	Participant education (X_1)
			-0.004	Knowledge (X2)
			0.081	Information sources (X3)
Organizational participation (X_8)	0.226	0.570	0.347	Direct participation in farming (X4)
			-0.002	Cosmopoliteness (X5)
			0.028	Innovativeness (X6)
			0.011	Risk orientation (X7)

indirect effect. Out of the eight independent variables, four variables [participant education (X1), knowledge (X2), information sources (X3), and cosmopoliteness (X5)] each have the highest indirect effect on the perception of farmers towards transformation through direct participation in farming and organizational participation. On the other hand, another three [innovativeness (X6), risk orientation (X7), organizational participation (X8)] have the highest indirect effect through direct participation in farming and participant education which are depicted in Table 14. However, path analysis revealed that just a few variables directly impacted farmers' perception levels. However, interconnected variables were principally involved for the effect of several variables on farmers' perceptions.

3.4 Conclusion

The most concerning health issue in rural Bangladesh has been identified as a high concentration of As in groundwater. The level of farmers' perception about the source of As contamination, As-induced ailment, its symptoms, and potential measures to minimize crop loading with As was investigated in this study. It has also explored the association between farmers' perception and their socioeconomic status and identified the predictor variables responsible for perception variances. These are crucial aspects in formulating policies for As mitigation and education programs in Bangladesh and all the As endemic nations. The findings of this study clearly show that As perception is not widespread in rural Bangladesh at the moment. While most participants had a poor to moderate perception about the As problem in irrigation water and its uptake by rice and vegetables, their knowledge gap is notably prominent regarding the mitigation measures available to prevent the contamination. Enhancing awareness by disseminating pertinent information through print and electronic media, personal localite, personal cosmopolite, method, and result demonstration may help individuals enhance their knowledge and perception. In addition, to successfully assure As relevant information and remedial measures to assist prevent further health repercussions from rice and vegetable intake, increasing the current education program is crucial, like the steps taken for combatting drinking water As issues in Bangladesh. Additionally, it has been found that perception is related to direct participation in farming, farmers' cosmopoliteness, opinionatedness, innovativeness, risk orientation, ownership of farm power and machinery (FPM), and organizational participation. Public awareness programs should expand and target the regular participants in any organization, farmers' leaders, middle to old-aged groups, and innovators in all areas.

CHAPTER 4

HUMAN HEALTH IMPACT DUE TO ARSENIC CONTAMINATED RICE AND VEGETABLES CONSUMPTION IN NATURALLY ARSENIC ENDEMIC REGIONS

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4.1 Introduction

A group-I carcinogen with a geological origin, arsenic (As) is widely distributed in the environment. Arsenic poisoning is substantial in Asian nations that produce rice, and endemic populations have been seen to suffer from As-related ailments (Brammer & Ravenscroft, 2009; Shaji et al., 2021). Hazardous heavy metals have a major detrimental effect on public health even in tiny amounts (Roleda et al., 2019; Yangli et al., 2021). Additionally, consumers' concerns about food safety are growing as living standards rise (Su et al., 2021; Yangli et al., 2021). The occurrence of As and its distribution in the food chain must be identified in order to assess the risk to human health (Rehman et al., 2021; Santra et al., 2013). In many endemic locations, deep tubewell drilling and surface water treatment have been used to supply drinking water free of As. Contaminated roundwater is still used for irrigation, especially during the dry seasons for rice and vegetables (Roychowdhury, 2008; Islam et al., 2017). Ninety percent of the world's rice is produced in Asian nations, with groundwater serving as a primary source of irrigation (Islam et al., 2016; Yu et al., 2020). Since rice is typically traded to locations that are often outside of the country where it is produced, we must view As hazards as global issues (Meharg et al., 2009). Due to the fact that only around 54% of the world's rice is used locally and the remainder is exported internationally across national borders, contaminated rice is often seen in the bowls of individuals who live far from the country of origin of the rice (Meharg et al., 2009).

In regions with higher As levels in soil or irrigated by As rich groundwater, vegetables have also supposedly been reported to contain elevated levels of As in addition to rice (Bhattacharya et al., 2012; Rehman et al., 2016). Asian nations also make up half of the world's vegetable export values (FAO/WITS, 2017). These resulted in an increased risk of As toxicity from dietary intakes of crops grown in As-contaminated groundwater, and depending on where they live, this may apply to both endemic and non-endemic people. Since the signs of arsenicosis do not appear for several months or even years after commencing a chronic As intake, it is essential to accurately monitor when someone is being exposed to hazardous levels of As. While the majority of As excreted from the body through urine, a little amount builds up in the hair and nails (Nguyen et al., 2019). Although there is a substantial correlation between urinary As levels and groundwater As (Gault et al., 2008; Wongsasuluk et al., 2018), collecting urine samples over a lengthy period of time in rural areas of developing nations may pose challenges due to the necessity to freeze urine samples during storage (Brima et al., 2006). Again, t There are considerable disadvantages to utilizing blood as an As biomarker, such as the difficulties in keeping blood samples and the invasive aspect of blood sample collection, despite the fact that blood As levels have been found to correlate well with groundwater As concentrations in Bangladeshi villages (Gault et al., 2008). As is attracted to the sulfhydryl groups in the keratin of hair and nails. The collection of these tissues is an intriguing method for determining previous As exposure since the matrix of the nails and hair is produced independently of the body's other metabolic processes (Gault et al., 2008). Hair grows faster than nails do and records As exposures for short period before the collection date, but fingernails take, on average, around six months longer to fully grow out (Fleckman, 1997; Gault et al., 2008). This indicates that fingernails can offer data on As exposure for a longer time frame than can hair samples. Nails grow more slowly than hair, which also accumulates exposure from a few months before collection (Gault et al., 2008). Another important aspect is that fish is a significant source of As exposure for humans, but that As from fish does not accumulate in scalp hair (Mandal et al., 2003; Kales & Christiani, 2005; Pullella & Kotsopoulos, 2020). As a result, avoiding confusion from prior exposure, hair analysis is highly suitable for assessing As exposure within a few months as a result of rice and vegetable intake (Harkins & Susten, 2003).

The accumulation of As in food crops, notably rice and vegetables irrigated with groundwater contaminated with as, has been extensively studied in previous years (Bhattacharya et al., 2012; Rehman et al., 2016; Reid et al., 2021). Arsenic accumulation in human hair, a potential body marker to indicate metal's body loading related health impact, primarily from the consumption of rice and vegetables grown in naturally As-contaminated regions while keeping safe drinking water as a control, is still to contribute to the knowledge base. Therefore, the focus of our research is on the pathway by which As is transferred into the bodies of farmers who drink As safe groundwater but eat rice and vegetables grown on the fields contaminated with As.

4.2 Materials and methods

4.2.1 Study area

Five well-known Upazilas (sub-districts) of Chandpur that are heavily As contaminated were chosen as the study area: Chandpur Sadar (Sadar), Faridganj, Matlab North, Kachua, and Hajiganj (Figure 2). Different samples such as soil, irrigation water, vegetables, and rice were collected from the farmers' fields who donated scalp hairs for analysis. Socio-demographic information and food consumption data were also collected form the same farmers.

4.2.2 Collection of farmer's socio-demographic and food consumption data

Data on sociodemographic characteristics and food consumption were gathered by administering a validated questionnaire in a face-to-face setting (Arrebola et al., 2009). The study samples were made up of 20 farmers who met certain requirements from each of the five study areas (Sadar, Faridganj, Matlab North, Kachua, and Hajiganj). In the year 2020, data were gathered from them concurrently with the collection of scalp hair samples. Farmers who had consumed their own rice and vegetables grown in their farms using contaminated groundwater as well as donated scalp hair for analysis met the selection criterion. The demographic data included age, body weight, residence duration (years), education, annual income, symptomatic/asymptomatic, occupation, family size, and farm size. The data on food consumption includes the amount of rice and vegetables consumed per day (g), the duration of exposure (years), the frequency of exposure (days/year), quantity of fruits and milk consumed, the amount of proteinaceous foods consumed (meat, fish, and eggs). To gather data on food intake, 39 crop products were divided into 6 clusters: meat (n = 3), vegetables (n = 8), fruits (n = 9), grains (n = 3), beverages (n = 1), and fish (n = 15). The study was authorized by The Education University of Hong Kong's Human Research Ethics Committee (HREC), and all participants signed informed consent forms.

4.2.3 Sample collection and preparation

Based on the study's objective, farmers were purposively selected to provide samples of their scalp hair, irrigation water, soils, rice, and vegetables. A 100 mL of water was collected after 5 minutes of pumping the irrigation pump, and 5 mL of 2M hydrochloric acid was added to the collected sample immediately. The sample was then transported to the lab on ice. The samples were later filtered using 0.45-Millipore filters. Direct soil samples were taken from the fields with standing crops. According to the guidelines of IGCP 259 (Fordyce et al., 2000), each soil sample was composed of a mixture of four sub-samples. Soils from the upper 0-20 cm horizon (i.e., upper horizon) were gathered to construct a composite sample (Khan et al., 2008). Before analysis, the soil samples were wrapped in Kraft paper after being screened to remove any stones, residues, or pebbles. They were then air dried, sieved twice through 2- and 0.149-mm mesh, and wrapped. Directly from the field, where soil and irrigation samples were taken, standing rice and edible sections of vegetables were harvested. Vegetables are commonly grown for sale in the study region, much like rice. In order to irrigate the vegetables grown alongside the rice or after it was harvested, groundwater from the same source as the rice was used. The plant samples include different types of rice (*Oryza sativa*), radish (*Raphanus sativus* L), arum roots (*Colocasia esculenta*), brinjal/eggplant (*Solanum melongena*), beans (*Phaseolus vulgaris*), potato (*Solanum tuberosum*), cabbage (*Brassica* oleracea var. capitata), cauliflower (Brassica oleracea var. botrytis L), tomato (*Solanum lycopersicum*), several leafy vegetables including Ceylon spinach *(Basella alba)*, arum leaf (*Colocasia esculenta*), red and stem amaranth *(Amaranthus spp), and* water spinach (*Ipomoea aquatic*). For each plant sample, up to four sub-samples were taken to create a composite sample. These samples were then safely preserved in zip-lock bags made of polyethylene before being immediately transferred to the laboratory (Zhuang et al., 2014). The chaff was removed from the rice grains. Plant samples were rinsed with tap water for about 5 minutes, followed by a deionized water rinse, blotting with filter paper, and oven drying at 60°C for 24 hours (Liu et al., 2010).

Prior to chemical digestion, rice and vegetable samples were pounded in a carnelian mortar. Four replications of each of the samples mentioned above were performed. Using stainless-steel scissors, scalp hair samples were taken from those owner farmers who had been purposively chosen. There were no female participants in this study, and hair samples were collected only from the men. Because the local male population typically gets haircuts regularly, making it easier to determine the concentration of As in hairs from short-term exposure than it is for females, who have long hair and are only ideal for tracking long-term exposure history (Bang et al., 2009). Hairs were gathered from all scalp sites with a mean of 1 gram to reduce the inter- and intra-hair variance of As levels on the same head (Hindmarsh, 2000; Mazumder, 2000). The samples were transferred to the lab in zip-lock bags wrapped in aluminum foil. Samples were kept at -20 °C until the chemical analysis (Wang et al., 2013).

To get rid of unwanted materials adhering to the samples, 5 mL of deionized water and methanol were used for two rinses (Hinwood et al., 2003).

4.2.4 Analysis and quality control

According to the method used by Huang et al. (2006), the concentration of As in samples of water, soil, grain, and vegetables was determined using an atomic fluorescence spectrophotometer (AF-610A, built in Beijing, China) (2006). Exactly 00.25g of soil was moistened with deionized water (a few drops) and placed in a 100-ml Erlenmeyer flask to determine the soil total As. Concentrated $HClO_4$, HNO_3, and HCl, in amounts of 2 ml, 5 ml, and 6 ml, respectively, were carefully mixed with the soil. To allow the reaction to subside, the digestion was kept going at roughly 150 °C in the flask covered with a little glass filter for about 1.5 hours. The digest was mixed with sulfourea solution (50 g/L) of 5 ml in a volumetric flask (50 ml), and the volume was made using double-deionized water. For the vegetable and grain As analysis, exactly 0.5 g of each sample (at <0.5 mm size) of vegetables and rice was placed into an Erlenmeyer flask (100 ml) and mixed with concentrated HNO_3 (20 ml) and H_2SO_4 (1.25 ml). After the overnight reaction, the digestion was completed by slowly boiling water on an electric heater. About 10ml brown-colored solution was digested once again with strong HNO_3 (5ml). Additional digestion was done by adding concentrated $HClO_4$ because the digestion was still inadequate even after two thirds more digestions with HNO_3 (2ml). However, the entire digestive process took 3–4 hours. The digest was transferred into a 25-ml measuring flask, spiked with 2.5ml of sulforea solution (50g/L), and then diluted with double-distilled water. Following digestion with a 4:1 ratio of HNO_3 and $HClO_4$, Liu et al. (2010)'s method was used to determine the amount of As in hair samples using a hydrogen generation-atomic fluorescence spectrometer (AFS-820, Beijing Titan Instruments Co., China). The digested samples were also dissolved in HCl at a 2 percent concentration. All reagents, however, were analytical grade or better. For quality assurance, certified reference materials like tomato leaves (NIST 1573a) were used. The reference material SRM Tomato leaves (NIST 1573a) has a verified value of 0.112±0.004 µg/g, but the found value ranged from 0.109 µg/g to 0.120 µg/g. Within the range of the certified As concentration, the reference material's As recoveries ranged from 88.9 to 91.8 percent.

4.2.5 Health risk assessment

The concentrations of the elements in food as well as the volume of food ingested daily determine the daily intake of heavy metal(loid) (Fu et al., 2008; Li et al., 2014). Furthermore, a person's body weight may have an impact on their tolerance to a particular heavy metal(loid) (Fu et al., 2008). Because of the consumption of rice and vegetables, the average As daily dosage (ADD) and hazard quotient (HQ) result in the As risk index for human health. The USEPA (2012) provided the following formula for calculating the average ADD through rice and vegetables:

$$ADD = \frac{C \times IR \times EF \times ED}{AT \times BW}$$

Where ADD is average daily dose (mg/kg/day), AT is the averaging time for noncarcinogens (365 days/year, EF × number of exposure years, ED), BW is body weight (kg), EF is the exposure frequency (day/year), IR is the rice or vegetables ingestion rate (g/day), ED is the exposure duration (years), and C is As concentration in rice grains or vegetables (mg/kg). The following equation was used to determine the hazard quotient (HQ). The HQ>1 indicates a significant health hazard brought on by As exposure.

$$\text{HQ} = \frac{\text{ADD}}{\text{RfD}}$$

RfD (reference dose) for As is 0.0003 mg/kg/day (USEPA, 2012).

The Hazard index (HI) represents the total HQ value. Here, HI is the total of the rice and vegetables HQ, and expressed as follows:

In this case, HI > 1 denotes a high risk of non-carcinogenic risk.

$$HI = \sum HQ$$

The carcinogenic risk was determined as per the average As content in rice and vegetable samples and the cancer risk probability in rice and vegetables by As absorption was calculated through Incremental Lifetime Cancer Risk (ILCR) equation as follows (Cao et al., 2014).

$$ILCR = CSF \times ADD$$

Where SF represents the cancer slope factor and SF of As is 1.5 $(mg/kg/day)^{-1}$ (USEPA, 2010).

4.2.6 Bioconcentration factor (BCF)

In order to assess the transferability of metal from soil to plant in a specific soil-plant system, the bioconcentration factor (BCF) was determined as the ratio of metal content in plant biomass to that in the soil (Bakhat et al., 2021; Huang et al., 2006; Marrugo-Negrete et al., 2015; Rehman et al., 2019). According to Liu et al. (2013) and Zhou et al. (2021), it is stipulated as follows:

$$BCF = C_{plant}/C_{soil}$$

In this case, grains and vegetables and the overall As concentration in soil, expressed as mg/kg on a dry wt. basis, are represented by C_{plant} and C_{soil}, respectively (Khan et al. 2010).

4.2.7 Statistical analysis

Bioconcentration factor (BCF), Correlations, Least Significance Difference (LSD), and Two-way analysis of variance (ANOVA) were analysed statistically with R (R core team 2019). Dendrogram and Principle component analysis (PCA) (Spanu et al., 2020) were administered by Minitab 18 statistical software (Shakoor et al., 2018). Other computations were made using Microsoft Excel 2019.

4.3 Results and discussion

4.3.1 Farmers socio-demographic and food consumption parameters

Figure 6 (a-q) highlights the sociodemographic and food consumption factors of the participants, all of whom were local residents and approximately two-thirds of whom were young to middle-aged and had passed primary school. A majority of their income, which was obtained from agriculture cultivation in small to medium farm holdings, was from agriculture, with 40% of them having low to medium income and 39% falling under the high to very high income group. Seventy percent of farmers had small to average families, and no responders had any symptoms associated with arsenicosis. Regarding food consumption habits (figure 6 (i-q)), all respondents drank As-safe water from government-installed tubewells 45% consumed >2 portions of eggs weekly; ; 65% consumed >3 portions of fish weekly; 66% consumed 500g to >900g of fruits weekly; 65% consumed >2 portions of meat weekly; 21% drank 250ml to 750ml weekly and 47% drank >750ml of milk weekly. Most respondents (78%) consumed up to 1.3 kg of vegetables per week, which is higher than the national average of 0.910 kg (Hassan & Ahmad, 2000), while 69 percent of respondents consumed between 3.5 and 4.2 kg of rice per week. The development of As-induced ailment and symptoms is significantly correlated with nutritional and socioeconomic status (Sampson et al., 2008). It has been discovered that persons with inadequate nutrition are more vulnerable to As poisoning than those with adequate nutrition (Santra et al., 2013).

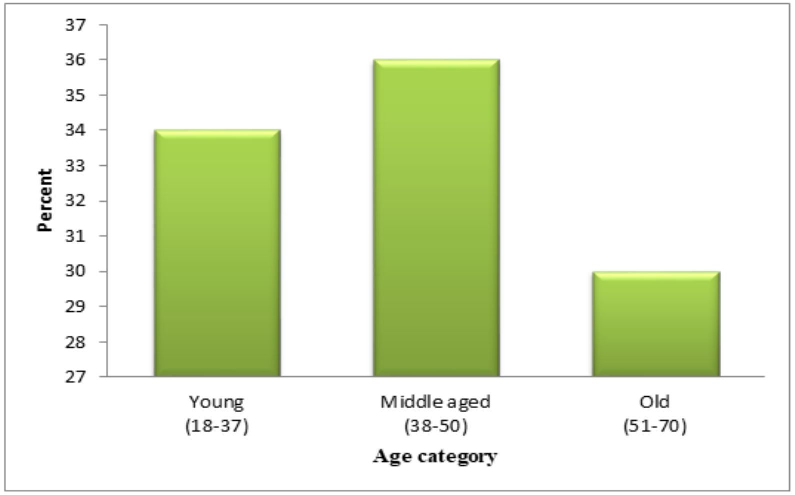

Figure 6a

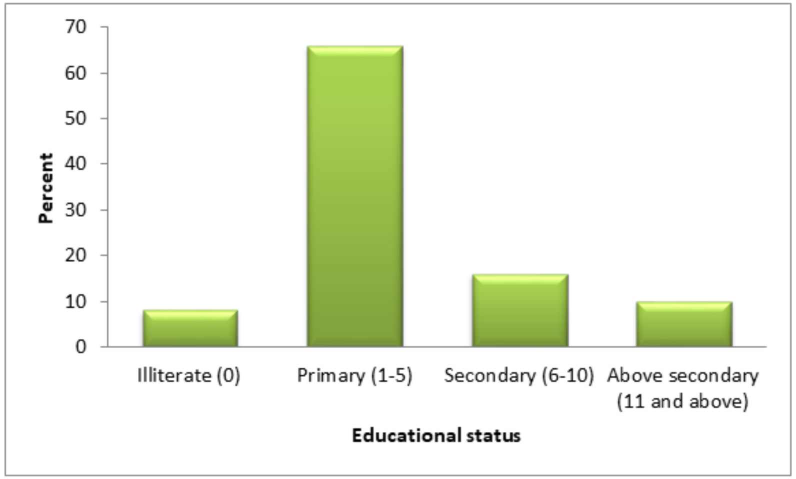

Figure 6b

Figure 6c

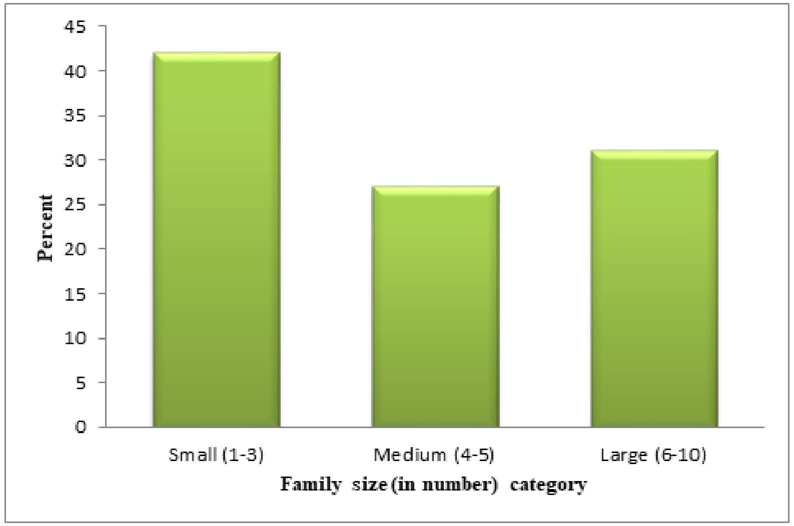

Figure 6d

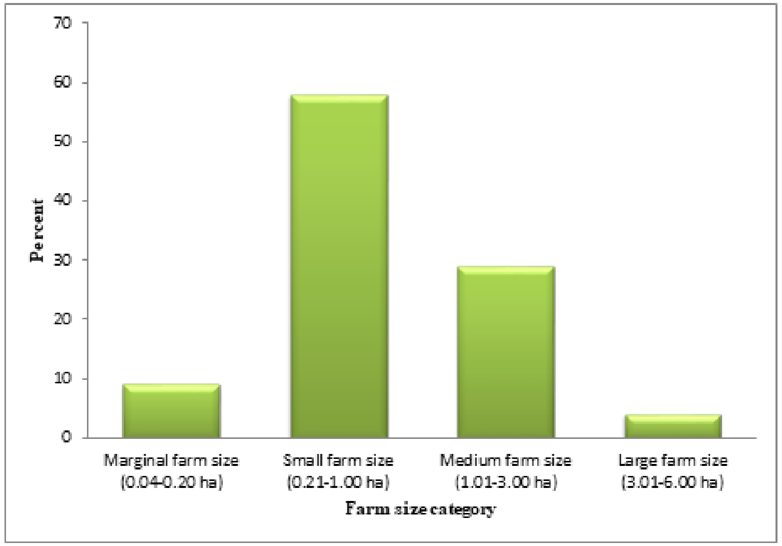

Figure 6e

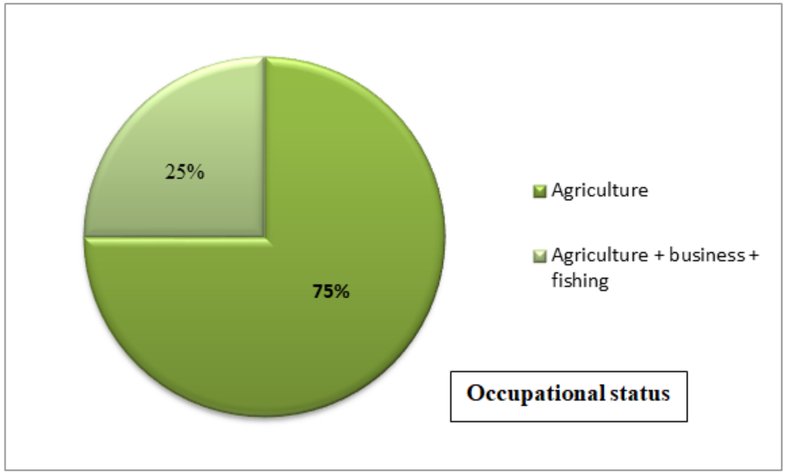

Figure 6f

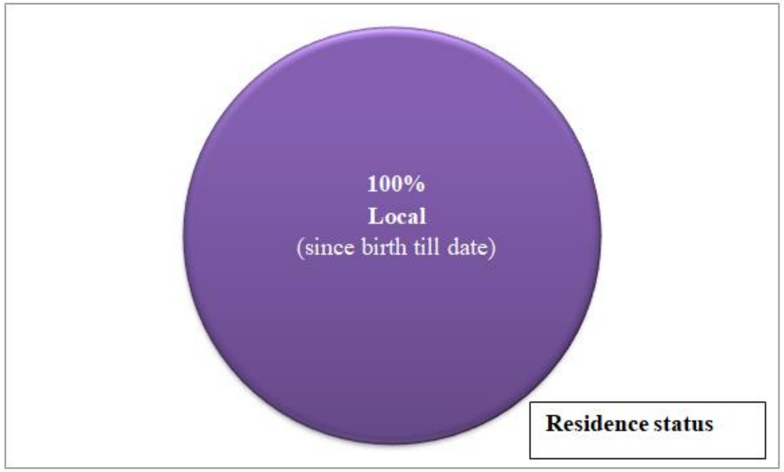

Figure 6g

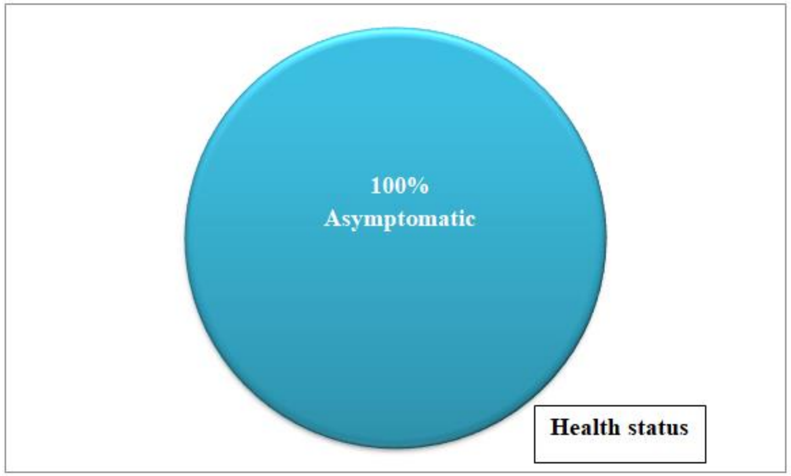

Figure 6h

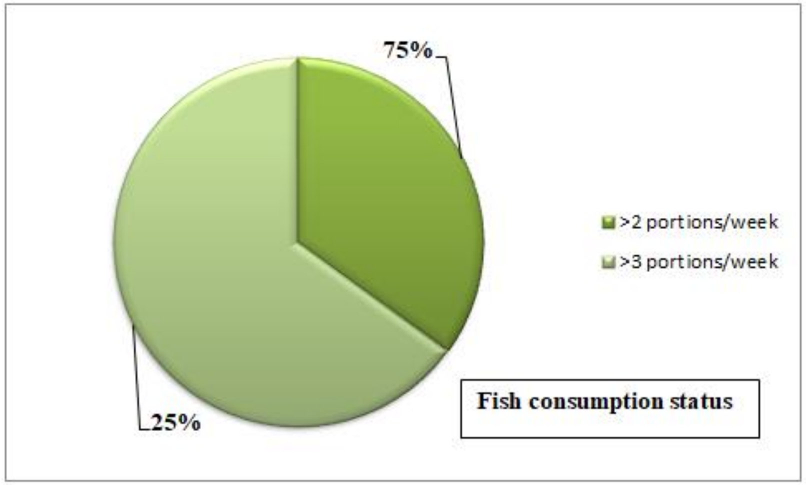

Figure 6i

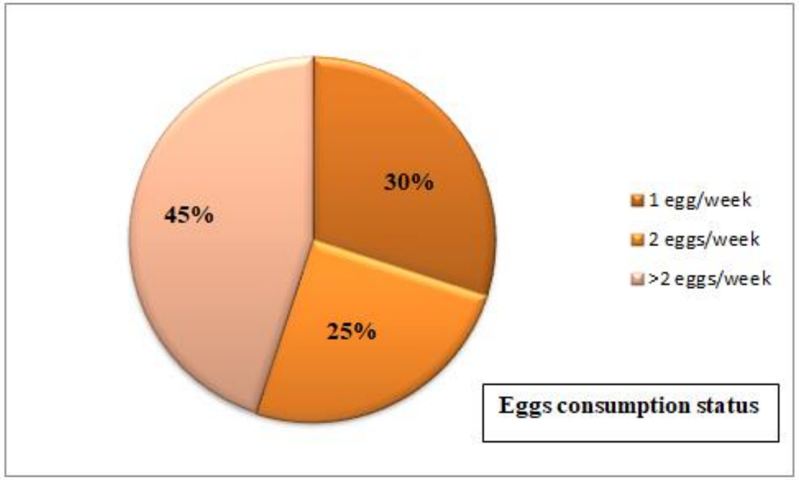

Figure 6j

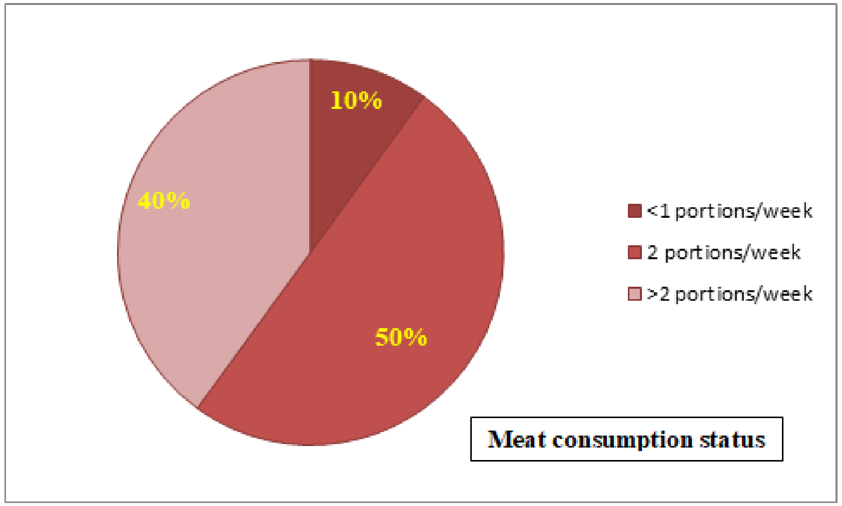

Figure 6k

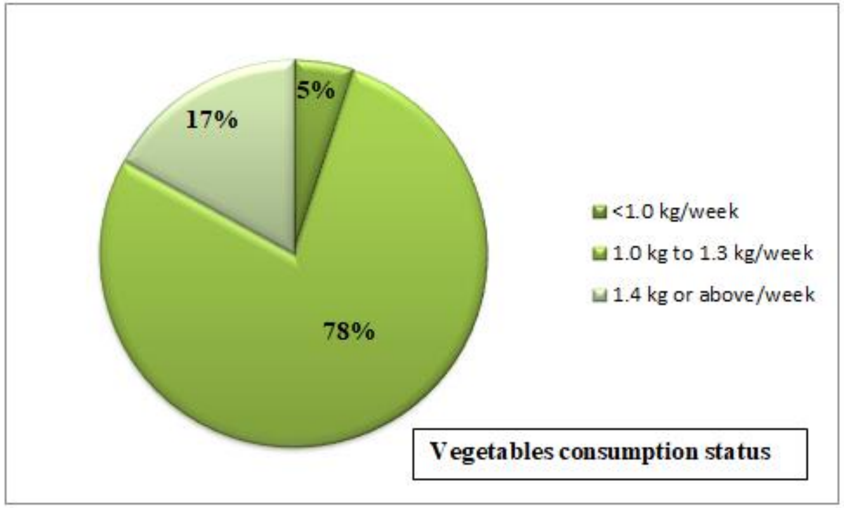

Figure 6l

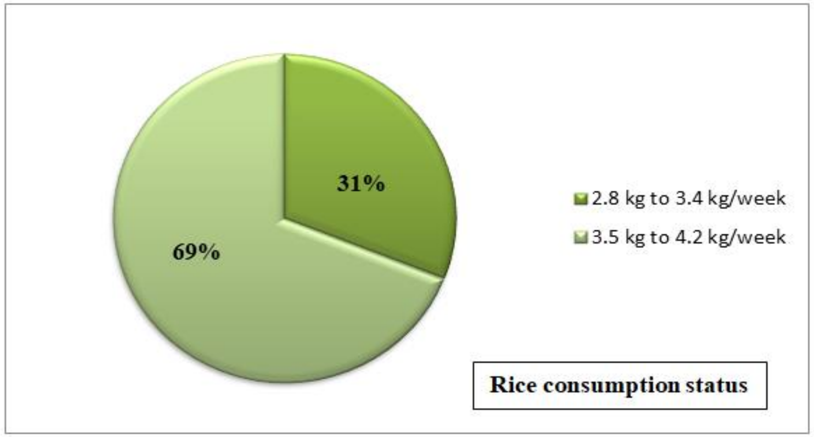

Figure 6m

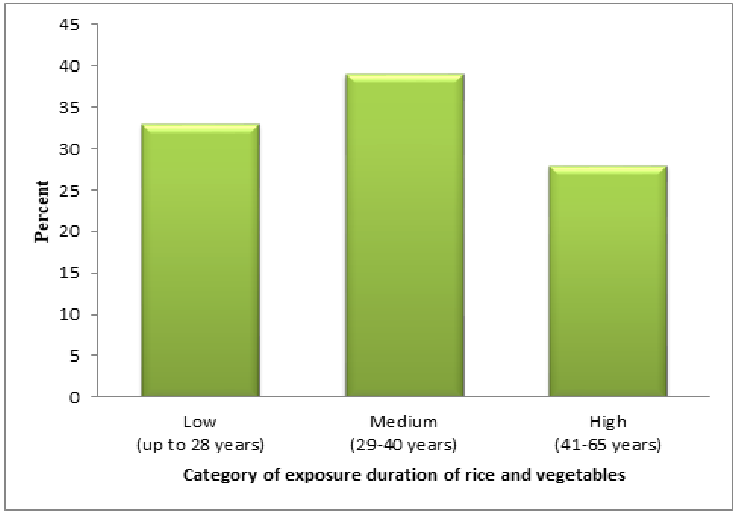

Figure 6n

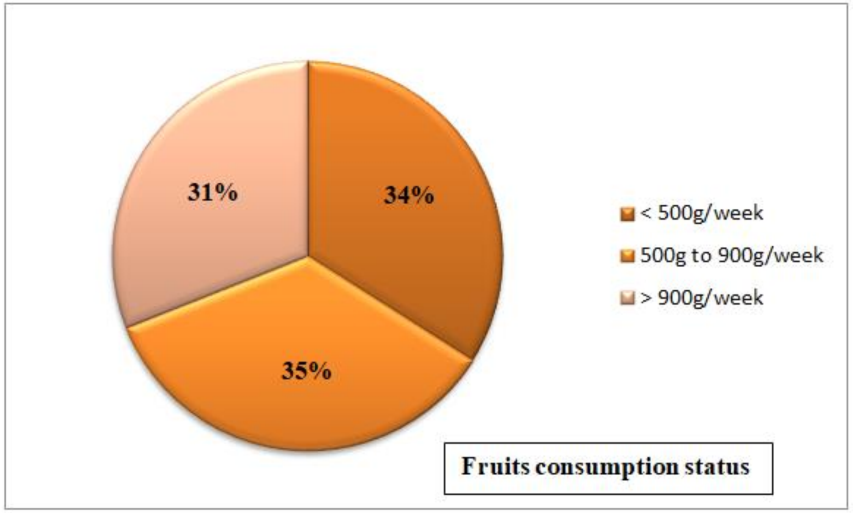

Figure 6o

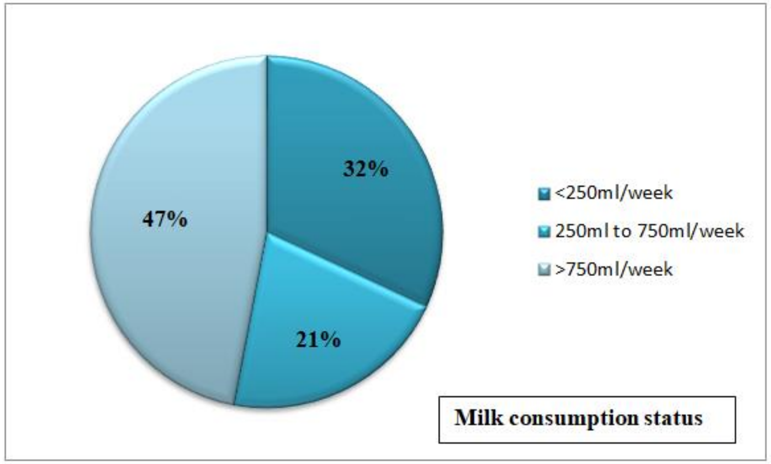

Figure 6p

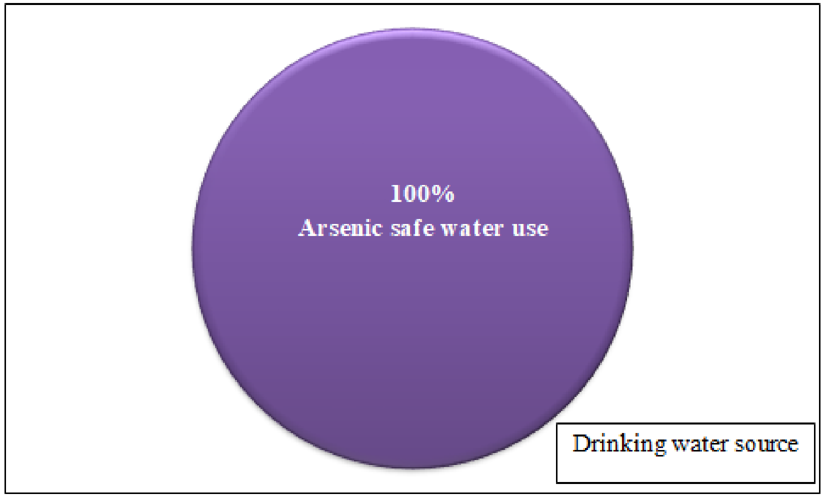

Figure 6q

Figure 6 (a-q): Farmers' socio-demographic and food consumption status

According to research, those with inadequate dietary status had poorer methylation and As detoxication capacities (Sharma & Flora, 2018; Biswas & Kumar Mukhopadhyay, 2020). According to some reports, individuals with severe arsenicosis ingested less protein-rich foods, whereas individuals with non-severe (mild/moderate) arsenicosis consumed more protein-rich foods (Nasrin et al., 2022). Vegetables have been revealed to have crucial protective effects against As-induced skin lesions and are good sources of antioxidant vitamins like A, E, C, and B-complex as well as a number of minerals like iron, copper, zinc, and selenium, all of which have been shown to be protective against As poisoning (Nasrin et al., 2022). Consumption of various gourds, non-leafy vegetable roots, and protein were similarly linked to a lower risk of As-induced skin lesions among Bangladeshi male and female units, according to a study by Pierce et al. (2011).

4.3.2 Arsenic in irrigation water and soils

Irrigation water from Matlab north, Kachua, and Hajiganj retained significantly higher amount ($p \leq 0.001$) of As compared with irrigation water from Sadar Upazila and Faridganj, while the highest and lowest As is detected in the irrigation water from Matlab north and Sadar, respectively (Table 15). Arsenic concentrations in groundwater used for irrigation ranged from 0.080 to 0.280, 0.096 to 0.327, 0.110 to 0.339, 0.065 to 0.370, and 0.039 to 0.365 mg/L with mean±SD of 0.152±0.052, 0.183±0.072, 0.249±0.080, 0.227±0.107, and 0.239±0.106 for Sadar, Faridganj, Matlab north, Kachua and Hajiganj, respectively. Arsenic-affected areas in Chandpur had higher As levels in irrigation water samples that came from groundwater sources compared to those that came from surface water sources (Saha & Ali, 2010). the detected groundwater As content was significantly higher than the FAO's and WHO's proposed 0.1 mg/L and 0.01 mg/L permissible limits for irrigation (Chakraborti et al., 2018; WHO, 2004). The elevated As levels in irrigation water at five separate places are equivalent to those found in some parts of Chandpur by Das et al. (2004) (0.07–0.42

mg/L) and Williams et al. (2006) (0.366 mg/L). The maximum As content in any of the five study zones of this investigation was higher than the groundwater As content in Chandpur, which was detected by Saha & Ali (2010) (varied from 0.073 to 0.132 mg/L). Soil As in the study locations is significantly different ($p \leq 0.05$), where soil As content from Kachua is very close to Hajiganj and Matlab north and that from Faridganj is very close to the Sadar (Table 15). The highest and lowest soil As content is evident in Matlab north and Faridganj, respectively. This present study revealed As concentrations in soils ranged from 7.50 to 32.67, 10.71 to 32.26, 13.31 to 30.68, 12.38 to 29.23, and 12.76 to 29.56 mg/kg dry wt. with mean±SD of 22.42±7.82, 22.03±7.51, 23.24±5.04, 18.78±4.33, 20.29±4.15 for Hajiganj, Kachua, Matlab north, Faridganj and Sadar, respectively.

The mean soil As content is higher than the global average (10 mg/kg) soil As level (Rahman et al., 2013), yet it is still within the FAO recommended (50 mg/kg) tolerable limit for agricultural soils (FAO, 1992). The amount of As found in this study is significantly higher than that found in Meharg & Rahman's (2003) Chandpur investigation (ranged from 6.8 to 18.4 mg/kg). Due to widespread irrigation with As contaminated groundwater rather than irrigation with surface water, As content of the topsoil layers rose in Chandpur (Saha, 2006). In addition to the natural augmentation caused by sediment deposition and the diagenesis process, extensive removal of As-rich groundwater for the irrigation of agricultural areas in Bangladesh has contributed to high As levels in surface soils (Das et al., 2004; Meharg & Rahman, 2003; Huq et al., 2020).

The debates that surround the buildup of As in soils are complex and center on questions of absorption, extent, as well as the chemical and bio-physical mechanisms that are at play.

Table 15:

Comparison of arsenic concentration in different components collected from naturally arsenic endemic five sub districts of Chandpur, Bangladesh

Locations	**As in irrigation water (mg/L) (against background value 0.1 mg/L by FAO and 0.01 mg/L by WHO; Chakraborti et al., 2018; WHO, 2004)**	**As in soil (mg/kg) (against global average 10 and FAO limit 50 mg/kg; FAO, 1992; Rahman et al., 2013)**	**As in vegetable (mg/kg) (against permissible limit 0.5 to 1.0 mg/kg; Liu et al., 2010; MAFF, 1997)**	**As in Grain (mg/kg) (against permissible limit 0.37 mg/kg; WHO, 2016)**	**As in hair (mg/kg) (against background value 0.08–0.250 and toxicity indicator 1.0 mg/kg; Arnold et al., 1990)**
Hajiganj (N=20)	0.231a (0.239±0.106)	22.5a (22.42±7.82)	2.50a (2.46±1.15)	0.499a (0.50±0.27)	1.29a
Kachua (N=20)	0.226a (0.227±0.107)	22.0ab (22.03±7.51)	2.02b (2.03±1.25)	0.457a (0.46±0.24)	1.27a
Matlab north (N=20)	0.246a (0.249±0.080)	23.6a (23.24±5.04)	2.19ab (2.17±1.18)	0.471a (0.47±0.19)	1.30a
Faridganj (N=20)	0.184b (0.183±0.072)	18.7c (18.78±4.33)	1.53c (1.53±0.85)	0.371b	0.882b

				(0.37±0.19)	
Sadar (N=20)	0.151c (0.152±0.05)	20.2bc (20.29±4.15)	1.22c (1.25±0.75)	0.256c (0.26±0.11)	0.732b
LS	***	*	**	***	***
CV (%)	6.36	8.61	5.74	9.65	6.17
SE (±)	0.013	0.96	0.164	0.032	0.11

In column, means followed by different letters are significantly different. ***indicates significant at 0.1% probability level; ** indicates significant at 1% probability level; and * indicates significant at 5% probability level. Mean±SD presented in parenthesis. N = number of farmers from whom samples were collected.

The evidence presented by one group of researchers suggests that there is a positive and causal relationship between the use of As contaminated groundwater for irrigation and higher As levels in the soil. For instance, the results of a survey of paddy soils over the entirety of Bangladesh carried out by Meharg & Rahman (2003) revealed that greater levels of As in the soil were closely linked with elevated levels of As content in irrigation water and long-term tubewell use. In a related manner, Alam & Sattar (2000), Norra et al. (2005), Das et al. (2008), and Sarkar et al. (2012) discovered a direct correlation between irrigating with As-contaminated groundwater and elevated soil As levels. All of these researchers considered As contaminated groundwater fot their studies.

There is also evidence from a number of studies that the contamination of soil with As has a significant lasting effect on several crops inclusing rice and vegetables (Abedin et al., 2002; Das et al., 2004; Khan et al., 2010). On the other hand, numerous studies have documented a wide range of rates at which As accumulates in soils that have been irrigated with As elevated groundwater. Arsenic leaching out during monsoon flooding is another factor that has been shown to influence As retention in soil and soil water. Other factors claimed to influence As retention in soil and soil water include the relatively high phosphorous (P) and low iron (Fe) concentrations in irrigation water (Duxbury & Panaullah, 2007); soil texture (Duxbury & Panaullah, 2007); and distance from the irrigation inlet (Pal et al., 2009; Roberts et al., 2011). When taken as a whole, these studies seem to indicate that there are significant variations in the soil qualities that exist at regional, local, and even within tubewell locations, which affect the accumulation and availability of As (Brammer & Ravenscroft, 2009).

4.3.3 Arsenic accumulation in vegetables

When compared to the other three locations, Faridganj and Sadar have significantly ($p \leq 0.01$) lower vegetable arsenic content. However, vegetable As content from Matlab North is pretty similar to that from Kachua and Hajiganj (Table 15). The mean±SD of vegetables As concentration was 1.25±0.75, 1.53±0.85, 2.17±1.18, 2.03±1.25, and 2.46±1.15 mg/kg and ranged from: 0.22 to 2.90 mg/kg (50% samples >1 mg/kg), 0.26 to 2.80 (65% samples >1 mg/kg), 0.23 to 3.68 (85% samples >1 mg/kg), 0.23 to 3.84 (70% samples >1 mg/kg), and 0.18 to 3.90 (85% samples >1 mg/kg) for Sadar, Faridganj, Matlab north, Kachua, and Hajiganj, respectively. Between nations, there are considerable differences in the maximum allowed levels (MPL) of As in vegetables (fresh weight). The MPL value is 0.5 mg/kg in China (Liu et al., 2010), 1.0 mg/kg in the Singapore (AVA, 2006), Ireland (FSA, 2000), and United Kingdom (MAFF, 1997). Bangladesh is one of several nations without legislation, and some researchers consider the MPL of As for fresh vegetables in Bangladesh is 1 mg/kg, which is the maximum food safety standard (Ahmad, 2000; Islam et al., 2012). The average As level of vegetables in all five locations was greater than 1, exceeding Bangladesh's acceptable level for food safety.

In Bangladesh, vegetables make up about 16% of the total diet (Hassan & Ahmad, 2000). This present study found that daily As consumption ranged from 0.53 to 12.37 μg from 140 to 205 g (on average 182 g) of vegetables in the study areas. The vegetables intake rate is less that the average intake of 205 g in Basantapur and Chiladi villages in the district of Noakhali in Bangladesh (Rahman et al., 2013), but much more than the average per capita ingestion of leafy and non-leafy vegetables in the village of Samta with 130 g for the adults (Alam et al., 2003). Among Bangladeshi adults, the amount of vegetables consumed varied from 126 to 169 grams per day, according to a study in Bangladesh (Khan et al., 2009). Considering 130g daily vegetables intake (Hassan & Ahmad, 2000), William et al. (2006) showed comparatively higher As ingestion from vegetables ranged from 0.9 to 16.9 μg/day. On the other hand, Alam et al. (2003) calculated an average intake of 5.6 g As/person/day from 130g of vegetables consumed in Samta village in Bangladesh. Rahman et al. (2013) estimated much less (2.3 μg only) As consumption from vegetables in Basantapur and Chiladi villages while Karim et al. (2008) reported very high (105 μg/day) As ingestion in Feni, Bangladesh considering 130g daily vegetables intake.

4.3.4 Arsenic accumulation in rice

Rice grains from Matlab north, Kachua, and Hajiganj contained significantly higher amount ($p \leq 0.001$) of As than grains from Sadar upazila and Faridganj, while the lowest As content was detected for Sadar and highest for Hajiganj (Table 15). The mean±SD of grain As concentration was 0.26±0.11, 0.37±0.19, 0.47±0.19, 0.46±0.24, 0.50±0.27 mg/kg and ranged from: 0.13 to 0.52, 0.12 to 0.65, 0.18 to 0.69, 0.11 to 0.89, and 0.06 to 0.86 mg/kg for Sadar, Faridganj, Matlab north, Kachua, and Hajiganj, respectively. Mean grain As content from Matlab north, Kachua, and Hajiganj exceeded the food safety level (0.37 mg/kg DW; WHO, 2016; Suriyagoda et al., 2018) while rice from Sadar and Faridganj were within the permissible limit. However, 20%, 45%, 60%, 50%, and 60%, of grain samples were resulted containing more As than the safe limit in Sadar, Faridganj, Matlab north, Kachua, and Hajiganj, respectively.

Again, 0.15 mg/kg is the safe limit of iAs in rice that China has recommended for south Asia (Chakraborti et al., 2018). According to Roychowdhury (2008), iAs makes up about 96.8% of the overall As content in rice, with rice from Asian nations containing up to 99 percent As (R ahman et al., 2014). In light of these recommendations, 100% of the rice from Matlab North, 85% of the grains from Sadar, Kachua, and Hajiganj and 95% from Faridganj are beyond the recommended level. The highest grain As content found in this study is equivalent to William s et al. (2006)'s finding of 0.91 mg/kg grains in Chandpur. However, grain As content from all the five study regions were below 1 mg/kg, which is consistent with earlier studies in Bangladesh (Abedin et al., 2002; Das et al., 2004; Meharg & Rahman, 2003; Williams et al., 2006; Islam et al., 2017).

4.3.5 Arsenic concentration in scalp hair

Significantly ($p \leq 0.001$) higher and statistically similar hair As level has been recorded in Matlab north, Kachua, and Hajiganj and compared to Sadar and Faridganj (Table 15). The typical background levels of As in human hair are a subject of debate. As concentrations of approximately 0.075 mg/kg hair are common in a population living in an uncontaminated environment, according to Nriagu (1994). From another viewpoint, As is commonly found in hair at background levels of 0.08–0.250 mg/kg (Arnold et al., 1990; National Food Authority, 1993; Sanz et al., 2007), however Chatt & Sidney (1988) believed that As naturally occurs at levels of 0.1–1.0 μg/g in human hair. According to Islam et al. (2011), As concentrations higher than 0.50 mg/kg in human hair suggest higher arsenicosis risks. Dart (2004) estimated that the hair As concentration in chronic poisoning patients ranged between 1 and 5 mg/kg, although it frequently exceeded 10 mg/kg. However, 1 mg As per kg hair has been unanimously established as the toxicity indicator (Chatt & Sidney, 1988; Arnold et al., 1990; National Food Authority, 1993; WHO, 2001; Habib et al. 2002; Audinot et al., 2004; Sanz et al., 2007). However, fatalities from As are reported at about 45 mg/kg (Mazumder, 2000).

In this study, the average (range) of As concentration in hair was detected 0.76 (0.28-1.75) mg/kg, 0.91 (0.29-2.18) mg/kg, 1.32 (0.40-2.48) mg/kg, 1.28 (0.36-2.38) mg/kg, and 1.30 (0.34-2.44) mg/kg for Sadar, Faridganj, Matlab north, Kachua, and Hajiganj, respectively. The maximum value of hair As surpassed the toxicity limit, whereas the minimum value is also over the background value proposed by Arnold et al. (1990) and National Food Authority (1993) for all five locations. In Hajiganj, hair As of 45% and 30% of respondents exceeded the toxicity indicator limit (1 mg/kg) and greater arsenicosis risks limit (As levels > 0.50 mg/kg; Islam et al., 2011), respectively. These records are 25% and 20% for Sadar Upazila, 35% and 45% for Matlab north, 50% and 30% for Kachua, and 35% and 20% for Faridganj suggesting a potential health concern amongst the locals.

Chowdhury et al. (2000) conducted a survey of 42 districts where residents previously consumed As contaminated groundwater containing an As concentration of >50 g/L. They examined 3,332 hair samples, and 93% of them showed levels of As beyond normal or toxic levels. However, the range was 0.28 to 28.06, the median was 2.49, and the average was 4.05. According to the research of Dhar et al. (1997) with 228 patients from Bangladesh who had arsenical skin lesions, the ranges and mean of As content in the hair samples were 0.10-20.82 mg/kg and 7.78 mg/kg, respectively. They found that while all of the samples had arsenical skin lesions, some percentages were in the safe range, despite the fact that the majority of the samples had As levels above the suggested value for a normal population. Again , they deduced from their observations and conversations with the patients and volunteers that switching to different sources of drinking water rather than stopping the long-term use of As-contaminated water is what puts the As level in hair back to normal. According to Rahman et al. (2015), samples of hair taken from people who drank As contaminated groundwater in the northwest of Bangladesh ranged in As concentration from 1.6 to 4.64 mg/kg. Another study conducted in Bangladesh revealed that the maximum and average values of hair-As were 19.84 and 1.1 mg/kg, respectively (Karim, 2000). A recent study by Sarker et al. (2021) in Bangladesh from the population consuming highly contaminated groundwater showed a similar high As content (2.89 to 5.51 mg/kg) in hair. The literature referenced here contains far more hair As than what the present study revealed. The reason is that the direct eating of As-contaminated groundwater by the study participants along with rice and vegetables should supply a higher amount of As than is possible for consumption of rice and vegetables alone or in combination of the both. For instance, Rahman et al. (2013) calculated that the daily median As ingestion by adults from vegetables and drinking water was 0.837 mg and 0.0023 mg, respectively. This shows that drinking water use significantly increases daily exposure to As. The main source of As intake, aside from drinking water contaminated with As, is food consumption (Joseph et al., 2015b). This current study found that a daily consumption of rice and vegetables resulted in an average As intake of 0.0092 mg, which was less than what could have been expected from drinking water contaminated with As. According to Arnold et al. (2003), excessive levels of As in hair may be associated with skin ailments, which could have an impact on the local population's health (Liu et al., 2010).

4.3.6 Correlation

The results of the study showed a significant positive correlation of groundwater As with soils, grains, and vegetables As, as well as between soil As and grains and vegetables As at each of the five locations separately (Table 16).

Table 16:

Correlation coefficient between different parameters

Locations	**Correlation co-efficient**
Irrigation water As vs Soil As concentration	
Hajiganj	0.957*
Kachua	0.984**
Matlab	0.882***
Faridganj	0.893*
Sadar	0.803*
Irrigation water As vs vegetables As	
Hajiganj	0.964***
Kachua	0.972**
Matlab	0.943*

Faridganj	0.854**
Sadar	0.932*
Irrigation water As vs grain As	
Hajiganj	0.981**
Kachua	0.964*
Matlab	0.962***
Faridganj	0.922*
Sadar	0.910*
Soil As vs Vegetables As	
Hajiganj	0.923**
Kachua	0.940*
Matlab	0.872***
Faridganj	0.804*
Sadar	0.882*
Soil As vs grain As	
Hajiganj	0.952*
Kachua	0.941***
Matlab	0.800**
Faridganj	0.792*
Sadar	0.734**

***indicates significant at 0.1% probability level; ** indicates significant at 1% probability level; and * indicates significant at 5% probability level

Irrigation water As significantly positively correlates with soil As ($p \le 0.001$), vegetables as ($p \le 0.001$), and grain as ($p \le 0.05$) for the combined data from all locations, whereas soil As is correlated with rice and vegetables As at 5% probability levels (Table 17). The amount of As that will typically be deposited in soils and absorbed by plants depends on how much As is present in irrigation water (Hussain et al., 2021; Shrivastava et al., 2020). Arsenic concentration in edible vegetable portions is strongly correlated with irrigation water and root-soil (Saha, 2006). According to Huq and Naidu's (2005) estimate, enhanced As elevated groundwater irrigation could result in As accumulation in rice fields of up to 5.5 kg/ha/year. Williams et al. (2007b) discovered that a small increase in the quantity of As in the soil can enhance the As content in the rice grains, even soils contain low levels of background As. Again, the investigations by Williams et al. (2007a, 2007b), Zavala & Duxbury (2008) and Reid et al. (2021), have shown a significant correlation between the irrigation water As concentration and grain As. Meharg & Rahman (2003) proposed significant correlations between As in soils, irrigation water, and rice grains following a thorough survey throughout Bangladesh. The study by Otero et al. (2016) also blatantly demonstrates a similar association. According to Baig & Kazi (2012), there is a strong correlation between As concentration in soils and irrigation water and that in vegetables. Similar conclusions were reached by Bundschuh et al. (2012) after analyzing pertinent literature. Additionally, for all five locations, this current study found significant positive correlations between As in scalp hair and that in rice, vegetables, and rice plus vegetables at various levels of significance (Table 18). At a 5% level of significance, a similar strong, positive correlation between hair and grain As, hair and vegetables as, and hair and rice+vegetables as was seen for all five study locations (Table 17).

Table 17:

Correlation coefficient of arsenic in different samples collected from from naturally arsenic endemic five sub districts of Chandpur, Bangladesh

Arsenic in different components	**Irrigation water As**	**Soil As**	**Vegetables As**	**Grain As**	**Scalp hair As**	**Vegetables + Grain As**
Irrigation water As	1					
Soil As	0.898***	1				
Vegetables As	0.935***	0.858*	1			
Grain As	0.947*	0.839**	0.891**	1		
Scalp hair As	-	-	0.859*	0.899*	1	
Vegetables + Grain As	0.952*	0.868*	0.997**	0.923**	0.879*	1

***indicates significant at 0.1% probability level; ** indicates significant at 1% probability level; and * indicates significant at 5% probability level

Yet again, for all locations and for the cumulative association with combined data, hair As is more strongly correlated with that of grains than vegetables. According to previous research, there is a direct relationship between As in drinking water with As in consumers' scalp hairs (Sanz et al., 2007; Gault et al., 2008; Kazi et al., 2009; Rahman et al., 2015; Brahman et al., 2 016; Joardar et al., 2021). Furthermore, prolonged discontinuation of drinking water contami nated with As allows the As level in scalp hairs back to its background levels (Dhar et al., 19 97). To gather the hair samples for this study, farmers who consume their own rice and vegetables are taken into consideration.

Another crucial fact is that, despite fish being a significant source of human exposure to As, fish As does not build up in scalp hair (Mandal et al., 2003; Kales & Christiani, 2005; Pullella & Kotsopoulos, 2020). As a result, hair analysis is excellently suited to identify As exposure within the last few months because of rice and vegetable consumption, which prevents confusion from prior exposure (Harkins & Susten, 2003). The positive association between scalp hair As with rice and vegetables As posed a serious concern about As ingestion through rice and vegetable diet in naturally As affected areas.

In addition, people with nutritional deficiencies were more susceptible to As toxicity than their counterparts who were well-nourished. This conclusion is supported by Santra et al. (2013)'s review of pertinent literature. There was no statistically significant correlation seen in the present study between participant age and hair As content. The outcome is comparable to that of Gault et al. (2008), who also found no statistically significant relationship between participant age and As content of scalp hair. However, a t a 1% significance level for each location and a 5% level for the combined data, hair As is revealed positively linked with grain As and vegetable As.

Table 18:

Correlation coefficient between scalp hairs arsenic with rice and vegetable arsenic

Locations	**Correlation co-efficient**
Vegetables As vs Hair As	
Hajiganj	0.796*
Kachua	0.943**
Matlab	0.870*
Faridganj	0.764***
Sadar	0.903*
Grain As vs Hair As	
Hajiganj	0.934**
Kachua	0.922*
Matlab	0.910**
Faridganj	0.881***
Sadar	0.933*
Combined vegetables As and grain As with Hair As	
Hajiganj	0.833***
Kachua	0.940**
Matlab	0.881*
Faridganj	0.802*
Sadar	0.934**

***indicates significant at 0.1% probability level; ** indicates significant at 1% probability level; and * indicates significant at 5% probability level

4.3.7 Bioconcentration factor (BCF)

When the bioconcentration factor (BCF) value is more than one (1), the plants are considered to be hyper heavy metal accumulators (Marrugo-Negrete et al., 2015). Sadar has a significantly ($p \leq 0.001$) lower BCF from soil to grains than the other four sites with statistically identical BCF (Figure 7). The BCF from soil to veggies varies greatly ($p \leq 0.001$) depending on the location, with Sadar recording the lowest BCF and Hajiganj recording the greatest (Figure 7). However, Faridganj and Hajiganj are extremely close to BCF in Matlab north and Kachua. For all five study locations, the BCF for vegetables and rice is less than one and varies from 0.0170 to 0.1520 (avg. 0.0821) and 0.0063 to 0.332 (avg. 0.0183), respectively. The primary cause might be the strong affinity of As for iron oxides, especially the inorganic parts, which can stick to iron minerals through adsorption and complexation mechanisms, preventing As from moving from soils to crops (Larios et al., 2012; Guo et al., 2020; Zhou et al., 2021). Again, reaching As up to the tops of plants requires a number of processes, whereas plant roots are exposed to As directly and initially. A substantial quantity of As is sequestered in roots, which severely restricts the movement of As towards the above-ground parts of the rice plant (Islam et al., 2021). In other research conducted in Bangladesh, the BCF value for vegetables and rice was observed to be less than one (Alam et al., 2003; Proshad et al., 2019). Vegetables reveal on average 4.5 (range 1.13-9.52) times higher as accumulators than rice, despite BCF values below 1. In their study conducted in Bangladesh, Proshad et al. (2019) also found that vegetables have a higher As bioaccumulation rate than rice. One explanation for this could be that certain vegetables have a unique ability to bioaccumulate As in their edible sections (Huang et al., 2006; Huq et al., 2006).

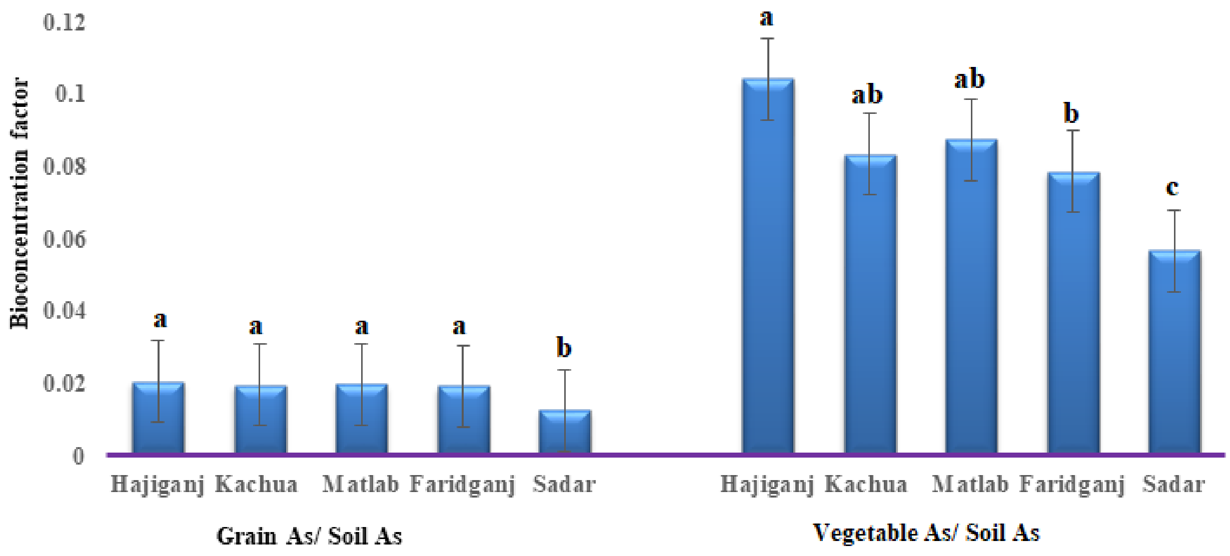

Figure 7: Bioconcentration factor (BCF) for rice grains and vegetables

In comparison to other vegetables, potatoes, arum roots, and green vegetables such Ipomea, arum leaves, stem amaranthus, red amaranthus accumulated more As, which contributed more to the average vegetable As content. Comparable to other studies conducted in Bangladesh, those vegetable items have a higher As accumulation potential (Das et al., 2004; Huq et al., 2006). In contrast, Mahal et al. (2011) found in Matlab of Chandpur, Bangladesh, that rice that were irrigated with groundwater accumulated more As than the vegetables irrigated with surface water. In a study at the Nadia district of West Bengal, India, Bhattacharya et al. (2010a) asserted a larger As accumulation in boro rice than the vegetables other than potato. In a similar vein, Huang et al. (2006) discovered that in the suburbs of Fujian Province, southeast China, there was a larger As transfer from soil to rice than vegetable accumulation.

4.3.8 Health risk assessment

Table 19 lists the average, maximum, and minimum exposure duration (ED), body weight (BW), exposure frequency (EF), and minimum and maximum averaging time for noncarcinogens (AT) values for study participants. The obtained data demonstrated that for all locations, the ADD (mg/kg/day) values for As by vegetable intake were higher than those from rice ingestion (Table 20). The ADD values showed that the As intake of the local population from rice and vegetables, and definitely from rice and vegetables together, was higher than the RfD limit (3.0×10-4 mg/kg/day) set by the USEPA (2012). Despite the fact that rice has a greater IR, participants' ADD was higher due to vegetables' higher As content. In this study, the average HQ value for vegetables was 1.5 times greater than for rice intake, and the HQ values of As through rice or vegetable consumption are both >1.0. (Table 20). In all five locations, the HI (total HQ) value through consumption of vegetables and rice thus surpassed 1.0, suggesting potential health risks from As pollution for the local population. The HI, HQ, and ADD and average ILCR for rice and vegetables have been shown in Table 19.

Table 21 shows the maximum and minimum ILCR and the percentage of consumers fitting into each risk category. While ILCR > 10^{-3} suggests a considerable risk and ILCR > 10^{-4} indicates threshold risk, the ILCR < 10^{-6} designates safe zone for the consumers (EPA, 2017; USEPA, 2000, 2016). The minimum and maximum ILCR is observed > 10^{-4} and > 10^{-3} for all the study locations, respectively. The average ILCR indicating 3.2, 4.9, 6.0, 5.8, and 6.3 individuals per 1000 people are at threshold risk for rice consumption in Sadar, Faridganj, Matlab north, Kachua, and Hajiganj, respectively. Conversely, 1.12 persons per 100 populaces and 9.0, 9.7, 7.1, and 5.5 persons per 1000 people are at threshold cancer risk owing to the consumption of vegetables in Hajiganj, Kachua, Matlab north, Faridganj, and Sadar, respectively.

Table 19:

The minimum, maximum and average values of per capita rice and vegetable ingestion rate, Exposure Duration (ED), Exposure Frequency (EF), Body Weight (BW) and minimum and maximum Averaging Time for noncarcinogens (AT)

Locatons	**Daily per capita rice consumption rate (kg) (Min/Max/Avg)**	**Daily per capita vegetable consumption rate (kg) (Min/Max/Avg)**	**BW-Body weight (kg) (Min/Max/Avg)**	**ED-Exposure duration (years) (Min/Max/Avg)**	**EF -Exposure frequency (day/year) (Min/Max/Avg)**	**AT- Averaging time for noncarcinogens (AT=EF*ED) (Min/Max)**
Hajiganj	0.450/0.600/0.509	0.140/0.205/0.180	55/67/60	12/50/29	365/365/365	4380/18250
Kachua	0.450/0.600/0.507	0.140/0.205/0.179	56/67/62	15/51/33	365/365/365	5475/18615
Matlab north	0.450/0.600/0.520	0.140/0.200/0.182	54/69/62	20/50/34	365/365/365	7300/18250
Faridganj	0.450/0.600/0.523	0.15/0.205/0.185	50/69/61	20/52/37	365/365/365	7300/18980

Sadar	0.400/0.600/0.507	0.145/0.205/0.180	55/67/61	20/65/37	365/365/365	7300/23725

Table 20:

Human risk assessment of arsenic through rice and vegetables consumption from naturally arsenic endemic five sub districts of Chandpur, Bangladesh

Location	**ADD$_{(rice)}$ (mg/kg/day)**	**ADD$_{(vegetables)}$ (mg/kg/day)**	**HQ**		**HI**	**ILCR**	
			Rice	**Vegetables**	**Rice+Vegetables**	**Rice**	**Vegetables**
Hajiganj	0.00417	0.00731	13.9	24.4	38.7	6.3×10^{-3}	1.12×10^{-2}
Kachua	0.00390	0.00602	13.0	20.1	32.7	5.8×10^{-3}	9.0×10^{-3}
Matlab north	0.00404	0.00647	13.5	21.6	35.0	6.0×10^{-3}	9.7×10^{-3}
Faridganj	0.00332	0.00480	11.1	16.0	26.7	4.9×10^{-3}	7.1×10^{-3}
Sadar	0.00215	0.00378	7.16	12.6	19.4	3.2×10^{-3}	5.5×10^{-3}

Table 21:

Incremental Lifetime Cancer Risk (ILCR) from rice + vegetables

Location	**Minimum ILCR**	**Maximum ILCR**	**%consumers under considerable risk**	**%consumers under threshold risk**	**%consumers under safe limit**
Hajiganj	1.68×10^{-03}	2.8×10^{-02}	85	15	Nil
Kachua	2.55×10^{-03}	3.03×10^{-02}	60	40	Nil
Matlab north	3.40×10^{-03}	2.71×10^{-02}	65	35	Nil
Faridganj	3.29×10^{-03}	2.50×10^{-02}	60	40	Nil
Sadar	2.41×10^{-03}	1.80×10^{-02}	30	70	Nil

All of the participating farmers in the study area had significantly higher HI and ILCR as well as higher ADD intake, but none of them showed any physical complications. According to one hypothesis OF Sampson et al. (2008), the transfer of As may not be recognized immediately since the symptoms of its exposure may remain dormant for a long time. The duration and severity of the exposure determine how quickly the symptoms of chronic As poisoning develop (Sun, 2004; Sarkar, 2009; Banerjee et al., 2011). Again, the length of time it takes for someone to develop arsenicosis varies according on the amount of As in their diet, their nutritional status, their genetic makeup, and other factors (Anawar et al., 2002; Banerjee et al., 2011). Since persons with a poor nutritional state have a lesser capacity for methylation and As detoxication, it has been demonstrated that those with low nutrition are more susceptible to As poisoning than those with proper nutrition (Santra et al., 2013; Sharma & Flora, 2018; Biswas & Kumar Mukhopadhyay, 2020). For example, the development of symptoms in only three years after consumption of drinking water containing tremendously elevated As (3500 μg L^{-1} water) was also associated with malnutrition and the socioeconomic status of the consumers (Sampson et al., 2008). However, clinical symptoms may not present in every member of an affected family (Banerjee et al., 2011), and the explanation for this disparity in illness manifestation is unknown (Santra et al., 2013).

After critically evaluating the nutritional and socioeconomic status of the farmers in the study area, it is recorded that the annual income of 60% of the participating farmers was reasonable (medium to very high) to afford proteinaceous, nutritional, and balanced diets (significance level) daily. The prime reason for the economic solvency is their simultaneous cultivation of vegetables with rice. Because of smooth river and road transportation facilities, farmers get a reasonable price from selling their produce. In addition to this, the involvement of the family members with business and some other income-generating activities and selling in the local and remote markets improved their financial status. The farmers' food habits might have protected them from the external appearance of the symptoms of arsenicosis, but still, the concern is there regarding their internal organ effect.

4.3.9 Principal component analysis (PCA) and Cluster analysis

Figure 8 shows the formation of three distinct groups with various eigenvector lengths. The angle between the eigenvectors shows the correlations between the different components, and the length of each eigenvector is proportional to the data variance for each item.

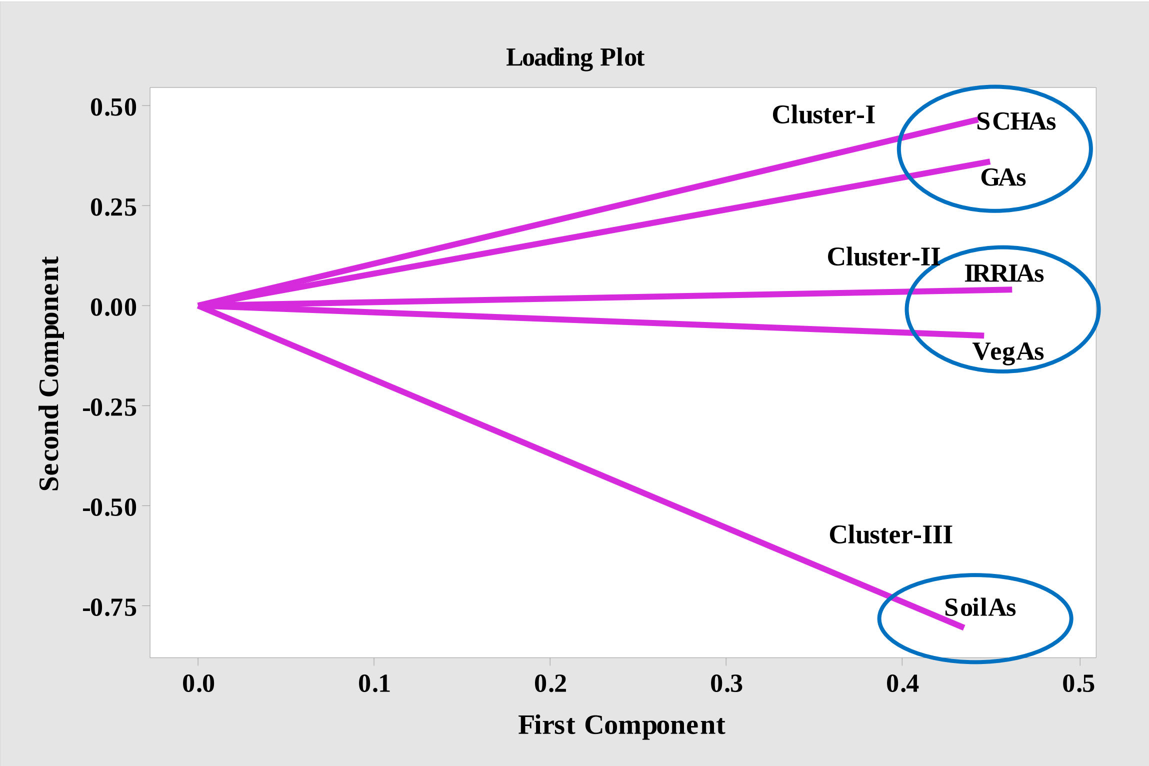

Figure 8: Principal component analysis (PCA) of As in different samples (SCHAs-scalp hair As, GAs- grain As, IRRIAs- irrigation water As, VegAs- vegetable As, SoilAs- soil As) collected from different sub-districts of Chandpur.

The parameters such as scalp hair As, grain, irrigation water As, vegetables As, and soil As are included in the five groupings denoted by clusters (I), (II), and (III), respectively. In this case, parameters with identical values are grouped together. It is probable that irrigation water As and vegetables As (cluster II) and scalp hair As and grain As (cluster I) both contribute to a similar variance.

Table 22:

Principal components and their eigenvalue, %variance and cumulative (%)

	PC1	**PC2**	**PC3**	**PC4**	**PC5**
Eigenvalue	4.5527	0.1877	0.1332	0.0921	0.0342
Proportion	0.911	0.038	0.027	0.018	0.007
Cumulative	0.911	0.948	0.975	0.993	1.000
Variable					
Irrigation water As	**0.462**	0.037	-0.109	0.129	-0.870
Soil As	0.435	-0.805	0.356	0.092	0.165
Vegetables As	**0.447**	-0.077	-0.713	-0.471	0.253
Grains As	**0.450**	0.358	-0.100	0.721	0.374
Scalp hair As	0.443	0.465	0.585	-0.483	0.110

Cluster (III) formed the length with the largest variance, while clusters (I) and (II) formed the length with the lowest variance. Group (I) and (II) among the three distinct groups exhibit strong positive associations. The results of PCA derived using the As contents of various parameters are shown in Table 22. The Table shows that the first principal component (PC), which has an eigenvalue greater than 1.0, describes the majority of the variation. The first PC explains 91.1% of the total variance and dominated by irrigation water As (0.462), grain As (0.450), and vegetables As (0.447) (Table 22). Values highlighted in bold in the Table are essential to understanding the PC because a bigger number denotes a more substantial contribution. As a result, among the PC1's loading values, irrigation water As, grain As, and vegetable As were the leading parameters.

Twenty farmers from each of the five locations were found in two clusters or groups, according to the arsenic accumulation pattern in the rooted UPGMA tree (figure 9). At a similarity coefficient of 92.12, five (05) parameters from various subdistricts were mostly split into clusters 1 and 2.

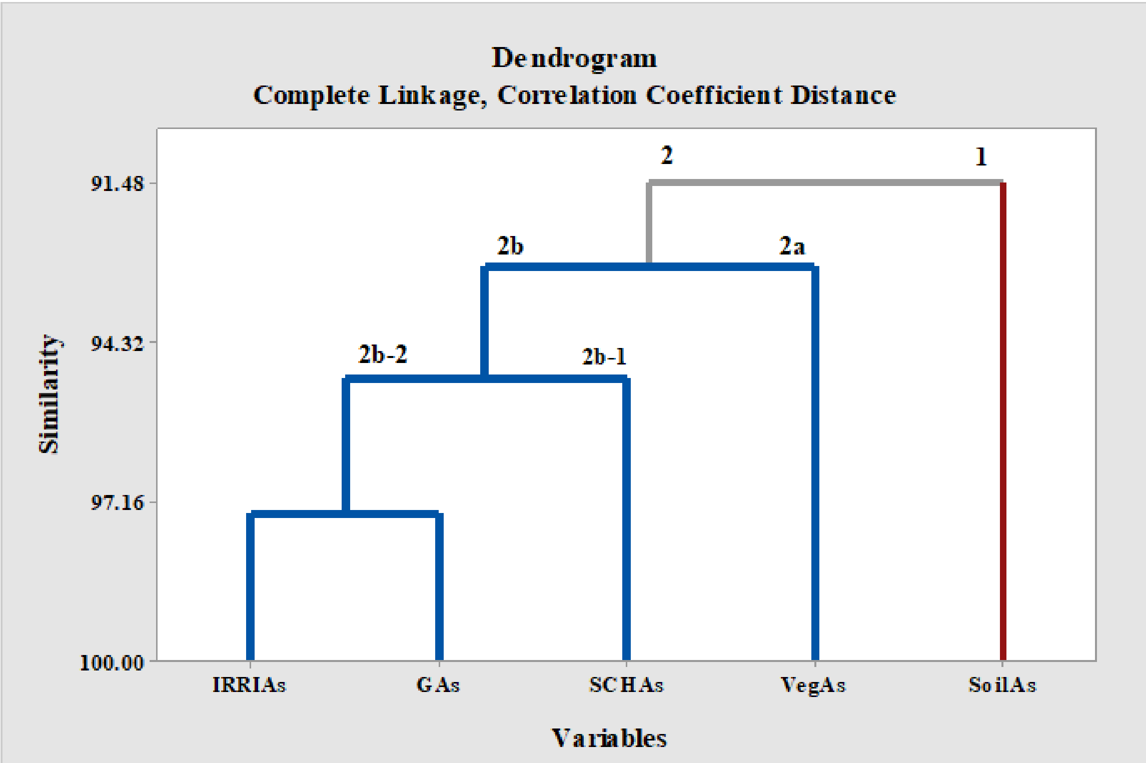

Figure 9: Hierarchical clustering between variables (SoilAs- soil As, VegAs- vegetable As, SCHAs-scalp hair As, GAs- grain As, IRRIAs- irrigation water As).

Again, Cluster 2 is split into 2 sub-clusters, 2a and 2b. Sub-cluster 2b is once more split into 2 sub-clusters, 2b-1 and 2b-2. Sub-subcluster 2b-2 eventually split into two groups, irrigation water As and grain As. While it has been discovered that vegetables As contribute more to human body loading than grain As, the position of grain As in-group and vegetables As in sub-cluster 2 shows the bigger variations in similarity.

4.4 Conclusion

The study revealed concerning health risks for almost all individuals due to consuming As-contaminated rice and vegetables in a naturally As-contaminated area. The results that have been found imply that the As content of scalp hair is related to a particular dietary pattern and sociodemographic factors. The bioconcentration factor (BCF) for rice and vegetables was less than 1, indicating that the plants were not hyper-As accumulators. Mean hair As either reached or fell below the toxicity limit. While roughly 2.8 per 100 individuals and 1.6 per 1000 people are at risk of considerable and threshold level cancer risk, respectively, the HQ for both grains and vegetables was > 1. The first principal component (PC1) accounts for 91.1 % of all variations. The most important factors to explain such significant variances were As in irrigation water, grain, and vegetables. However, as they provide relatively little As to the human body, this study did not consider the respondents' tea consumption, accidental soil ingestion, smoking, or betel nut chewing status. Once more, sociodemographic and food consumption data relied on farmers' spot memories, which had to be relied upon because they could not be independently verified. Future research should, however, take into account the abovementioned two drawbacks with an observation study for a complete result.

CHAPTER 5

ARSENIC ACCUMULATION IN RICE: ALTERNATIVE IRRIGATION REGIMES PRODUCE RICE SAFE FROM ARSENIC CONTAMINATION

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5.1. Introduction

Arsenic is a Group I carcinogenic metalloid, and its abundance in groundwater is a potential health concern (Islam et al., 2017). Globally, 75% of rice is produced in 79 million ha of lowland irrigated with approximately 1.2×10^{15} L of groundwater (Bouman et al., 2007; Price et al., 2013). In many regions of the world, including Asia, a substantial amount of groundwater is used, particularly in dry season crops (Islam et al., 2017; Islam et al., 2019). For example, about 60% of rice production in the Boro season directly depends on groundwater irrigation in Bangladesh (Islam et al., 2017). Because of the special cultivation method under waterlogged situations, rice accumulates a higher quantity of As (Islam et al., 2017; Xu et al., 2008). Irrigation with As-rich groundwater deposits a substantial amount of As in paddy soils, leading to further As accumulation in non-irrigated rice (Meharg & Rahman, 2003) and significant losses in yield (Panaullah et al., 2009). Arsenite is abundant in flooded paddy soils, which are ideal for rice cultivation (Cao et al., 2017). However, AsV is found in the rice rhizosphere due to oxygen release by rice roots and microbial oxidation (Jia et al., 2014). Furthermore, methylated As species, such as dimethylarsinic acid (DMA), exist in paddy soils as a result of microbial transformation (Huang et al., 2011). Rice roots absorb arsenite by silicon transporters, whereas AsV is absorbed through P transporters (Ma et al., 2008; Zhao et al., 2009). Because rice cannot methylate As in vivo, the methylated As in rice is most likely derived from the rhizosphere (Jia et al., 2013; Lomax et al., 2012). The AsIII transporter Lsi1 has been found to mediate the uptake of methylated As in rice (Li et al., 2009a), but the role of other transporters in this process is unknown (Cao et al., 2017).

Rice is consumed by more than fifty percent of the global population for subsistence and nutritional contribution (Islam et al., 2017; Price et al., 2013). Therefore, rice is regarded as a crucial source for As exposure, particularly for the people consuming considerable quantities of rice (Islam et al., 2019). Ultimately, As accumulated in rice from contaminated groundwater and soils is still considered the major dietary contributor to As intake for the people drinking As free water. It is economically unfeasible to employ the water-treatment techniques used for drinking water to treat the massive amounts of water used for irrigation, particularly in rice fields (Brammer, 2009; Hossain et al., 2005). Since soil redox potential is responsible for controlling the mobility of As in submerged paddy soil, irrigation water management could be a potential means to decrease As toxicity in paddy fields followed by As loading in grains (Zhao et al., 2010). Aerobic rice cultivation was reported to minimize As bioaccumulation rice grain (Li et al., 2009b). Compared with flooded rice, aerobic cultivation showed 10–fold smaller As uptake by several hundred global rice cultivars (Norton et al., 2012). Xu et al. (2008) reported 10-15 times higher As accumulation in grains in flooded rice compared with aerobically grown paddies. Similar to aerobic rice cultivation, intermittent ponding (IP) is also reported to decrease As accumulation in rice plants (Rahaman et al., 2011). The study of Stroud et al. (2011) in Bangladesh revealed a lower accumulation of grain-As in IP than continuous flooding (CF). In Arkansas, 41% lower grain As accumulation was reported in IP compared with continuously flooded rice (Somenahally et al., 2011). Shrivastava et al. (2020) reported a gradual reduction of grain As by 40-63% in IP compared with CF in a consecutive four-year study. According to Talukder et al. (2011), IP decreased by 86% and 62% As accumulation in straw and grains, respectively. As a semiaquatic plant, paddy cultivation typically needs a flooding state to ensure maximum yields (Sarkar et al., 2012); therefore, substantial grain yield losses have been recorded under aerobic practices (BasuA & SarkarC, 2010; Peng et al., 2006) but yield increase is evident in intermittent irrigation management (Shrivastava et al., 2020).

Apart from the above, few researchers investigated the influence of rice cultivar in bioaccumulation of As from the As-contaminated groundwater and soils. In a glasshouse study, Rahman et al. (2007) found the As accumulation of BRRI dhan28 (0.23 ± 0.05 mg/kg) was higher than BRRI dhan29 (0.16 ± 0.08 mg/kg) in both the brown and polish rice grains in Bangladesh. A similar trend is also reported in a pot study by Huda et al. (2009). In contrast, field research of Ahmed et al. (2010) found that in nine different environments BRRI dhan29 (mean 0.27 mg/kg) was a slightly higher As accumulator than BRRI dhan28 (mean 0.25 mg/kg), but both were similar to the mean concentration measured in 20 boro rice varieties (0.26 mg/kg). On the other hand, Islam et al. (2004) observed a significant difference in As bioaccumulation in those two varieties; for example, BRRI dhan29 accumulated 0.644 mg/kg As whereas As content in BRRI dhan28 was only 0.312 mg/kg. Arsenic accumulation in BRRI dhan29 is higher in field trials than the BRRI dhan28 has also been reported in the study of Jahiruddin et al. (2017). Again, exploring proper irrigation regimes and suitable rice cultivars are expected to minimize As uptake and translocation in rice (Islam et al., 2017). A few studies have been conducted to report the influence of irrigation management integrated with rice cultivars (Carracelas et al., 2019; Islam et al., 2017; Shrivastava et al., 2020). Mostly pot experiments were undertaken under greenhouse conditions or controlled environments. Therefore, it is crucial to determine the bioaccumulation level of As in field conditions with modified groundwater management integrated with commonly cultivated rice varieties. Till date all the water management practices included the direct application of groundwater to the rice fields to investigate the specific impact. A study by Das et al. (2016) with three treatments, AWD, non-flooded (NF), and flooded (CF) practices, explored insignificant differences in soil As levels and found a decrease in grain As in the order of NF < AWD < CF treatment. The studies of Acharjee et al. (2021) and Chou et al. (2016) support this finding concerning As reduction in AWD practice compared with CF practice. Acharjee et al (2021) revealed significant As reduction in rice under treatment AWD compared with treatment CF.

Temporary storage of As contaminated groundwater should substantially decrease it's As content because of the oxidation of As with atmospheric oxygen and resultant co-precipitation with iron oxides (Halder, 2013; Park et al., 2016). According to Halder (2013), future research should focus on the impact of irrigating rice fields with temporarily-stored groundwater instead directly applying to rice plants. Alternate wetting and drying practice with temporarily stored groundwater might show dual impact on As reduction in rice. Researchers have paid very little attention to the field-based study considering this mechanism to date thus still need to contribute to the existing knowledge base. Therefore this present study aims to investigate (1) the impact of alternative irrigation regime with temporarily stored groundwater on alleviating the bioaccumulation of As; (2) varietal suitability to decrease the bioaccumulation of As in rice; and (3) suitable rice variety that accumulates less As along with appropriate irrigation regime for use in areas with groundwater containing elevated levels of A.

5.2. Materials and methods

5.2.1 Experimental sites

Chandpur, a highly As contaminated southeastern district in Bangladesh, has been selected to conduct the field trial. The study was conducted in Matlab North Upazila in Chandpur district (figure 2). It is positioned in the southeastern side of Bangladesh adjoining the copulation of the Ganges i.e. Padma and Meghna Rivers. It is surrounded on the north by Daudkandi and Gazaria Upazila, on the south by Hajiganj Upazila and Chandpur Sadar, on the east Kachua Upazila, and on the west Bhedarganj Upazila and Munshiganj Sadar. This zone is well interconnected with Dhaka and neighboring districts by highways. It is around 60 km south-east direction of Dhaka, the capital city of Bangladesh. People in most of the villages use various water sources including ponds, khal and river as surface water sources, dug well, rainwater harvester, shallow and deep tubewells. The southeastern region of Bangladesh, where the study area is situated, is a zone with an elevated level of As in groundwater. As per the “spatial distribution map” developed by the “British Geological Survey (BGS) and DPHE” (BGS & DPHE, 2001), this study area is an evidently well-known hotspot of As pollution in groundwater (Rahman, 2009). Approximately 80% of the tubewells in this region have >50μg/L As (Jakariya et al., 2007), with maximum As detected 1318 μg/L (Anawar et al., 2002; Chakraborti et al., 2010). It is appraised that over 90% of residents of this region use tubewell as a potable water source (Jakariya, 2007) and for irrigation purposes (Rahman, 2009).

5.2.2 Selected rice genotypes and treatments with irrigation water management

The field trial was conducted in the dry winter (*boro*) season in January-May (BRRI, 2004) of 2019. Two popular cultivars, BRRI dhan28 and BRRI dhan29, were grown locally in the *boro* season. The genetic subpopulation of these varieties is *indica* and photosensitivity is low (BRRI, 2004; Ahmed et al., 2010). Both the varieties are medium-slender, white-grain rice (BRRI, 2004; Sandhi et al., 2017). BRRI dhan28 is a short duration (140 days) cultivar whereas BRRI dhan29 requires 160 days to harvest and it is resistant to sheath blight disease and alternate wetting and drying practice is highly recommended for it (BRRI, 2004). BRRI dhan28 and BRRI dhan29 are two important varieties, and it is estimated that these varieties were grown approximately in 60% of the entire boro rice-cropped regions all over Bangladesh (Hossain et al., 2013; Huhmann et al., 2017). These two rice cultivars were cultivated to detect the influence of different irrigation practices on each of the two varieties. There were five treatments practiced in three rice fields with four replications. Three irrigation sources were used: (i) river water (RW, as control), (ii) As contaminated groundwater (AsW), and (iii) temporarily stored As contaminated groundwater (TSG) where the groundwater was stored overnight in the nearby storage ditch for TSG practice. The five treatments were (1) Alternate Wetting and Drying (AWD) with AsW, (2) Continuous Flooding (CF) with AsW, (3) AWD with TSG, (4) CF with TSG, and (5) CF with RW. The first two treatments, treatment-1 & treatment-2, were conducted in field-1, treatments-3 & treatment-4 were practiced in field-2, and the control practice, treatments-5, was administered in field-3. So basically, there are two types of irrigation management, viz. CF and AWD, to be applied. For CF, fields were inundated with up to 5 cm water over the soil surface (Chou et al., 2016). For AWD practice, polyvinyl chloride (PVC) tubes sized 30 cm in length and 10 cm in diameter are usually inserted below the 15 cm soil surface to observe the level of water under the surface of the soil (Yao et al., 2012; Yang et al., 2017). In the lower 15 cm part of the PVC pipe, holes (about 0.5 cm in diameter) are perforated at 3 cm lateral and 1 cm vertical intervals (Chou et al., 2016; Yang et al., 2017). The rest 15 cm to be kept upward extended to prevent ponded water from flowing onto the PVC tubes. Since rice seedlings require almost 15 days for getting established in the main field (Sarkar et al., 2012), therefore the first AWD cycle to be deployed at 15 DAT (days after transplanting), and this cycle remain continued until flower initiation (Price et al., 2013). After that, the continuous ponding was maintained in all the plots till 12 days before harvesting to a height of 5 cm above the soil surface (Bouman et al., 2007; Sarkar et al., 2012). The wetting and drying cycle involves direct ponding the paddy field with arsenic-contaminated groundwater then letting it to dry out up to 15 cm under the surface of the soil (Bouman et al., 2007; Price et al., 2013; Islam et al., 2017); again, the field was re-flooded to a height of 5 cm above the surface of the soil (Chou et al., 2016; Islam et al., 2017) and then the next drying cycle will begin (Price et al., 2013; Islam et al., 2017). However, in AWD with TSG, all the steps were similar to AWD practice but only temporarily stored groundwater was supplied instead of direct irrigation. For TSG irrigation and control practice, water was pumped directly to the fields from the storage ditch or river, respectively, using a water pump. Whereas As contaminated groundwater was supplied at all the other plots directly from the shallow tubewell. Four replications in irrigation practice for each field were conducted in plots with 3m by 3m areas (Chou et al., 2016). Seedlings were raised in As-free seedbeds with As-free water. In all the plots, 35-day old seedlings were transplanted (BRRI, 2004; Sarkar et al., 2012; Islam et al., 2017). Seedlings of both cultivars were transplanted in a spacing of 20cm × 15cm distance and three seedlings per hill according to the recommendation of BRRI for both the varieties (BRRI, 2004), and traditional field management practices were administered (Chi et al., 2018). In order to minimize water flow, double bunds were constructed to separate the main plots, and the plastic film was inserted 20 cm below the surface of the soil to cover all the bounds to prevent seepage between plots (Yao et al., 2012).

5.2.3 Soil, irrigation water, and plant sampling and characterizations

To measure arsenic concentration, soil, water, and rice plants were collected before transplantation and at different growth stages (Das et al., 2016). The whole plant, including roots and soil samples, were procured from each plot's central zone within 0.5 m of the area at 45 and 80 DAT (days after transplanting) and during harvesting (including grains) (Sarkar et al., 2012).. Each sample would be a mixture of four sub-samples randomly sampled inside the plot (Khan et al., 2008). Soil sub-samples were collected from 0 to 150 mm from the surface using a soil auger (Sarkar et al., 2012). At three times, during transplanting and at 45 & 80 DAT, water samples were collected. Exact 100 mL of water was collected from the fields and filtered using 0.45-µ Millipore filters. Added 5 mL of 2M HCl, stored in sampling polypropylene bottles, and transferred to the laboratory on ice. The average As concentration in irrigation water in the three fields were with: treatment 1: 0.214 mg/kg, treatment 2: 0.228 mg/kg; treatment 3: 0.112 mg/kg, treatment 4: 0.112 mg/kg; and treatment 5: 0.003 mg/kg.

5.2.4 Rice plant and soil sample preparation and chemical analysis

Preparation of soil and plant samples and their chemical analysis was done based on the methods of Huang et al. (2006). The soil samples were screened to pick stones/gravels/residues, air-dried, ground, and sieved twice using 2- and 0.149-mm mesh and wrapped in Kraft paper until analysis. Soil physico-chemical characteristics are shown in Table 23. Samples of rice plants, including grain, husk, straw, and roots were collected and cleaned of surface soil within two minutes to retain absorbed As using 0.2% HCl solution followed by As free tap water and deionized water. The samples were dried in an oven for 15–30min and 12– 24 h at the temperature of 80–90 °C and 65°C, respectively. The dried samples were weighed and ground to pass through a sieve sized 0.5-mm.

5.2.4.1 Soil total and soil available arsenic determination. Soil total and soil available As was determined based on the procedure followed by Huang et al. (2006). To determine soil total As, 0.25g of soil was wetted with deionized water (a few drops) into a 100-ml Erlenmeyer flask. The soil was mixed with 2-ml, 5-ml, and 6-ml of concentrated $HClO_4$, HNO_3, and HCl, respectively. The digestion continued at ∼150 °C in the flask covered with a small glass filter using an electric heater for around 1.5 h to let the reaction die down. Sulfourea solution (50 g/L) of 5 ml was mixed with the digest in a volumetric flask (50-ml) and made the volume using double deionized water. The extraction procedure was as follows to determine soil available As: taking 5.0g soil into a plastic bottle (250 mL), 75ml of NaH_2PO_4 (0.5 mol/L) was mixed and shaken on a reciprocating shaker for 2h at 250 rpm. Quantitative filter paper (9cm diameter) was used to filter the suspension immediately. Using 10% HCl (carrying solution) and 1.5% potassium borohydride (reducing agent), the determination was carried out.

5.2.4.2 Rice arsenic determination. Rice As was also determined according to the method adopted by Huang et al. (2006). Exact 0.5g from each sample (<0.5mm) of the rice grain, husk, straw, and roots was taken into an Erlenmeyer flask (100ml) and concentrated H_2SO_4 (1.25ml), and HNO_3 (20ml) were mixed with it. After the overnight reaction, the digestion was carried out on an electrical heater by gently boiling. The brown color solution of approximately 10ml was again digested adding concentrated HNO_3 (5ml). As the digestion was found incomplete even after 2/3 extra digestions with HNO_3, additional digestion was carried out by adding concentrated $HClO_4$ (2ml). However, the whole digestion process required 3–4h total time. After transferring the digest in a measuring flask of 25-ml, 2.5ml sulfourea solution (50g/L) was used to spike the digest, followed by making the volume with double deionized water.

5.2.5 Instrumentation and quality control

Atomic fluorescence spectrophotometry (AF-610A, made in Beijing, China) (Huang et al., 2006) was used to carry out all the analysis in this study. Certified reference material such as Tomato leaves (NIST 1573a) was administered for quality control. The certified value of the reference material SRM Tomato leaves (NIST 1573a) is 0.112±0.004 µg/g, where the found value was 0.109 µg/g to 0.120 µg/g.

5.2.6 Statistical analysis

Translocation factor (TF) is the ratio of metal content in the shoot to that in the root, whereas Bioconcentration factor (BCF) was calculated as the ratio of metal content in plant biomass to that in the soil and is usually used to evaluate the transferability of metal from soil to plant in a given soil-plant system (Bakhat et al., 2021; Huang et al., 2006; Marrugo-Negrete et al., 2015; Rehman et al., 2019). Here BCF for rice grain As with both soil total (BCF_{total}) and available (BCF_{avail}) As and TF for shoot & root and grain & shoot As ratios have been calculated in R (R Core Team 2019). Data were analyzed by two-way analysis of variance (ANOVA) and least significance difference test (LSD) with Statistix 10 to analyze the difference among treatments (Irshad et al., 2020) and the effect of irrigation regime management and rice cultivar on the bioaccumulation of As in rice. Principle component analysis (PCA) (Spanu et al., 2020) was performed with Minitab software (version 19.1.1.0) (Shakoor et al., 2018). Microsoft Excel 2019 was administered to conduct other statistical analyses.

5.3 Results and discussion

5.3.1 Physico-chemical properties of the study soil

The total soil As and available soil As levels ranged from 10.93 to 23.56 mg/kg and 0.114 to 4.149 mg/kg, respectively. All the three fields, such as field-1, field-2, and field-3 (control), contained total As concentration above the permitted global average As level for agricultural soil, i.e., 10 mg/kg (Rahman et al., 2013), where field-1 and field-2 contained almost double As content than the permitted limit. Scattered soil contamination was recorded with 20-30 mg/kg of As in the central part of Bangladesh (Meharg & Rahman, 2003). A minor elevation in soil As content may facilitate higher As accumulation in the grains of rice (Williams et al., 2007b), even containing lower As level <10 mg/kg (Otero et al., 2016). The physico-chemical characteristics of the study soil have been shown in Table 23.

Both the mobilization and the uptake of As by rice and vegetables are dependent on soil p^H and the elements Fe (iron), Manganese (Mn), P (phosphorus), and S (sulfur). The solubility and bioavailability of As are directly impacted by soil p^H because As speciation and leaching rely on soil p^H (Quazi et al., 2011; Chatterjee et al., 2013). Both higher and lower p^H levels impact on crop's ability to absorb and accumulate As. It might be because As-binding species, including Fe-oxyhydroxide complexes, become more soluble at very low p^H (p^H 5) and increase the uptake of As by plants. Bhattacharya et al. (2010b) also supported a negative correlation between rice As content and soil p^H. On the other hand, some researchers (Campbell et al., 1985; Ahmed et al., 2011) also indicate a positive correlation between soil p^H and As accumulation. According to Masscheleyn et al. (1991), lowering the p^H of a soil solution decreases the amount of dissolved As (mostly arsenate) under oxidized conditions while raising it (primarily arsenite) under reducing conditions. This is consistent with the p^H dependency of As adsorption on Fe oxides. The mobilization of As in the area around the roots, which in turn promotes As accumulation in the plant, is facilitated by higher soil p^H (typically p^H 8.5), which also increases the negative surface charges, such as hydroxyl ions. This process occurs when As is desorbable from Fe-oxides (Ahmed et al., 2011).

In soils, manganese oxides are frequently described as being in amorphous form; however, different crystalline forms have also been found (Childs, 1975). Although lithiophorite is also prevalent in Australian soils, birnessite and vernadite are the most frequent Mn oxides (McKenzie, 1989). Many soils contain Fe oxides such ferrihydrite, goethite, hematite, and lithogenic magnetite (Schwertmann & Taylor, 1989). Despite being called "amorphous Fe hydroxide," ferrihydrite possesses a short-range-ordered structure and is not a genuine hydroxide (Schwertmann & Taylor, 1989). The formation of Fe/Mn oxides is influenced by both biotic and abiotic oxidations (Tebo et al., 2004; Fortin & Langley, 2005). Mn/Fe-rich structures in soil profiles are typically produced due to the localization of Mn/Fe oxides (Suda & Makino, 2015). A Fe oxide precipitate known as Fe plaque is frequently found on the roots of rice plants and other aquatic plants (Chen et al., 1980; Otte et al., 1989). Mn/Fe nodules or mottles are common in soils, particularly in soils with poor drainage, and are thought to be the result of localized reoxidation and co-precipitation after Mn(II) and Fe(II) migrated within the soil profile (Szymański et al., 2014). In soil samples, the amount of oxalate-extractable Mn (i.e., Mn oxides) increases the rate of oxidation of As(III) (Manning and Suarez, 2000).

The redox chemistry of iron, which is one of these elements, plays a key influence in the behavior of As in the soil medium. FeOOH acts as the main sorbent utilized for both iAs species, arsenite and arsenate (Takahashi et al. 2004; Heikens et al. 2007). The soil type and the availability of oxygen are two crucial factors that could promote FeOOH to discharge As species into the soil medium. This is because As is released into the soil when both of these factors are present. Due to the presence of a greater proportion of FeOOH in clayey soil in comparison to sandy soil, the As concentration in former is considerably higher than that of sandy soil (Fitz & Wenzel 2002). Even though there is a greater concentration of As present in the clayey soil, the clayey soil is less harmful than the sandy soil because the As is more strongly attached with the clayey soil than it is with the sandy soil. The capacity of FeOOH to dissolve is significantly impacted by the oxygen content of the soil. Under anoxic state, FeOOH is generally get reduced rapidly, which results in the release of arsenate into the soil medium, where it is eventually reduced to arsenite. On the other hand, under oxic state, FeOOH is relatively insoluble and is regarded as an As sink (Heikens et al. 2007). Meanwhile, a recent investigation in the river Meghna floodplain (located at the central region of Bangladesh) area by Saha & Rahman (2020) has identified that reductive dissolution of Fe and Mn oxyhydroxides was the principal process of As release in the groundwater system.

In addition to Fe, phosphorus, which is thought to be an analog of arsenate, plays a key role in the process of As absorption and accumulation in crops (Zhao et al., 2010). Phosphorus is in competition for adsorption sites at the surfaces of iron oxide with iAs compounds, including arsenate and arsenite (Hossain et al., 2009). Because of this, it has been demonstrated that the addition of phosphate could result in the remobilization of sorbed arsenate from exchangeable sites, which would then result in an increase in the soluble concentration, bioavailability, and transport of arsenate away from soils (Abedin et al., 2002). In the past, it was hypothesized that the widespread use of groundwater for irrigation purposes and the application of fertilizer containing phosphorus in Bangladesh's crop fields could potentially trigger the release of As into the country's groundwater system. On the other hand, it was found that it does not exist in a number of

Table 23:

Physico-chemical properties of the study soils

Elements	**Field-1**	**Field-2**	**Field-3**
Sand %	64.72	60.72	50.72
Silt %	13.28	11.28	15.28
Clay %	22.0	28.0	34.0
	Sandy loam	Sandy loam	Loam
p^H	7.07	4.56	5.40
EC	0.46	0.60	0.37
OC %	0.49	0.77	0.69
Total N %	0.05	0.07	0.06
P %	0.19	0.18	0.19
K %	0.64	0.63	0.90
S %	0.69	0.39	0.36
Ca %	0.65	0.60	0.53
Mg %	0.34	0.31	0.28
Cu %	0.002	0.003	0.002
Fe %	0.26	0.25	0.24

Mn %	0.12	0.11	0.11
Zn %	0.009	0.008	0.008
B %	0.007	0.006	0.006
As (mg/kg)	22.581	21.958	11.062

As-contaminated places, such as the central eastern section of Bangladesh (Acharyya et al. 2000; Saha & Rahman 2020). Both the speciation and mobilization of As in the soil media can be influenced by sulfur in two different ways: (1) Sulfide produced from bacterially mediated sulfate reduction can reduce and trap As as As-sulfide minerals in the sediment (e.g., orpiment (As_2S_3) and realgar (AsS)), and (2) Sulfide can also reduce As-bearing iron oxides, liberating the As that was previously absorbed by the iron oxides (Saalfield et al. 2009; Fischer et al. 2021). Arsenic leaching from as-sulfide mineral sources may also be affected by the cyclical changes in temperature and precipitation that occur in Bangladesh. The throughput of the dry season, such as sulfide minerals that are oxidized, leads to the repartitioning of As into ferric hydroxides, which is maintained by the reductive dissolution of iron and As during the subsequent wet season, as found by Polizzotto et al. (2005). As a result, cyclic redox conditions in the sediments located near the surface of Bangladesh have an effect on the amount of As that is mobilized in the country's groundwater system.

5.3.2 Impact of water management on grain yield

Based on weathering and geology, soil usually retains 5 to 15 mg/kg of As (Mandal & Suzuki, 2002). However, the naturally occurring average As concentration in soils is reported 10 mg/kg worldwide (Das et al. 2002). Higher soil As (~70 mg/kg) can impact grain yield significantly (Huhmann et al., 2017; Panaullah et al., 2009). In this current study, soil total As ranges from 10.93 to 23.56 mg/kg. Therefore, yield contribution in this present study is mostly based on water management, i.e., AWD or CF (Table 24). The AWD practice showed a positive contribution to increasing rice grain yield. Alternate wetting and drying (AWD) and continuous flooding (CF) caused significant yield differences (P<0.05) between the rice genotypes. The grain yield on CF ranged 4.38 to 4.75 t/ha for BRRI dhan28 and 5.20 to 5.34 t/ha for BRRI dhan29, whereas the AWD irrigation regime produced 5.75 to 5.90 t/ha for BRRI dhan28 and 7.35 to 7.40 t/ha for BRRI dhan29., AWD practice augmented the yield of rice grain by 19.49% to 23.83% for BRRI dhan28 and 27.84% - 29.25% for BRRI dhan29, compared with CF.

Table 24:

Percent yield contribution of water management

Variety and irrigation water source	**Yield (t/ha)**		**% yield increase in AWD practice**
	AWD	CF	
BRRI dhan28 with As contaminated water irrigation	5.75	4.38	23.826
BRRI dhan29 with As contaminated water irrigation	7.35	5.2	29.251
BRRI dhan28 with stored water irrigation	5.9	4.75	19.491
BRRI dhan29 with stored water irrigation	7.4	5.34	27.837

Islam et al. (2017) found similar results while they reported yield increase by 7-38% in AWD compared with CF. Similarly, a 12 to 18% yield increase was reported by Talukder et al. (2011), Chu et al. (2015), Liu et al. (2013), and Islam et al. (2019) in AWD practice. Song et al. (2021) also recorded increased yield in rice grain AWD practice compared with CF at the same Phosphate rate. The possible explanation of yield increase in this study due to AWD practice is that AWD boosts water use efficiency and enhances yield through increasing the proportion of productive tillers, reducing the angle of the topmost leaves (letting more light to penetrate the canopy), and reconfiguring shoot and root function, exerting altered root-to-shoot signaling of phytohormones such as cytokinins and abscisic acid (ABA) (Yang & Zhang 2010). The variety with the highest grain yield was BRRI dhan29 (7.4 t/ha) against its potential yield of 7.5 t/ha under AWD practice with stored water, followed by BRRI dhan29 in AWD practice with As water. The lowest grain yield was recorded for BRRI dhan28 (4.38 t/ha) under CF with As water against its potential 6 t/ha yield.

5.3.3 Impact of water management on As bioaccumulation in rice grain, husk, straw, and roots

The reduction in average As concentration in TSG due to storing overnight was 50.73% from the directly supplied groundwater. Because groundwater storage increases the co-precipitation of As with iron oxides due to oxidation with ambient oxygen, it is envisaged that As input from irrigation water to the rice field and subsequent absorption by rice plants will be significantly reduced (Halder, 2013). Further, it's possible that the increased phytoavailability of As in the CF treatment is related to increased reductive mobilization of As in flooded conditions (Roberts et al, 2010). The possible mechanism behind the less As accumulation in rice due to AWD practice is the changes in oxidation and reduction process due to irrigation management (Chou et al., 2016). Because As is redox-sensitive, it adsorbed significantly with mineral soil components (e.g., iron (hydr)oxides) during the drying periods, reducing its mobility and subsequent uptake by rice plants (Halder, 2013). This result agrees with the findings of some previous studies (Norra et al., 2005; Roberts et al., 2007). Arsenic content in stored groundwater decreases rapidly with time (Hussain et al., 2021; Norra et al., 2005). In their study, Roberts et al. (2007) observed a reduction of As concentration in groundwater up to 69% within the first 24 h after irrigation. The partitioning of As in rice plant followed the similar order of genotype effect, i.e., roots>straw>husk>grain, and according to Chou et al. (2014, 2016), this order was observed regardless of the rice variety and cultivation method used. Similar findings were reported by Bogdan & Schenk (2012), Chou et al. (2016), and Rahman et al. (2004). Arsenic partitioning in rice grains was observed at 2.97 to 4.13% (husks and brown rice, except control). This content is a little higher than the findings of Chou et al. (2016) and Rahman et al. (2007), who reported 1 to 2% and 1%, respectively. Since root faces the direct exposure to soil As, it regulates As uptake and translocation or restricts As transportation towards the aboveground parts (Chou et al., 2016), this was the prime cause for greater As accumulation in rice roots in both the rice genotypes (Chowdhury et al., 2018; Shrivastava et al., 2017; Upadhyay et al., 2021). Different treatments caused significant variations ($P<0.001$) in As content in rice grain, husk, straw, and roots (Table 25). The lowest average grain As concentration was recorded under AWD with TSG irrigation practice 0.107 mg/kg for BRRI dhan28 and 0.117 mg/kg for BRRI dhan29, except for control practice.

On the other hand, the highest concentration was recorded under CF with AsW for BRRI dhan28 (0.277 mg/kg) and BRRI dhan29 (0.295 mg/kg). BRRI dhan29 was the higher As accumulator for all the treatments than BRRI dhan28. This finding agrees with Islam et al. (2019), who revealed a 12-21% reduction in grain As content in AWD practice. Islam et al. (2017) reported almost similar findings. They revealed that the As level in rice grains significantly varied because of the differences in irrigation regimes and soil As level. They also found a 17-38% higher As accumulation rate for CF practice than the AWD. On the other hand, while comparing AWD with TSG and CF with AsW, a substantial 61.37% of grain As reduction was recorded in this study. The possible explanation is that in AWD with TSG practice, temporarily stored groundwater was used containing approximately 50% less As than the original groundwater content. Plants uptake As both from the soil background As and irrigation water; therefore, groundwater containing less As should facilitate less As accumulation in rice (Abedin et al., 2002; Alam & Rahman, 2004; Rahman et al., 2010;

Upadhyay et al., 2021). The straw of rice may directly absorb arsenic present in irrigation water helps subsequent elevation in As concentration in straw (Alam & Rahman, 2004; Rahman et al., 2010). Similar to the grain As accumulation pattern, As loading in the husk, straw, and roots was lower in both the rice cultivars in AWD with TSG irrigation practice, except for the control.

Table 25:

Effect of different treatments on arsenic bioaccumulation

Treatments	Root As (mg/kg)			Straw As (mg/kg)			Husk As (mg/kg)	Grain As (mg/kg)
	45 DAT	80 DAT	Harvesting	45 DAT	80 DAT	Harvesting		
AWD with AsW	21.610 b	21.906 b	22.440 b	5.2500 b	5.6337 b	5.8838 b	0.7088 b	0.2103 b
CF with AsW	23.849 a	24.305 a	24.836 a	7.0163 a	7.7413 a	8.4050 a	1.0143 a	0.2859 a
AWD with TSG	15.685 d	15.923 d	16.151 d	4.1925 d	4.4475 d	4.9338 d	0.5115 d	0.1115 d
CF with TSG	18.039 c	17.820 c	17.984 c	4.4575 c	4.7700 c	5.0250 c	0.6701 c	0.1394 c
CF with RW	7.494 e	7.738 e	7.871 e	1.1313 e	1.1862 e	1.3225 e	0.1575 e	0.0140 e
Level of significance	***	***	***	***	***	***	***	***
CV (%)	0.31	0.24	0.25	0.89	1.03	1.04	2.53	1.35
SE (±)	0.026	0.021	0.021	0.019	0.024	0.026	0.0077	0.0010

In column, means followed by different letters are significantly different, ***means at 0.1% level of probability

The average lower and higher As accumulation in the husk, straw, and roots were recorded for BRRI dhan28 and BRRI dhan29 in AWD with TSG and CF with AsW, respectively. AWD practice decreased As availability in rhizosphere soil and thus reduced As concentration in porewater (Pan et al., 2014; Yang et al., 2019). However, since very low As containing river water (average As content 0.003 mg/kg) was used for control in a field (average total As content 11.06 mg/kg) containing As close to the permitted global average As level for agricultural soil, the lowest As content in grain, husk, straw, and roots was recorded.

5.3.4 Effect of rice genotypes on As bioaccumulation in rice grain, husk, straw, and roots

A significant ($P<0.001$) cultivar difference was recorded in the bioaccumulation of As (dry wt.) in roots, straw, husk, and rice grain (Table 26). The mean As content in these plant parts decreased in the order as roots>straw>husk>grain. The rice varieties cultivated in this field trial revealed significant ($P<0.001$) differences in grain As level (Table 26). Arsenic content in rice grain varied from 0.013 mg/kg to 0.298 mg/kg in BRRI dhan29 and in BRRI dhan28, the range was 0.010 mg/kg to 0.280 mg/kg. Between the two rice varieties, BRRI dhan29 is the more As accumulator than BRRI dhan28. The possible explanation is that the shoot biomass production, plant height and tiller numbers of rice plant significantly determined by As content in the growth medium. All those three parameters in BRRI dhan29 are generally higher than the BRRI dhan28 when cultivated in As contaminated regions which ultimately triggers higher As load in different plant parts of BRRI dhan29 (Rahman et al., 2007). Ahmed et al. (2010) reported that the average As accumulation rate for BRRI dhan29 (0.292 mg/kg)

Table 26:

Effect of different rice genotype on arsenic bioaccumulation

Varieties	**Root As (mg/kg)**			**Straw As (mg/kg)**			**Husk As (mg/kg)**	**Grain As (mg/kg)**
	45 DAT	**80 DAT**	**Harvesting**	**45 DAT**	**80 DAT**	**Harvesting**		
BRRI dhan28	17.096 b	17.21 b	17.511 b	4.1570 b	4.5050 b	4.8120 b	0.5743 b	0.1476 b
BRRI dhan29	17.574 a	17.866 a	18.202 a	4.6620 a	5.0065 a	5.4160 a	0.6505 a	0.1568 a
Level of significance	***	***	***	***	***	***	***	***
CV (%)	0.31	0.24	0.25	0.89	1.03	1.04	2.53	1.35
SE (±)	0.016	0.013	0.013	0.012	0.015	0.016	-	0.00065

In column, means followed by different letters are significantly different, ***means at 0.1% level of probability

was higher than that for BRRI dhan28 (0.271 mg/kg) through their field trial. In their field study, Jahiruddin et al. (2017) also observed similar findings. Islam et al. (2004) Claimed BRRI dhan29 to accumulate approximately double As than BRRI dhan28. In contrast to the field trial results, pots and greenhouse experiments depict opposite results. Glasshouse study Rahman et al. (2007) revealed BRRI dhan28 (0.230 ± 0.050 mg/kg) to accumulate more As than BRRI dhan29 (0.160±0.080 mg/kg). Under similar experimental conditions, Huq (2008) found BRRI dhan28 to accumulate more arsenic than BRRI dhan29. On the other hand, through two pot experiments at the net house, Iqbal et al. (2019) observed BRRI dhan28 as the lower accumulator than BRRI dhan29. The highest husk (1.109 mg/kg), straw (7.90 mg/kg), and root (24.79 mg/kg) As was observed in BRRI dhan29. Arsenic uptake by roots and its transportation towards the aboveground portions includes several stages, creating a significant variation of As contents among cultivars (Islam et al., 2017). Researchers recorded vast genetic differences for As accumulation in rice grain and As speciation. Ye et al. (2012) found genotypic variations pose significant differences in As bioaccumulation in rice plants. The Indica rice was reported to consistently accumulate higher As (21–296 μg/kg) in rice grains compared with Japonica (5–274 μg/kg) (Jiang et al., 2012); which indicates that bioaccumulation potential substantially controls the As accumulation in rice irrespective of the concentration of total available As (Islam et al., 2017; Jiang et al., 2012; Ye et al., 2012).

5.3.5 Water management and genotype combined influence on As accumulation in rice

The concentration of As in rice grains, husk, straw, and root were significant (P<.001) for two-way interactions of irrigation management with rice varieties (Table 27). AWD accumulated less As in grains of both the rice cultivars compared with CF. Of all the treatment combinations, CF with As water × BRRI dhan29 accumulated the highest grain As (0.2950 mg/kg) in grain whereas AWD with stored water × BRRI dhan28 produced grains with the lowest As content (0.1065 mg/kg), except for the control practice, and they were statistically different with other combinations. Of the treatment combinations, CF with As water × BRRI dhan29 incorporated the highest As content (1.1058 mg/kg) in the husk, whereas the combination of AWD with stored water × BRRI dhan28 produced husks with the lowest (0.4870 mg/kg), except for the control practice. The highest As concentration,7.0825 mg/kg and 24.150 mg/kg, in straw and root was obtained in CF with As water × BRRI dhan29 combination, and the lowest straw and root As concentration was found for the combination of AWD with stored water × BRRI dhan28 with 3.6075 and 15.160 mg/kg, respectively. However, the highest grain, husk, straw, and root As for control practice were 0.0163, 0.1875, 1.1825, and 7.555 mg/kg for the combination of CF with river water × BRRI dhan29, and the lowest level of As were 0.0117, 0.1275, 1.0800, 7.432 mg/kg for the combination of CF with river water × BRRI dhan28, respectively. The highest and lowest As accumulation in rice in CF-As water × BRRI dhan29 and AWD-TSG × BRRI dhan28 combination, respectively, can be explained in the following way.

In general, continuous flooding of paddy fields accumulates more As in rice plants than alternate wetting and drying (AWD) practice (Chou et al., 2016; Das et al., 2016). Again, BRRI dhan29 requires almost one month more to harvest than BRRI dhan28 (BRRI, 2004). This may be the reason for the higher As accumulation rate in this variety. Therefore, this combined interaction of CF-As water × BRRI dhan29 increased the As content in different parts of the rice plant. In contrast, since long storing period consequences in the As bound to Fe(oxy)hydroxides and clay (Hussain et al., 2021), TSG supplies lower As content to the paddy fields resulting in less As accumulation in rice. At the same time, less time at the rice field may result in less As translocation in BRRI dhan28. Consequently, the combined influence resulted lowest As content in BRRI dhan28 in AWD-TSG × BRRI dhan28 combination. Rice variety may influence the performance of water management in paddy fields. Several studies have reported that the performance of AWD is largely determined by

Table 27:

Interaction effect of treatments and varieties on arsenic bioaccumulation

Treatments× varieties	**Root As (mg/kg)**			**Straw As (mg/kg)**			**Husk As (mg/kg)**	**Grain As (mg/kg)**
	45 DAT	**80 DAT**	**Harvesting**	**45 DAT**	**80 DAT**	**Harvesting**		
Treatment 1× BRRI dhan28	21.525 d	21.870 d	22.370 d	5.1875 d	5.6450 c	5.8150 d	0.6850 d	0.2065 d
Treatment 1× BRRI dhan29	21.695 c	21.942 c	22.510 c	5.3125 c	5.6225 c	5.9525 c	0.7325 c	0.2140 c
Treatment 2× BRRI dhan28	23.548 b	23.905 b	24.373 b	6.9500 b	7.6350 b	8.2925 b	0.9228 b	0.2768 b
Treatment 2× BRRI dhan29	24.150 a	24.705 a	25.300 a	7.0825 a	7.8475 a	8.5175 a	1.1058 a	0.2950 a
Treatment 3× BRRI dhan28	15.160 h	15.470 h	15.708 h	3.6075 h	3.9100 g	4.2500 g	0.4870 g	0.1065 h
Treatment 3× BRRI dhan29	16.210 g	16.375 g	16.595 g	4.7775 f	4.9850 e	5.6175 e	0.5360 f	0.1165 g
Treatment 4× BRRI dhan28	17.815 f	17.123 f	17.267 f	3.9600 g	4.2100 f	4.4800 f	0.6495 e	0.1365 f
Treatment 4× BRRI dhan29	18.263 e	18.517 e	18.700 e	4.9550 e	5.3300 d	5.5700 e	0.6908 d	0.1423 e
Treatment 5× BRRI dhan28	7.432 j	7.685 j	7.840 j	1.0800 j	1.1250 i	1.2225 i	0.1275 i	0.0117 j
Treatment 5× BRRI dhan29	7.555 i	7.790 i	7.903 i	1.1825 i	1.2475 h	1.4225 h	0.1875 h	0.0163 i
Level of significance	***	***	***	***	***	***	***	***

CV (%)	0.31	0.24	0.25	0.89	1.03	1.04	2.53	1.35
SE (±)	0.037	0.030	0.030	0.027	0.034	0.037	-	0.0014

In column, means followed by different letters are significantly different, ***means at 0.1% level of probability

rice cultivar (Bueno et al., 2010; Islam et al., 2017; Luo, 2010). This current study showed that the rice cultivar played a vital role with water management on As bioaccumulation.

5.3.6 Principal component analysis (PCA): effect of treatments on different As content parameters

In figure 10a, there are five distinct groups formed with different eigenvector lengths. Each eigenvector length is proportional to the variance in the data for individual items, and the angle between the eigenvectors signifies the correlations among the different items. The five groups indicated by (I), (II), (III), (IV), and (V) include the parameters such as straw As, grain and soil available As, irrigation water and husk As, root As, and soil total As, respectively. Here, parameters of similar types clustered in the same group except for groups (II) and (III). The possible explanation is that soil available As and grain As (group (II)) and irrigation water As and husk As (group (III)) contribute to the similar variance. Group (II) and (IV) formed the highest length, and group (V) formed the lowest length indicating the highest and lowest variances. Among the five distinct groups, (I), (II), (III), and (IV) show strong positive correlations with each other.

Again, if we consider only water management as a principal variant (figure 10b), the water management applied in different fields cluster separately. Based on the As status of the water management, there are five distinct clusters in the Principal Component Analysis **(**PCA) outcome. Cluster (I) and (II) represent AWD and CF practice with As contaminated waterrespectively. Cluster (III) and (IV) depict the AWD and CF practice with stored water. However, cluster (V) represents the CF with river water. Such distinct clustering suggests that the diverse As level was due to the influence of irrigation management during cultivation. However, the gap of the dots inside the clusters represents the variation in As accumulation rate between the varieties.

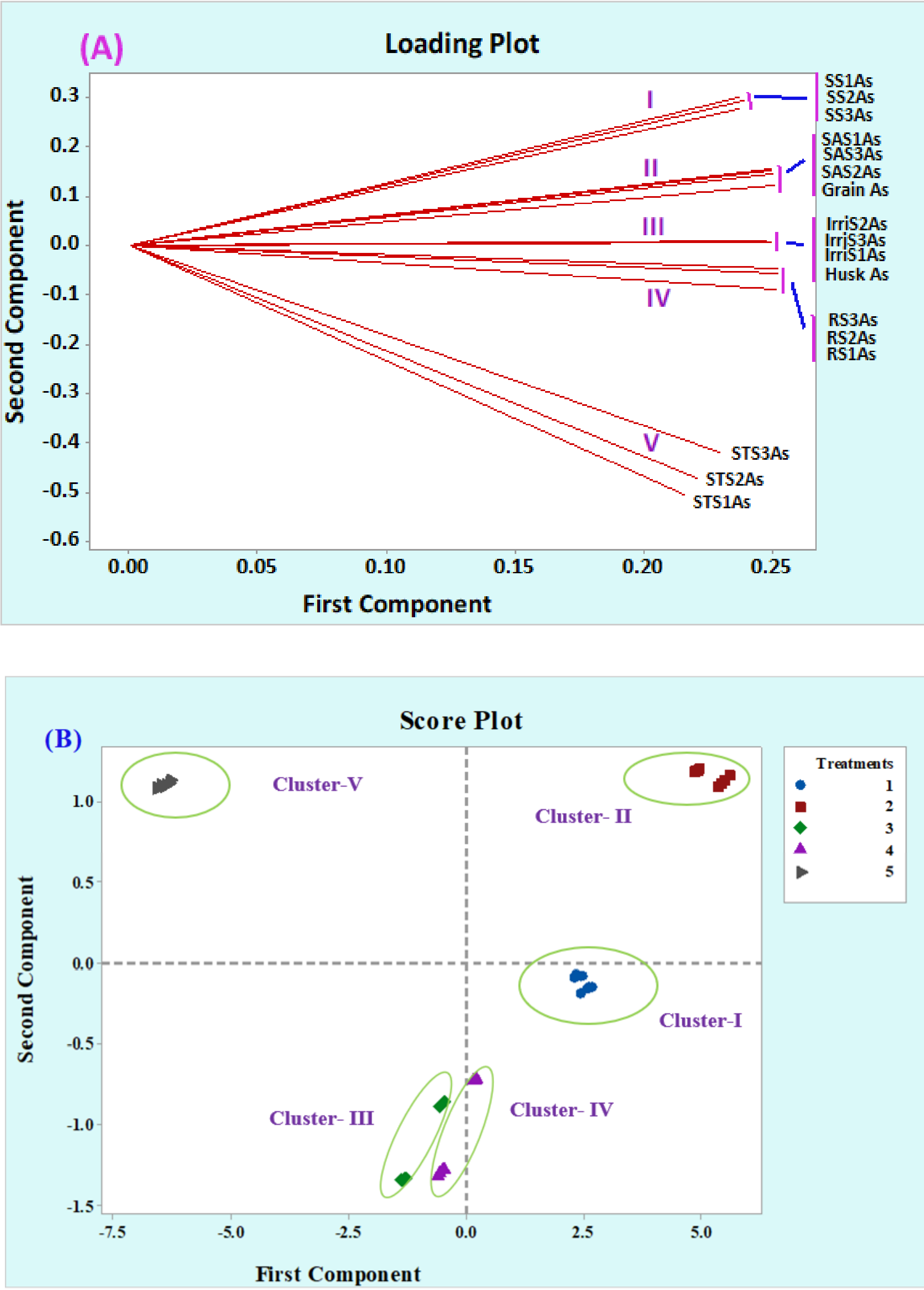


Figure 10: Principle component analysis (PCA) (A) loading plot (SS1As- straw As step 1, SS2As- straw As step 2, SS3As- straw As step 3; SAS1As- soil available As step 1, SAS2As- soil available As step 2, SAS3As- soil available As step 3; IrriS1As- irrigaiton water As step 1, IrriS2As- irrigaiton

water As step 2, IrriS3As- irrigaiton water As step 3; RS1As- root As step 1, RS2As- root As step 2, RS3As- root As step 3; STS1As- soil total As step 1, STS2As- soil total As step 2, STS3As- soil total As step 3) and (B) score plot

Despite the similar irrigation management on two different rice varieties, BRRI dhan28 and BRRI dhan29, As accumulation was different in varieties. For example, in Cluster (III), AWD was applied with stored water on BRRI dhan28 and BRRI dhan29. Since As accumulation was different in both the varieties, the gap of the dots inside the cluster occurred. Similarly, a remarkable gap is seen for the cluster (IV). On the other hand, this gap was comparatively small in clusters (I) and (II), representing small differences in As accumulation in the varieties. However, almost no gap is seen for the cluster (V), representing that the As accumulation rate in two varieties for CF with river water was almost similar variation and have the eigenvalue of more than 1.0. Table 28 contains the results of PCA calculated with the As contents of different parameters. According to the Table, the first two PCs explain 97.7% data variation. PC1 explains 91.7% of the existing variability in the data dominated by irrigation water As, soil total, and available As, root As, straw As, and husk As (Table 28). The 6% data variation explanation of total variation by PC2 is largely dominated by irrigation water As, soil available As, straw As, and husk As. Since the larger number designates a more significant contribution, values indicated as bold in the Table are crucial in explaining the PC. Therefore, irrigation water As, soil available As, root As, and husk As were the dominant parameters amongst the loading values of the PC1. On the other hand, the straw As was the only dominant parameter for the second principal component.

Table 28:

Principal components and their eigenvalue, %variance and cumulative (%)

	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**	**PC8**	**PC9**	**PC10**
Eigenvalue	15.595	1.012	0.291	0.058	0.026	0.011	0.003	0.002	0.001	0.001
Proportion	0.917	0.060	0.017	0.003	0.002	0.001	0.000	0.000	0.000	0.000
Cumulative	0.917	0.977	0.994	0.997	0.999	1.000	1.000	1.000	1.000	1.000
Variable										
IrriS1As	**0.249**[a]	0.006	-0.312	0.183	-0.145	-0.244	-0.437	-0.147	-0.550	-0.342
IrriS2As	**0.245** [a]	0.006	-0.448	0.195	0.098	-0.290	0.601	-0.054	0.221	-0.294
IrriS3As	**0.247** [a]	0.009	-0.389	0.200	-0.030	-0.159	-0.424	0.084	0.435	0.246
STS1As	0.215	-0.504	0.243	0.145	-0.169	0.342	-0.197	-0.228	0.268	-0.356
STS2As	0.221	-0.471	0.222	0.073	-0.107	-0.188	0.376	0.095	-0.280	0.065
STS3As	0.229	-0.419	0.090	0.124	-0.043	-0.199	-0.068	0.204	0.021	0.313
SAS1As	**0.249** [a]	0.154	-0.038	-0.165	-0.412	0.188	0.050	0.032	-0.032	0.052
SAS2As	**0.249** [a]	0.153	-0.047	-0.155	-0.397	0.185	0.173	0.023	-0.074	0.015

SAS3As	**0.250** [a]	0.144	-0.064	-0.146	-0.271	0.254	0.013	0.208	-0.110	0.064
RS1As	**0.251** [a]	-0.088	-0.101	-0.167	0.371	0.337	0.001	-0.461	0.122	0.002
RS2As	**0.252** [a]	-0.058	-0.104	-0.072	0.360	0.243	-0.003	0.275	-0.111	0.050
RS3As	**0.252** [a]	-0.047	-0.122	-0.060	0.353	0.170	-0.022	0.264	-0.194	0.298
SS1As	0.237	**0.300** [a]	0.295	0.308	0.276	0.020	0.036	-0.301	-0.333	0.022
SS2As	0.238	**0.292** [a]	0.291	0.193	0.126	0.079	-0.025	0.487	0.235	-0.479
SS3As	0.237	**0.278** [a]	0.377	0.329	-0.112	-0.198	-0.005	-0.170	0.188	0.364
Husk As	0.247 [a]	0.011	0.270	-0.663	0.152	-0.506	-0.178	0.006	0.085	-0.177
Grain As	0.251	0.121	-0.055	-0.239	-0.081	-0.047	0.124	-0.325	0.127	0.128

[a]Larger number indicates a more significant contribution. The bold values are the major contributors to each principal component.

IrriS1As= Irrigation water As in step 1; IrriS2As= Irrigation water As in step 2; IrriS3As= Irrigation water As in step 3; STS1As= soil total As in step 1; STS2As= soil total As in step 2; STS3As= soil total As in step 3; SAS1As= soil available As in step 1; SAS2As= soil available As in step 2; SAS3As= soil available As in step 3; RS1As= root As in step 1; RS2As= root As in step 2; RS3As= root As in step 3; SS1As= straw As in step 1; SS2As= straw As in step 2; SS3As= straw As in step 3.

5.3.7 Correlations

The correlation of different parameters for each of the practices has been demonstrated in Table 29. Positive significant correlation between irrigation water with soil total As has been observed for all the practices except for AsW-CF (BRRI dhan28). Other studies also reported a significant relationship while applied As contaminated groundwater in paddy soils (Kar et al., 2013; Otero et al., 2016; Mukherjee et al., 2017). Like the soil total As, soil available As also showed a significant positive correlation with irrigation water. However, a non-significant relationship is reported for AsW-AWD (BRRI dhan29) and AsW-CF (BRRI dhan28). As a general rule, the more the As present in irrigation water, the more the As can be deposited in soils and absorbed by plants (Hussain et al., 2021; Roychowdhury et al., 2005; Shrivastava et al., 2020). A significant positive relationship was observed while determining the correlation between soil total and soil available As for all the practices. This indicates that the total As largely determines the amount of available As (Baroni et al., 2004). This finding agrees with the observation of Huang et al. (2006) and Kar et al. (2013), who

Table 29:

Correlation of different parameters for the treatments practiced

Parameters	**Practice**	**Significance**
Irrigation water with soil total As	AsW-AWD (BRRI dhan28)	.994**
	AsW-AWD (BRRI dhan29)	.961*
	AsW-CF (BRRI dhan28)	NS
	AsW-CF (BRRI dhan29)	.993**
	TSG-AWD (BRRIdhan28)	.985*
	TSG-AWD (BRRIdhan29)	.999**

	TSG-CF (BRRI dhan28)	.995**
	TSG-CF (BRRI dhan29)	.969*
Irrigation water with soil available As	AsW-AWD (BRRI dhan28)	.966*
	AsW-AWD (BRRI dhan29)	NS
	AsW-CF (BRRI dhan28)	NS
	AsW-CF (BRRI dhan29)	.999**
	TSG-AWD (BRRIdhan28)	.953*
	TSG-AWD (BRRIdhan29)	.963*
	TSG-CF (BRRI dhan28)	.975*
	TSG-CF (BRRI dhan29)	.992**
Soil total with soil available As	AsW-AWD (BRRI dhan28)	.989*
	AsW-AWD (BRRI dhan29)	.970*
	AsW-CF (BRRI dhan28)	.983*
	AsW-CF (BRRI dhan29)	.997**
	TSG-AWD (BRRIdhan28)	.978*
	TSG-AWD (BRRIdhan29)	.963*
	TSG-CF (BRRI dhan28)	.970*
	TSG-CF (BRRI dhan29)	.975*
Irrigation water As with grain As	AsW-AWD (BRRI dhan28)	.968*
	AsW-AWD (BRRI dhan29)	NS
	AsW-CF (BRRI dhan28)	NS
	AsW-CF (BRRI dhan29)	.991**
	TSG-AWD (BRRIdhan28)	NS
	TSG-AWD (BRRIdhan29)	.996**
	TSG-CF (BRRI dhan28)	.973*

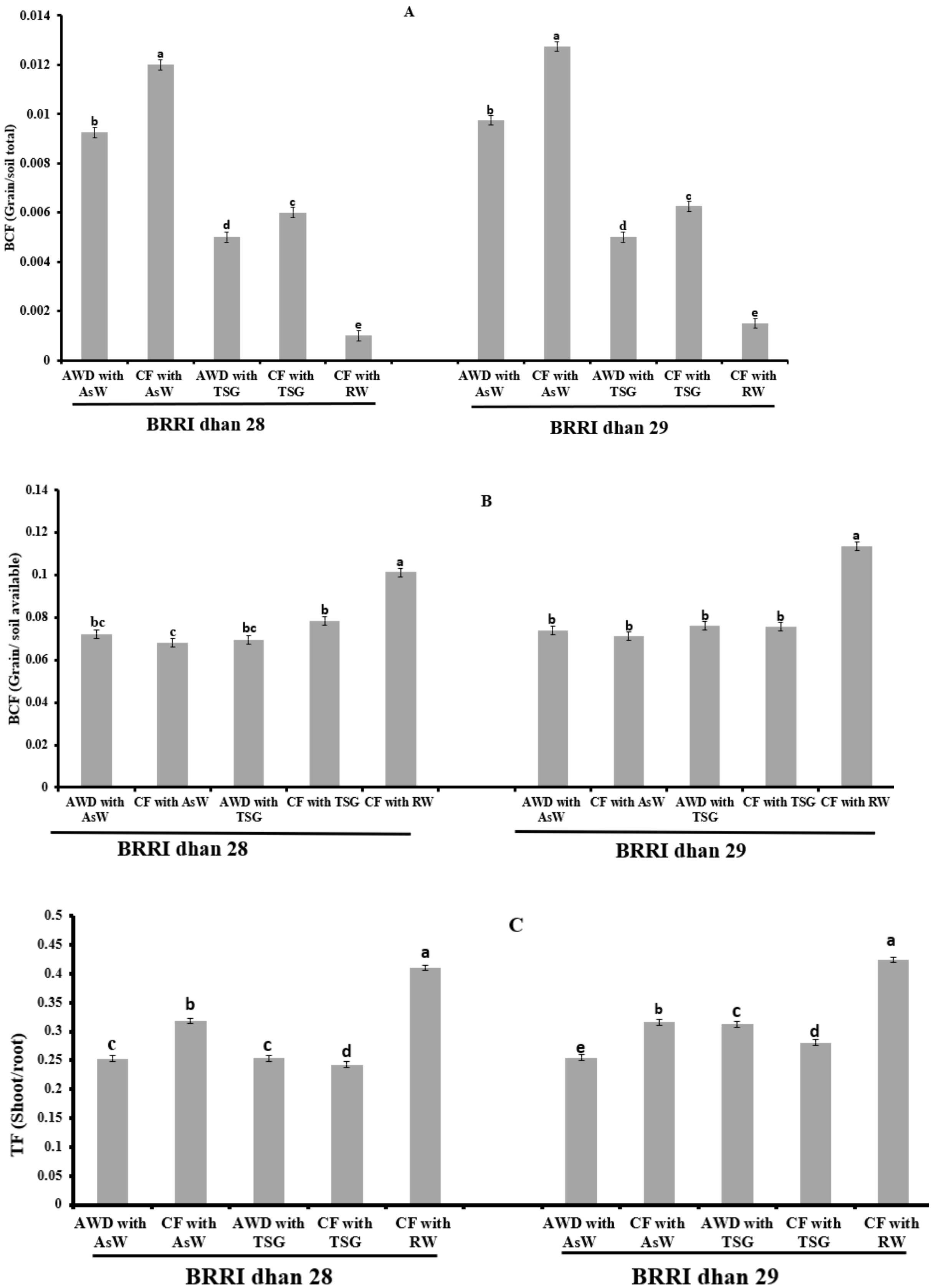
	TSG-CF (BRRI dhan29)	.977*
	Control-CF (BRRI dhan28)	.960*
	Control-CF (BRRI dhan29)	NS
Soil total As with grain As	AsW-AWD (BRRI dhan28)	.988*
	AsW-AWD (BRRI dhan29)	.984*
	AsW-CF (BRRI dhan28)	.985*
	AsW-CF (BRRI dhan29)	.977*
	TSG-AWD (BRRIdhan28)	.977*
	TSG-AWD (BRRIdhan29)	.993**
	TSG-CF (BRRI dhan28)	NS
	TSG-CF (BRRI dhan29)	.999**
	Control-CF (BRRI dhan28)	NS
	Control-CF (BRRI dhan29)	.951*
Soil Available As with grain As	AsW-AWD (BRRI dhan28)	.998**
	AsW-AWD (BRRI dhan29)	.998**
	AsW-CF (BRRI dhan28)	.974
	AsW-CF (BRRI dhan29)	.987*
	TSG-AWD (BRRIdhan28)	.979*
	TSG-AWD (BRRIdhan29)	.976*
	TSG-CF (BRRI dhan28)	.956*
	TSG-CF (BRRI dhan29)	.985*
	Control-CF (BRRI dhan28)	NS
	Control-CF (BRRI dhan29)	NS

*Correlation is significant at 0.05 level (two-tailed)

**Correlation is significant at 0.01 level (two-tailed) reported positive and significant correlations between the available As and the total As for paddy rice soils. When calculating the correlation between grain As with irrigation water As, most CF practices showed a significant positive relationship except for Control-CF (BRRI dhan29). In addition to the above, AsW-AWD (BRRI dhan28) and TSG-AWD (BRRIdhan29) demonstrated a significant positive relationship. The study of Otero et al. (2016) clearly showed a positive association between As content in flooded water and that in rice grains. The study of Mukherjee et al. (2017) also supports this finding. Significant positive correlation of grain As with both soil total and soil available As was observed in all the treatments except for TSG-CF (BRRI dhan28) and control [Control-CF (BRRI dhan28) for soil total and Control-CF (BRRI dhan28) and Control-CF (BRRI dhan29) for soil available As] in this present study. The study of (Kar et al., 2013; Mukherjee et al., 2017) showed that the As content in rice is significantly correlated with the available As in soil. However, they did not find such relationship between As in rice grain and total As in soil. In contrast, a significant positive association between soil total As and grain As was reported by Duxbury and Panaullah (2007).

5.3.8 Bioconcentration factor (BCF) and Translocation factor (TF)

Both the bioconcentration factor (BCF) and translocation factor (TF) for BRRI dhan28 and BRRI dhan29 were less than one in all the treatments (Figure 11). The plants are regarded as hyper heavy metal accumulators when the BCF value exceeds one (1) (Marrugo-Negrete et al., 2015). Although this present study showed considerably low BCF values, a substantial amount of As was sequestered in both varieties' rice roots. The TF values for ‘root to shoot’ and ‘shoot to grain’ were also found below one indicating lower As translocation from ‘root to shoot’ and ‘shoot to grain’ in those rice varieties. Metal phytoextraction requires the TF


A
BCF (Grain/soil total)
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
a
b
c
d
e
AWD with AsW
CF with AsW
AWD with TSG
CF with TSG
CF with RW
BRRI dhan 28
BRRI dhan 29
B
BCF (Grain/ soil available)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
bc
c
bc
b
a
AWD with AsW
CF with AsW
AWD with TSG
CF with TSG
CF with RW
BRRI dhan 28
BRRI dhan 29
C
TF (Shoot/root)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
c
b
c
d
a
e
AWD with AsW
CF with AsW
AWD with TSG
CF with TSG
CF with RW
BRRI dhan 28
BRRI dhan 29

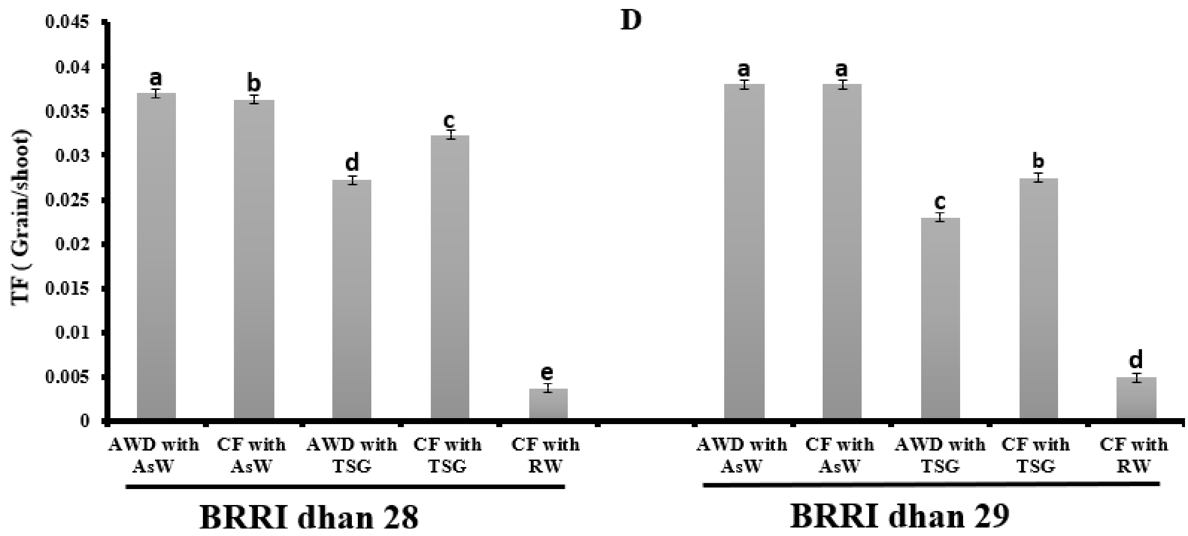


Figure 11: Effect of different treatments on (A) BCF for grain/soil total arsenic (B) BCF for grain/soil available arsenic (C) TF for shoot/root arsenic and (D) TF for grain/shoot arsenic levels. For each parameter, the values (mean of four replications) having different letters indicate significant difference at 0.1% probability level

and BCF value above one (Rehman et al., 2019). The maximum BCF of soil total As to grain was facilitated under CF for both the varieties. At the same time, no significant difference is observed in BCF for soil available As to grain. On the other hand, a significant difference is evident for TF based on varietal and treatment variations. For example, the TF (root to shoot) for AWD with AsW and AWD with TSG in BRRI dhan28 and BRRI dhan29 differed significantly from corresponding CF practices. For both the varieties, the value of TF in AWD with TSG was higher than the corresponding CF practices. Noticeably, the highest value for TF (root to shoot) was recorded for CF with RW in both the rice varieties. The TF (shoot to grain) for AWD with AsW and AWD with TSG in BRRI dhan28 were significantly different from corresponding CF practices, but no such difference was observed in AWD and CF with AsW, whereas AWD and CF with TSG were significantly different for BRRI dhan29. Among all the treatments, the lower TF (shoot to grain) is observed in AWD with TSG for both the varieties except for the control which indicates reasonable suitability of this practice to produce As safe grains. However, the lowest value for TF (shoot to grain) was recorded for CF with RW in both the rice varieties. Based on the obtained value to BCF and TF (<1), it can be said that BRRI dhan28 and BRRI dhan29 are well suited for phytostabilization of As in the naturally As burdened soils with groundwater.

5.4 Conclusions

In terms of reducing As bioaccumulation in rice grain, the combination of AWD irrigation with TSG was highly effective. This practice decreased 61.37% and 60.34% grain As for BRRI dhan28 and BRRI dhan29, respectively, compared with CF with AsW. Arsenic bioaccumulation in rice is significantly different between the varieties. The apposite selection of irrigation regime and rice genotype can provide 19.49% to 29.25% more grain yields adding value for food security. These findings advocate that AWD-TSG irrigation management significantly reduced grain As accumulation and augmented yield percentage compared with CF-AsW. Therefore, choosing appropriate water management together with suitable rice cultivars in As burdened areas could efficiently minimize grain As bioaccumulation without compromising grain yields. All the treatments produced non-metal accumulator plants with less translocation of As in aboveground aerial parts rice plants. The result of the experiment suggests the cultivation of BRRI dhan29 with AWD-TSG management as a promising practice to produce As–safe rice with benefiting food security. However, future research should consider integrating water management with other As mitigating strategies to avail the dual effect for bioaccumulation of As in rice.

CHAPTER 6

GENERAL DISCUSSION

6.1 Farmers perception

This study has examined farmers' perception on As contaminated groundwater irrigation for rice and vegetable cultivation, its associated health impact, and mitigation strategies. The majority of the farmers did not have adequate perceptions and were indifferent to As translocation to rice and vegetables from the contaminated groundwater irrigation due to several factors, such as their knowledge of As severity in crops, low awareness, and market conditions. This led the farmers to prioritize the increased productivity rather than the quality. In the absence of proper regulations and guidelines for the production of As contamination free rice and vegetables, the choice of crop either with As-water or other non-contaminated sources is still totally facultative. As still there is no provision in the domestic and international market to provide a premium price for As-safe rice and vegetables, the farmers even with good perceptions, do not bother to control As contamination. Furthermore, they were unaware of the health risks attributed to consuming contaminated rice and vegetables. The application status of farmers' irrigation management tactics showed that most farmers do not use As mitigating irrigation practices. Farmers' common practice is to irrigate their rice and vegetable fields as shareholders, where they get the required amount of water for their fields simultaneously with other partners. Often they get an excessive amount of water with minimum costs in this practice. The irrigation management technologies, such as AWD or raised bed cultivation, require personal machine ownership, which involves a higher initial production cost for machinery purchase. Therefore the limited number of the farmers who could maintain irrigation management was due to their possession of such machinery and large farm sizes. In their opinion, AWD or raised bed cultivation significantly reduces the water requirement and is feasible for the long-run cultivation plan. However, farmers might use the above-suggested As mitigating irrigation management tactics if the relevant department builds awareness and provides incentives/subsidies to buy the machinery.

Farmers were indifferent to cultivating less As accumulating rice cultivars. Lack of knowledge and appropriate importance regarding the variety selection endanger human health. As investigated by some researchers, the application of Phosphate fertilizer (Jayasumana et al., 2015) and pesticides (Campos, 2002) may worsen As levels in the crop fields and subsequent uptake by the rice and vegetables. However, almost no farmers have proper awareness and knowledge regarding those fertilizers' application. Most of the farmers in the present study reported that they preferred to get advice on fertilizers and pesticide usage from the dealers. Most farmers lack adequate perceptions regarding the adulterated fertilizers and pesticides, hence may often get cheated by the dealers. Regarding health risk context due to As exposure from drinking water, the majority of the people are aware in this study area. This was primarily because of the awareness-building initiatives from the government and non-government organizations from the very early stage of As detection in the groundwater of Bangladesh.

Nevertheless, the opposite scenario is true for the As contaminated rice and vegetable consumption. As discussed earlier, most farmers are still unaware of the As accumulation fact in rice and vegetables from contaminated groundwater, which leads most farmers to remain undecided regarding whether those crops may impact health. The prime target of this study was to identify the exact scenario regarding farmers' perception in those regards to getting conclusion and suggest future research prospects. Farmers' perception was influenced by their socioeconomic and psychological characteristics, such as farmers' education, knowledge, information sources, direct participation in farming, cosmopoliteness, opinionatedness, innovativeness, risk orientation, farm power and machinery (FPM), and organizational participation.

This study identified five predictor variables through stepwise multiple regression that explain 88 percent of the variances in farmers' perceptions. The results indicate that the farmers' knowledge is the most crucial characteristic that strongly influences their perception of the harmful effect of As contaminated groundwater irrigation. Direct participation in farming is the second contributor to perception variance. Farmers engaged in farming activities are likely to get exposed to practical field-based problems and often unknowingly identify the way. Farmers with higher perception levels were revealed to have greater farming engagement. Regarding the third predictor, the information source use, although majority of the farmers in the study area do not have good exposure to the mass media and print media to avail agro-based information, contact with agriculture officers, sub-assistant agriculture officer (SAAO), fertilizers, pesticides and seed dealers, family members, relatives and skilled farmers contributed to the respondents' information sources which finally influenced their perceptions. Participants' education, the fourth crucial characteristic, significantly determines their perceptions. It also appears that education influences other characteristics of the farmers, such as knowledge of As contaminated groundwater use and information sources. The fifth predictor characteristic was farmers' organizational participation. The participation of farmers in different social or management organizations allowed them to be exposed to several programs and communicate with people from various walks, which usually mature their background, knowledge, and experience, thus contributing to shaping their perception of the impact of rice and vegetable cultivation with As contaminated groundwater irrigation.

Path analysis was carried out since stepwise multiple regression analysis does not show independent variables' direct and indirect influence separately. According to Dewey & Lu (1959), a path coefficient is simply a standardized partial regression co-efficient and as such measures the direct influence of one variable upon another and permits the separation of the correlation co-efficient into components of direct and indirect effects. Path coefficient analysis is superior to multiple regression analysis as it is free of effects of measuring unit of the variables, whatever be the actual units of measurement for the variables (Li, 1954). In the present study, path analysis was computed to clearly understand the eight selected independent variables' direct and indirect effects, which were entered into the stepwise multiple regression analysis on farmers' perception (dependent variable). Variables through which substantial indirect effects were channeled were also explored. The path analysis findings would help formulate a proper extension policy strategy to achieve sustainable As-safe rice and vegetable production.

The direct effect of education on farmers' perception of As contaminated groundwater irrigation for rice and vegetable cultivation was positive, which explored that the education had a good direct effect. The total indirect effect of education was also positive and substantial, which indicated that education had a substantial indirect effect on influencing the farmers' perception. The indirect effect was mostly channeled through knowledge, information sources, direct participation in farming, cosmopoliteness, innovativeness, risk orientation, and organizational participation. It may be inferred that other variables remaining constant, education had a substantial influence on farmers' perception and was an essential determinant of farmers' perceptual behaviors.

Farmers' knowledge had negative direct effect on farmers' perception whereas total indirect effect was positive and substantial. The indirect effect was mostly channeled through participant education, information sources, direct participation in farming, cosmopoliteness, innovativeness, risk orientation, and organizational participation. It may be inferred that other variables remaining constant, knowledge had a substantial negative influence on farmers' perception. However, knowledge appeared to be important in determining the farmers' perception of the harmful effects of As elevated groundwater irrigation, as this variable had a substantial indirect influence on farmers' perception through the parameters mentioned above. Like knowledge, cosmopoliteness also had a negative direct effect but a positive and substantial total indirect effect on farmers' perception. The indirect effect was mostly channeled through participant education, knowledge, information sources, direct participation in farming, innovativeness, risk orientation, and organizational participation. Information sources had a positive direct and substantial indirect influence on farmers' perceptions. The indirect effect was mostly channeled through participant education, knowledge, direct participation in farming, cosmopoliteness, innovativeness, risk orientation, and organizational participation.

The direct effect of "direct farming participation" on farmers' perception was positive and substantial. The total indirect effect of education was also positive and substantial, indicating that "direct farming participation" had a substantial indirect effect in influencing the farmers' perception. The indirect effect was mostly channeled through participant education, knowledge, information sources, cosmopoliteness, innovativeness, risk orientation, and organizational participation. It may be inferred that other variables remaining constant, education had a substantial influence on farmers' perception and was an essential determinant of farmers' perceptual behaviors. In a similar pattern, the direct effect of innovativeness on farmers' perception of As contaminated groundwater irrigation for rice and vegetable cultivation was positive, which explored that the innovativeness had a good direct effect. The total indirect effect of innovativeness was also positive and substantial, which indicated that education had a significant indirect effect on influencing the farmers' perception. The indirect effect was mostly channeled through participant education, knowledge, information sources, direct participation in farming, cosmopoliteness, risk orientation, and organizational participation. It may be inferred that other variables remaining constant, innovativeness had a substantial influence on farmers' perception and was an essential determinant in respect of farmers' perception. Similarly, risk orientation and organizational participation had positive direct and substantial positive indirect effects on perception. Here the indirect effect was channeled through participant education, knowledge, information sources, direct participation in farming, cosmopoliteness, innovativeness, and organizational participation for risk orientation; and participant education, knowledge, information sources, direct participation in farming, cosmopoliteness, innovativeness, and risk orientation for organizational participation. Therefore, it may be inferred that other variables remaining constant, risk orientation and organizational participation, independently had a substantial influence on farmers' perception and was an essential determinant regarding farmers' perceptions.

6.2 Health risk assessment

Arsenic in irrigation water ranged from 0.039 to 0.370 mg/L (mean 0.210 mg/L) for all the five study locations. Groundwater As concentration used for irrigation surpassed the safe limit, i.e., <0.01mg/L, proposed by WHO (WHO, 2004; Arain et al., 2009). On the other hand, only 15% of groundwater samples from Hajiganj and Kachua, 10% from Faridganj, 5% from Sadar, and none from Matlab north contained a permissible As limit, i.e., 0.1 mg/L, recommended by FAO (Chakraborti et al., 2018). Regarding soil As content, Dudka & Miller (1999) found that As concentration in soil exceeding 40 mg/kg may be harmful to exposed organisms based on conservative risk analysis. When the concentration of As was over 100 mg/kg, it would be a severe risk to the pregnant women and their offspring, with specific birth anomalies such as neural tube defects (Desesso et al., 1998). Soils in the range of 20-30 mg/kg As are scattered throughout the central belt of Bangladesh, mostly associated with the high zones of groundwater As contamination (Meharg & Rahman, 2003). In our present study, the highest soil As level was recorded as 32.67 mg/kg, and none of the sampled agricultural soils from five different locations contained >40 mg/kg, indicating non-significant As contamination in soils. Except for 10% of samples collected from Hajiganj, all the samples surpassed the global average soil As level, i.e., 10 mg/kg (Rahman et al., 2013).

The origin of rice, its varieties and cultivars, and even the growing season, all had a substantial impact on the amount of As that was present in the uncooked rice. Market basket surveys conducted in the European Union (EU), the United States of America, Philippines, Australia, Japan, Canada, and China, as well as in South and Southeast Asian nations, have uncovered regional differences in the total As content observed in rice. Meharg et al. (2009) published a study not too long ago that examined the differences in total and inorganic As concentrations found in rice across different geographic locations. The As content of the EU rice ranged from 0.13 to 0.22 µg/g dry wt. on average, with a mean concentration of 0.18 µg/g dry wt. (Torres-Escribano et al., 2008). Williams et al. (2005) found that the total As content in EU rice ranged from 0.13-0.20 µg/g dry wt. Rice samples taken from a few different districts in West Bengal, India, that are located in As-affected areas showed As concentrations ranged anywhere from 0.04 to 0.43 µg/g dry wt. Other studies have also shown the variations of total As concentration in rice for other geographical areas such as Australia (0.02-0.03 µg/g dry wt. (Williams et al., 2006)), Canada (0.02-0.11 µg/g dry wt. (Heitkemper et al., 2001; Williams et al., 2005)), China (0.02-0.46 µg/g dry wt.). According to those findings, rice originating in the Philippines, Australia, and Canada has the lowest overall As burden, but rice originating in Bangladesh and India (West Bengal) has the greatest burden. Additionally, rice from Taiwan and Vietnam has been found to have substantial amounts of As. These changes had a very apparent relationship with the amount of pollution, the type of contamination, and the methods used to cultivate the rice. Arsenic burden in rice can also be affected by factors such as the chemistry of the soil, the source of As, As concentrations in soil, and the geochemistry of the region. Within a given geographical location, the levels of As that can be found in rice might also vary from region to region. Rice from the United States exhibited considerable differences in total As levels depending on area (Booth, 2007). Rice from California contains, on average, about 40 percent less As than rice from the south central United States, which includes Mississippi, Arkansas, Texas, Louisiana, and Missouri. This information was gleaned from a market basket survey of As in US rice that was conducted by Williams et al. (2007a). It is believed that the soils in the south central United States possessed greater levels of As due to the insecticides applied to cultivate cotton (Booth, 2008). In Bangladesh and West Bengal, areas that were contaminated with As and areas that were not contaminated with As had very different levels of As in their rice. However, contaminated areas of this region had very consistent levels of As in their rice across a wide range of concentrations. The direct contribution of highly contaminated subsurface irrigation water and paddy soils rather than any of the other sources is the primary reason for the high As concentrations found in raw rice in countries in South Asia that have an As endemic. Meharg & Rahman (2003) also discovered variations in the As concentration in various rice varieties grown in the research station of the Bangladesh Rice Research Institute (between 0.043 and 0.206 µg/g dry wt.) and in those collected from various districts across the country (between 0.058 and 1.835 µg/g dry wt.). Additionally noted seasonal shifts in the As quantity found in Bangladeshi rice by Duxbury et al. (2003). The average content of As in aman rice was found to be 0.11 µg/g dry wt. while the average concentration of As in boro rice was found to be 0.18 µg/g dry wt.

Rice is the most important staple food in Bangladesh, and it accounts for up to 80 percent of the daily caloric intake (Huq et al., 2006). The average daily rice consumption in Bangladesh ranges from 400–650 g (Rahman et al., 2006), making it one of the countries with the highest per capita rice consumption figures in the world (Abdullah et al., 2006). Since the total As level of rice is 0.1 µg/g, consuming 650g of rice per day would result in an intake of 65 µg, which is equivalent to 0.065 mg of As and is the greatest amount of As that can be obtained from any food source. Other relevant topics relating to As exposure from rice diet are the concentration of As species in rice and the bioavailability of As in rice (Laparra et al., 2005).

On average, Asian rice contains mainly iAs out of the total As content (Rahman et al., 2014) and the absolute bioavailability of arsenite is the highest, followed by arsenate, dimethylarsenate (DMA), and monomethylarsenate (MMA) (Juhasz et al., 2006).

When it comes to vegetables, the amount of As a person is exposed to is directly related to the amount of As that is consumed in vegetables as well as the amount of As that is present in vegetables (Rahman et al., 2018). Arsenic is typically accumulated and stored in the root tuber of root vegetables, while As transfer to the above-ground sections of the plant is typically very limited (Rahman et al., 2013). Although the As concentrations in the majority of the vegetables did not surpass 4 mg/kg dry wt., there were a few vegetables that contained As at levels as high as 158 mg/kg dry wt. (such as peeled arum root) and as high as 8 mg/kg dry wt. (such as gourd leaf). The levels of As found in vegetables grown in Bangladesh ranged from 0.1–2.0 mg/kg wet weight (wet wt.) and 0.1–0.8 mg/kg wet wt., respectively, in leafy and non-leafy vegetables (Tani et al., 2012). According to the findings of another study, the concentrations of As in leafy and non-leafy vegetables grown in Bangladesh ranged from 0.04–0.46 mg/kg wet wt. (the median value for this range is 0.11 mg/kg wet wt.), and from 0.011–0.15 mg/kg wet wt. (the median value for this range is 0.03 mg/kg wet wt.) (Rahman et al., 2013). The consumption of vegetables in Bangladesh is reported to be 238 g per person per day (Joseph et al., 2015a), which indicates that consumers could be exposed to 26.18 mg and 7.14 mg of As per day, respectively, from their diets consisting of leafy and non-leafy vegetables, depending on the types of vegetables they eat. According to the findings shown above, vegetables, in addition to rice, have the potential to be an important source of As exposure for people living in Bangladesh through their diet, where As-free drinking water is used.

Arsenic loading in rice and vegetables in naturally endemic regions is predominantly due to the high As content in soils and groundwater irrigated (Huang et al., 2006; Bhattacharya et al., 2012; Rehman et al., 2016; Reid et al., 2021). The immediate and long-t erm implication of using contaminated water for irrigating crop fields is of pressing concern (Williams et al., 2006). There is increasing evidence that, at least in certain areas, soil arsenic levels have increased due to irrigating with As-contaminated water (Alam & Sattar, 2000; Roychowdhury et al., 2002b; Meharg & Rahman, 2003). Rice obtained from districts with contaminated waters (>50 µAs/L) was more elevated than rice from uncontaminated districts (<50 µAs/L)-exhibiting a significant statistical difference (Williams et al., 2006). Groundwater As concentrations are undoubtedly essential factors in predicting rice grain As levels (Roychowdhury et al., 2002b; Williams et al., 2006).

Irrespective of limited As translocation, a positive correlation existed between soil As vs. irrigation water As; soil As vs. grain As/vegetables As; and irrigation water As vs. grain As/vegetables As. This As accumulation pattern indicates that As in both groundwater and soil positively impacts the grain and vegetables As content. However, there was a total change in the scenario once As entered the plant tissue. The BCF (soil-grain) is the most crucial data to consider while assessing rice/vegetable consumption risk. The BCF from soil to grains or edible portions of vegetables is influenced by several factors like soil As concentration, the ability of plants to induce antioxidant enzymes, and phytochelatins production. (Gupta & Ahmad, 2014; Dubey et al., 2016; Paulelli et al., 2019). Further, thiol-rich peptides formed due to sulfur supplementation of paddy soils may have reduced As translocation from roots to grains because of their high affinity for As (III) (Zhang et al., 2011; Kumarathilaka et al., 2018). Besides the physicochemical properties, As uptake by plants is also controlled by tolerance mechanisms (physiological/biochemical) taking place in different plant tissue (Sharma et al., 2020).

Mean As content in ricegrains exceeded 0.37 mg/kg in Hajiganj, Kachua, and Matlab north, while grains from Faridganj and Sadar were below that limit. Nearly 15% of samples from

Hajiganj, Kachua, and Sadar, 5% from Faridganj, and none from Matlab north contained As 15 mg/kg (the limit for iAs suggested by China for south Asian rice). This is considered since closely hundred percent of As in Asian rice is reported as iAs (Rahman et al., 2014). Like rice, As content in vegetables also contributes to higher As transfer to the human body with higher levels. Only 15%, 5%, 10%, 25%, and 10% of collected vegetable samples contained As within 0.5 mg/kg (safe limit suggested by China, since still there is no specific regulation for vegetables by Bangladesh) in Hajiganj, Kachua, Matlab north, Faridganj, and Sadar, respectively. Even at the safe limit, chronic and higher amounts of exposure to As can impact human health in the long run. The farmers in the study areas consume rice as the staple food primarily three times a day with an average of 0.512 kg. In addition, farmers consume an average of 0.181 kg of vegetables with rice every day. The average daily intake (ADI) of As from rice and vegetables is higher than the reference dose (RfD) limit for As. An HQ > 1 has been revealed for both the grains and vegetables. According to the ILCR calculation, 2.8 persons in every 100 people and 1.6 persons in every 1000 are at considerable and threshold risk, respectively. Despite such severe risks existed, farmers were asymptomatic of As-related ailments. This circumstance could be explained that the farmers intake more nutritious meals, including proteinaceous foods, vegetables, and fruits. This survey reported that farmers' vegetable consumption rate is significantly higher than the average national vegetable intake, 0.130 kg (Alam et al., 2003). The cumulative As content coming from the rice and vegetables contributed to the human body's severe As loading as expressed by their scalp hair analysis. This present study revealed a maximum hair As value exceeding the toxicity level, while the minimum value exceeds the background value, as suggested by Arnold et al. (1990) and National Food Authority (1993). Scalp hair As is significantly correlated with that of grain and vegetables, indicating a significant As loading to the human body from rice and vegetable consumption cultivated with contaminated groundwater.

6.3 Mitigation strategy

Recently, the high As level in rice from South and South East Asia has become a major concern not only for the countries that produce the rice in question but also for the nations that import rice from this region. Arsenic levels in rice grain taken from the western portion of Bangladesh, which is contaminated with As, ranged from 0.03 to 1.84 µg/g dry wt. (Meharg & Rahman, 2003). According to Williams et al. (2006), the As level in aman (dry season) rice ranged between 0.04 and 0.92 µg/g dry wt. (mean 0.08-0.36 µg/g dry wt.), while the As level in boro (monsoon season) rice collected from the southern part of the country ranged between 0.04 and 0.91 µg/g dry wt. (mean 0.14-0. Arsenic concentrations in aman and boro rice were found to be between 0.18 and 0.31 and 0.21-0.27 µg/g dry wt., respectively, in the same study that looked at rice collected from markets throughout the country. These findings were in line with their earlier research. Islam et al. (2004) observed As levels ranging from 0.05 to 2.05 µg/g dry wt. in samples of boro rice taken from three districts in southern Bangladesh (Faridpur, Rajbari, and Gopalganj). Rahman et al. (2006) also discovered a high amount of As in uncooked rice (0.57-0.69 µg/g dry wt.) obtained from the Satkhira district in Bangladesh, which is an extremely As-contaminated area. These investigations all point to the presence of high levels of As in the uncooked rice produced in Bangladesh.

Arsenic contamination of soil and groundwater and consequent accumulation of As in high concentrations in rice grains are severe issues in Bangladesh, India, and other parts of the world. The present study focused on evaluating special water management, i.e., temporally stored groundwater (TSG) irrigation of As stress amelioration in rice plants in field conditions. Arsenic concentration in paddy soil (0-20 cm) has been mainly attributed to As contaminated groundwater for irrigation (Barla et al., 2017; Upadhyay et al., 2019b). In this work, the temporal storing of groundwater significantly reduced (up to 50% from the original) As levels. The prime mechanism for this reduction can be explained as the storing of groundwater facilitates the co-precipitation of As with the iron oxides due to oxidation with atmospheric oxygen; it is expected that the input of As from irrigation water to the rice field would be reduced substantially (Halder, 2013). However, the percent As reduction in groundwater due to storing in this present study is lower than that reported by Roberts et al. (2007), up to 69% within the first 24 h, after irrigating with As contaminated water.

The total soil As levels in all the experimental fields exceeded the global average As level for agricultural soil (Rahman et al., 2013) but was below the permissible limit of 50 mg/kg proposed by FAO (FAO, 1992). The bioavailable fraction of soil-As is an important parameter that governs the build-up of As in various rice plant tissues. The exchangeable portion is one of the main bioavailable contents of As that are taken up by rice plants (Sarkar et al., 2017; Upadhyay et al., 2019b). The As bioavailability was found to be higher in experimental fields than in control fields. Thus, higher total As of soil also led to more bioavailable As, resulting in greater As accumulation in rice plants in experimental fields than in control fields (Chowdhury et al., 2020; Shrivastava et al., 2020). Conclusively, As build-up in different rice tissues, including grains, was primarily linked to groundwater As input and soil As concentration.

The majority of As deposited in rice roots and thereafter, a small fraction of As translocated to straw, followed by husk and grains, for all the trial fields. Rice can transport oxygen from the surrounding air all the way down to its stem, and then release it into the rhizosphere through its roots, which makes the As uptake mechanisms in rice more complicated (Brammer & Ravenscroft, 2009). This results in the formation of an oxidized zone surrounding the roots, which leads to the oxidation and precipitation of iron resulting a coating (Liu et al., 2006). According to Hu et al. (2007), sulfur both encourages the production of iron plaque in the rhizosphere and decreases the buildup of As in rice. In a separate piece of research, Hu et al. (2005) found that the application of phosphate fertilizer reduced the amount of iron plaque that formed on the surface of rice roots. Although the formation of iron plaque on the rice root surface should increase As adsorption and therefore act as an As filter, some studies showed that significant amounts of As are taken up by rice plants even in this condition.

The As concentration pattern in rice plants followed the same order viz; root> shoot> husk> grain as observed in earlier studies (Chou et al., 2014, 2016; Shrivastava et al., 2018, 2021). The highest grain As reduction was recorded in AWD-TSG practice with 61.37% and 60.34% from CF-AsW for BRRI dhan28 and BRRI dhan29, respectively. This practice could reduce the grain As below 15 mg/kg (the limit for iAs suggested by China for south Asian rice) for both the rice varieties. Since Asian rice accumulates 86% to 99% iAs out of the total (Rahman et al., 2014), this practice is suitable even for addressing this circumstance. The possible explanation for reducing grain As content in AWD-TSG practice is that temporal storing of As-elevated groundwater significantly reduced As content in water, and the supply of that water coupled with AWD practice reduced As translocation to the rice grains. Paddy straw and husks are widespread cattle feed used in Bangladesh. The significant As content in straw due to AsW irrigation may contribute to As loading in cattle bodies and enter into the food chain through the cattle, posing a threat to human health (Das et al. 2004). AWD-TSG practice reduced 48.62% and 34.39% straw As, and 46.74% and 51.35% husk As for BRRI dhan28 and BRRI dhan29, respectively.

CHAPTER 7

CONCLUSION, LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

7.1 Conclusion

This study assessed farmers' perception regarding rice and vegetable contamination due to As-elevated groundwater irrigation and explored associated health impact, mitigation strategies, and farmers' socioeconomic status influencing their perception. It also revealed the farmers' health risks due to As contaminated rice and vegetable consumption. And finally, we conducted a field trial to suggest As mitigating irrigation practice to produce safe rice from As contamination.

The perception study revealed that only one fourth of the farmers giving the positive message with good perceptions regarding the As contamination scenario in rice and vegetables, even the additional 36% of people with moderate perception gives cause for optimism. Although ten of farmers' socioeconomic characteristics were positively significant ($p \leq 0.01$) likely to influence their perceptions at positive direction, distinctive emphasis should be given to participants knowledge, direct participation in farming, information sources used, participant education, and organizational participation, the five socioeconomic factors explain 88 percent variances in perception. Path analysis depicts that direct participation in farming presents the highest positive total effect (0.855) and direct effect (0.503), whereas information sources show the highest positive indirect effect (0.624).

The health risk assessment study suggested the bioconcentration factor (BCF) for rice and vegetables As is < 1, maximum and minimum hair As beat toxicity and background limit, respectively, both rice grains and vegetables have an HQ > 1, around 2.8 per 100 people are at considerable cancer risk. The first principle component (PC1) explains 91.1% of the total variances. Dendrogram shows vegetables As contribute more to human body loading than grain As while correlation analysis showed hair As is significantly ($p \leq 0.05$) correlated with that in rice and vegetables indicating a positive direction of relationship exists.

The mitigation study suggested that AWD with temporarily stored groundwater (TSG) decreased by 61% grain As, bioconcentration and translocation factor were <1 for both the cultivars indicating both the rice varieties were non-hyper As accumulatior. The first principle component explained 91.7% of the variability in As loading, grain As content was determined by genotypic variation coupled with water regimes alteration, AWD augmented grain yields up to 29.25% compared with CF.

In general, this study revealed a significant threat to human health due to As contaminated rice and vegetable consumption. Despite the As level in irrigation water, soils, vegetables, rice, and scalp hairs exceeding the acceptable limit in all five locations, farmers' perception is far behind the actual field status of As level and its transfer source. This clearly shows that As perception is not widespread in rural Bangladesh, although there significant As contamination and transfer to the crops is evident. Understanding the field level status and farmers ' perspectives is crucial to formulate As mitigation policy and suggest future research prospects in a sustainable context. Several socioeconomic factors such as farmers' knowledge, direct participation in farming, information sources, participant education, and organizational participation determined farmers' perceptions. Special attention must be ensured to emphasize those factors while taking further steps in As research.

7.2 Limitations and recommendations for future research

This study assessed a preliminary context, i.e., farmers’ perception on As contaminated groundwater irrigation for rice and vegetable cultivation. We recommend further studies on farmers’ attitudes toward adopting As mitigating strategies in an interdisciplinary context, emphasizing the socioeconomic status revealed in this study influencing farmers’ perception.

For health risk assessment, this study included only males for hair samples collection purposes due to some particular reason. Almost all adult men have unique tea-taking habits, at home or outside. This study ensured all participants drank As-free water and even used safe water for tea preparation at home. However, whether they took tea made with As free water outside was not ensured. Another point is that betel leaf and betel nuts may contain As, but eating those items was not considered in this study. The study covered five heavily As contaminated sub-districts of Chandpur, Bangladesh. In addition to scalp hairs, future research should include urine analysis to inspect immediate As exposure status due to rice and vegetable consumption on a broad scale encompassing several districts.

For mitigation strategy, the field trial was conducted for one year in a dry period requiring groundwater irrigation for rice cultivation. Each treatment was replicated four times to ensure greater validity, and similar results were revealed for all the replicated plots of each treatment. However, it would be worthwhile to do further research in more than one year at different locations with different subspecies of rice cultivars from japonica and indica to test whether the As reducing findings of this study are identical and take steps for its dessimination.

This current study included only one As mitigation practice in rice i.e. alternative irrigation management (AWD). However, future studies should also consider combining water management practices with technical agronomic approaches such as seed priming, nanotechnology, or biochar application on a broad scale at the field level.

This current study did not consider the assessment of the human health risk differences between pre and post-ingestion of rice produced by adopted mitigation strategy (AWD and/or AWD+TSG). However, future study should assess the human health risk differences between pre and post-ingestion of remediated rice obtained from field trials through biomarker analysis.

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Appendix A: Interview Schedule

Interview schedule for the study on
Arsenic in rice and vegetables: Human body loading, perception and mitigation strategy

Date________________ Serial no. ______________________
Name of the respondent Mobile No.____________________
____
Village______________________ Union ______________________
Thana______________________________ Post office____________________
District ____________________

Please answer to the following questions:

1. **Age**:_____________ years

2. **Education**: please state status of your education
   a) Passed class_____________ c) can read only_______________
   b) Can read & write_____________ d) cannot read & write_____________

3. **Family education including you**

Sl. No.	Level of education	Score	No. of family member (total)	Total
1	Can't read & write at all	0		
2	Can read only	1		
3	Can read & write only	2		
4	Primary or equivalent	3		
5	Junior high school level or equivalent	4		
6	SSC or equivalent	5		
7	HSC or equivalent	6		
8	Bachelor	7		
9	Masters	8		

4. **Family size and effective family size**

Male/female	Upto 4 years of age (number)	4 years & above (effective family size in number)	Total number
Male (including self)			
Female			
Total number			

5. Direct participation in farming

Sl. No.	Farm operations	Extent of participation			
		Regularly	Rarely	Occasionally	Not at all
1	To what extent you plough your land by yourself?				
2	To what extent you select plant variety by yourself?				
3	To what extent you sow or plant your land in your own hand?				
4	To what extent you handle irrigation pump or machinery?				
5	To what extent you irrigate your land by yourself?				
6	To what extent you harvest crops by yourself?				

6. Knowledge: Please respond to the following parameters as per your know hows

Question	Correct/expected answer	Assigned points	Obtained score
A. Respondent Knowledge about Arsenic Poisoning			
1. Have you heard about arsenic contamination problem?	Yes	Yes=4; No=0	
2. If yes, how long ago did you first heard about it?	One year or more	<1 year=0; 1 year=1; 2 years=2; 3 years=3; >3 years=4	
B. Respondents Knowledge about the Cause/Source of Arsenic Poisoning			
3. What is the primary source of arsenic poisoning in soil & crops?	Irrigation with As-contaminated groundwater;	Correct=1 Wrong=0	
4. What are the other sources of arsenic poisoning in soil & crops?	As pesticides use; Fertilizer (especially TSP) use	1 correct answer=1 pts. 2 correct answer=2 pts.	
C. Respondents Knowledge about Symptoms of Arsenic Poisoning			
5. What are the early symptoms of arsenic poisoning (list at least two)?	Darkening of skin on palms, dark spots on the body, and keratosis	1 correct answer=2 pts. 2 correct answer=4 pts.	
6. What are the more visible symptoms of arsenic poisoning	Darkening of skin on palms, dark spots on the	1 correct answer=2 pts.	

(list at least two)?	body, and keratosis, and cardiovascular and respiratory disorder	2 correct answer=4 pts.	
D. Respondents Knowledge about Arsenic-Related Diseases			
7. What are the diseases caused because of arsenic poisoning (list at least two)?	Keratosis, gangrenous ulcer, skin, lung, and bladder cancer	1 correct answer=2 pts. 2 correct answer=4 pts.	
8. How long does it take to develop visible symptoms?	2–10 years	2 4yrs.=2 pts. >4 yrs.=4 pts.	
9. How long does it take to develop cancer?	5–20 years	5–9 yrs.=2 pts. >9 yrs.=4 pts.	
E. Respondents Knowledge about Preventive Measures			
10. How can arsenic be reduced in crop fields (list at least one)?	AWD, raised bed cultivation, using surface water, using stored groundwater	1 correct answer=1 pts. 2 correct answer=2 pts. 3 correct answer=3 pts.	
F. Respondents Knowledge about Solution to the Arsenic Problem			
11. What is the solution to the arsenic problem (list at least one)?	Irrigation with water from non-contaminated sources	1 correct answer=1 pts. 2 correct answer=2 pts.	

7. **Information sources use:** Please indicate your extent of use of information sources regarding the use of irrigation water for crop production

Sl. No.	Information sources	Extent of use of information sources (number)				
		Most often (4)	Often (3)	Sometimes (2)	Rarely (1)	Never (0)
A)	**Mass media**					
1	Radio	1/day	1/week	1/month	1/season	0
2	Television	1/day	1/week	1/month	1/season	0
3	Educational film	1/season	1/2 season	1/year	1/2 year	0
4	Newspaper	1/day	1/week	1/month	1/season	0
5	Poster	1/month	1/season	1/2 season	1/year	0
6	Leaflet	1/week	1/month	1/season	1/year	0
7	Booklet	1/week	1/month	1/season	1/year	0
8	Magazine	1/week	1/month	1/season	1/year	0
B)	**Group contact**					
1	Result demonstration	1 season	1/year	1/2 year	1/3 or> years	0
2	Farmers' training	1 season	1/year	1/2 year	1/3 or> years	0
3	Field days	1 season	1/year	1/2 year	1/3 or>	0

					years	
C)	**Personal cosmopolite**					
1	Agriculture officer	1/month	1/season	1/2 season	1/year	0
2	Other dept. officer	1/month	1/season	1/2 season	1/year	0
3	SAAO	1/fortnight	1/month	1/season	1/ year	0
4	Dealers	1/fortnight	1/month	1/season	1/ year	0
5	NGO workers	1/fortnight	1/month	1/season	1/ year	0
D)	**Personal localities**					
1	Family members	1/day	1/week	1/fortnight	1/month	0
2	Relatives	1/day	1/week	1/fortnight	1/month	0
3	Friends and neighbors	1/day	1/week	1/fortnight	1/month	0
4	Skilled farmers	1/week	1/fortnight	1/month	1/season	0

8. **Farm size:** Please indicate the area of land in your possession

Sl. No.	Type of land use	Land area		Total area (ha)
		Local unit	Hectare (ha)	
A	Land under own cultivation			
B	Land given to others on borga			
C	Land taken from others on borga			
D	Land given to others on lease			
E	Land taken from others on lease			
F	Homestead area			

Farm size= A+{½ (B+C) + E + F}-D

9. **Annual income:** Please indicate the production and income of your family from different sectors in the last year

Sl. No.	Source of income	Amount of production	Price per unit (TK.)	Total (TK)
A	**Agriculture**			
1	Rice			
2	Vegetables			
3	Wheat			
4	Jute			
5	Oilseed			
6	Spices & condiments			
7	Fruits			
8	Other crops			
B	**Business**			
C	**Services**			
D	**Labour**			
E	**others**			

10. Use of agricultural credits:

a) Did you need any credit last year? Yes________________.
No.________________

b) If yes, did you take credit? Yes_______________. No____________________

If yes, please give the detail particulars of credit you have taken last year from different sources

Sl. No.	Source of credit	Amount of credit received	Nature of use		
			Amount used in agriculture	Amount used in other purposes	What are the other purposes
1	Bangladesh Krishi Bank				
2	Commercial Bank (mention the name)				
3	Grameen Bank				
4	BRAC				
5	ASA				
6	Other NGOs (mention the name)				
7	Village money leader				
8	Businessman				
9	Neighbours				
10	Others (if any)				

11. Social/Organizational participation: Please indicate your involvement in following social organization

Sl. No.	Name of social organization	Not involved	Nature of involvement		Nature of attendance in the meeting		
			As a member	As an office bearer	Regularly	occasionally	never
1	Farmers' co-operative society (KSS)						
2	Bazar committee						
3	Mosque committee						
4	Madrasha committee						
5	School committee						
6	NGO committee						
7	Village Defense Party						
8	Local government organization						
9	One house one farm program						

10	Others (if any)						

12. Cosmopoliteness: Please indicate the extent of your visit to the following places during the last one year

Sl. No.	Places of visit	Extent of visit (number)			
		Often	Occasionally	Rarely	Never
1	Other villages (per month)	10 or more	5-9	1-4	0
2	Own upazila sadar (per month)	8 or more	4-7	1-3	0
3	Other upazila (per month)	6 or more	3-5	1-2	0
4	District head quarter (per month)	8 or more	4-7	1-3	0
5	Capital or cities (per year)	3 or more	2	1	0
6	Outside of the country (life time)	3 or more	2	1	0

13. Opinionatedness: Please indicate the extent of your offering of opinion to the other fellow farmers

Sl. No.	Subject of opinion	Extent of offering opinion (number)			
		High	Medium	Low	No
1	Selection of crop variety for cultivation (per season)	Above 20	11-20	1-10	0
2	Use of irrigation (per season)	Above 20	11-20	1-10	0
3	Management of intercultural operations (per season)	Above 10	6-10	1-10	0
4	Seed preservation for different crops (per season)	Above 20	11-20	1-10	0

14. Innovativeness: if you have adopted the following technologies please mention their duration of adoption after your first hearing of the same

Sl. No.	Name of technology	Do not use	Duration of adoption (year)				
			Within 1 year	Within 2 years	Within 3 years	Within 4 years	Within 5 years
A	**Variety selection**						
1	Use of arsenic tolerant rice variety (e.g. BRRI dhan11, BRRI dhan 22, BRRI dhan 49)						
B	**Irrigation practices**						
1	Practice AWD						
2	Practice raised bed cultivation						
3	Surface water irrigation						
C	**Cultivation of As removing plants**						
1	**Fern**- Male fern/worm fern (*Dryopteris filix-mas*)						
2	**Herbs**- Shial mutra (*Blumea lacera*)/ Assam						

	lota (*Mikania cordata*)/ Nakful (*Ageratum conyzoides*)						
3	**Shrubs**- Clerodendrum trichotomum/ Benna/ (verenda/ Castor oil plant- *Ricinus communis*)						
D	**Use of chemical fertilizers to reduce effect of arsenic on crop productivity**						
1	Apply more urea						
2	Apply more MoP						
3	Apply more gypsum fertilizer						
4	Apply more zinc sulphate						
E	**Indigenous Technical Knowledge (ITK)**						
5	Did mulching						
6	Apply cow dung						
7	Apply Ash						

15. Risk orientation: Please indicate your opinion on the following statements

Sl. No.	Statements	Extent of opinion				
		Strongly agree	Agree	Undecided	Disagree	Strongly disagree
-1	Sometimes dealers cheat farmers by selling adulterated fertilizers which ultimately increase As toxicity in crop fields					
-2	Sometimes dealers cheat farmers by selling adulterated pesticides which ultimately increase As toxicity in crop fields					
+3	Training received decreases As accumulation in cultivated crops					
-4	Lack of agricultural credit hampers buying irrigation machinery					
-5	Farmers cannot buy irrigation machinery due to high price which ultimately hamper desirable irrigation management					
-6	Non-availability of electricity to run irrigation pump hampers desirable irrigation management					
-7	Lack of essential farmers' training on water management is one of the major reasons of As entering in food chain					
+8	Through raised seed bed practice, uniform seedlings were					

	obtained due to less As accumulation in seedlings					
+9	Alternate Wetting and Drying (AWD) practice helped reducing As in soil and rice					
+10	Aerobic rice cultivation reduced unfilled grains due to less As accumulation					

16. Ownership of farm power and machinery: Please indicate your possession of the following farm equipment

Sl. No.	Type	Score for each	Number	Total score
1	Country plough	1		
2	Hand sprayer	2		
3	Rice weeder	1		
4	Shallow tubewell (STW) (joint ownership)	3		
5	Power tiller	4		
6	Shallow tubewell (STW) (single ownership)	4		
7	Harvester	4		

17. Farmers' perception: Please indicate your opinion on the following irrigation water use scenario for rice and vegetables production

Assessment parameters	Sl. No.	Constructs	Extent of opinion			
			Strongly agree	Agree	Disagree	Strongly disagree
Perception on As-contaminated water (AsW) or As free water use	-1	For me, no **As-contaminated water (AsW)** means no rice/vegetable production				
	+2	I can produce rice/vegetables without AsW				
	-3	Why on earth would I use AsFW to produce vegetables?				
	+4	Why on earth would I use AsW to produce rice/vegetable				
	-5	AsW for rice/vegetable production is available throughout a year				
	+6	AsFW for rice/vegetable production is available throughout a year				
	+7	AsW for use in vegetable production is seasonal				
	-8	AsFW for use in vegetable				

		production is seasonal				
Drivers of irrigating AsW	-9	Easily accessible				
	-10	I can irrigate with other shareholders of pumps				
	-11	I pay little money to get AsW for use in my rice/vegetable production				
	-12	Scarcity of AsFW				
	-13	Decrease production cost				
	-14	Saving AsFW for household use				
Effect of AsW irrigation on crop fields	+15	Crop fields contaminated with arsenic				
	+16	Decreases soil fertility				
	+17	Irrigation canals and rice/vegetables fields become red				
	+18	Land become hard				
	+19	Rice/vegetables yield near irrigation channel/STW is low				
Effect of AsW Irrigation on rice & vegetables	+20	Less tillering				
	+21	Plants become shorter in height				
	+22	Plant growth not uniform				
	+23	Plants do not flower uniformly				
	+24	grains do not mature uniformly				
	+25	More unfilled grains				
	+26	Decrease rice yield				
	+27	Arsenic may accumulate in rice/vegetables upon irrigating with AsW				
Effect of fertilizers & pesticide use	+28	Application of pesticide may induce As in crop fields				
	+29	Application of chemical fertilizers add As in soils				
Health impact	+30	Consumption of contaminated rice/vegetables may transfer As to human body				
	+31	As may cause cancers				

	+32	Skin lesson				
Farmers' practiced As mitigation strategy	+33	Irrigate and allow the field to dry (AWD)				
	+34	Use stored groundwater for irrigation				
	+35	Practice raised bed cultivation				
	+36	Use surface water for irrigation				
	+37	Apply more urea				
	+38	Apply more MoP				
	+39	Apply more gypsum fertilizer				
	+40	Apply more zinc sulphate				
	+41	Did mulching				
	+42	Apply cow dung				
	+43	Apply Ash				

Suggestion of Farmers:

Please mention your suggestion to reduce As contamination in rice & vegetables

Sl. No.	Measures suggested
1	
2	
3	
4	
5	

Thanks for your cooperation!

Signature of Interviewer
Date:

Appendix B: Questionnaire

Questionnaire for Collecting Farmers' Demographic and Food Consumption Data

Demographic Part

Name of the author: _______

Hair sample: _ _ _ _ _ _ _ _ _ _ _ Sample no.: __________

1. Name of the participant: ____________________; Mobile No:_____________________; Education______________

2. Village: ___________________Age_______ years; height:_________ cm; weight: _______ kg

3. Please indicate your following status:

Parameters	**Status**	**Parameters**	**Status**
Education		Occupation	
Symptomatic/asymptomatic		Family size	
Annual income		Farm size	

4. Residence period in your current location: _ _ __ _ Years

5. Have you previously lived outside your current residence for a long time (more than half a year)?
   Yes [ ] No [ ]

If yes, please mention → Residence: _ _ _ _ _ _ _ _ _ _ _ _ _ Month; location of residence: _____________

6. Apart from farming, do you do any other work Yes [ ] No [ ]

If yes, please mention: specific types of work ___________________ engaged in __________________

7. Do you smoke? Yes [ ] No [ ]

If yes, please mention: smoking every day: ________ stick; smoke for: ______ years

8. Source of drinking water:

Arsenic free tubewell [ ] Arsenic contaminated tubewell [ ] Other [ ], note: _______________

9. Please mention the origins of your consumed rice [Please √]:

(a) own field or farm [ ] (b) buy from market [ ]

10. Please mention the origins of your consumed vegetables [Please √]:

(a) own field or farm [ ] (b) buy from market [ ]

11. Source of irrigation water:

Underground water [ ] Surface water [ ] Other [ ], note: _______________

Dietary Consumption Part

Please mention the frequency and quantity of the followings foods consumed

1. Grains

I. Rice

a. Frequency of rice consumed

Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 plate) 100 ☐ (1 plate) 200 ☐ (2 plate) 300 ☐(3 plate) 400 ☐(4 plate) 500 ☐(5 plate)

II. Wheat

a. Frequency of rice consumed

Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 bread) 50 ☐ (2 bread) 75 ☐ (3 bread) 100 ☐(4 bread) 150 ☐(5 bread) 200 ☐(6 bread)

III. Maize

a. Frequency of rice consumed

Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 bread) 50 ☐ (2 bread) 75 ☐ (3 bread) 100 ☐(4 bread) 150 ☐(5 bread) 200 ☐(6 bread)

2. Vegetables

I. Leafy vegetables

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/2 saucer) 100 ☐ (1 saucer) 150 ☐(1+1/2 saucer) 200 ☐(2 saucer) 250 ☐(2+1/2 saucer)

II. Potato

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/2 saucer) 100 ☐ (1 saucer) 150 ☐(1+1/2 saucer) 200 ☐(2 saucer) 250 ☐(2+1/2 saucer)

III. Raddish

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/2 saucer) 100 ☐ (1 saucer) 150 ☐(1+1/2 saucer) 200 ☐(2 saucer) 250 ☐(2+1/2 saucer)

IV. Brinjal/Eggplant

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/2 saucer) 100 ☐ (1 saucer) 150 ☐(1+1/2 saucer)
200 ☐(2 saucer) 250 ☐(2+1/2 saucer)

V. Tomato

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/2 saucer) 100 ☐ (1 saucer) 150 ☐(1+1/2 saucer)
200 ☐(2 saucer) 250 ☐(2+1/2 saucer)

VI. Cauliflower

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/2 saucer) 100 ☐ (1 saucer) 150 ☐(1+1/2 saucer)
200 ☐(2 saucer) 250 ☐(2+1/2 saucer)

Vll. Cabbage

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/2 saucer) 100 ☐ (1 saucer) 150 ☐(1+1/2 saucer)
200 ☐(2 saucer) 250 ☐(2+1/2 saucer)

Vlll. Beans

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/2 saucer) 100 ☐ (1 saucer) 150 ☐(1+1/2 saucer)
200 ☐(2 saucer) 250 ☐(2+1/2 saucer)

lX. Others-1 (name:______________________)

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/2 saucer) 100 ☐ (1 saucer) 150 ☐(1+1/2 saucer) 200 ☐(2 saucer) 250 ☐(2+1/2 saucer)

X. **Others-2** (name:______________________)

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)
0 ☐ (0 saucer) 50 ☐(1/2 saucer) 100 ☐ (1 saucer) 150 ☐(1+1/2 saucer)00 ☐(2 saucer) 250 ☐(2+1/2 saucer)

X. **Others-3** (name:______________________)

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed
0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)
0 ☐ (0 saucer) 50 ☐(1/2 saucer) 100 ☐ (1 saucer) 150 ☐(1+1/2 saucer) 200 ☐(2 saucer) 250 ☐(2+1/2 saucer)

3. Meat

I. Beef

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

II. Chicken

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

Mutton

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

Others (name____________________)

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

4. Fish

I. Hilsha 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed
0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)
0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

II. Tuna 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

III. Rupchanda 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

IV. Crab 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed
0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)
0 ☐ (0 piece) 50 ☐(1 piece) 100 ☐ (2 piece) 150 ☐(3 piece)
200 ☐(4 piece) 250 ☐(5 piece)

V. Panghas 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

c. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

VI. Rui 

a. Frequency of consuming

Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

c. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

VII. Katla 

a. Frequency of consuming

Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

VIII. Taki 

a. Frequency of consuming

Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

c. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

IX. Tilapia 

a. Frequency of consuming

Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

c. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

X. **Punti** 

a. Frequency of consuming

Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

XI. **Tengra** 

a. Frequency of consuming

Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

XII. **Mola** 

a. Frequency of consuming

Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

XIII. Koi 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

XIV. Shing 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

XV. Magur 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

XVI. Shrimp 

a. Frequency of consuming

Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 25☐(1/3 saucer) 50 ☐ (1/2 saucer) 100 ☐(1 saucer) 150 ☐(1+1/2 saucer) 200 ☐(2 saucer)

XVII. Others-2 (name____________________)

a. Frequency of consuming

Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer)

200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

XVIII. Others-3 (name____________________)

a. Frequency of consuming

Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

XIX. Others-4 (name____________________)

a. Frequency of consuming

Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

XX. Others-5 (name___________________)

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1/3 saucer) 100 ☐ (1/2 saucer) 150 ☐(1 saucer) 200 ☐(1+1/2 saucer) 250 ☐(2 saucer)

5. Fruits

i. Apple 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 portion) 25 ☐(1/4 portion) 50 ☐ (1/2 portion) 100 ☐(1 piece) 200 ☐(2 pieces) 300 ☐(3 pieces)

ii. Banana 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 portion) 50 ☐(1piece) 100 ☐ (2 portion) 150 ☐(3 piece) 200 ☐(4 pieces) 250 ☐(5 pieces)

iii. Mandarin 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 portion) 25 ☐(1/4 portion) 50 ☐ (1/2 portion) 100 ☐(1 piece) 200 ☐(2 pieces) 300 ☐(3 pieces)

iv. Water melon 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 portion) 50 ☐(1portion) 100 ☐ (2 portion) 150 ☐(3 portion) 200 ☐(4 portion) 250 ☐(5 portion)

v. Grape 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1 saucer) 100 ☐ (2 saucer) 150 ☐(3 saucer) 200 ☐(4 saucer) 250 ☐(5 saucer)

vi. Guava 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 portion) 50 ☐(1piece) 100 ☐ (2 portion) 150 ☐(3 piece) 200 ☐(4 pieces) 250 ☐(5 pieces)

vii. Mango 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 100 ☐(1/2 saucer) 200 ☐ (1 saucer) 300 ☐(1+1/2 saucer) 400 ☐(2 saucer) 500 ☐(2+1/2 saucer)

viii. Jackfruit 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 100 ☐(1/2 saucer) 200 ☐ (1 saucer) 300 ☐(1+1/2 saucer) 400 ☐(2 saucer) 500 ☐(2+1/2 saucer)

ix. Litchi 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1 saucer) 100 ☐ (2 saucer) 150 ☐(3 saucer) 200 ☐(4 saucer) 250 ☐(5 saucer)

x. Milk 

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 glass) 125 ☐(1/2 glass) 250 ☐ (1 glass) 375 ☐(1+1/2 glass) 500 ☐(2 glass) 625 ☐(2+1/2 glass)

xi. Other drink-1 (name___________________)

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 glass) 125 ☐(1/2 glass) 250 ☐ (1 glass) 375 ☐(1+1/2 glass) 500 ☐(2 glass) 625 ☐(2+1/2 glass)

xii. Other drink-2 (name___________________)

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 glass) 125 ☐(1/2 glass) 250 ☐ (1 glass) 375 ☐(1+1/2 glass) 500 ☐(2 glass) 625 ☐(2+1/2 glass)

xiii. Other fruits-1 (name_________________)

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1 saucer) 100 ☐ (2 saucer) 150 ☐(3 saucer) 200 ☐(4 saucer) 250 ☐(5 saucer)

xiv. Other fruits-2 (name_________________)

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 saucer) 50 ☐(1 saucer) 100 ☐ (2 saucer) 150 ☐(3 saucer) 200 ☐(4 saucer) 250 ☐(5 saucer)

xv. Other fruits-3 (name__________________)

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 portion) 50 ☐(1piece) 100 ☐ (2 portion) 150 ☐(3 piece) 200 ☐(4 pieces) 250 ☐(5 pieces)

xvi. Other fruits-4 (name__________________)

a. Frequency of consuming
Daily ☐ Weekly ☐ Monthly ☐

Number of times consumed

0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

b. Weight of each consumption (g)

0 ☐ (0 portion) 50 ☐(1piece) 100 ☐ (2 portion) 150 ☐(3 piece) 200 ☐(4 pieces) 250 ☐(5 pieces)

Appendix C: Human Research Ethical Approval

香港教育大學
The Education University of Hong Kong

13 February 2020

Mr Md ROKONUZZAMAN
Research Postgraduate Programmes
Graduate School

Dear Mr Rokonuzzaman,

Application for Ethical Review <Ref. no. 2019-2020-0187>

I am pleased to inform you that approval has been given by the Human Research Ethics Committee (HREC) for your research project:

Project title: Arsenic in Rice and Vegetables: Human Body Loading, Perception and Mitigation Strategy

Ethical approval is granted for the project period from 13 February 2020 to 12 August 2021. If a project extension is applied for lasting more than 3 months, HREC should be contacted with information regarding the nature of and the reason for the extension. If any substantial changes have been made to the project, a new HREC application will be required.

Please note that you are responsible for informing the HREC in advance of any proposed substantive changes to the research proposal or procedures which may affect the validity of this ethical approval. You will receive separate notification should a fresh approval be required.

Thank you for your kind attention and we wish you well with your research.

Yours sincerely,

[redacted]

Patsy Chung (Ms)
Secretary
Human Research Ethics Committee

c.c. Professor CHOU Kee Lee, Chairperson, Human Research Ethics Committee

香港新界大埔露屏路十號
10 Lo Ping Road, Tai Po, New Territories, Hong Kong
T (852) 2948 8888 F (852) 2948 6000 www.eduhk.hk

Appendix D: Consent Form

CONSENT FORM FOR PARTICIPANTS

THE EDUCATION UNIVERSITY OF HONG KONG

Department of Science and Environmental Studies

CONSENT TO PARTICIPATE IN RESEARCH

Arsenic in Rice and Vegetables: Human body loading, perception and mitigation strategy

I ____________________ hereby consent to participate in the captioned research supervised by Dr. Li Wai Chin and conducted by Md. Rokonuzzaman, who are staff and students of the Department of Science and Environmental Studies in The Education University of Hong Kong, respectively.

I understand that information obtained from this research may be used in future research and may be published. However, my right to privacy will be retained, i.e., my personal details will not be revealed.

The procedure as set out in the **attached** information sheet has been fully explained. I understand the benefits and risks involved. My participation in the project is voluntary.

I acknowledge that I have the right to question any part of the procedure and can withdraw at any time without negative consequences.

Name of participant ____________________

Signature of participant ____________________

Date ____________________

INFORMATION SHEET

Arsenic in rice and vegetables: Human body loading, perception and mitigation strategy

You are invited to participate in a project supervised by Dr. Li Wai Chin and conducted by Md. Rokonuzzaman, who is staff and student of the Department of Science and Environmental Studies in The Education University of Hong Kong, respectively.

The introduction of the research

A) Why were you chosen for this research?

As stated earlier, farmers from an arsenic-affected agricultural area have been chosen purposively for this research. The main reason is that if farmer's participatory involvement can be assured in this research they will easily understand the reality and they may adopt mitigation strategies which lead them to save the population by minimizing the problems related to arsenic toxicities.

The methodology of the research

A) Describe how many participants you will include in this study

A total of 200 active rice and vegetable growers (hair donors) in the age range above 18 will constitute the participants of the study

B) Procedure of the research

Data will be collected related to farmers' personal, social, economic and psychological background.
Altogether individual farmer needs to participate for 1 (one) hour for only a single day.

C) Potential benefits (including compensation for participation)

However the participation will be voluntary and no compensation for participation will be made.

The potential risks of the research

There is no possibility of occurring any potential risk or discomfort to the participants in this study.

If you would like to obtain more information about this study, please contact Md. Rokonuzzaman at telephone number [redacted] or their supervisor Dr. Li Wai Chin at telephone number [redacted]
If you have any concerns about the conduct of this research study, please do not hesitate to contact the Human Research Ethics Committee by email at hrec@eduhk.hk or by mail to Research and Development Office, The Education University of Hong Kong.

Thank you for your interest in participating in this study.

Md Rokonuzzaman
Principal Investigator