Volume: 5, Issue: 8
Page: 305-328
2021

International Journal of
Science and Business
Journal homepage: ijsab.com/ijsb

IJSAB International

A review of arsenic contamination and evaluation of its role by water quality index in Faridpur Sadar Upazila, Bangladesh

Anika Tahsin & Md. Aminul Islam Khan

Abstract

Large-scale mass poisoning through arsenic contaminated groundwater is a global concern and Bangladesh is among the countries exposed to high concentrations of arsenic in groundwater. As arsenic is a widespread contaminant, several studies have been conducted on it but only a few of these studies were held on micro regions by assessing its role on water quality index. In this study, the source and mobilization of arsenic, its effect on soil and plant, level and consequence of toxicity in human health along with current and potential methods to eliminate arsenic from groundwater in Bangladesh were reviewed based on previous researches. Along with the review, an experimental study was also carried out in an arsenic prone region of Bangladesh named Faridpur Sadar Upazila to delineate the role of arsenic in contamination by generating two synthetic scenarios where water quality was measured by the weighted arithmetic water quality index (WQI) method. From the review it was found that, both geogenic, as well as anthropogenic sources, contribute to arsenic affluence in groundwater in Bangladesh. The most accepted theory states that the Himalayan is the primary geogenic source of arsenic in the Bangladesh. Arsenic arrived in the aquifer transported with sediments which eventually releases into groundwater by several biogeochemical processes. This arsenic-contaminated groundwater is extensively used for drinking purpose and irrigation resulting in accumulation of arsenic in human body, soils and plants. Moreover, the accumulated arsenic in soil and plants transmits into the human body jeopardizes human health. Though, several arsenic removal technologies are now in practice in Bangladesh, more eco-friendly and convenient methods may be utilized to attenuate the level of toxicity. The experimental study revealed that, if the arsenic amount was reduced from the present condition, the overall WQI increases considerably. At one location, the index changed from category E to category B while considering a synthetic scenario of no arsenic in water. This indicates that arsenic is the key pollutant of groundwater in the area. This paper expects the kind attention of the local people and policymakers about the severity of arsenic pollution in the region.

IJSB
Accepted 12 July 2021
Published 29 July 2021
DOI: 10.5281/zenodo.5144547

Keywords: *Arsenic, Water Quality Index (WQI), Drinking Water, Water Contamination, Source and Health Impact, Bangladesh.*

About Author (s)

Anika Tahsin, Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh

Md. Aminul Islam Khan (corresponding author)**,** Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh. Email: aminulislam381@gmail.com

1. Introduction

In Bangladesh, groundwater is the key supplier of water for drinking, domestic purpose, and irrigation. Therefore, the quality of groundwater plays a vital role in maintaining the quality of human life which is controlled by different factors like anthropogenic activities, geologic formation, and mineralogy of the area (Swarnokar et al., 2019). Unfortunately, in Bangladesh, the quality along with the quantity of groundwater is deteriorating (Islam et al., 2017). Presently, the deterioration of groundwater quality is an emerging problem in Bangladesh (Shahidullah et al., 2000; Raihan and Alam, 2008; Bahar and Reza, 2010; Rahman et al., 2012; Biswas et al., 2014). Being the principal groundwater contaminant in Bangladesh (Figure-1), arsenic poisoning has become among the most significant natural catastrophes in the world (Das et al., 2004). When, contamination has become a major threat to Earth's stability and human survival (Landrigan et al., 2018), globally the first toxic substance reported to propagate in the hydrosphere is arsenic (Masuda, 2014). River basins of Southeast Asia which lie within GBM Delta is severely affected by arsenic contamination in groundwater (Panaullah et al., 2009; Tondel et al., 1999; Chakraborti et al., 2013; Chakraborti et al., 2016). Specifically in West Bengal and Bangladesh, arsenic concentration as high as 1000 µg/L which makes it the most contaminated groundwater of the world (Mondal et al., 2007; Chowdhury et al., 1997; Bhattacharya et al., 2014). It is anticipated that, apart from different anthropogenic activities, the primary source of arsenic is geogenic which is the Himalayan. Originating from the Himalayan, arsenic enters the aquifer system being sorbed into sediments and under different biogeochemical processes and chemical conditions, arsenic releases, and mobilizes into groundwater.

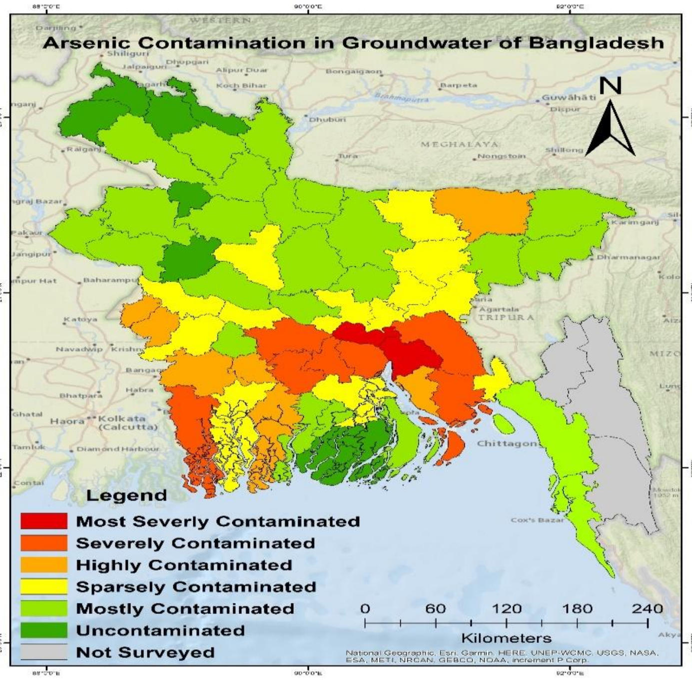

Figure-1: Overview of arsenic contaminated regions of Bangladesh (Chowdhury et al., 2006)

It is termed as the class (I) human carcinogenic element which is widely distributed in both organic and inorganic form in the environment (Hughes et al., 2011; Bailey et al., 2009). Through drinking water along with industrial activities, almost 100 million people are exposed to more than 50µg/L arsenic concentrations (Moon et al., 2012; Vather, 2008). Consumption of inorganic arsenic-contaminated groundwater for drinking purposes in Bangladesh is one of the largest mass poisonings in history (Smith et al., 2000). Generally, arsenic is found in subsurface water. Around 30-35 million people are using arsenic-contaminated drinking water in Bangladesh (BGS, 2001). Originating from bedrock and leaching into groundwater, inorganic arsenic is of major concern for drinking water (Welch et al., 2000). Moreover, agrarian production utilizing arsenic-contaminated irrigation water endangers food quality (Juhasz et al., 2006). This poses a potential risk to human health as its toxicity can transmit into the human body through the consumption of groundwater and plant-animal food chain. Moreover, constantly recurring exposure to arsenic is the prime cause of arsenic-induced mortality (Chen and Ahsan, 2004). Different research testified the relations of arsenic exposure with different diseases (i.e., cancer, diabetes, bronchitis hypertension, skin lesions, and other vascular diseases) (Rahman et al., 1999; Chen et al., 1995; Mitra et al., 2004). Arsenic also affects the liver, kidney (Yuan et al., 2010), and lungs (Smith et al., 2006) along with causing skin diseases (Yu et al., 2006) and bladder cancer (Marshall et al., 2007). The presence of high arsenic concentration in aquifer led to widespread arsenic poisoning which augmented the necessity to study arsenic into groundwater in the region and the most researched groundwater system in the world is Bangladesh (Smedly and Kinniburgh, 2002; Haque and Johannesson, 2008; Haque,2018; Mukherjee, 2018).In Bangladesh, arsenic poisoning in groundwater has been identified in 59 districts out of 64 districts around the country (Islam et al., 2004). Arsenic contamination is a key factor affecting the deterioration of groundwater quality especially in the central part of Bangladesh (Kinniburgh and Smedley, 2001) and Faridpur is among the most dreadfully affected districts among these (Saifullah ,1999; Frisbie et al., 2002; Murcott, 2012). A study conducted by (Khan and Bakar, 2020) revealed that, in the Faridpur district, the risk of having an arsenic level greater than 10 ppb in household drinking water is greater than 70%. If attention is not given, this situation might exacerbate. Thus, comprehensive knowledge of the source, mobilization, and effect of arsenic on human health in Faridpur is required to delineate the complete arsenic situation of the region. Moreover, to comprehend the severity of the problem, it is also necessary to envisage the picture without the problem. For this reason, analysis of the change of water quality along with different levels of arsenic in drinking water is irrefutable to evaluate the effect of arsenic. In this regard, the water quality index (WQI) is among the most efficacious and convenient methods (Akter et al., 2016). As different types of pollutants coexist in groundwater and the WQI represents the quality of water considering the effect of all these pollutants, it will be convenient to observe the effect of change of arsenic level on overall water quality. What if the concentration of arsenic was reduced to half of the present concentration or what if there was no arsenic in the area? How the water quality would have been? How much influence does arsenic have on the water quality of the region?

The present study intends to bring to light the severity of arsenic pollution of groundwater in Faridpur Sadar Upazila, an arsenic affected unit under the Faridpur district of Bangladesh. The review will provide plausible reasons for arsenic enrichment, the effect of arsenic on the plant, conventional arsenic remedial technologies, and the effect of arsenic on the human health concentrating the region. Along with that, an experimental study was also carried out to demonstrate the acuteness of arsenic on groundwater using the Weighted Arithmetic water quality index method. The aim was to alert the local people and policymakers about arsenic pollution by illustrating its present scenario along with its effect on the whole water quality.

2. Review on source, mobilization, toxicity, health impact, and remedial technologies of arsenic

2.1 Source and Mobilization of arsenic

Groundwater containing a high concentration of arsenic has been identified in Bangladesh, West Bengal (India), Argentina, Chile, Hungary, China, and Vietnam which has urged the

reevaluation of the reasons behind the source and distribution of arsenic in the natural system (Smedley and Kinniburgh, 2002). The alluvial aquifers of the Ganges delta are contaminated with naturally appearing arsenic (Kabir et al., 2016). In the Bengal delta, arsenic was first discovered in 1980 whereas, in 1993, a trace of arsenic was identified in three districts of Bangladesh. Globally, Bangladesh is among the most dreadfully affected region to arsenic contamination occupying a large number of people directly exposed to arsenic toxicity (Smedley and Kinniburgh, 2002). Adjacent to the banks of major rivers, the most severely arsenic affected areas are situated (Zimmermann et al., 2010). The scale of arsenic concentration in Bangladesh has augmented the necessity of an in-depth study of the alluvial aquifers. Several studies have been conducted to identify the origin and abundance of arsenic in the groundwater of Bangladesh. Faridpur district is situated on the Ganges delta. Here, it was found that arsenic concentration increases with depth in wells (Nickson et al., 1998). The average soil arsenic concentration of the Faridpur District was found to be almost three times higher than the world limit (Ahsan et al., 2009). A comprehensive study conducted by (Bodrud-Doza et al., 2016) established that both geogenic and anthropogenic sources i.e., rock-water interaction are responsible for deteriorating the quality of groundwater in Faridpur. Being situated within the Ganges delta, the occurrence and mobilization mechanism of arsenic in the Faridpur district largely follows the Ganges Delta.
The concentration of arsenic increases from 20-40 m depth below ground and again decreases to a considerably low concentration between 100-200m (Ravenscroft et al., 2005). The shallow aquifer is the main source of arsenic which has been exploited mostly (Das et al., 2004). Arsenic in the shallow aquifer may increase over the years (Ravenscroft et al., 2005). On the other hand, in most cases, deep aquifers are found to be free of arsenic contamination. In the case of soil, the mean concentration of arsenic in surface soil (0- 15 cm) is usually higher than sub-surface soil (30 cm depth) (Ravenscroft et al., 2011). Clay soils have a greater affinity to bind with arsenic compared to sandy soil (Heikens et al., 2006). The geological and geochemical condition at different depth of soil determines the concentration of arsenic. During monsoon, when the water table is replenished by water, the arsenic seeps into the tube well (Karim et al., 1997). It is anticipated that, for a thousand years, arsenic has been present in groundwater (Akhter and Ali, 2011). Both anthropogenic activities and geogenic processes are responsible for high arsenic enrichment in groundwater in Bangladesh (Hossain et al., 2006; Josepth et al., 2015). The anthropogenic activities include the use of pesticides and fertilizers, extensive use of coal in thermal power plants, expansion of chemical industries, mining, overexploitation of shallow aquifer, and irrigation using arsenic-contaminated water (BGS, 2001; Christodoulidou et al., 2012; Kumar et al., 2016; Stollenwerk et al., 2016; Huq et al., 2018; Harvey et al., 2006) reveals that the utilization of irrigation water in rice fields may transport arsenic from near-surface sediments. For the geogenic source of arsenic, it is anticipated that the source may lie upstream of Bangladesh where arsenic is sorbed to iron oxyhydroxides (Nickson et al., 2000). The main geogenic source is assumed to be the Himalayan orogenic belt. The aquifer sediments of N and NW parts of Bangladesh are postulated to be originated from here (Verma et al., 2019). As Arsenic can derive from several kinds of bedrock, the arsenic enriched minerals in this region are hypothesized to be derived from chemical weathering of the Himalayan rocks (Albright et al., 2012; Acharyya et al., 2000; Guillot and Charlet, 2007; Mukherjee et al., 2014). Different geological processes like rock weathering, deposition of hydrochemical ore, volcanic movement, bushfire, flooding, and leaching of geological formation in the Himalayan range make it an arsenic reservoir (Huq et al., 2018). Eventually, this arsenic enriched sediment was transported to the Ganges Delta Basin by sedimentary process (Chakraborty et al., 2015; Huq et al., 2020). After that, under the favorable biogeochemical condition of the aquifer, arsenic enters into groundwater from the arsenic sorbed sediment.

It has been noted that, compared to the arsenic concentration in soils and sediments, groundwater bears less arsenic concentration. For instance, a study conducted by (Seddique et al., 2011) found an arsenic concentration of 5 to 16 mg/kg in aquifer sediments wherein groundwater was > 1 mg/L. This indicates that arsenic concentration in groundwater depends predominantly on the aquatic environment and chemical condition of the host phase which are redox condition and pH of water that control the escape of arsenic from aquifer sediment (Masuda, 2018). It was observed that moderate alkalinity, $HCO3^-$ and low concentration of NO_3^- and SO_4^{2-} induce the release of arsenic into groundwater (Huq et al., 2018; Bayatkashkoli et al., 2017). Bangladesh is subjected to arsenic contamination due to aquifers containing Cenozoic sediments (Masuda, 2018; Ravenscroft et al., 2005). The aquifers are alluvial formation which consists of the Pleistocene and Holocene sediments of the Ganges Delta (Christodoulidou et al., 2012). In the aquifers, iron oxyhydroxide exists as sedimentary grains or coatings. Under the reductive dissolution of iron oxyhydroxide, the arsenic sorbed to its releases. The higher concentration of dissolved organic carbon (DOC) and a lower concentration of NO_3^- and SO_4^{2-} indicate the reducing environment of the subsurface aquifer of Ganges Delta Plain where plentiful organic matter is deposited with sediment containing iron and manganese (Halim et al., 2009; Kinniburgh and Smedley,2001). Microbial metabolism of organic matter of sediments stimulates the reduction of iron (Swarnokar et al., 2019). From this, it can be inferred that biodegradation of organic matter and reductive dissolution of iron oxyhydroxide are the two dominant mechanisms that release arsenic into aquifers (Halim et al., 2009). Another study suggests that at the lower part of the Holocene aquifer, enrichment of organic matter, and biotite along with the chemical dissolution of these substances have a contribution to the arsenic release mechanism (Seddique et al., 2008). The hypothesis that due to lowering of water level, oxygen enters into the aquifer and executes oxidation of arsenic bearing pyrite thus release of arsenic to groundwater occurs (Das , 1995; Das et al., 1996) is discordant as if this has occurred then arsenic would not be present in groundwater and be adsorbed to FeOOH which is the product of oxidation (Thornton , 1996). According to many authors, long-term geochemical changes and due to oxidation of arsenopyrites (core compound of arsenic), arsenic released in aquifers (Mandal et al., 1996). Though some authors contradict this by stating that arsenopyrite does not directly mobilize arsenic (Halim et al., 2009).

As stated above, a moderate alkaline environment along with reductive conditions resulting from biogeochemical activities, act as a key factor in the amplified arsenic release into groundwater. The process of flushing solutes from aquifers and transport them into the subsurface is complex. Different studies (Mukherjee et al., 2008; Radloff et al., 2017; Tareq et al., 2013) have stated that, in mobilizing arsenic, redox reaction associated with microbial activities plays a key role. The organic matter present in the aquifer act as the factor to conduct the redox reaction of iron oxyhydroxide which consequently mobilizes arsenic (Tareq et al., 2013; Reza et al., 2010; Xie et al., 2012). In the case of Bangladesh, both the reductive environment of aquifer along with redox reaction of iron oxyhydroxide is responsible for the occurrence and mobilization of arsenic (Shamsuddaha et al., 2008). Moreover, a substantial amount of organic matter derived from anthropogenic sources like pesticides, insecticides, human waste may accumulate in shallow aquifers and thus influence the mobilization of arsenic. The reduction of arsenate to arsenite can also act as a factor contributing mobilization of arsenic (Huq et al., 2020). The redox reaction influenced predominantly by microbial activities plays a vital role in arsenic mobilization (Harvey et al., 2005). Also, the ion exchange mechanism of different arsenic host substances like sediment, chlorine enriched wastewater, phosphate fertilizer plays a significant role in arsenic mobilization (Caporale et al., 2018; Mukhopadhyay et al., 2017; Nazari et al., 2017; Yang et al., 2017; Gao et al., 2013; Michael and Khan, 2016). Sulfate-reducing bacteria like Acinetobacter and Brevundimonas play a vital role in SO_4^{2-} a reduction which in turn poses an influential role in arsenic mobilization (Bahar et al., 2016; Xie et al., 2013; Akhter et al., 2017; Zhang et al., 2017). This indicates the importance of the presence of sulfate-reducing bacteria in groundwater. From all these, it can be inferred those different types of substances originating both from geogenic and anthropogenic sources are associated with different biogeochemical processes which along with their influence in the aquifer environment play a significant role in mobilizing arsenic in the groundwater of Bangladesh. A diagram showing the key feature and mechanism governing the arsenic occurrence in Bangladesh is shown in figure-2.

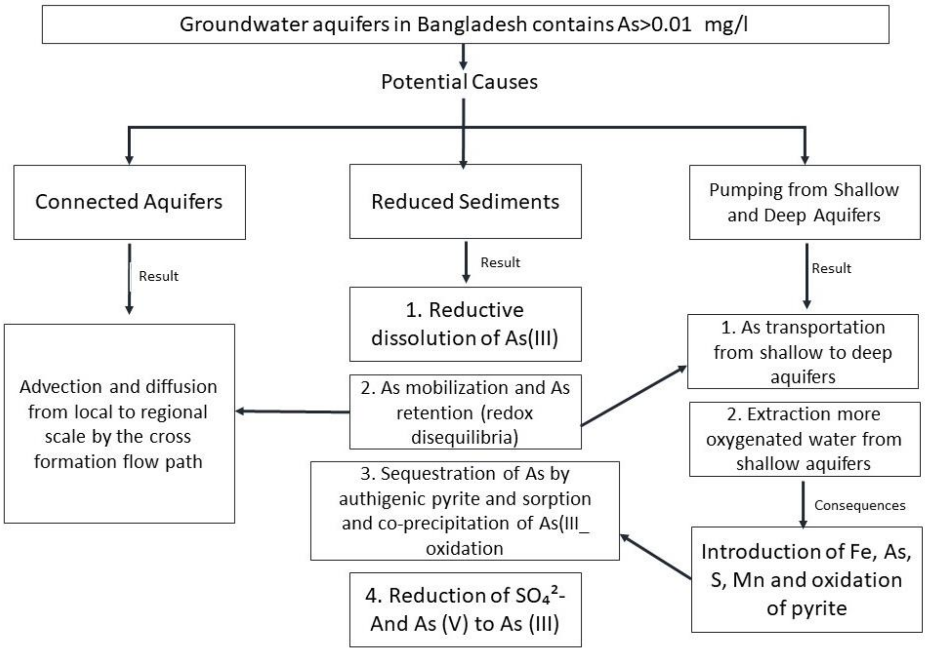

Figure-2: Key features and mechanism governing arsenic occurrence in Bangladesh (Mukherjee et al., 2011; Huq et al., 2020)

2.2 Soil toxicity and Phytotoxicity

From an agricultural point of view, arsenic-contaminated irrigation water jeopardizes human health as it can convey toxicity to both crop and soil and can be transported into the food chain (Meharg et al., 2009; Zhao et al., 2010; Heikens et al., 2007; Huq et al., 2006; Juhasz et al., 2006; Williams et al., 2005; Zavala et al., 2005). In Bangladesh, arsenic concentration in surface soil has been raised due to the extensive extraction of arsenic-contaminated groundwater (Meharg et al., 2003). A study conducted by (Das et al., 2004), found a significant linkage between the level of arsenic contamination in water and the amount of arsenic in the soil which resulted in a higher accumulation of arsenic in rice, vegetables, and fishes in areas experiencing a higher level of arsenic contamination. Moreover, human exposure to arsenic elevates through the plant-animal-human path if cattle are fed rice straw which is grown using arsenic-contaminated water (Abedin et al., 2002).

The concentration of soil arsenic also disturbs rice plant growth. Arsines (formation when arsenic comes in contact with acid) harms rice plant roots which hinders nutrient uptake of plants (Chakraborti et al., 2013). As the concentration of arsenic in soil increases, the rice straw arsenic content also increases. It was also found that rice naturally accumulates arsenic (Lin et al., 2015; Su et al., 2010; Williams et al., 2007) which is a major issue as Bangladesh is one of the leading countries producing rice. Compared (Islam et al., 2004) to other districts,

the level of arsenic contamination both is soil, and water was found to be severe in Faridpur district. A study conducted in the Faridpur district revealed that using arsenic-contaminated shallow groundwater for irrigation for a longer period (16-17 years) led to the accumulation of arsenic in the soil which resulted in higher arsenic concentration in rice. (Heikens et al., 2007). Moreover, being the main diet of cattle, rice straw adversely affects the condition of animal health and it was found that the arsenic concentration of cattle manure is almost the same as the arsenic concentration of the straw (Panaullah et al., 2009). This in terms led to an increase of human exposure to arsenic as manure is utilized as kitchen fuel (Pal et al., 2007).
A micro-regional study on (Kabir et al., 2016) Faridpur Sadar Upazila of the Faridpur district of Bangladesh found that in a rice plant, straw and husk accumulate the highest amount of arsenic followed by rice grain. The study found that, on rice straw, 57% had arsenic concentration more than 2 ppm whereas only 13% contained less than 1 ppm arsenic. It was also found that, if the elevation of the land is taken into account, the lower areas contain a higher amount of arsenic concentration than elevated areas as irrigation water could retain for a longer period in lower elevated land. In that sense, micro elevation can play as an arsenic accumulating factor into the soil. Arsenic accumulation increases in rice plants if irrigation water is arsenic contaminated which may transmit to the food chain.

2.3 Impact on human health

Arsenic contamination is considered a global concern as almost 140 million people are exposed to arsenic-contaminated drinking water (concentration >10 ppb) worldwide (Argos et al., 2010; Rahman et al., 2002). Arsenic exposure through drinking water greater than the WHO recommended concentration (WHO, 2011) has adverse influences on human health (Bhattacharya et al., 2014). According to the International Agency for Research on Cancer, arsenic is classified as Group 1 carcinogenic to humans (IARC, 2004). Rather than air and soil, ingestion by diet is the prime medium of arsenic in humans (Khan et al., 2009; Ourshalimian et al., 2019). Moreover, chronic ingestion of higher concentration arsenic leads to severe complexity in the health system. Furthermore, the chemical composition of arsenic holds significance in this regard. It was found that arsenic (III) is more toxic than Arsenic (V) (Hughes et al., 2011) and the inorganic form is usually more toxic than the organic form. Studies confirmed the association of arsenic exposure to the growth factor, signaling, cancer, metabolism-related diseases, and metabolic syndrome, Tumorigenesis in the skin, kidneys, bladder, liver, and lungs, kidney failure, adverse reproductive outcomes, skin lesions, peripheral neuropathy, cardiovascular disease diabetes mellitus, chronic bronchitis and hematological diseases (Rehman et al., 2020; Ditzel et al., 2016; Shi et al., 2014; Arteel et al., 2008; Mandal et al., 2001; Cantor et al., 2006; IARC, 1982). From children to adults, chronic arsenic consumption via drinking water led to pulmonary disorders along with complications in the dermatological, cardiovascular, neurological, and reproductive systems (Vahter, 2008, Argos et al., 2015; Chen et al., 2004; Chen et al., 2011; Dauphine et al., 2013; Smith et al., 1998; Sohel et al., 2010; Vahter et al., 2006; Waserman et al., 2004).

Chronic ingestion of arsenic can cause skin diseases like hyperpigmentation and hyperkeratosis. (Merian et al., 1981; WHO, 1981) Moreover, due to chronic arsenic consumption, the Blackfoot disease occurs which causes dry gangrene and sometimes ends with separating the affected part of the body. (WHO, 1981). "Arsenicosis"- a medical complication can occur due to long-term exposures to arsenic which is more like to occur in the skin and some of its symptoms are composed of keratosis, melanosis, and pigmentation (Rahman et al., 2009; McCarty et al., 2011). Chronic exposure to arsenic can enhance the risk of cancer and non-cancerous health hazards (Medina-Pizzali et al., 2018; Sharma et al., 2017). Some evidence shows that arsenic ingestion has the potential to cause cancer of the liver, bladder, and other organs (WHO, 1981; Smith et al., 1992). Prolonged exposure to arsenic may lead to dermatological, respiratory, cardiovascular, and neurological diseases (Broberg et al., 2014). Through drinking, consumption of arsenic of 10 to 300µg/L which is labeled as low to a moderate level, different types of neurological and respiratory complications, skin lesions, circulatory disorders, diabetes, hepatic and renal dysfunction including mortality due to chronic diseases occurs (Chen et al., 2009). In different studies, arsenic exposure seems to have a positive correlation with spontaneous abortion (Borzsonyi et al., 1992; Milton et al., 2005; Ahmed et al., 2001), preterm birth (Ahmed et al., 2001), stillbirth (Borzsonyi et al., 1992; Milton et al., 2005; Ahmed et al., 2001; Hopenhayn-Rich et al., 1992), low birth-weight (Smith et al., 1992), and infant mortality (Hopenhayn-Rich et al., 1992),). A low level of arsenic can have an association with hyperuricemia and gout (Kuo et al., 2015).

Arsenic exposure may change life-sustaining processes like metabolism, stress, and damage responses, cell signaling, and growth factor signaling (Bustaffa et al., 2014; Ghosh et al., 2008). High arsenic exposure may have negative impacts on the cardiovascular system which can increase morbidity and mortality rate (Navas-Acien et al., 2005; States et al., 2009). Exposure to arsenic through drinking water is considered to be a cause of excess mortality due to cardiovascular illness amongst inhabitants in some countries including Taiwan, Chile, and Japan (WHO, 1981). Arsenic toxicity can target the brain easily (Munday et al., 2013). Different studies (Rahman et al., 1999; Chen et al., 1995; Yang et al., 2007; Parvez et al., 2010) have found a connection between long-standing arsenic consumption and hypertension tendency in humans. Arsenic is responsible for few respiratory diseases including shortness of breath, chronic cough, blood in sputum, chest sounds, and other breathing issues (Parvez et al., 2010). Organisms that are exposed to arsenic, experience detrimental effect on the immune system (Selgrde et al., 2007; Vahter, 2008).

Bangladesh is a country that is facing a disastrous arsenic hazard in human history (Khan et al., 2003). As surface water is unsafe for drinking due to microbial contamination, more than 90% of people of Bangladesh depend on groundwater. In surface water, arsenic is found as arsenic (v) and groundwater arsenic exists as arsenic (III). Compared to arsenic (v), arsenic (III) is more toxic and it can be easily absorbed through the skin of the human body. In Bangladesh, the detrimental effects of arsenic on human health were first identified after 1993. The fact that the people affected by arsenic poisoning mainly extract drinking water from shallow tube wells was established during the late 1990s (Ravenscroft et al., 2005; Smith et al., 2000; Chowdhury et al., 1999). For drinking and cooking purposes, most people were directly exposed to the most toxic arsenic (III). In Bangladesh, of a total of 64 districts, the arsenic level of 53 districts is more than 0.01 mg/l and 42 districts more than 0.05 mg/l. (Chowdhury et al., 2000). 29% of tube-wells of 61 districts out of 64 districts of Bangladesh contain high concentration arsenic (Khan et al., 2006). It was estimated that 57 million natives in Bangladesh consume drinking water having an arsenic concentration of more than 0.01 mg/L (DPHE, 2001). By 1997, several cases of arsenic-induced dermal lesions were identified in Bangladesh (Smith et al., 2000; Smedley, 2002). According to Chowdhury et al. (2000) random examination of 11180 people, 2736(24.47%) found having arsenical skin diseases in 27 districts of Bangladesh with an arsenic level in drinking water above 0.30 mg/l (Chouwdhury et al., 2000). Disease like diffuse melanosis spotted melanosis, leucomelanosis, mucus membrane melanosis, diffuse keratosis, spotted keratosis, hyperkeratosis, gangrene, squamous cell carcinoma, skin, kidney, lung, liver, and bladder cancer were identified in Bangladesh and West Bengal by several epidemiological studies (Tondel et al., 1999; Mandal et al., 1996, Saha, 1995; Dhar et al., 1997; Mazumder et al., 1998). A study in Bangladesh shows that exposure to arsenic concentration may affect the mental health of individuals (Li et al., 2013) (e.g., depression). It was found that spontaneous abortion, stillbirth, and neonatal death are taking place due to the consumption of arsenic concentration up to 1710 μg/L via drinking. (Milton et al., 2005). Several studies have found that (Juan et al., 2001; Haque et al., 2003; Tondel et al., 1999), in Bangladesh, intake of high concentration arsenic led to arsenic-induced skin cancer. Drinking arsenic-contaminated water results in lung cancer (Ferreccio et al., 2000) as human lungs are highly vulnerable (Ravenscroft et al., 2005; Christodoulidou et al., 2012; Halim et al., 2009) to arsenic. A study conducted on Faridpur, Nawabgonj, Jessore, and Narayanganj area suggests that the person exposed to arsenic in drinking water are more likely to have hypertension with an average crude prevalence ratio of 1.7(Rahman et al., 1999). Another recent study on the relationship of arsenic exposure and reproductive health in Faridpur Sadar shows a trivial but statistically significant relationship between birth-defect and arsenic exposure (Kwok et al., 2006). The average range of arsenic concentration of four areas (Faridpur, Jessore, Narayangonj, and Nawabgonj) of Bangladesh range from 0.01-2.04 mg/l with skin lesions prevalence ratio of 30.1/100 in male and 26.5/100 in female (Tondel et al., 1999). 408 numbers of sampling test of arsenic in Faridpur shows an average concentration of 0.29 mg/l with the highest concentration of 1.62 mg/l. In Faridpur, 21% of the problems of skin diseases was found to be linked with arsenic contamination (Alaim et al., 2007). An overview of arsenic-induced health effects on the human body is shown in figure-3.

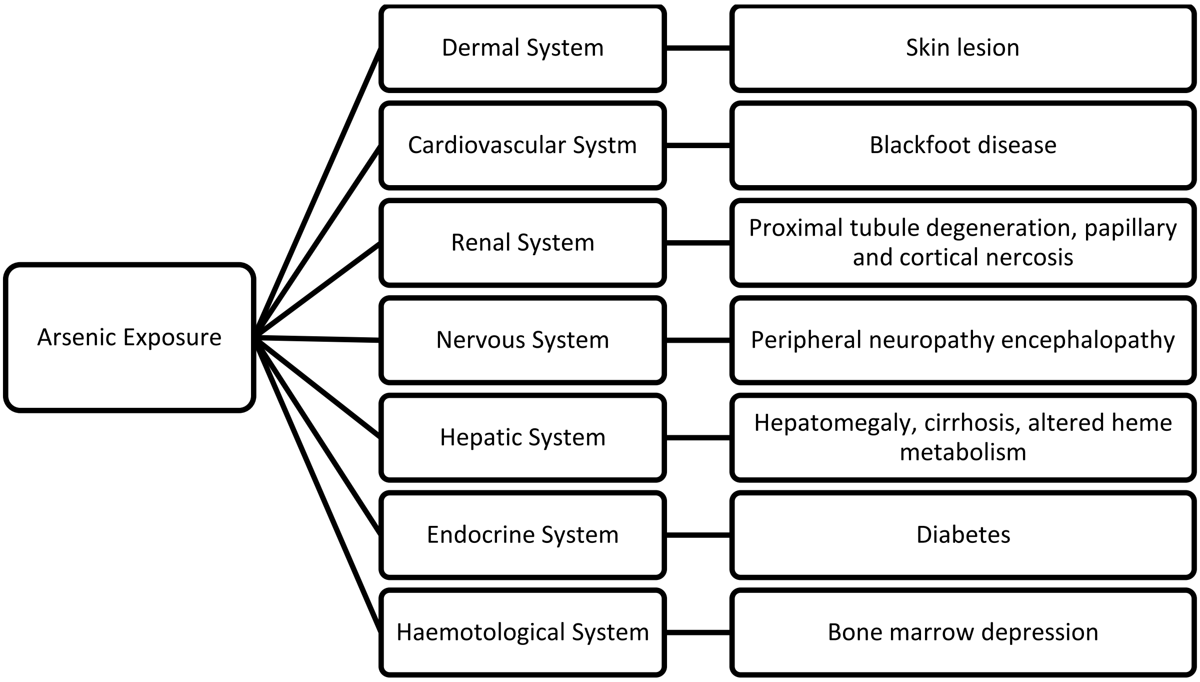

Figure-3: An overview of key effects of arsenic on important organ systems of human (Argos et al., 2015; Chen et al., 2011; Smith et al., 1998, Sohel et al., 2010; Wasserman et al., 2004; Ferreccio et al., 2013; Vahter, 2009; Abdul et al., 2015)

2.4 Remedial technologies

Reducing arsenic concentration from drinking water is a tough task for Bangladesh (IARC, 2004). In Bangladesh, sediments containing a comparatively high concentration of oxalate-extractable iron tended to be areas containing high- arsenic groundwater (BGS, 2001) which discloses the importance of the role of iron oxides. In the Faridpur district, processes like aeration, coagulation, and sand- filtration are used to remove a considerable amount of arsenic by co-precipitation with iron. As arsenic is sorbed to iron oxyhydroxide, arsenic can be removed partly from water through aeration, flocculation, and flirtation technique. Locally this process can be utilized by stirring the contaminated water with an alum stick and keep it settled overnight which will aid the process of floc formation of iron oxyhydroxide and then filtering that (Nickson et al., 2000). In Bangladesh, extraction of amorphous iron oxides using acid ammonium oxalate has been extensively used on sediments (BGS, 2001) since in general the correlation between Fe and extractable arsenic was found to be good.

Nowadays, green chemistry methods to remove the toxic elements from natural resources in an eco-friendly and recyclable way are becoming a point of interest. In this regard, the bioremediation of arsenic is one of the economic and eco-friendly ways to treat arsenic-contaminated water (Kumar et al., 2020). Like phosphorus, arsenic is simply taken up by many plants (Tu and Ma, 2003). According to different recent studies, arsenic can be remediated using phytoremediation (Allen, 2001; Forstner 1998; Bhattacharya et al., 2007), bacteria (Takeuchi et al., 2007; Liu et al., 2011; Routh et al., 2007; Dey et al., 2016), Algae (Becker, 1985; Baar et al., 2013; Wang et al., 2013), Fungi, and Yeast (Chen et al., 2007; Mukharjee et al., 2010) in an eco-friendly way.

3 Materials and Methods

3.1 Study area

Faridpur Sadar is an Upazila under the Faridpur district and is located in the central part of Bangladesh (Figure-4). The total area is about 10.44 sq. km. A river named Kumar runs alongside the Upazila. The Upazila lies between 23°29’ and 23°34’ North latitudes and 89°43’ and 89°56’ East longitudes. The total population of the study area is 469410 with a population density of 1137 per sq. km (BBO, 2013). At present, arsenic contamination and the presence of iron, salinity, and manganese in groundwater along with lowering of the water table and dearth of a suitable aquifer are major problems that are responsible for potable water scarcity over the area.

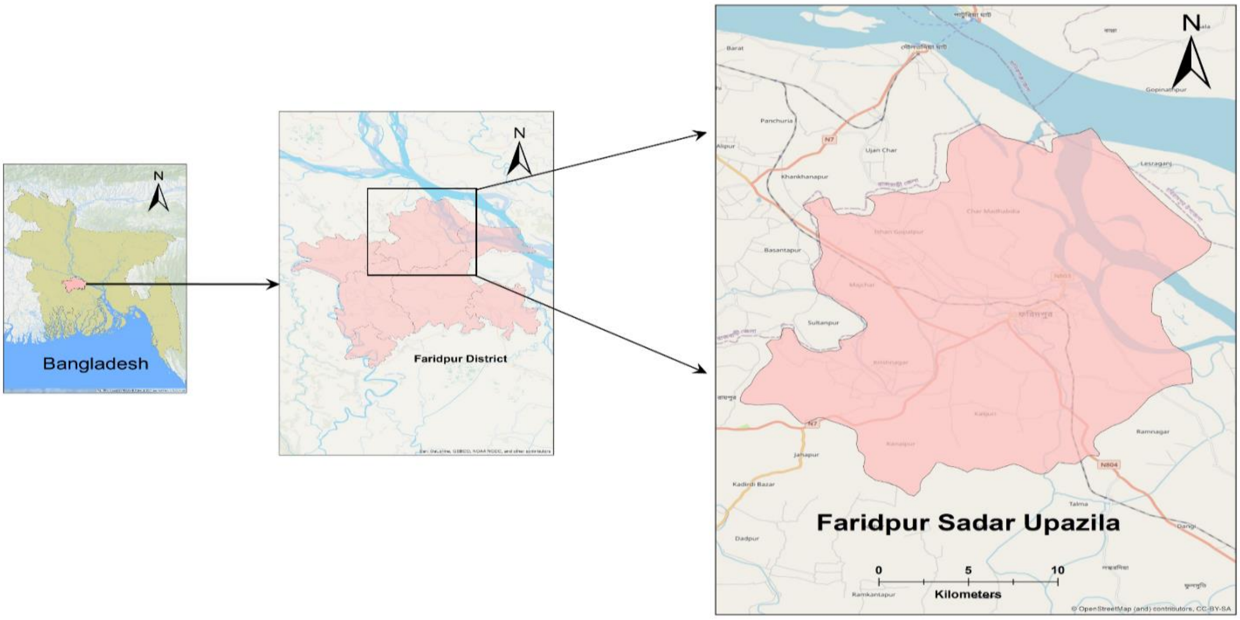

Figure-4. Map of the study area (Faridpur Sadar Upazila)

3.2 Sample Collection, testing, and calculation of Water Quality Index

For sample collection, tube wells of 300-400m depth were chosen for the abstraction of groundwater and testing. A total of eight sampling points was selected (Figure-5) and from each point, four samples were collected during the post-monsoon period (November 2017). Samples were collected after flushing water from the bore hand pump for five minutes. Dried sample bottles which were washed with distilled water were used for storing the samples. For the WQI calculation, nine parameters were chosen, which are: arsenic, pH, temperature, turbidity, dissolved oxygen (DO), nitrate, total dissolved solids (TDS), iron, and biological oxygen demand (BOD) (Khan and Tahsin, 2020). All the parameters were tested at the laboratory within 48–72 hours of the sample collection using standard procedures (204) except for temperature using mercury thermometer and pH with Wagtech field test kit. While collecting, the geographic location of the sampling points was recorded using a portable global positioning system (GPS) meter. The geographical location of the sampling points and their names are tabulated in table-1 and the arithmetic average of the four samples from each sampling points are shown in table-2.

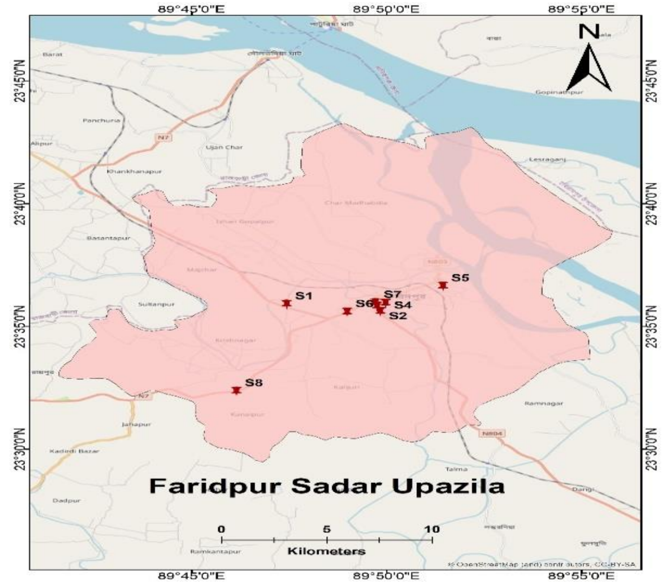

Figure-5: Location of the sampling points

Table-1: Geographical position and names of the sampling points

Location	Latitude	Longitude	Sample Name
Faridpur Dhaka highway	23.598094	89.790735	S1
Faridpur vanga highway	23.593173	89.830853	S2
Faridpur chowdhury bari	23.596809	89.829397	S3
Faridpur Ambika Road	23.598832	89.83297	S4
Faridpur Tepakhola	23.610315	89.857498	S5
Faridpur municipal water supply	23.592767	89.816582	S6
Goalchamot near bus stand	23.599045	89.828608	S7
Knaipur Bazar	23.539072	89.769213	S8

Source: Field study

Table- 2: Estimated concentration of parameters in the sampling points

Sample Name	pH	Turbidity (NTU)	Nitrate (mg/L)	Temp (°C)	DO (mg/L)	TDS (mg/L)	Iron (mg/L)	Arsenic (mg/L)	BOD (mg/L)
S1	7.47	6.54	0	23	1.3	477	1.1	0	0.5
S2	7.43	7.28	0	24.63	1.77	696	0.7	0.06	0.6
S3	7.2	6.45	0	23.67	1.4	712	0.9	0	0.17
S4	7.33	7.46	0	23.58	1.33	557	0.7	0.07	0.3
S5	7.39	1.41	0	24.33	1.37	462	0.2	0.03	0.2
S6	7.41	9.83	0	25.1	1.8	724	0.3	0.01	0.43
S7	7.09	12.4	0	25.3	1.63	941	0.6	0.02	0.6
S8	7.32	6.34	0	24.9	1.92	802	1.2	0	0.4

Source: Primary data

Considering these input parameters, the water quality index was calculated using the weighted arithmetic water quality index method which is widely applied for evaluation of water quality and till now the most successful attempt (Brown et al., 1972). Applying this method, the index was calculated and the obtained values illustrate the current state of the WQI of the study area (table-3). The calculation procedure is elaborately described in Khan and Tahsin, 2020 (Khan and Tahsin, 2020). Here, the weightage of parameters was assumed to be inversely proportional to the recommended standard value of the corresponding parameter. For example, the permissible range of Arsenic was the lowest which was 0-0.05 mg/l whereas for TDS it was 0-1000 mg/l which is the highest among all the parameters. For this reason, the weightage of arsenic (0.754186) was the highest while TDS had the lowest weightage (0.000038). For determining the permissible range ECR, 1997 was followed (Standard, 1997). The obtained value of the weightage of the parameters is shown in table-4.

Table- 3: Current WQI of the study area

Location	Sample Name	WQI	Remarks	Category
Faridpur Dhaka highway	S1	52.68	C	Poor water quality
Faridpur Vanga highway	S2	151.11	E	Unsuitable for drinking purpose
Faridpur Chowdhury bari	S3	20.74	A	Excellent water quality
Faridpur Ambika Road	S4	137.90	E	Unsuitable for drinking purpose
Faridpur Tepakhola	S5	66.05	C	Poor water quality
Faridpur municipal water supply	S6	58.25	C	Poor water quality
Goalchamot near bus stand	S7	90.51	D	Very Poor water quality

Source: Khan and Tahsin, 2020

Table- 4. Unit Weight assigned to input parameters

Parameter	Weightage (Wi)
Arsenic	0.754186
BOD	0.188547
Iron	0.037709
DO	0.006285
P^H	0.004436
Turbidity	0.003771
Nitrate	0.003771
Temp	0.001257
TDS	0.000038

Source: Khan and Tahsin, 2020

3.3 Generation of Scenarios

The impact of arsenic on overall WQI was studied by generating two synthetic scenarios (Scenario 1 and 2). Scenarios were generated by varying the concentration of arsenic from the present condition. In these scenarios, the concentration of other input parameters was kept the same as the present condition to observe the sole impact of arsenic on water quality. The description of the scenarios is listed in table-5.

Table-5: Description of the scenarios

Scenario Name	State of concentration of arsenic in drinking water
Present Condition	Similar to present condition
Scenario-1	50% reduction from present condition
Scenario-2	No arsenic in the area

Source: Contemplation for the purpose of the study

4. Result and discussion

The current condition of the water quality parameters and overall water quality index (WQI) of the study area can be perceived from table-2 and table-3 respectively. As illustrated in table-5, when the scenarios were introduced in the sampling points, the corresponding WQI oscillated. The fluctuation of WQI with the reduction of arsenic concentration from the present situation is illustrated in figure-6. Here, for samples S1, S3, and S8, no change in WQI is seen in scenario-1 and scenario-2 as there is no arsenic in that area. For, sample S2, with an arsenic concentration of 0.06mg/l, the present WQI was of category E (unsuitable for drinking purpose) and the value of the index was 151.11. In scenario-1, 50% reduction of arsenic concentration from present condition, no change was observed in the category but the value of index became 105.85. While, in scenario-2, no arsenic in the sample was considered, the WQI rose to category C (poor water quality) with an index value of 60.60. Similarly, for sample S6, the present WQI was of category C (poor water quality) with an arsenic concentration of 0.01mg/l. In scenario-1 the value of the index became 50.70 without changing the category. In scenario-2, the WQI rose to category B (good water quality) with an index value of 43.16. For sample S7 similar occurrence was observed, where arsenic concentration was 0.02mg/l. Here, the index value of the water quality became 75.42 from 90.51 for scenario-1. In scenario-2, the WQI rose to category C (poor water quality) from category D.

In case of sample S4, the present water quality was of category E (unsuitable for drinking purpose) with the highest arsenic concentration of 0.07 mg/l. While arsenic concentration reduced to 50% of present arsenic concentration in scenario-1, the index rose to category D (very poor water quality). In scenario-2, when the absence of arsenic was considered, the WQI rose to B (good water quality). The WQI of sample S5 was found to be of category C (poor water quality) with an arsenic concentration of .03mg/l. The index rose to category B (good water quality) in scenario-1. In scenario-2, which represents no arsenic in that area, the WQI changed into category A (Excellent water quality). Observing the fluctuation of the WQI in different scenarios, it was found that samples having higher arsenic content resulted in a lower water quality index. At the same time, the fluctuation of WQI in different scenarios was found to be maximum where arsenic concentration was highest. This has occurred because of the highest value of weightage in the arsenic parameter. Therefore, a reduction of arsenic value increases the quality of water significantly.

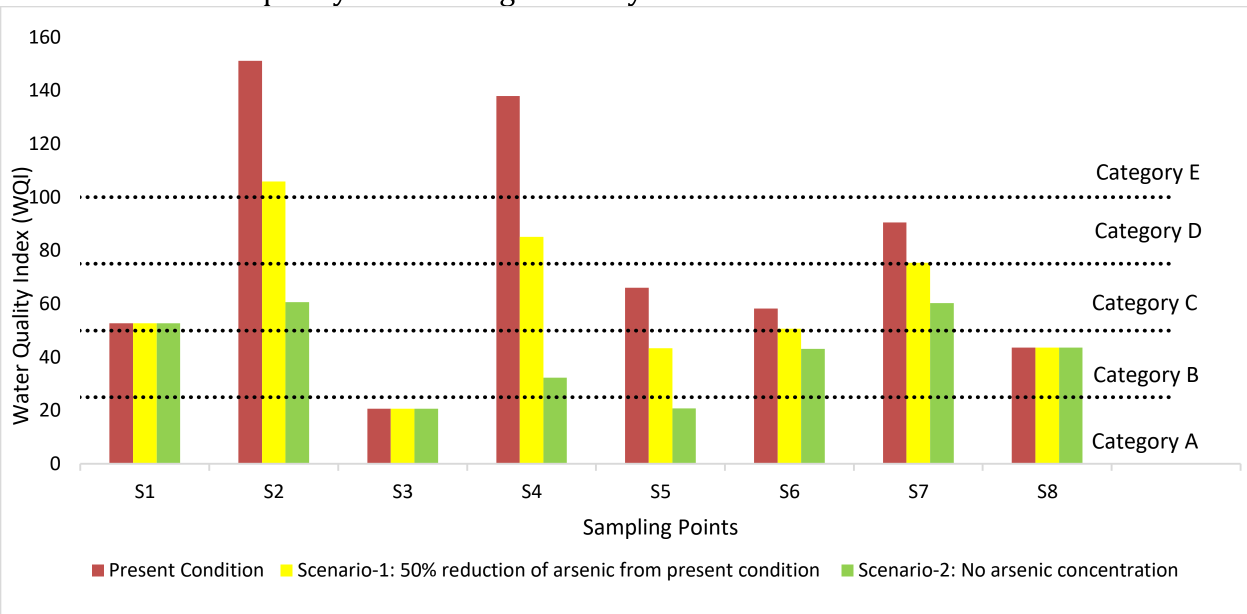

Figure-6. Fluctuations of WQI in different scenarios

5. Conclusion:

The high concentration of arsenic in groundwater has introduced a new challenge of survival to the human race. The pervasive toxicity of arsenic has insinuated in natural as well as the human system. From the review, it can be deduced that, originating from the Himalayan, arsenic entered the aquifer of Bangladesh by sedimentary processes. The characteristics of sediment in Bangladesh make it an ideal host of arsenic and under a reductive chemical environment, it enters into groundwater. Biodegradation of organic matter and reductive dissolution of iron oxyhydroxide are the two dominant mechanisms that release arsenic into aquifers. While the aquifer aids in the high concentration of arsenic in groundwater, different anthropogenic activities also contribute to this phenomenon. Widespread use of chemical fertilizer and insecticides, expansion of mining, use of coal in a power plant is identified to be the leading contributors to arsenic contamination. Furthermore, overexploitation of shallow aquifers is increasing the contamination of arsenic in deep aquifers. Eventually, from the ingestion of arsenic-containing groundwater and plants, human health is being vulnerable to several life-threatening diseases. People of arsenic-contaminated regions pose a serious health crisis due to this toxic metalloid. The experimental study on Faridpur Sadar Upazila revealed that alone arsenic pollutants can deteriorate the water quality index. More studies are needed giving special attention to the micro regions in order to find zone specific mobilization process, quantification of its impact on human system and water quality along with finding more user-friendly and green mitigation strategies so that the water quality may ameliorate. Moreover, this study aspires that, the findings may draw attention among the people of the arsenic-contaminated region about the role of arsenic concentration in water quality as well as in human health.

References

Abdul, K. S. M., Jayasinghe, S. S., Chandana, E. P., Jayasumana, C., & De Silva, P. M. C. (2015). Arsenic and human health effects: A review. Environmental toxicology and pharmacology, 40(3), 828-846.

Abedin, M. J., Cresser, M. S., Meharg, A. A., Feldmann, J., & Cotter-Howells, J. (2002). Arsenic accumulation and metabolism in rice (Oryza sativa L.). Environmental science & technology, 36(5), 962-968.

Acharyya, S. K., Lahiri, S., Raymahashay, B. C., & Bhowmik, A. (2000). Arsenic toxicity of groundwater in parts of the Bengal basin in India and Bangladesh: the role of Quaternary stratigraphy and Holocene sea-level fluctuation. Environmental Geology, 39(10), 1127-1137.

Ahmad, S. A., Sayed, M. H., Barua, S., Khan, M. H., Faruquee, M. H., Jalil, A., ... & Talukder, H. K. (2001). Arsenic in drinking water and pregnancy outcomes. Environmental health perspectives, 109(6), 629-631.

Ahsan, D. A., DelValls, T. A., & Blasco, J. (2009). Distribution of arsenic and trace metals in the floodplain agricultural soil of Bangladesh. Bulletin of environmental contamination and toxicology, 82(1), 11-15.

Ahsan, H., Chen, Y., Parvez, F., Zablotska, L., Argos, M., Hussain, I., ... & Van Geen, A. (2006). Arsenic exposure from drinking water and risk of premalignant skin lesions in Bangladesh: baseline results from the Health Effects of Arsenic Longitudinal Study. American Journal of Epidemiology, 163(12), 1138-1148.

AJaim, W. M. H., & Hossain, M. (2007). Arsenic Contamination And Human Health: A Socioeconomic Study In Some Selected Areas Of Bangladesh. Bangladesh Journal of Agricultural Economics, 30(454-2016-36416), 81-91.

Akhter, M., Tasleem, M., Alam, M. M., & Ali, S. (2017). In silico approach for bioremediation of arsenic by structure prediction and docking studies of arsenite oxidase from Pseudomonas stutzeri TS44. International Biodeterioration & Biodegradation, 122, 82-91.

Akter, T., Jhohura, F. T., Akter, F., Chowdhury, T. R., Mistry, S. K., Dey, D., ... & Rahman, M. (2016). Water Quality Index for measuring drinking water quality in rural Bangladesh: a cross-sectional study. Journal of Health, Population and Nutrition, 35(1), 1-12.

Albright, A. M., Saari, E. L., Leaver, J. M., & Dillon, S. M. (2012). Leaching of Metals into Groundwater-Understanding the Causes and an Evaluation of Remedial Approaches.29. S.K. Mandal, Ind. J. Physiol. Sc. Vol-3. No-1. 2016.

Allen, A. (2001). Containment landfills: the myth of sustainability. Engineering Geology, 60(1-4), 3-19.

APHA. (2005). Standard methods for the examination of water and wastewater (21st ed.). Washington, DC: American Public Health Association.

Argos, M., Chen, L., Jasmine, F., Tong, L., Pierce, B. L., Roy, S., ... & Rahman, M. (2015). Gene-specific differential DNA methylation and chronic arsenic exposure in an epigenome-wide association study of adults in Bangladesh. Environmental health perspectives, 123(1), 64-71.

Argos, M., Kalra, T., Rathouz, P. J., Chen, Y., Pierce, B., Parvez, F., ... & Sarwar, G. (2010). Arsenic exposure from drinking water, and all-cause and chronic-disease mortalities in Bangladesh (HEALS): a prospective cohort study. The Lancet, 376(9737), 252-258.

Arteel, G. E., Guo, L., Schlierf, T., Beier, J. I., Kaiser, J. P., Chen, T. S., ... & States, J. C. (2008). Subhepatotoxic exposure to arsenic enhances lipopolysaccharide-induced liver injury in mice. Toxicology and applied pharmacology, 226(2), 128-139.

Bahar, M. M., & Reza, M. S. (2010). Hydrochemical characteristics and quality assessment of shallow groundwater in a coastal area of Southwest Bangladesh. Environmental Earth Sciences, 61(5), 1065-1073.

Bahar, M. M., Megharaj, M., & Naidu, R. (2013). Bioremediation of arsenic-contaminated water: recent advances and future prospects. Water, Air, & Soil Pollution, 224(12), 1722.

Bahar, M. M., Megharaj, M., & Naidu, R. (2016). Oxidation of arsenite to arsenate in growth medium and groundwater using a novel arsenite-oxidizing diazotrophic bacterium isolated from soil. International Biodeterioration & Biodegradation, 106, 178-182.

Bailey, K., Xia, Y., Ward, W. O., Knapp, G., Mo, J., Mumford, J. L., ... & Thai, S. F. (2009). Global gene expression profiling of hyperkeratotic skin lesions from inner Mongolians chronically exposed to arsenic. Toxicologic pathology, 37(7), 849-859.

Bayatkashkoli, A., Kameshki, B., Ravan, S., & Shamsian, M. (2017). Comparing of performance of treated particleboard with alkaline copper quat, boron-fluorine-chromium-arsenic and Chlorotalonil against Microcerotermes diversus and Anacanthotermes vagans termite. International Biodeterioration & Biodegradation, 120, 186-191

Becker, E. W. (1983). Limitations of heavy metal removal from waste water by means of algae. Water Research, 17(4), 459-466.

BgS, D. (2001). Arsenic contamination of groundwater in Bangladesh. British Geological Survey (Technical Report, WC/00/19. 4 Volumes). British Geological Survey, Keyworth..

BgS, D. (2001). Arsenic contamination of groundwater in Bangladesh. British Geological Survey (Technical Report, WC/00/19. 4 Volumes). British Geological Survey, Keyworth..

Bhattacharya P, Naidu R, Polya DA, Mukherjee A, Bundschuh J, Charlet L (2014) Arsenic in hydrological processes-sources, speciation, bioavailability and management. J Hydrol 518:279–283

Bhattacharya, P., Mukherjee, A. B., Bundschuh, J., Zevenhoven, R., & Loeppert, R. H. (Eds.). (2007). Arsenic in soil and groundwater environment: biogeochemical interactions, health effects and remediation. Elsevier.

Bhattacharya, P., Naidu, R., Polya, D. A., Mukherjee, A., Bundschuh, J., & Charlet, L. (2014). Arsenic in hydrological processes-Sources, speciation, bioavailability and management. JHyd, 518, 279-283.

Biswas, R. K., Roy, D. K., Islam, A. R. M. T., Rahman, M. M., & Ali, M. M. (2014). Assessment of drinking water related to arsenic and salinity hazard in Patuakhali district, Bangladesh. International Journal of Advanced Geosciences, 2(2), 82-85.

Bodrud-Doza, M., Islam, A. T., Ahmed, F., Das, S., Saha, N., & Rahman, M. S. (2016). Characterization of groundwater quality using water evaluation indices, multivariate statistics and geostatistics in central Bangladesh. Water Science, 30(1), 19-40.

Börzsönyi, M., Bereczky, A., Rudnai, P., Csanady, M., & Horvath, A. (1992). Epidemiological studies on human subjects exposed to arsenic in drinking water in southeast Hungary. Archives of Toxicology, 66(1), 77-78.

Broberg, K., Ahmed, S., Engström, K., Hossain, M. B., Mlakar, S. J., Bottai, M., ... & Vahter, M. (2014). Arsenic exposure in early pregnancy alters genome-wide DNA methylation in cord blood, particularly in boys. Journal of developmental origins of health and disease, 5(4), 288-298.

Bustaffa, E., Stoccoro, A., Bianchi, F., & Migliore, L. (2014). Genotoxic and epigenetic mechanisms in arsenic carcinogenicity. Archives of toxicology, 88(5), 1043-1067.

CANTOR, K. P., WARD, M. H., MOORE, L., & LUBIN, J. (2006). 20 Water Contaminants. Cancer epidemiology and prevention, 382.

Caporale, A. G., Adamo, P., Azam, S. M., Rao, M. A., & Pigna, M. (2018). May humic acids or mineral fertilisation mitigate arsenic mobility and availability to carrot plants (Daucus carota L.) in a volcanic soil polluted by As from irrigation water?. Chemosphere, 193, 464-471.

Celik, I., Gallicchio, L., Boyd, K., Lam, T. K., Matanoski, G., Tao, X., ... & Caulfield, L. E. (2008). Arsenic in drinking water and lung cancer: a systematic review. Environmental Research, 108(1), 48-55.

Chakraborti, D., Rahman, M. M., Ahamed, S., Dutta, R. N., Pati, S., & Mukherjee, S. C. (2016). Arsenic groundwater contamination and its health effects in Patna district (capital of Bihar) in the middle Ganga plain, India. Chemosphere, 152, 520-529.

Chakraborti, D., Rahman, M. M., Murrill, M., Das, R., Patil, S. G., Sarkar, A., ... & Das, K. K. (2013). Environmental arsenic contamination and its health effects in a historic gold mining area of the Mangalur greenstone belt of Northeastern Karnataka, India. Journal of hazardous materials, 262, 1048-1055.

Chakraborty, M., Mukherjee, A., & Ahmed, K. M. (2015). A review of groundwater arsenic in the Bengal Basin, Bangladesh and India: from source to sink. Current Pollution Reports, 1(4), 220-247.

Chen, B., Xiao, X., Zhu, Y. G., Smith, F. A., Xie, Z. M., & Smith, S. E. (2007). The arbuscular mycorrhizal fungus Glomus mosseae gives contradictory effects on phosphorus and arsenic acquisition by Medicago sativa Linn. Science of the Total Environment, 379(2-3), 226-234.

Chen, C. J., Hsueh, Y. M., Lai, M. S., Shyu, M. P., Chen, S. Y., Wu, M. M., ... & Tai, T. Y. (1995). Increased prevalence of hypertension and long-term arsenic exposure. Hypertension, 25(1), 53-60.

Chen, C. L., Hsu, L. I., Chiou, H. Y., Hsueh, Y. M., Chen, S. Y., Wu, M. M., ... & Blackfoot Disease Study Group. (2004). Ingested arsenic, cigarette smoking, and lung cancer risk: a follow-up study in arseniasis-endemic areas in Taiwan. Jama, 292(24), 2984-2990.

Chen, Y., & Ahsan, H. (2004). Cancer burden from arsenic in drinking water in Bangladesh. American journal of public health, 94(5), 741-744.

Chen, Y., Graziano, J. H., Parvez, F., Liu, M., Slavkovich, V., Kalra, T., ... & Hasan, R. (2011). Arsenic exposure from drinking water and mortality from cardiovascular disease in Bangladesh: prospective cohort study. Bmj, 342, d2431.

Chen, Y., Parvez, F., Gamble, M., Islam, T., Ahmed, A., Argos, M., ... & Ahsan, H. (2009). Arsenic exposure at low-to-moderate levels and skin lesions, arsenic metabolism, neurological functions, and biomarkers for respiratory and cardiovascular diseases: review of recent findings from the Health Effects of Arsenic Longitudinal Study (HEALS) in Bangladesh. Toxicology and applied pharmacology, 239(2), 184-192.

Chowdhury, A. M. R., Jakariya, M., & Ahmed, A. H. T. J. (1999). Village Health Workers Can Test Tubewell Water for Arsenic. DRINKING WATER CONTAMINATION BYARSENIC IN RURAL AREAS OF BANGLADESH POSSIBLE SOLUTION AND AWARENESS BUILDING, 44.

Chowdhury, M. A. I., Uddin, M. T., Ahmed, M. F., Ali, M. A., & Uddin, S. M. (2006). How does arsenic contamination of groundwater causes severity and health hazard in Bangladesh.

Chowdhury, T. R., Mandal, B. K., Samanta, G., Basu, G. K., Chowdhury, P. P., Chanda, C. R., ... & Saha, K. C. (1997). Arsenic in groundwater in six districts of West Bengal, India: the biggest arsenic calamity in the world: the status report up to August, 1995. In Arsenic (pp. 93-111). Springer, Dordrecht.

Chowdhury, U. K., Biswas, B. K., Chowdhury, T. R., Samanta, G., Mandal, B. K., Basu, G. C., ... & Roy, S. (2000). Groundwater arsenic contamination in Bangladesh and West Bengal, India. Environmental health perspectives, 108(5), 393-397.

Christodoulidou, M., Charalambous, C., Aletrari, M., Kanari, P. N., Petronda, A., & Ward, N. I. (2012). Arsenic concentrations in groundwaters of Cyprus. Journal of Hydrology, 468, 94-100.

Christodoulidou, M., Charalambous, C., Aletrari, M., Kanari, P. N., Petronda, A., & Ward, N. I. (2012). Arsenic concentrations in groundwaters of Cyprus. Journal of Hydrology, 468, 94-100.

Das, D. (1995). Bore-hole soil-sediment analysis of some arsenic affected areas. In Int. Conf. on Arsenic in groundwater: Causes, effects and remedy.

Das, D., Samanta, G., Mandal, B. K., Chowdhury, T. R., Chanda, C. R., Chowdhury, P. P., ... & Chakraborti, D. (1996). Arsenic in groundwater in six districts of West Bengal, India. Environmental Geochemistry and Health, 18(1), 5-15.

Das, H. K., Mitra, A. K., Sengupta, P. K., Hossain, A., Islam, F., & Rabbani, G. H. (2004). Arsenic concentrations in rice, vegetables, and fish in Bangladesh: a preliminary study. Environment international, 30(3), 383-387

Das, H. K., Mitra, A. K., Sengupta, P. K., Hossain, A., Islam, F., & Rabbani, G. H. (2004). Arsenic concentrations in rice, vegetables, and fish in Bangladesh: a preliminary study. Environment international, 30(3), 383-387.

Das, H. K., Mitra, A. K., Sengupta, P. K., Hossain, A., Islam, F., & Rabbani, G. H. (2004). Arsenic concentrations in rice, vegetables, and fish in Bangladesh: a preliminary study. Environment international, 30(3), 383-387.

Dauphiné, D. C., Smith, A. H., Yuan, Y., Balmes, J. R., Bates, M. N., & Steinmaus, C. (2013). Case-control study of arsenic in drinking water and lung cancer in California and Nevada. International journal of environmental research and public health, 10(8), 3310-3324.

Dey, U., Chatterjee, S., & Mondal, N. K. (2016). Isolation and characterization of arsenic-resistant bacteria and possible application in bioremediation. Biotechnology reports, 10, 1-7.

Dhar, R. K., Biswas, B. K., Samanta, G., Mandal, B. K., Chakraborti, D., Roy, S., ... & Khan, A. W. (1997). Groundwater arsenic calamity in Bangladesh. Current Science, 48-59.

Ditzel, E. J., Nguyen, T., Parker, P., & Camenisch, T. D. (2016). Effects of arsenite exposure during fetal development on energy metabolism and susceptibility to diet-induced fatty liver disease in male mice. Environmental health perspectives, 124(2), 201-209.

DPHE, B. (2001). Arsenic contamination of groundwater in Bangladesh. Summary British Geological Survey WC/00/19, 1, 1-15.

Ferreccio, C., González, C., Milosavjlevic, V., Marshall, G., Sancha, A. M., & Smith, A. H. (2000). Lung cancer and arsenic concentrations in drinking water in Chile. Epidemiology, 673-679.

Ferreccio, C., Smith, A. H., Durán, V., Barlaro, T., Benítez, H., Valdés, R., ... & Pérez, L. (2013). Case-control study of arsenic in drinking water and kidney cancer in uniquely exposed Northern Chile. American journal of epidemiology, 178(5), 813-818.

Förstner, U., & Haase, I. (1998). Geochemical demobilization of metallic pollutants in solid waste—implications for arsenic in waterworks sludges. Journal of geochemical exploration, 62(1-3), 29-36.

Frisbie, S. H., Ortega, R., Maynard, D. M., & Sarkar, B. (2002). The concentrations of arsenic and other toxic elements in Bangladesh's drinking water. Environmental Health Perspectives, 110(11), 1147-1153.

Gao, X., Su, C., Wang, Y., & Hu, Q. (2013). Mobility of arsenic in aquifer sediments at Datong Basin, northern China: effect of bicarbonate and phosphate. Journal of Geochemical Exploration, 135, 93-103.

Ghosh, P., Banerjee, M., Giri, A. K., & Ray, K. (2008). Toxicogenomics of arsenic: classical 138-301.

Gibb, H., Haver, C., Gaylor, D., Ramasamy, S., Lee, J. S., Lobdell, D., ... & Sams, R. (2011). Utility of recent studies to assess the National Research Council 2001 estimates of cancer risk from ingested arsenic. Environmental health perspectives, 119(3), 284-290.

Guha Mazumder, D., Purkayastha, I., Ghose, A., Mistry, G., Saha, C., Nandy, A. K., ... & Majumdar, K. K. (2012). Hypertension in chronic arsenic exposure: A case control study in West Bengal. Journal of Environmental Science and Health, Part A, 47(11), 1514-1520.

Guillot, S., & Charlet, L. (2007). Bengal arsenic, an archive of Himalaya orogeny and paleohydrology. Journal of Environmental Science and Health, Part A, 42(12), 1785-1794.

Halim, M. A., Majumder, R. K., Nessa, S. A., Hiroshiro, Y., Uddin, M. J., Shimada, J., & Jinno, K. (2009). Hydrogeochemistry and arsenic contamination of groundwater in the Ganges Delta Plain, Bangladesh. Journal of hazardous materials, 164(2-3), 1335-1345.

Haque, R., Mazumder, D. G., Samanta, S., Ghosh, N., Kalman, D., Smith, M. M., ... & De, B. K. (2003). Arsenic in drinking water and skin lesions: dose-response data from West Bengal, India. Epidemiology, 174-182.

Haque, S. E. (2018). An Overview of Groundwater Quality in Bangladesh. In Groundwater of South Asia (pp. 205-232). Springer, Singapore.

Haque, S., Ji, J., & Johannesson, K. H. (2008). Evaluating mobilization and transport of arsenic in sediments and groundwaters of Aquia aquifer, Maryland, USA. Journal of Contaminant Hydrology, 99(1-4), 68-84.

Harvey, C. F., Ashfaque, K. N., Yu, W., Badruzzaman, A. B. M., Ali, M. A., Oates, P. M., ... & Ahmed, M. F. (2006). Groundwater dynamics and arsenic contamination in Bangladesh. Chemical Geology, 228(1-3), 112-136.

Harvey, C. F., Swartz, C. H., Badruzzaman, A. B. M., Keon-Blute, N., Yu, W., Ali, M. A., ... & Oates, P. M. (2005). Groundwater arsenic contamination on the Ganges Delta: biogeochemistry, hydrology, human perturbations, and human suffering on a large scale. Comptes Rendus Geoscience, 337(1-2), 285-296.

Heikens, A. (2006). Arsenic contamination of irrigation water, soil and crops in Bangladesh: Risk implications for sustainable agriculture and food safety in Asia. RAP Publication (FAO

Heikens, A., Panaullah, G. M., & Meharg, A. A. (2007). Arsenic behaviour from groundwater and soil to crops: impacts on agriculture and food safety. In Reviews of environmental contamination and toxicology (pp. 43-87). Springer, New York, NY.

Hopenhayn-Rich, C., Browning, S. R., Hertz-Picciotto, I., Ferreccio, C., Peralta, C., & Gibb, H. (2000). Chronic arsenic exposure and risk of infant mortality in two areas of Chile. Environmental health perspectives, 108(7), 667-673.

Hossain, M. (2006). F1 Arsenic contamination in Bangladesh: An overview1 Agriculture. Ecosystems and Environment, 113, 1-161.

Hughes, M. F., Beck, B. D., Chen, Y., Lewis, A. S., & Thomas, D. J. (2011). Arsenic exposure and toxicology: a historical perspective. Toxicological Sciences, 123(2), 305-332.

Huq, M. E., Fahad, S., Shao, Z., Sarven, M. S., Khan, I. A., Alam, M., ... & Cheng, Q. (2020). Arsenic in a groundwater environment in Bangladesh: Occurrence and mobilization. Journal of Environmental Management, 262, 110318.

Huq, M. E., Su, C., Li, J., & Sarven, M. S. (2018). Arsenic enrichment and mobilization in the Holocene alluvial aquifers of Prayagpur of Southwestern Bangladesh. International Biodeterioration & Biodegradation, 128, 186-194.

Huq, M. E., Su, C., Li, J., & Sarven, M. S. (2018). Arsenic enrichment and mobilization in the Holocene alluvial aquifers of Prayagpur of Southwestern Bangladesh. International Biodeterioration & Biodegradation, 128, 186-194.

Huq, S. I., Joardar, J. C., Parvin, S., Correll, R., & Naidu, R. (2006). Arsenic contamination in food-chain: transfer of arsenic into food materials through groundwater irrigation. Journal of health, population, and nutrition, 24(3), 305.

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, World Health Organization, & International Agency for Research on Cancer. (2004). Some drinking-water disinfectants and contaminants, including arsenic (Vol. 84). IARC.

International Agency for Research on Cancer. (1982). International Agency for Research on Cancer monographs on the evaluation of carcinogenic risks to humans. The Agency.

Islam, A. T., Shen, S., Bodrud-Doza, M. D., & Rahman, M. S. (2017). Assessing irrigation water quality in Faridpur district of Bangladesh using several indices and statistical approaches. Arabian Journal of Geosciences, 10(19), 418.

Islam, M. R., Jahiruddin, M., & Islam, S. (2004). Assessment of arsenic in the water-soil-plant systems in gangeticfloodplains of Bangladesh. Asian Journal of Plant Sciences (Pakistan).

Islam, M. R., Jahiruddin, M., & Islam, S. (2004). Assessment of arsenic in the water-soil-plant systems in gangeticfloodplains of Bangladesh. Asian Journal of Plant Sciences (Pakistan).

Joseph, T., Dubey, B., & McBean, E. A. (2015). A critical review of arsenic exposures for Bangladeshi adults. Science of the Total Environment, 527, 540-551.

juan Guo, X., Fujino, Y., Kaneko, S., Wu, K., Xia, Y., & Yoshimura, T. (2001). Arsenic contamination of groundwater and prevalence of arsenical dermatosis in the Hetao plain area, Inner Mongolia, China. In Molecular mechanisms of metal toxicity and carcinogenesis (pp. 137-140). Springer, Boston, MA.

Juhasz, A. L., Smith, E., Weber, J., Rees, M., Rofe, A., Kuchel, T., ... & Naidu, R. (2006). In vivo assessment of arsenic bioavailability in rice and its significance for human health risk assessment. Environmental Health Perspectives, 114(12), 1826-1831.

Juhasz, A. L., Smith, E., Weber, J., Rees, M., Rofe, A., Kuchel, T., ... & Naidu, R. (2006). In vivo assessment of arsenic bioavailability in rice and its significance for human health risk assessment. Environmental Health Perspectives, 114(12), 1826-1831.

Kabir, M. S., Salam, M. A., Paul, D. N. R., Hossain, M. I., Rahman, N. M. F., Aziz, A., & Latif, M. A. (2016). Spatial variation of arsenic in soil, irrigation water, and plant parts: a microlevel study. The Scientific World Journal, 2016.

Kabir, M. S., Salam, M. A., Paul, D. N. R., Hossain, M. I., Rahman, N. M. F., Aziz, A., & Latif, M. A. (2016). Spatial variation of arsenic in soil, irrigation water, and plant parts: a microlevel study. The Scientific World Journal, 2016.

Karim, M. M., Komori, Y., & Alam, M. (1997). Subsurface arsenic occurrence and depth of contamination in Bangladesh. Journal of Environmental Chemistry, 7(4), 783-792.

Khan, J. R., & Bakar, K. S. (2020). Targeting at risk households in Bangladesh exposed to arsenic contamination: a spatial analysis. International Journal of Environmental Health Research, 30(1), 1-12.

Khan, M. A. I., & Tahsin, A. EVALUATION OF DRINKING WATER QUALITY IN TERMS OF WATER QUALITY INDEX FOR FARIDPUR SADAR UPAZILA. 5th International Conference on Civil Engineering for Sustainable Development, KUET, Khulna, Bangladesh, 2020.

Khan, M. M. H., Aklimunnessa, K., Ahsan, N., Kabir, M., & Mori, M. (2006). Case-control study of arsenicosis in some arsenic contaminated villages of Bangladesh.

Khan, M. M. H., Sakauchi, F., Sonoda, T., Washio, M., & Mori, M. (2003). Magnitude of arsenic toxicity in tube-well drinking water in Bangladesh and its adverse effects on human health including cancer: evidence from a review of the literature. Asian Pacific Journal of Cancer Prevention, 4(1), 7-14.

Khan, N. I., Owens, G., Bruce, D., & Naidu, R. (2009). Human arsenic exposure and risk assessment at the landscape level: a review. Environmental Geochemistry and Health, 31(1), 143.

Kinniburgh, D. G., & Smedley, P. (2001). Arsenic contamination of groundwater in Bangladesh.

Kumar, M., Rahman, M. M., Ramanathan, A. L., & Naidu, R. (2016). Arsenic and other elements in drinking water and dietary components from the middle Gangetic plain of Bihar, India: health risk index. Science of the Total Environment, 539, 125-134.

Kumar, M., Yadav, A., & Ramanathan, A. L. (2020). Arsenic Contamination in Environment, Ecotoxicological and Health Effects, and Bioremediation Strategies for Its Detoxification. In Bioremediation of Industrial Waste for Environmental Safety (pp. 245-264). Springer, Singapore

Kuo, C. C., Weaver, V., Fadrowski, J. J., Lin, Y. S., Guallar, E., & Navas-Acien, A. (2015). Arsenic exposure, hyperuricemia, and gout in US adults. Environment international, 76, 32-40.

Kwok, R. K., Kaufmann, R. B., & Jakariya, M. (2006). Arsenic in drinking-water and reproductive health outcomes: a study of participants in the Bangladesh Integrated Nutrition Programme. Journal of Health, Population and Nutrition, 190-205.

Landrigan, P. J., Fuller, R., Acosta, N. J., Adeyi, O., Arnold, R., Baldé, A. B., ... & Chiles, T. (2018). The Lancet Commission on pollution and health. The lancet, 391(10119), 462-512.

Li, X., Li, B., Xi, S., Zheng, Q., Lv, X., & Sun, G. (2013). Prolonged environmental exposure of arsenic through drinking water on the risk of hypertension and type 2 diabetes. Environmental Science and Pollution Research, 20(11), 8151-8161.

Lin, S. C., Chang, T. K., Huang, W. D., Lur, H. S., & Shyu, G. S. (2015). Accumulation of arsenic in rice plant: a study of an arsenic-contaminated site in Taiwan. Paddy and water environment, 13(1), 11-18.

Liu, S., Zhang, F., Chen, J., & Sun, G. (2011). Arsenic removal from contaminated soil via biovolatilization by genetically engineered bacteria under laboratory conditions. Journal of Environmental Sciences, 23(9), 1544-1550.

Mandal, B. K., Chowdhury, T. R., Samanta, G., Basu, G. K., Chowdhury, P. P., Chanda, C. R., ... & Das, D. (1996). Arsenic in groundwater in seven districts of West Bengal, India–the biggest arsenic calamity in the world. Current science, 976-986.

Mandal, B. K., Ogra, Y., & Suzuki, K. T. (2001). Identification of dimethylarsinous and monomethylarsonous acids in human urine of the arsenic-affected areas in West Bengal, India. Chemical research in toxicology, 14(4), 371-378.

Marshall, G., Ferreccio, C., Yuan, Y., Bates, M. N., Steinmaus, C., Selvin, S., ... & Smith, A. H. (2007). Fifty-year study of lung and bladder cancer mortality in Chile related to arsenic in drinking water. Journal of the National Cancer Institute, 99(12), 920-928

Masuda, H. (2018). Arsenic cycling in the Earth's crust and hydrosphere: interaction between naturally occurring arsenic and human activities. Progress in Earth and Planetary Science, 5(1), 68.

Masuda, H. (2018). Arsenic cycling in the Earth's crust and hydrosphere: interaction between naturally occurring arsenic and human activities. Progress in Earth and Planetary Science, 5(1), 68.

Masuda, H. (2018). Arsenic cycling in the Earth's crust and hydrosphere: interaction between naturally occurring arsenic and human activities. Progress in Earth and Planetary Science, 5(1), 68.

Mazumder, D. N. G., Haque, R., Ghosh, N., De, B. K., Santra, A., Chakraborty, D., & Smith, A. H. (1998). Arsenic levels in drinking water and the prevalence of skin lesions in West Bengal, India. International journal of epidemiology, 27(5), 871-877.

McCarty, K. M., Hanh, H. T., & Kim, K. W. (2011). Arsenic geochemistry and human health in South East Asia. Reviews on environmental health, 26(1), 71-78.

Medina-Pizzali, M., Robles, P., Mendoza, M., & Torres, C. (2018). Arsenic intake: impact in human nutrition and health. Revista peruana de medicina experimental y salud publica, 35(1), 93-102.

Meharg, A. A., & Rahman, M. M. (2003). Arsenic contamination of Bangladesh paddy field soils: implications for rice contribution to arsenic consumption. Environmental science & technology, 37(2), 229-234.

Meharg, A. A., Williams, P. N., Adomako, E., Lawgali, Y. Y., Deacon, C., Villada, A., ... & Raab, A. (2009). Geographical variation in total and inorganic arsenic content of polished (white) rice. Environmental science & technology, 43(5), 1612-1617.

Merian, E. (1981). Evaluation of the carcinogenic risk of chemicals to humans: Some metals and metallic compounds. Chmsp, 10(7), N22.

Michael, H. A., & Khan, M. R. (2016). Impacts of physical and chemical aquifer heterogeneity on basin-scale solute transport: Vulnerability of deep groundwater to arsenic contamination in Bangladesh. Advances in Water Resources, 98, 147-158.

Milton, A. H., Smith, W., Rahman, B., Hasan, Z., Kulsum, U., Dear, K., ... & Ali, A. (2005). Chronic arsenic exposure and adverse pregnancy outcomes in Bangladesh. Epidemiology, 82-86.

Mitra, S. R., Mazumder, D. G., Basu, A., Block, G., Haque, R., Samanta, S., ... & Smith, A. H. (2004). Nutritional factors and susceptibility to arsenic-caused skin lesions in West Bengal, India. Environmental health perspectives, 112(10), 1104-1109.

Mondal, P., Balomajumder, C., & Mohanty, B. (2007). A laboratory study for the treatment of arsenic, iron, and manganese bearing ground water using $Fe3+$ impregnated activated carbon: effects of shaking time, pH and temperature. Journal of hazardous materials, 144(1-2), 420-426.

Moon, K., Guallar, E., & Navas-Acien, A. (2012). Arsenic exposure and cardiovascular disease: an updated systematic review. Current atherosclerosis reports, 14(6), 542-555.

Mukherjee A, Das D, Mondal SK, Biswas R, Das TK, Boujedaini N, Khuda-Bukhsh R (2010) Tolerance of arsenate-induced stress in Aspergillus niger, a possible candidate for bioremediation. Ecotoxicol Environ Saf 73:172–182

Mukherjee, A. (2018). Overview of the Groundwater of South Asia. In Groundwater of South Asia (pp. 3-20). Springer, Singapore.

Mukherjee, A., & Fryar, A. E. (2008). Deeper groundwater chemistry and geochemical modeling of the arsenic affected western Bengal basin, West Bengal, India. Applied Geochemistry, 23(4), 863-894.

Mukherjee, A., Fryar, A. E., Scanlon, B. R., Bhattacharya, P., & Bhattacharya, A. (2011). Elevated arsenic in deeper groundwater of the western Bengal basin, India: Extent and controls from regional to local scale. Applied Geochemistry, 26(4), 600-613.

Mukherjee, A., Verma, S., Gupta, S., Henke, K. R., & Bhattacharya, P. (2014). Influence of tectonics, sedimentation and aqueous flow cycles on the origin of global groundwater arsenic: paradigms from three continents. Journal of hydrology, 518, 284-299.

Mukhopadhyay, R., Manjaiah, K. M., Datta, S. C., Yadav, R. K., & Sarkar, B. (2017). Inorganically modified clay minerals: Preparation, characterization, and arsenic adsorption in contaminated water and soil. Applied Clay Science, 147, 1-10.

Murcott, S. (2012). Arsenic contamination in the world. IWA publishing.

Navas-Acien, A., Sharrett, A. R., Silbergeld, E. K., Schwartz, B. S., Nachman, K. E., Burke, T. A., & Guallar, E. (2005). Arsenic exposure and cardiovascular disease: a systematic review of the epidemiologic evidence. American journal of epidemiology, 162(11), 1037-1049.

Nazari, A. M., Radzinski, R., & Ghahreman, A. (2017). Review of arsenic metallurgy: Treatment of arsenical minerals and the immobilization of arsenic. Hydrometallurgy, 174, 258-281.

Nickson, R. T., McArthur, J. M., Ravenscroft, P., Burgess, W. G., & Ahmed, K. M. (2000). Mechanism of arsenic release to groundwater, Bangladesh and West Bengal. Applied Geochemistry, 15(4), 403-413.

Nickson, R., McArthur, J., Burgess, W., Ahmed, K. M., Ravenscroft, P., & Rahmanñ, M. (1998). Arsenic poisoning of Bangladesh groundwater. Nature, 395(6700), 338-338.

Ourshalimian, S., Naser, A. M., Rahman, M., Doza, S., Stowell, J., Narayan, K. V., ... & Gribble, M. O. (2019). Arsenic and fasting blood glucose in the context of other drinking water chemicals: a cross-sectional study in Bangladesh. Environmental research, 172, 249-257.

Pal, A., Nayak, B., Das, B., Hossain, M. A., Ahamed, S., & Chakraborti, D. (2007). Additional danger of arsenic exposure through inhalation from burning of cow dung cakes laced with arsenic as a fuel in arsenic affected villages in Ganga–Meghna–Brahmaputra plain. Journal of Environmental Monitoring, 9(10), 1067-1070.

Panaullah, G. M., Alam, T., Hossain, M. B., Loeppert, R. H., Lauren, J. G., Meisner, C. A., ... & Duxbury, J. M. (2009). Arsenic toxicity to rice (Oryza sativa L.) in Bangladesh. Plant and soil, 317(1-2), 31.

Parvez, F., Chen, Y., Brandt-Rauf, P. W., Slavkovich, V., Islam, T., Ahmed, A., ... & Balac, O. (2010). A prospective study of respiratory symptoms associated with chronic arsenic exposure in Bangladesh: findings from the Health Effects of Arsenic Longitudinal Study (HEALS). Thorax, 65(6), 528-533.

Radloff, K. A., Zheng, Y., Stute, M., Weinman, B., Bostick, B., Mihajlov, I., ... & Schlosser, P. (2017). Reversible adsorption and flushing of arsenic in a shallow, Holocene aquifer of Bangladesh. Applied Geochemistry, 77, 142-157.

Rahman, M. (2002). Arsenic and contamination of drinking-water in Bangladesh: a public-health perspective. Journal of Health, Population and Nutrition, 193-197.

Rahman, M. A. T. M. T., Rahman, S. H., & Majumder, R. K. (2012). Groundwater quality for irrigation of deep aquifer in southwestern zone of Bangladesh. Songklanakarin J. Sci. Technol, 34(3), 345-352.

Rahman, M. M., Ng, J. C., & Naidu, R. (2009). Chronic exposure of arsenic via drinking water and its adverse health impacts on humans. Environmental geochemistry and health, 31(1), 189-200.

Rahman, M., Tondel, M., Ahmad, S. A., Chowdhury, I. A., Faruquee, M. H., & Axelson, O. (1999). Hypertension and arsenic exposure in Bangladesh. Hypertension, 33(1), 74-78.

Raihan, F., & Alam, J. B. (2008). Assessment of groundwater quality in Sunamganj of Bangladesh.

Ravenscroft, P., Brammer, H., & Richards, K. (2011). Arsenic pollution: a global synthesis (Vol. 94). John Wiley & Sons.

Ravenscroft, P., Burgess, W. G., Ahmed, K. M., Burren, M., & Perrin, J. (2005). Arsenic in groundwater of the Bengal Basin, Bangladesh: Distribution, field relations, and hydrogeological setting. Hydrogeology Journal, 13(5-6), 727-751.

Ravenscroft, P., Burgess, W. G., Ahmed, K. M., Burren, M., & Perrin, J. (2005). Arsenic in groundwater of the Bengal Basin, Bangladesh: Distribution, field relations, and hydrogeological setting. Hydrogeology Journal, 13(5-6), 727-751.

Rehman, M. Y. A., van Herwijnen, M., Krauskopf, J., Farooqi, A., Kleinjans, J. C., Malik, R. N., & Briedé, J. J. (2020). Transcriptome responses in blood reveal distinct biological pathways associated with arsenic exposure through drinking water in rural settings of Punjab, Pakistan. Environment International, 135, 105403.

Reza, A. S., Jean, J. S., Lee, M. K., Liu, C. C., Bundschuh, J., Yang, H. J., ... & Lee, Y. C. (2010). Implications of organic matter on arsenic mobilization into groundwater: evidence from northwestern (Chapai-Nawabganj), central (Manikganj) and southeastern (Chandpur) Bangladesh. Water research, 44(19), 5556-5574.

Routh, J., Saraswathy, A., & Collins, M. D. (2007). Arsenicicoccus bolidensis a novel arsenic reducing actinomycete in contaminated sediments near the Adak mine (northern Sweden): Impact on water chemistry. Science of the total environment, 379(2-3), 216-225.

Safiullah, S. (1999). Report on monitoring and mitigation of arsenic in the ground water of Faridpur Municipality. Savar, Bangladesh: Department of Chemistry, Jahangirnagar University, 66.

Saha, K. C. (1995). Chronic arsenical dermatosis from tube-well water in West Bengal during 1983-1987. Indian J. Dermatol., 40, 1-12.

Seddique, A. A., Masuda, H., Mitamura, M., Shinoda, K., Yamanaka, T., Nakaya, S., & Ahmed, K. M. (2011). Mineralogy and geochemistry of shallow sediments of Sonargaon, Bangladesh and implications for arsenic dynamics: focusing on the role of organic matter. Applied geochemistry, 26(4), 587-599.

Seddique, A. A., Masuda, H., Mitamura, M., Shinoda, K., Yamanaka, T., Itai, T., ... & Biswas, D. K. (2008). Arsenic release from biotite into a Holocene groundwater aquifer in Bangladesh. Applied Geochemistry, 23(8), 2236-2248.

Selgrade, M. K. (2007). Immunotoxicity—The risk is real. Toxicological Sciences, 100(2), 328-332.

Shahidullah, S. M., Hakim, M. A., Alam, M. S., & Shamsuddoha, A. T. M. (2000). Assessment of groundwater quality in a selected area of Bangladesh. Pakistan Journal of Biological Sciences (Pakistan).

Shamsudduha, M., Uddin, A., Saunders, J. A., & Lee, M. K. (2008). Quaternary stratigraphy, sediment characteristics and geochemistry of arsenic-contaminated alluvial aquifers in the Ganges–Brahmaputra floodplain in central Bangladesh. Journal of Contaminant Hydrology, 99(1-4), 112-136.

Sharma, S., Kaur, I., & Nagpal, A. K. (2017). Assessment of arsenic content in soil, rice grains and groundwater and associated health risks in human population from Ropar wetland, India, and its vicinity. Environmental Science and Pollution Research, 24(23), 18836-18848.

Shi, X., Wei, X., Koo, I., Schmidt, R. H., Yin, X., Kim, S. H., ... & Watson, W. H. (2014). Metabolomic analysis of the effects of chronic arsenic exposure in a mouse model of diet-induced fatty liver disease. Journal of proteome research, 13(2), 547-554.

Smedley, P. L., & Kinniburgh, D. G. (2002). A review of the source, behaviour and distribution of arsenic in natural waters. Applied geochemistry, 17(5), 517-568.

Smith, A. H., Goycolea, M., Haque, R., & Biggs, M. L. (1998). Marked increase in bladder and lung cancer mortality in a region of Northern Chile due to arsenic in drinking water. American journal of epidemiology, 147(7), 660-669.

Smith, A. H., Hopenhayn-Rich, C., Bates, M. N., Goeden, H. M., Hertz-Picciotto, I., Duggan, H. M., ... & Smith, M. T. (1992). Cancer risks from arsenic in drinking water. Environmental health perspectives, 97, 259-267.

Smith, A. H., Lingas, E. O., & Rahman, M. (2000). Contamination of drinking-water by arsenic in Bangladesh: a public health emergency. Bulletin of the World Health Organization, 78, 1093-1103.

Smith, A. H., Lingas, E. O., & Rahman, M. (2000). Contamination of drinking-water by arsenic in Bangladesh: a public health emergency. Bulletin of the World Health Organization, 78, 1093-1103.

Smith, A. H., Marshall, G., Yuan, Y., Ferreccio, C., Liaw, J., von Ehrenstein, O., ... & Selvin, S. (2006). Increased mortality from lung cancer and bronchiectasis in young adults after exposure to arsenic in utero and in early childhood. Environmental health perspectives, 114(8), 1293-1296.

Sohel, N., Vahter, M., Ali, M., Rahman, M., Rahman, A., Streatfield, P. K., ... & Persson, L. Å. (2010). Spatial patterns of fetal loss and infant death in an arsenic-affected area in Bangladesh. International Journal of Health Geographics, 9(1), 53.

Standard, B. (1997). The environment conservation rules 1997. Government of the People's Republic of Bangladesh, Dhaka.

States, J. C., Srivastava, S., Chen, Y., & Barchowsky, A. (2009). Arsenic and cardiovascular disease. Toxicological sciences, 107(2), 312-323.
STATISTICS, B. B. O. (2013). District Statistics 2011. Ministry of Planning, Government of The People's Republic of Bangladesh.
Stollenwerk, K. G., Breit, G. N., Welch, A. H., Yount, J. C., Whitney, J. W., Foster, A. L., ... & Ahmed, N. (2007). Arsenic attenuation by oxidized aquifer sediments in Bangladesh. Science of the Total Environment, 379(2-3), 133-150.
Su, Y. H., McGrath, S. P., & Zhao, F. J. (2010). Rice is more efficient in arsenite uptake and translocation than wheat and barley. Plant and Soil, 328(1-2), 27-34.
Swarnokar, S. C., Hassan, N., Rahman, M., Islam, M. M., & Ara, M. H. (2019). Assessment of Groundwater Quality in a Tidal River Basin of the Ganges Delta in Bangladesh. Journal of Geoscience and Environment Protection, 7(5), 131-151.
Takeuchi, M., Kawahata, H., Gupta, L. P., Kita, N., Morishita, Y., Ono, Y., & Komai, T. (2007). Arsenic resistance and removal by marine and non-marine bacteria. Journal of biotechnology, 127(3), 434-442.
Tareq, S. M., Maruo, M., & Ohta, K. (2013). Characteristics and role of groundwater dissolved organic matter on arsenic mobilization and poisoning in Bangladesh. Physics and Chemistry of the Earth, Parts A/B/C, 58, 77-84.
Thornton, I. (1996). Sources and pathways of arsenic in the geochemical environment: health implications. Geological Society, London, Special Publications, 113(1), 153-161.
Tondel, M., Rahman, M., Magnuson, A., Chowdhury, I. A., Faruquee, M. H., & Ahmad, S. A. (1999). The relationship of arsenic levels in drinking water and the prevalence rate of skin lesions in Bangladesh. Environmental health perspectives, 107(9), 727-729.9
Tondel, M., Rahman, M., Magnuson, A., Chowdhury, I.A., Faruquee, M.H., Ahmad, S.A., 1999. The relationship of arsenic levels in drinking water and the prevalence rate of skin lesions in Bangladesh. Environ. Health Perspect. 107, 727-729
Tu, C., & Ma, L. Q. (2003). Effects of arsenate and phosphate on their accumulation by an arsenic-hyperaccumulator Pteris vittata L. Plant and soil, 249(2), 373-382.
Vahter, M. (2008). Health effects of early life exposure to arsenic. Basic & clinical pharmacology & toxicology, 102(2), 204-211.
Vahter, M. (2009). Effects of arsenic on maternal and fetal health. Annual review of nutrition, 29, 381-399.
Vahter, M. E., Li, L., Nermell, B., Rahman, A., Arifeen, S. E., Rahman, M., ... & Ekström, E. C. (2006). Arsenic exposure in pregnancy: a population-based study in Matlab, Bangladesh. Journal of Health, Population and Nutrition, 236-245.
Verma, S., Mukherjee, A., Mahanta, C., Choudhury, R., Badoni, R. P., & Joshi, G. (2019). Arsenic fate in the Brahmaputra river basin aquifers: Controls of geogenic processes, provenance and water-rock interactions. Applied Geochemistry, 107, 171-186.
Wang, Z., Luo, Z., & Yan, C. (2013). Accumulation, transformation, and release of inorganic arsenic by the freshwater cyanobacterium Microcystis aeruginosa. Environmental Science and Pollution Research, 20(10), 7286-7295.
Wasserman, G. A., Liu, X., Parvez, F., Ahsan, H., Factor-Litvak, P., van Geen, A., ... & Momotaj, H. (2004). Water arsenic exposure and children's intellectual function in Araihazar, Bangladesh. Environmental health perspectives, 112(13), 1329-1333.
Welch, A. H., Westjohn, D. B., Helsel, D. R., & Wanty, R. B. (2000). Arsenic in ground water of the United States: Occurence and geochemistry. Ground water, 38(4), 589
Williams, P. N., Price, A. H., Raab, A., Hossain, S. A., Feldmann, J., & Meharg, A. A. (2005). Variation in arsenic speciation and concentration in paddy rice related to dietary exposure. Environmental science & technology, 39(15), 5531-5540.
Williams, P. N., Raab, A., Feldmann, J., & Meharg, A. A. (2007). Market basket survey shows elevated levels of As in South Central US processed rice compared to California: consequences for human dietary exposure. Environmental science & technology, 41(7), 2178-2183.
World Health Organization. (1981). Arsenic-Environmental Health Criteria 18.
World Health Organization. Guidelines for Drinking-Water Quality, fourth edn.(Geneva: WHO)(2011).

Xie, X., Wang, Y., & Su, C. (2012). Hydrochemical and sediment biomarker evidence of the impact of organic matter biodegradation on arsenic mobilization in shallow aquifers of Datong Basin, China. Water, Air, & Soil Pollution, 223(2), 483-498.

Xie, X., Wang, Y., Ellis, A., Li, J., Su, C., & Duan, M. (2013). Multiple isotope (O, S and C) approach elucidates the enrichment of arsenic in the groundwater from the Datong Basin, northern China. Journal of hydrology, 498, 103-112.

Yang, G. M., Zhu, L. J., Santos, J. A., Chen, Y., Li, G., & Guan, D. X. (2017). Effect of phosphate minerals on phytoremediation of arsenic contaminated groundwater using an arsenic-hyperaccumulator. Environmental Technology & Innovation, 8, 366-372.

Yang, H. T., Chou, H. J., Han, B. C., & Huang, S. Y. (2007). Lifelong inorganic arsenic compounds consumption affected blood pressure in rats. Food and chemical toxicology, 45(12), 2479-2487.

Yu, H. S., Liao, W. T., & Chai, C. Y. (2006). Arsenic carcinogenesis in the skin. Journal of biomedical science, 13(5), 657-666.

Yuan, Y., Marshall, G., Ferreccio, C., Steinmaus, C., Liaw, J., Bates, M., & Smith, A. H. (2010). Kidney cancer mortality: fifty-year latency patterns related to arsenic exposure. Epidemiology, 103-108.

Zavala, Y. J., & Duxbury, J. M. (2008). Arsenic in rice: I. Estimating normal levels of total arsenic in rice grain. Environmental Science & Technology, 42(10), 3856-3860.

Zhang, J., Ma, T., Feng, L., Yan, Y., Abass, O. K., Wang, Z., & Cai, H. (2017). Arsenic behavior in different biogeochemical zonations approximately along the groundwater flow path in Datong Basin, northern China. Science of the Total Environment, 584, 458-468.

Zhao, F. J., McGrath, S. P., & Meharg, A. A. (2010). Arsenic as a food chain contaminant: mechanisms of plant uptake and metabolism and mitigation strategies. Annual review of plant biology, 61, 535-559.

Zimmermann, M., Glombitza, K. F., & Rothenberger, B. (2010). Disaster risk reduction programme for Bangladesh 2010-2012. Published by the Swiss Agency for Development and Cooperation (SDC) Directorate of Humanitarian Aid and SHA.

Cite this article:

Anika Tahsin & Md. Aminul Islam Khan (2021). A review of arsenic contamination and evaluation of its role by water quality index in Faridpur Sadar Upazila, Bangladesh. *International Journal of Science and Business*, *5*(8), 305-328. doi: https://doi.org/10.5281/zenodo.5144547

Retrieved from http://ijsab.com/wp-content/uploads/800.pdf

Published by

IJSAB International