Studies on chronic exposure to arsenic toxicity through food chain and drinking water with respect to rice grain contamination in selected sites of West Bengal and search for mitigation options

Thesis submitted

by

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THESIS DETAILS

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This is to certify that the thesis entitled " **Studies on chronic exposure to arsenic toxicity through food chain and drinking water with respect to rice grain contamination in selected sites of West Bengal and search for mitigation options** " is prepared and submitted by **Madhurima Joardar**, registered as Ph.D. scholar on **17th January, 2018**, with **Registration number: D-7/ISLM/09/18** for the award of **Ph.D.** ***(Engineering)*** degree from Jadavpur University, is absolutely based upon her own work under the supervision of **Dr. Tarit Roychowdhury**, Associate Professor, School of Environmental Studies, Jadavpur University, Kolkata - 700032 and that neither this thesis nor any part of it has been submitted for any degree/diploma or any other academic award anywhere before.

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STATEMENT OF ORIGINALITY

I, **Madhurima Joardar,** registered as a research scholar on **17th January, 2018** with **Registration number: D-7/ISLM/09/18** do hereby declare that this thesis entitled "***Studies on chronic exposure to arsenic toxicity through food chain and drinking water with respect to rice grain contamination in selected sites of West Bengal and search for mitigation options***" contains literature survey and original research work done as part of Doctoral studies.

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Dedicated to Almighty

&

my Parents

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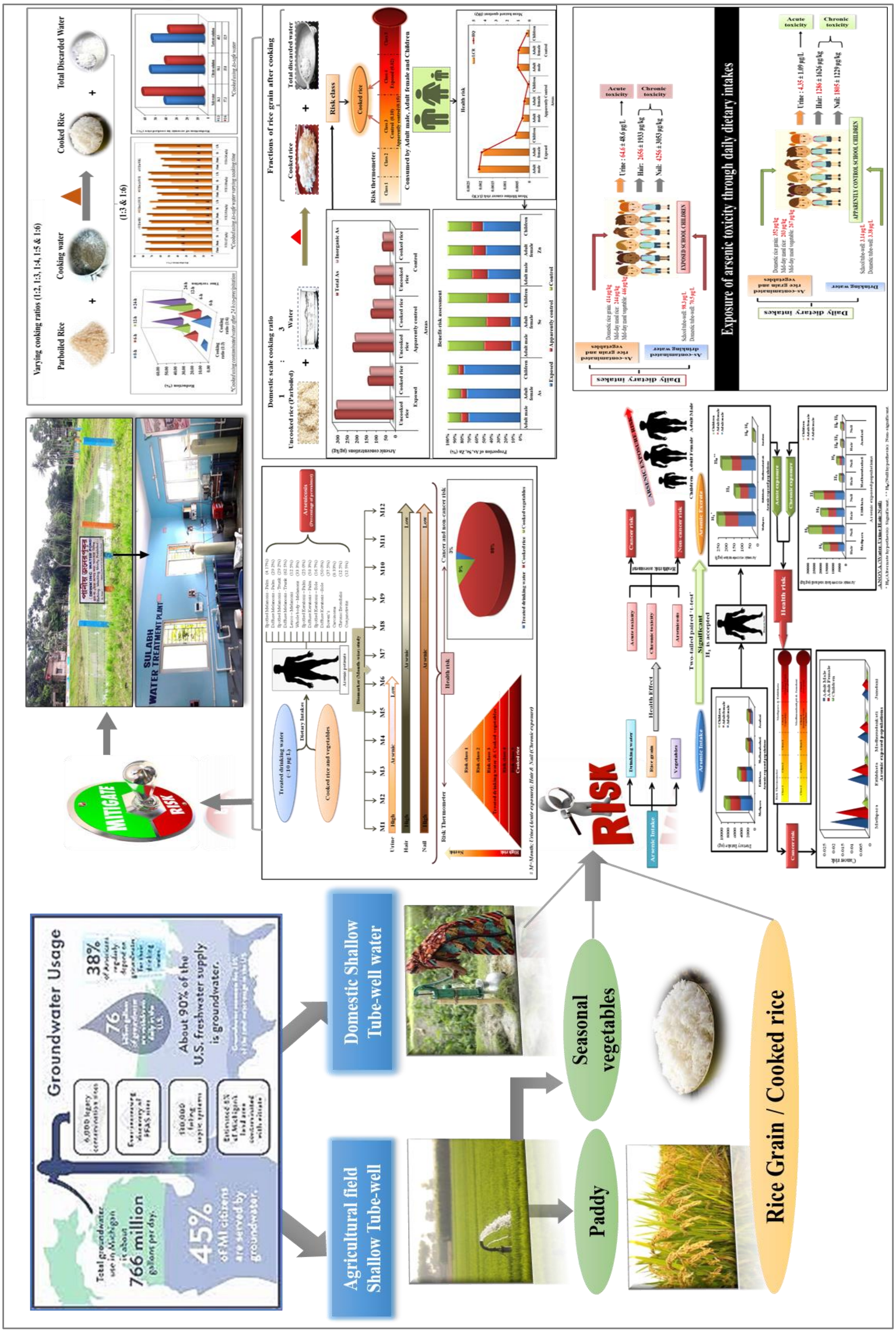
ABSTRACT

Presence of arsenic (As), a naturally occurring toxic metalloid (human carcinogen) in groundwater has been a recurring problem worldwide. Arsenic contamination along with its consumption poses considerable health exposure and risk to differently exposed populations. Perception of health risk has been assessed on inhabitants being exposed to As through dietary foodstuffs (drinking water, rice, and vegetables). One of the most crucial environmental concerns is natural groundwater As contamination in rural Bengal and its resulting toxic effect poses threats to human health. Foremost, the study highlights the As contamination scenario in the As-affected Gaighata, Deganga and Swarupnagar blocks of North 24 Parganas district, West Bengal, India. According to the groundwater quality indexing, 36% and 25% of deep tube-well water samples are characterized under 'good water quality', recommended for drinking purposes in the respective Gaighata and Deganga blocks. Gaighata and Swarupnagar blocks showed As categorized under considerable contamination, whereas, quantitative estimation of ecological risk has been regarded under the very high risk class. Apart from As-contaminated drinking water, rice As contamination and its consumption pose a significant health threat to humans. Rice grain which is considered as a staple food crop of rural Bengal, poses an additional danger to differently exposed inhabitants. Health risk through post-monsoonal rice cultivars is lower compared to pre-monsoonal rice cultivars. Moreover, the health risks through unpolished rice are higher compared to polished rice. Intake of inorganic As (iAs) is measured as a probable area of concern depending on health risk. Rice contributes approx. 89.5% of iAs, which is being nurtured in exposed areas and transported to control areas. The respective contribution of iAs in uncooked and cooked rice are nearly 96.6, 94.7, 100% and 92.2, 90.2, 94.2% from exposed, apparently control and control areas. Benefit-risk evaluation supported that the Se-rich values in cooked rice are effective in avoiding the toxic effect and potential risk from the associated metal (As). On a subjective note, the biomarkers of the As (urine, scalp hair, and nail) were analyzed to put forward the effectiveness of acute and chronic As exposure and its level of toxicity on human health. Acute and chronic effects of As toxicity were observed based on the recent and long-term rate of exposure of the populations. Statistical interpretation proves a significant relationship between drinking water and biomarkers, as well as justifies that the consumption of As-contaminated dietary intakes is the considerable pathway of health risk exposure. A potential area of concern has been put forward related to sub-chronic exposure in children due to As

toxicity through contaminated drinking water and rice. An awareness campaign was organized for the As exposed school children in the school campus on the As pollution and directed them to consume As-safe water. The pond (surface water) was chemically treated by slow sand filtration process, monitored by adding disinfectant like bleaching powder and supplied to the inhabitants and maintained by a local non-Government organization (Madhusudankati Krishak Kalyan Samity) collaborating with ‘Sulabh International Social Service Organization’ located in Madhusudankati village has been used by the school authority and children in domestic scale for drinking and cooking activities. A follow-up health exposure study after 8 months on the exposed school children showed a noteworthy declining trend of As accumulation in urine and other biological tissues of the exposed children after minimizing the level of As contamination. A longitudinal health effect study on a group of chronic arsenicosis patients for one-year highlighted the impact of treated (surface water) mainly used for drinking water along with continuous consumption of contaminated dietary foodstuffs. According to the risk thermometer (SAMOE), the different daily dietary foodstuffs have been categorized under 5 different risk classes along with their concern level. The carcinogenic (ILCR) and non-carcinogenic risks (HQ) through dietary intakes for adults were much higher than the respective recommended threshold level i.e. 1×10^{-6} and 1, compared to the children. As a mitigation strategy, different cooking methodologies has been used to reduce As in cooked rice. Cooking with water after co-precipitation process i.e. 24h showed 48.6 and 59.1% As reduction in cooked rice using respective ratio of 1:3 and 1:6. Further, 1 h soaking contact time with As-safe water showed 41.9% As reduction in soaked rice followed by cooking with As-safe water reduces 70% of As in cooked rice. An attempt has been taken to resist As in cooked rice using chelating agents like citrate and tartrate solution at the time of soaking using photo-catalysis method. Since, huge availability of As-safe water is of serious concern in As-prone areas, so use of citrate and tartrate solution (1:10) at the time of soaking followed by cooking with As-safe water reduces As up to 50.1% and 48.5%, respectively maintaining the domestic scale cooking ratio of 1:3. Overall, the study focuses on supply of As-safe water mainly for drinking purposes to the As-exposed populations through a proper surface water treatment plant to prevent the severe health threat. Use of As-contaminated groundwater must be avoided during agricultural as well as cooking practices to restrict As entry in crops (rice) and vegetables leading to prevention of food chain contamination. Presence of micronutrients in rice is highly effective in avoiding the toxic effect and potential risk through As. So, promoting awareness program on As severity and proper healthy nutritional food is highly recommended for the endangered population to fight against the devastating calamity of As.

GRAPHICAL ABSTRACT



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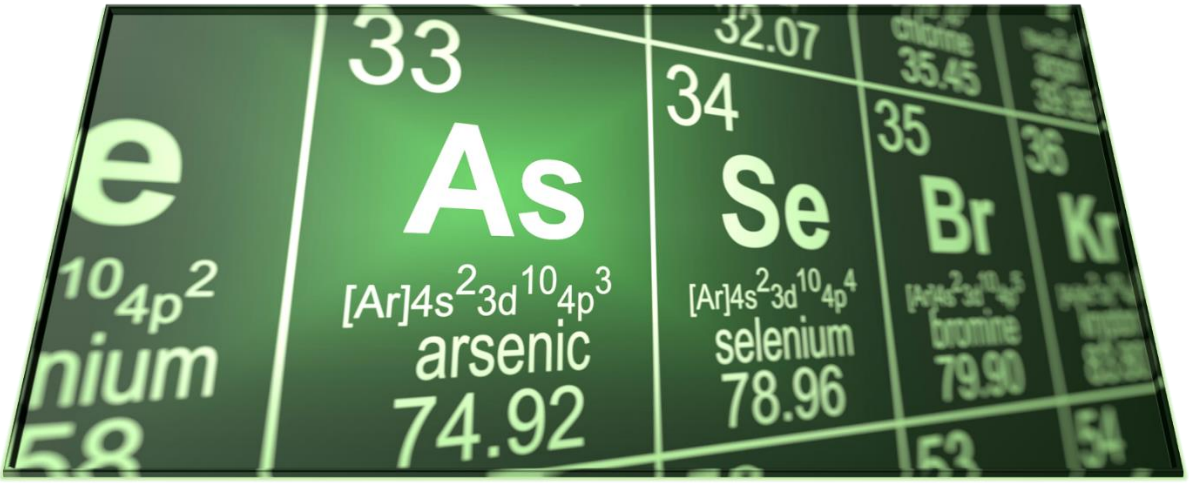
Health exposure & Arsenical skin manifestations

Chapter One

Introduction



1.1. CHEMISTRY OF ARSENIC

Arsenic (As) is a naturally occurring hazardous metalloid and is categorized under "Group I" human carcinogen (IARC, 2012). Atomic number, atomic weight and chemical configuration of As is 33, 74.9 and $1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $3d^{10}$ $4s^2$ $4p^3$. In the environment, the two As oxidation states that are most prevalent are pentavalent arsenate (V) and trivalent arsenite (III). As (III) is significantly more poisonous than As (V). Arsenic can exist mainly in two different forms, i.e., inorganic and organic (Zhao et al., 2010). Arsenic is typically found in arsenate, arsenite, dimethylarsinic acid, and monomethylarsonic acid. The order of As toxicity: As (III)>MMA (III)>DMA (III)>DMA (V)>MMA (V)>As (V). Due to naturally occurring As in groundwater, As poisoning is a major issue on a global scale. Nearly 80% of human diseases are water-borne, hence the groundwater quality is also of utmost importance for healthy and sustainable life (Das and Nag, 2015). Natural groundwater pollution is actually caused due to extreme use of groundwater, which catalyzes the process of chemical weathering (minerals) below the aquifers. Agricultural and industrial processes, mineralization sources contribute to the daily incursion of hazardous contaminants into groundwater, posing a major health risk to humans (Wu and Sun, 2016). Due to toxic and carcinogenic effect of As, World Health Organization (WHO) has established a permissible value of As i.e. 10 μg/L in drinking water (WHO, 2011a). Concerns about As impact on human health are raised by the toxic substance's pervasiveness in the environment, its biological toxicity, and redistribution.

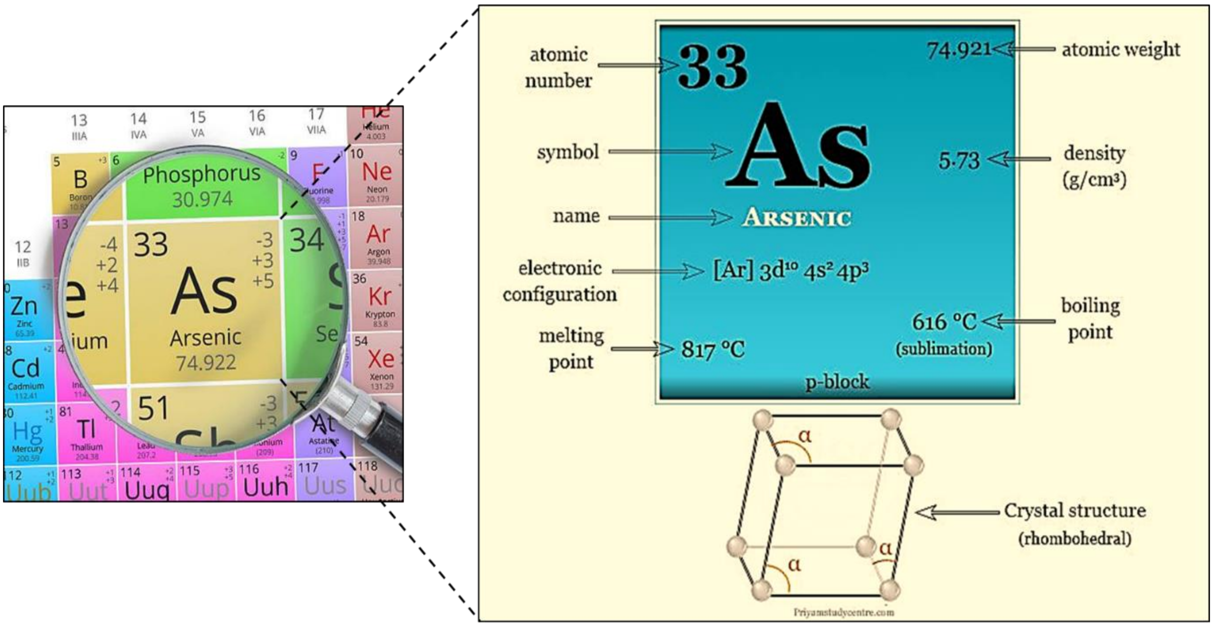


Fig. 1. Structure and chemistry of arsenic

1.2. ARSENIC IN ENVIRONMENT

1.2.1. Source and Distribution

One of the most pervasive harmful substances in the environment is As. Toxic effect of As, mobility and providence in the environment are all governed by the aforementioned web of mechanism that depends on the minerals, species distribution and biological processes (Bowell et al., 2014). Alchemist Albertus Magnus, in the thirteenth century was successful in isolating the chemical element from orpiment, an As sulfide (As_2S_3). Presence of As can either be geogenic or anthropogenic and it can be present in organic as well as in inorganic forms. Carbon and hydrogen are associated with organic forms but iron, nickel or cobalt together with sulfide is associated with the inorganic forms (Jang et al., 2016). For centuries, it has been regarded as a potent toxin, which is frequently used as a venom in both authentic and fictional crimes, and has worldwide led to considerable human health impact (Bowell et al., 2014). Arsenic can be found in a variability of minerals, which includes arsenopyrite (FeAsS), orpiment (As_2S_3), realgar (As_2S_2), and pyrite solid solutions (FeS_2) (Chakraborti et al., 2000). After sulfide minerals are weathered, As is also present in sedimentary environments, primarily adsorbed by Fe (III) and Mn (IV) (Acharyya et al., 1999).

Mobilization of As in the environment is aided by natural mineralization and microbial activity, but anthropogenic activities have made As contamination worse. Meanwhile, mining, industrial and agricultural activities contribute to an increase in As pollution (Panagiotaras et al., 2011). Arsenic's toxicity and mobility mainly depends on its chemical form and valence state. Chemical compounds containing As exhibit a range of its toxicity and solubility (Ghosh and Singh, 2009). Several reactions, including precipitation, adsorption/co-precipitation, and reduction/oxidation, regulate the groundwater As mobilization. Arsenic is a notable releaser, and its mobility into groundwater is directly impacted by the reductive breakdown of iron and aluminum metallic oxides and the activity of indigenous metal reducing bacteria (Shankar and Shanker, 2014).

Polya and Charlet (2009) has put into view several concepts on the sources of As and its mobilizing mechanisms in groundwater from the Bengal delta. When dissolved organic carbon (DOC) is led into the subsurface aquifers, reduction of iron oxy-hydroxides occurs along with successive release of associated As in groundwater (Harvey et al., 2002). Additionally, it was stated that anaerobic metal-reducing microorganisms might be crucial in As mobilization in sediments from the Bengal delta (Islam et al., 2004).

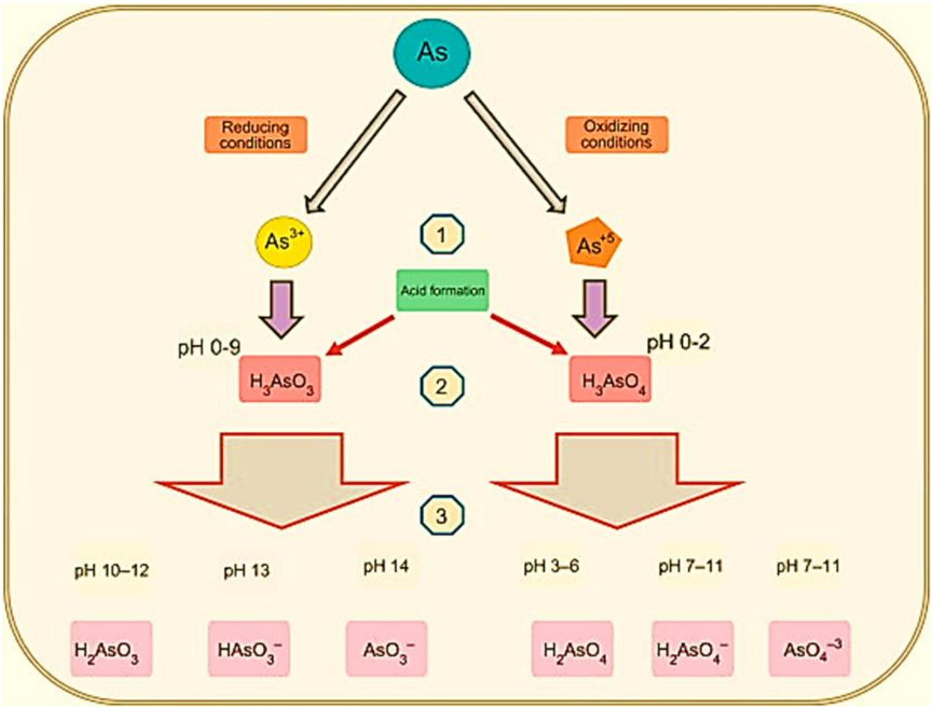


Fig. 2. Chemistry, occurrence and exposure of arsenic

Due to excessive levels of As in groundwater, the Ganga-Meghna-Brahmaputra (GMB) river basin is in danger (Chakraborti et al., 2013; Goswami et al., 2020). Elevated levels of As in the groundwater has been also revealed by School of Environmental Studies of Jadavpur University as in Madhya Pradesh (1999), Bihar and Uttar Pradesh (2003), Jharkhand (2004) and Allahabad-Kanpur track (2009), respectively (Chakraborti et al., 2018). In case of West Bengal, high As contaminated groundwater has been observed primarily in Burdwan, North 24 Parganas, Howrah, Hooghly, Nadia and Kolkata districts, respectively (Shaji et al., 2021). Due to increased concentrations of As in groundwater, the situation with regard to As contamination is most horrible in the Bengal delta, which includes Bangladesh and Bengal (Chakraborti et al., 2018; Chowdhury et al., 2000). Arsenical health risks have affected a significant portion of the people in the nine districts of West Bengal as a result of drinking As-contaminated water (Chakraborti et al., 2009; Rahaman et al., 2013).

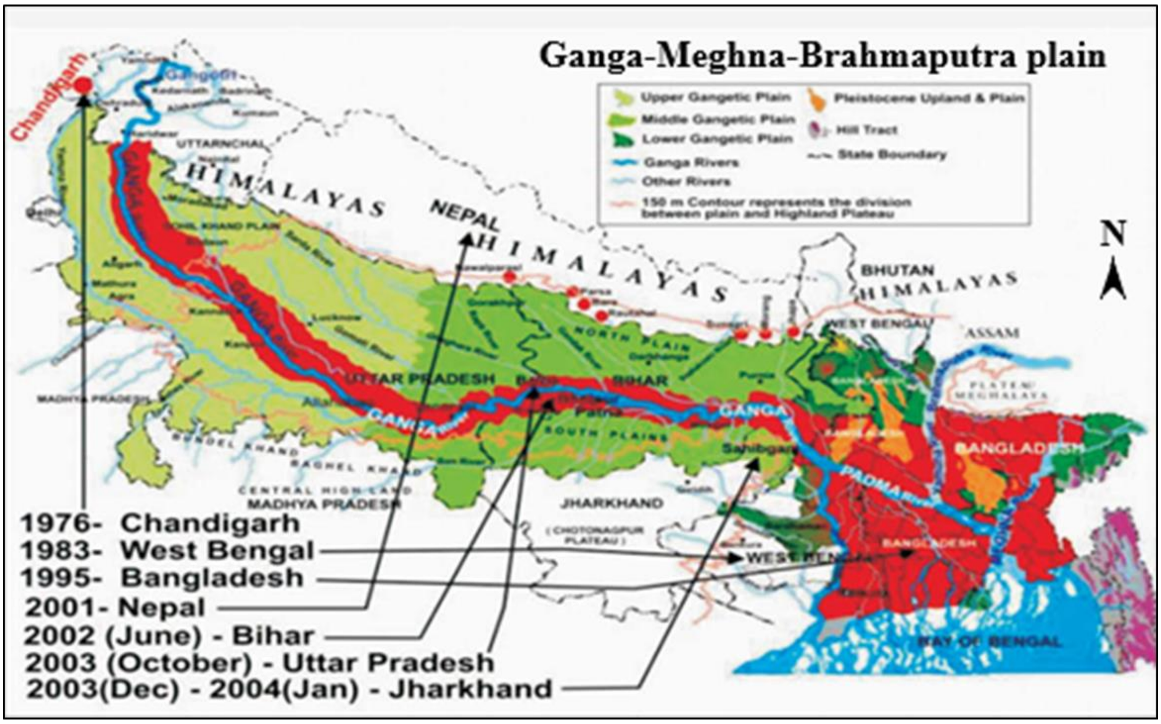


Fig. 3. Arsenic scenario in Ganga-Meghna-Brahmaputra plain (Source: Chakraborti et al., 2013)

The Himalayas and Tibetan Plateau are the major sources of As and also act as As carriers for West Bengal (Das et al., 2012; Mukherjee et al., 2021; Podgorski et al., 2020). For a long time, groundwater from both the confined and unconfined aquifers has been the safest water source for drinking purposes (Das and Mondal, 2021). In groundwater, numerous aspects influence the origin and occurrence of As, like solid-phase precipitation-dissolution of As-bearing minerals, aquifer ion-exchange capacity, adsorption-desorption, redox kinetics, mineralogical characteristics, fresh organic matter content, microbial activity and anthropogenic influences (Das and Mondal, 2021; Das et al., 2021). In groundwater the particular nature, source of As mobilization procedure is still unidentified. The well-known source of As contamination in nature is geogenic. Numerous theories have been hypothesized on the possible sources and mobilization mechanism of As in the Gangetic belt of West Bengal (Das et al., 2012). According to Lenoble et al. (2002) iron oxy-hydroxides are well known for their strong ability to absorb As. However, dissolved organic carbon (DOC) and reductive dissolution of As-rich iron-oxyhydroxide in subterranean aquifers cause the release of As into the groundwater (Acharyya et al., 1999; Das and Mondal, 2021; Kar et al., 2011). Some authors support the fact of “oxidation hypothesis”, according to the development of an oxidation front during the lowering of groundwater levels (Das et al., 1995; Acharyya, 1999). This leads to the breakdown of pyrite or arsenopyrite in the drained part of the sediments, releasing As into the groundwater. The mobilization of As during aquifer recharge after rainfall may be aided by the breakdown of iron (hydro) oxide (Chakraborti et al., 2016). Due to the increased pH conditions, arsenate can contaminate groundwater and simultaneously desorp the negatively charged metal oxides in the aquifers (De et al., 2022; Kim et al., 2012; Maity et al., 2017).

1.2.2. Arsenic species

Several distinct oxidation states of As (-3, 0, +3, +5) can be found in nature. In the environment As exists in organic and inorganic forms. The two most significant iAs are Arsenate (As (V)) and Arsenite (As (III)). It commonly manifests itself in groundwater as the oxy-anions of trivalent As (III) and pentavalent As (V) (Nriagu, 1994). Biological activity (methylation processes catalyzed by bacteria, algae, and yeasts) produces the organic forms of As, which typically signify pollution. Although there exist two most prevalent organic species in soil i.e. mono-methylarsenic acid (MMA) and di-methyl arsenic acid (DMA), which have a lower natural occurrence than inorganic (iAs) (Abedin et al., 2002; Fitz and Wenzel, 2002). Processes of reduction and oxidation (redox) play a significant role in regulating the species of inorganic As in soil. As (V) predominates in aerobic (oxidizing) environment, while As (III) prevails in anaerobic (reducing) situations. Also, in an investigational paddy field, under non-flooded environment, 30% of the As was present as As (III), whereas, in flooded environment it is up to 70%. (Takahashi et al., 2004).

1.3. ARSENIC IN GROUNDWATER

1.3.1. Indian Scenario

India, is the world’s most populous country, which consists 17% of the world's populace. However, the world's land area is incredibly small (2.4%), and the country's expanding populace is struggling with water scarcity. As an alternative, sewage and industrial waste have historically been dumped in surface water. The populace has turned their attention towards groundwater in order to fulfill the demand of drinking water in both rural and urban areas. The ground water quality measurement policy is another issue of concern, as is the uneven distribution of ground water (Bhattacharya et al., 2015). Among the diverse range of naturally occurring pollutants, the increasing concentration of natural As, a well-known carcinogen, is concerning. Arsenic contamination in groundwater over 50 µg/L was found in 13 districts of Bihar, situated near rivers like the Ganga and Gandak (Smedley et al., 2005). One of the worst natural groundwater disasters which affects mankind (human health) is groundwater As pollution in the Ganga-

Brahmaputra plains, India and the Padma-Meghna plains, Bangladesh. However, South and Southeast Asian nations are most badly impacted, particularly Bangladesh and the nearby West Bengal area (Polya and Charlet, 2009; Mukherjee et al., 2008). The GMB River Basin, which is the 13th-largest river basin in the world, has a substantial bed load of silt. The GMB river system contributes the most sediments to the Bay of Bengal, which contain various trace elements, including As (Kuehl et al., 1989). Arsenic contamination can be found in Bangladesh's Padma-Meghna-Brahmaputra plain, Bangladesh's Terai area, the Terai area of Nepal, and several Indian states like Assam, Jharkhand, Uttar Pradesh, Bihar, and West Bengal, (part of the Indo-Gangetic alluthroughl plain) (Chakraborti et al., 2004). Chakraborti et al. (2003) identified groundwater As pollution in the middle and upper Gangetic plain (Bihar and Uttar Pradesh). According to Das et al. (2020) the GMB plain is covered by 12 states in India and Bangladesh with varying levels of As contamination.

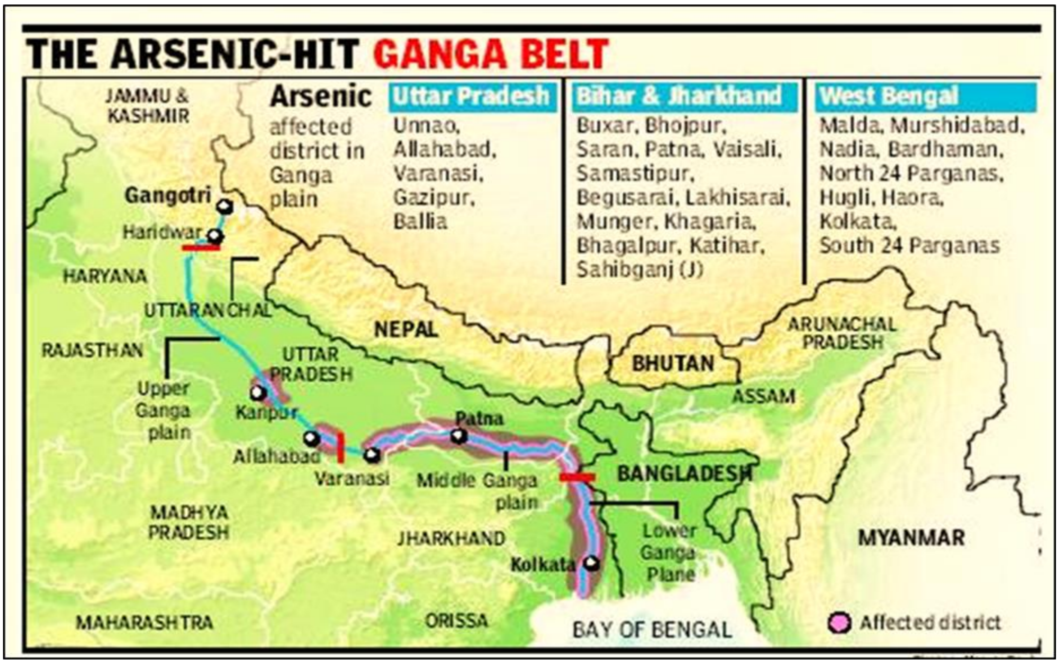


Fig. 4. Arsenic affected districts in Ganga-belt (Source: Panda, 2015)

1.3.2. Ganga Meghna Brahmaputra Plain

In the beginning, the world was slow to understand the prevalent nature of As pollution and even slower to distinguish the extent of enduring As intoxication. Over 500 million people live in the Ganga River basin, which occupies over 26% of India's mainland and is one of the world's most fertile and heavily populated areas. According to reports, the Ganga is one of the most polluted rivers in the world, with a concentration of As that is nearly 3000 times greater compared to the safe limit set by the WHO, along with other toxins like chromium, cadmium, lead, copper, and mercury, insecticides, and pathogenic microorganisms. As a result, over 50 million people in our country are currently at risk from groundwater As pollution (Chakraborti et al., 2018; WHO, 2003). In India, the level of groundwater As pollution has been rising exponentially over the past few years. The excessive-extraction of groundwater through hand tube-wells and redox conditions have triggered the mobilization of As in the Ganga River basin, in other words the tube-wells are now-a-days pumping up poisons from the womb of the earth (Guha Mazumder and Dasgupta, 2011). River water in Tibet was initially discovered to be contaminated with As, as a result of wastewater discharge from a geothermal power station (Chakraborti et al., 2018). In India, Chandigarh and a few villages in the Punjab and Haryana area of north India provided the first reports of groundwater poisoning with As (Datta and Kaul, 1976). Another case of As contamination was first detected in the year 1978 in the lower Gangetic plain of West Bengal, India and about 16.6 million individuals residing in 8 districts of West Bengal (according to 2001 census) are at risk (Das et al., 2018). In 1984, about 6 million individuals in West Bengal were exposed to As contaminated groundwater and reported a huge number of As-induced skin lesions in individuals from Kolkata area (Guha Mazumder and Dasgupta, 2011). Additionally, elevated amounts of As in the groundwater were discovered by SOES in the following states: Jharkhand in 2004; Bihar and Uttar Pradesh in 2003; Madhya Pradesh in 1999; and together with the Allahabad-Kanpur track in 2009 (Chakraborti et al., 2018). In case of West Bengal, high As contaminated groundwater has been observed primarily in Burdwan, North 24 Parganas, Howrah, Hooghly, Nadia and Kolkata districts, respectively (Shaji et al., 2021).

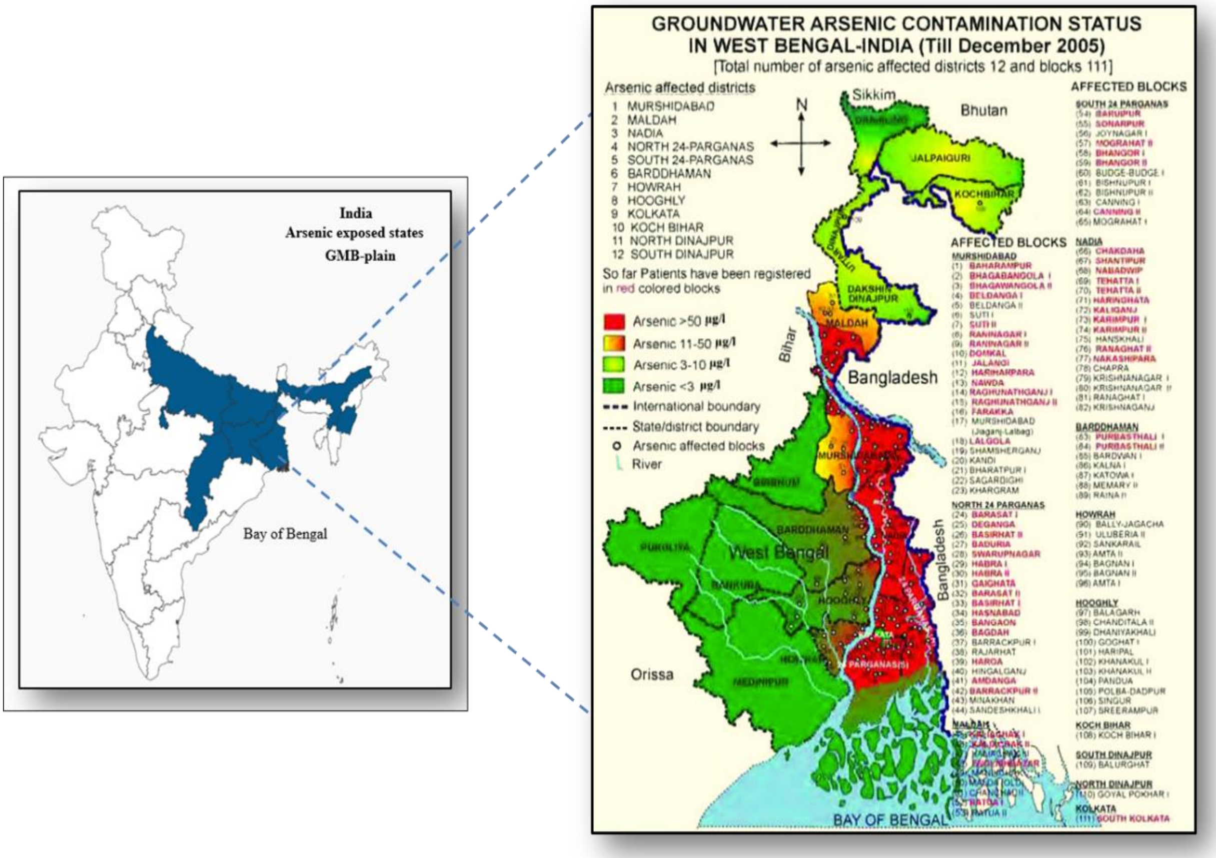


Fig. 5. Groundwater arsenic contamination status in West Bengal (Source: Sengupta et al., 2009)

1.3.3. West Bengal Scenario

For the past 40 years, As has been recognized as a harmful environmental contaminant that may cause cancer when consumed through contaminated groundwater or crops because of long-standing exposure (IARC, 2012; Grosse et al., 2019). From West Bengal, India districts namely, North 24 Parganas, Nadia, Murshidabad, South 24 Parganas are highly affected with As, where approximately 6 million people are suffering from major As induced health risks (Rahaman et al., 2013). In West Bengal, India, Gaighata is stated as a severely As-prone block, from 22 blocks located in a district North 24 Parganas district (Chakraborti et al., 2009). With a mean As concentration of 113 µg/L (ranged from 10–900 µg/L) in groundwater (n=3061) has been recorded As-contaminated above 10 µg/L in all 107 mouzas of 13 gram panchayats in Gaighata block (Roychowdhury, 2010). Groundwater in the deep tube-wells (400-600 ft or 122-183 m) installed by the local government is also tainted with As in addition to domestic shallow tube-wells (100 ft or 30.5 m) (Roychowdhury, 2010). A recent report on groundwater quality of Nadia district showed that total 17 blocks are As contaminated with a highest concentration of 206 µg/L in Chakdah block. It was also reported that almost 52% of groundwater samples contain As concentration greater than the permissible value (10 µg/L) in drinking water (Das et al., 2020). Another study report from Raninagar II block under Murshidabad district showed that approximately 54.6% of groundwater (domestic tube-wells) samples are with As concentration above 10 µg/L in drinking water, while almost 37.3% of irrigation water samples are with As concentration above the recommended value. According to Das et al. (2021b) among 9 As affected gram panchayats, Malibari-II is the worst exposed area having mean As value of 141 µg/L, ranging from <3 to 995 µg/L in domestic shallow water and 294 µg/L, ranging from 69.7 to 990 µg/L in agricultural water. The situation is very alarming, as recently a municipality i.e. Rajpur-Sonarpur Municipality, Sonarpur block (South 24 Parganas district) displayed a huge percentage of groundwater As contamination. About 16% of the analyzed groundwater samples covering 35 wards, controlled by Kolkata Metropolitan Development Authority reported with levels above the permissible limit of As (De et al., 2022). Mean As concentration has been observed as 56.2 µg/L, ranging from 10.1-213 µg/L in the samples of this municipality, having unsafe As levels in drinking water (De et al., 2022).

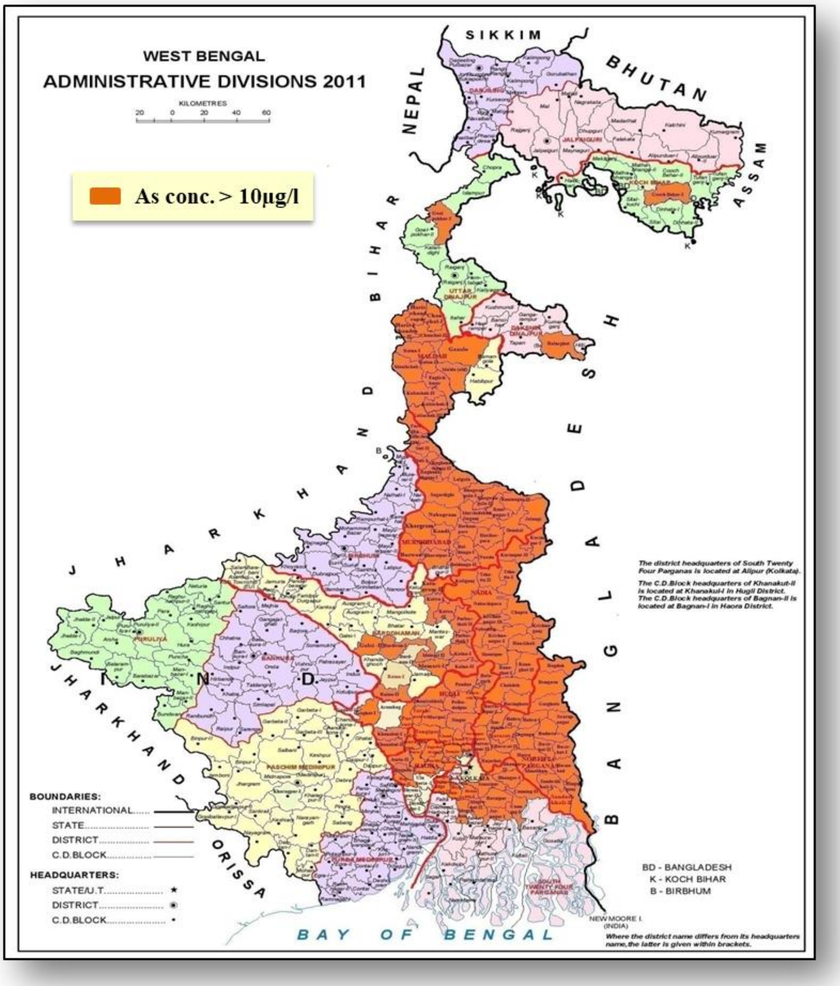


Fig. 6. Present scenario of groundwater contamination in West Bengal (SOES)

1.4. ARSENIC IN FOOD CHAIN

Arsenic pollution is substantial in Asian nations that produce rice, and endemic populations have been seen to suffer from As-related disorders (Brammer & Ravenscroft, 2009; Shaji et al., 2021). Hazardous heavy metals have a major detrimental effect on public health even in small amounts (Roleda et al., 2019). Additionally, consumers' concerns about food safety are growing as living standards are improving day to day. The presence of As and its distribution in the food chain must be identified in order to assess the danger to human health (Rehman et al., 2021; Santra et al., 2013). In many endemic areas, deep tube-well drilling and surface water treatment have been employed to supply drinking water safe of As. Contaminated groundwater is still utilized for irrigation, especially during the dry seasons for rice and vegetables (Islam et al., 2017; Roychowdhury, 2008). About 90% 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).

1.4.1. Arsenic distribution pattern during agricultural practices with special reference to paddy

Apart from exposure through As contaminated drinking water, continued exposure through intake of As contaminated crops and vegetables degrade the physiological system in several fragments of our state (Bhattacharya et al., 2010a, b; Santra et al., 2013). In West Bengal, variety of food crops are cultivated in As-contaminated fields and groundwater. Das et al. (2021b) also showed that approximately 12.5 tons of As has been withdrawn per year through agricultural shallow water in Raninagar II block, Murshidabad. According to the evaluation, the As deposition rate per land per year is 1.08 kg/ha and the accumulation of rice grain As from that land deposit is 0.18 %. Cultivation practices on aforesaid As-contaminated fields of staple crops like rice and seasonal vegetables is a major pathway for human exposure. West Bengal cultivates the largest amount of paddy annually and primarily uses contaminated groundwater for cultivation practice in As exposed area. Hence, we have tried to investigate the variation of As concentrations in different portions of whole paddy plant, root as well as soil during the periods of pre-monsoonal season (Chowdhury et al., 2018a). As the water is contaminated, As enters into the paddy plant through its root and then translocate to the tiller of the rice grain in a descending order and our finding exactly corresponds to the fact of translocation (Chowdhury et al., 2018a). Apart from this, leaf, pedicel, stem, root, root soil and surface soil showed a diverse similar pattern of As accumulation and distribution throughout the cultivation phase. Arsenic concentration declines in reproductive phase from vegetative phase followed by a noteworthy surge in ripening phase. Arsenic accumulations in leaf, stem and root showed a mean decrease percentage of 52%, 54% and 94%, respectively in reproductive phase compared to the vegetative phase. Higher iron concentrations in reproductive phase of the root soil established the formation of Fe plaques on the surface of the root by sequential extraction method. SEM study and EDXA spectra revalidate the finding by giving large iron and small As peak. Mainly iron plaque can prevent As uptake by plants through sequestration. Comparative investigation of the root soil's total dissolution and sequential extraction revealed increases of 19% and 88% in the vegetative and ripening phases, respectively, but especially a steep rise of 607% in the reproductive period. Following a drop of 71% in the ripening phase, the sequential digesting process of root soil in three separate phases of the growth period revealed a rise of 186% in total As content from the vegetative to reproductive phase. Finally, discharge of the iron plaques from the root surface is caused by co-precipitation of As with iron expelled from crystallized Fe plaque (Chowdhury et al., 2018a). Alternatively, due to scarcity of rain water or delayed monsoon farmers often use groundwater at the time of irrigation to meet the water requirement pattern. Consequently, the next study dealt with Aman or monsoonal paddy seasonal cultivation along with its phase-wise As accumulation from exposed and control areas of Bengal (Chowdhury et al., 2020b). So, in this case, the collective effect of groundwater and rainwater makes a distributed flow of As in plants, since rainwater has a major factor in adulterating the bio-available As. It demonstrated that As concentration is highest in root which decreases with the height of a plant like paddy. Here, SEM studies proved that no such iron plaque formation occurred in root soil which binds As. Monsoonal cultivation practices performs as a mitigation strategy to reduce accumulation of As in rice grains which is ascertained by this study. Mean As concentration in rice grain was found to be 350 and 224 µg/kg in exposed and control sites, respectively. Monsoonal rice As concentration amounts to be one-third of pre-monsoonal grain irrespective of the variety/cultivar and area of cultivation (Chowdhury et al., 2020b). Hassan et al. (2017) highlighted that intake of rice with 80 µg/kg of As on a daily basis has almost the same consequence as drinking water with 10 µg/L of iAs.

1.4.2. Rice grain (paddy)

Worldwide, rice (*Oryza sativa*) is recognized as one of the utmost essential food crop. Since rice production requires a significant amount of water, using contaminated groundwater for irrigation over an extended period of time may cause As concentrations in agricultural soil to rise and eventually accumulate in rice plants. The irrigation water contaminates the paddy soil, which increases the possibility of bioaccumulation of As in paddy plants. The range of total soil As concentrations, which fell below the European Community's recommended upper limit of 20000 µg/kg for agricultural soil. The distribution of As in raw rice in the root, straw, husk, and grain prevents the entire amount from being absorbed by humans. But the findings clearly demonstrated that the level of As contamination in irrigation water and soil is connected with the amount of As present in paddy plants (Rahman et al., 2007). Regardless of rice variety, Rahman et al. (2007) found that root As accumulation was 28 and 75 times greater compared to stem and rice, respectively. The reports by Abedin et al. (2002) was found to be compatible with this measure of greater As accumulation in roots. High As levels in rice straw pose a risk to livestock that eat the contaminated straw, which could then indirectly endanger human health through tainted beef and dairy products (Das et al., 2021a). Rice grains can accumulate up to 2000 µg/kg of As, which is significantly more than the WHO-acceptable value of 1000 µg/kg (Delowar et al., 2005; Islam et al., 2004; Meharg et al., 2003). Rice contributed the most to the daily As intake, according to Ohno et al. (2014) analysis, it has been found that a mean contribution to total As exposure from drinking water was 13% while that from cooked rice was 56%.

The principal exposure pathway for any pollution present in the water body is groundwater, mostly used for drinking. This exposure pattern does not exclude As. The same contaminated water has a significant influence on agricultural land in addition to being utilized for drinking. When the same water is utilized for irrigation, it also contributes As to the crop through absorption and surface deposition in the soil (Brammer, 2009). It is generally known that eating rice cultivated in As-contaminated areas in rural West Bengal exposes us to As, and this exposure is becoming a growing problem (Williams et al., 2005; Mondal & Polya, 2008).

Arsenic has been categorized by the IARC (International Agency for Research on Cancer) as a Group-I human cancer-causing agent, the category with the highest health risks (Zavala and Duxbury, 2008). According to Meharg et al. (2008), each country has its own set of regulations regarding the maximum tolerated/acceptable concentrations (MTCs) of As in rice and the application of the "As Low As Reasonably Practical" (ALARP) principle with regard to the statistical incidence of As-induced cancer.

With 5,900,000 acres dedicated to rice farming alone, Bengal is considered as one of the top states in India for rice production (Signes et al., 2008). However, the usage of As-contaminated groundwater for agricultural purposes has caused in excessive As deposition in the irrigated soil, contaminating the majority of crop fields in West Bengal (Roychowdhury et al., 2002a, 2005). There are 88,750 km2 of As-contaminated land in West Bengal, of which 38,861 km2 are highly damaged zones, including the districts named Murshidabad, North 24 Parganas, Nadia, South 24 Parganas and Maldah, where rice production is a common occurrence (Santra et al., 2013). One of the few areas with moderate As contamination is Hooghly and Bardhaman districts, where, rice farming is a common practice.

Rice is a kharif crop that necessitates lots of rain / rain-water for proper growth. However, in a country like India with modest rainfall, groundwater is mostly used for agricultural practices.

As(III), the dominant and most toxic species under anaerobic conditions, is made readily bioavailable by As contamination of groundwater, which is used to create the water logged condition for rice cultivation (creating anaerobiosis), thereby enhancing accumulation of this toxic metalloid in the crop. DMA and iAs are discovered to be the principal species existing in rice, which has been determined to be one of the foremost As exposure routes to humans through the food chain, aside from drinking water (Signes et al., 2008; Williams et al., 2005; Ohno et al. 2007). Jackson et al. (2012) reported that rice and rice products, infant meals, and sports drinks contained greater levels of iAs than the acceptable limit for drinking water of 10 µg/L. Zavala and Duxbury (2008) suggested that the typical limit of As in rice should be between 82 to 202 µg/kg, which is significantly less than the safe level (only for unexposed locations) advised by WHO (1000 µg/kg) (WHO, 2006). A limit of 100 µg/kg of As for newborn rice cereal, has just been proposed by the Food and Drug Administration (FDA, 2016). The majority of rice produced in Asian nations has been found to contain levels of As that are significantly above the FDA limit for newborns but under the WHO permitted range. Higher As concentrations in several tests imply that these nations may contain certain agricultural lands that are seriously contaminated with As. However, there is no evidence on the as content of parboiled rice and the majority of market basket surveys or field surveys to detect as in rice were conducted using raw rice.

1.4.3. Vegetables

Vegetables are a significant category of human food, hence various publications evaluated the levels of As in various vegetables and mushrooms. One of the greatest food produces in the world, after maize, rice, and wheat, is the potato (*Solanum tuberosum*) (Leff et al., 2004). According to Bhattacharya et al. (2010), rice showed a higher As buildup than potatoes. According to an analysis by Rahman et al. (2013), total As concentrations in food crops in Malda, West Bengal ranged up to 1464 µg/kg, with potatoes having the highest concentration (456 µg/kg), followed by rice grains (429 µg/kg). Vegetables from the Jalangi and Domkal blocks in West Bengal, India, tested positive for As with mean levels of 20.9 µg/kg and 21.2 µg/kg, respectively (Roychowdhury et al., 2003). Since leafy veggies have been found to have higher levels than non-leafy vegetables (11-145 µg/kg; 41-464 µg/kg) (Williams et al., 2006). From Bangladesh's Munshiganj and Monohordi, a range of 19-2334 µg/kg As in cooked vegetables has been discovered (Smith et al., 2006). According to statistics on As in vegetables, some vegetable produce can have As concentrations as high as those of rice on a dry weight basis.

Various amounts of As contamination have been found in the majority of food products (Jones, 2007). The highest quantities of As of any common human food are found in roots and tubers (Peryea, 2001). The vegetables with the highest As content are those with leaves, bulbs, and roots. In areas with greater As levels in soil or groundwater, vegetables have been also reported to contain elevated levels of As in addition to rice (Bhattacharya et al., 2012; Rehman et al., 2016). These resulted in an increased risk of As toxicity from regular dietary intakes which are locally nurtured in As-contaminated soil with groundwater mainly depending on the respective ingestion rate, exposure of the inhabitants from both endemic and non-endemic populace. Since the symptoms of arsenicosis appear after long-standing As exposure, so it is essential to monitor the deposition rate of As in human body to analyze the level of toxicity. Majority of As species excretes from the human body through urine, whereas, major build up occurs in the biological tissues (keratin cells) like scalp hair and nails of a human body (Nguyen et al., 2019).

1.5. ADVERSE HEALTH EFFECTS

1.5.1. Dermatological manifestations

Over 100 million people have been exposed to hazardous amounts of As due to the endemic groundwater As poisoning in the Gangetic plains (Argos et al., 2012). The clinical diseases known as arsenicosis are caused by the consumption of As through food and water. In the chronic type of the disease, symptoms appear 6 to 24 months after exposure to As (Saha et al., 1999). Exposed individuals show keratosis, raindrop pigmentation, hyper- or hypo-pigmentation, melanosis, and other kinds of skin problems (Guha Majumder et al., 2012). Adding up to, long-term As exposure causes multi-organs, patho-physiological alterations, such as neonatal mortality, respiratory failure, dyspepsia, liver and cardiovascular deterioration, paraesthesia, and anaemia. Moreover, cancer in skin, urinary bladder and lungs are common consequences of prolonged As exposure. Consumption of contaminated dietary foodstuffs shows more serious health risk compared to dermal exposure (Zhang et al., 2019). It has been observed that carcinogenic risk is higher in adults compared to children, whereas, non-carcinogenic risk are apparently high in children compared to adults. In addition to cancer, As ingestion is also associated with other non-cancerous diseases like atherosclerosis, hypertension, diabetes mellitus, etc. (WHO, 2001).

Chronic lung disease, chronic liver disease, neuropathy, and in addition to skin manifestations, are the main causes of morbidity in the human populace from an As-contaminated area, whereas cancer and chronic lung ailment are the main causes of mortality in the As -exposed populace (Mitra et al., 2004). The essential effects of As on human body have recently been thoroughly reviewed by Bhowmick et al. (2018), with a focus on babies and community-based mitigating strategies. Additionally, As poisoning worsens people's socio-cultural amenities by lowering their standards of life and livelihood (Rahman et al., 2018).

In West Bengal, As pollution has turned into the most horrible scenario in districts named North 24 Parganas, Murshidabad, South 24 Parganas, and Nadia (Chakraborti et al., 2009; Santra et al., 2013). The populaces residing here suffer from several arsenical health hazards which often lead to death (Rahman et al., 2005a, 2014; Roychowdhury, 2010). Acute and chronic As exposure causes cardiovascular and respiratory complications, neurological disorders, diarrhea, abdominal ache, or lungs dysfunction as well as carcinogenic health problems (Chakraborti et al., 2017). Arsenic toxicity has adverse effect on reproductive system, pre mature birth, neonatal and mortality rate in individuals (Chakraborti et al., 2013).

Continuous ingestion of As leads to rain-drop pigmentation, skin thickening, keratosis, black-foot disease, melanosis, gangrene trailed by cancerous diseases (Rahman et al., 2009, Ratnaike, 2003). Oral As exposure through drinking water also resulted in hearing loss (He et al., 2019; Shokoohi et al., 2021). On the other hand, the extent of chronic As exposure in a populace is manifested by the distinct skin lesions or symptoms (Karagas et al., 2015; Maity et al., 2012). The level of toxicity is diagnosed by estimating As deposition in the biomarkers i.e. urine, hair and nail of human body system (RGI, 2003; Vahter et al., 1994).

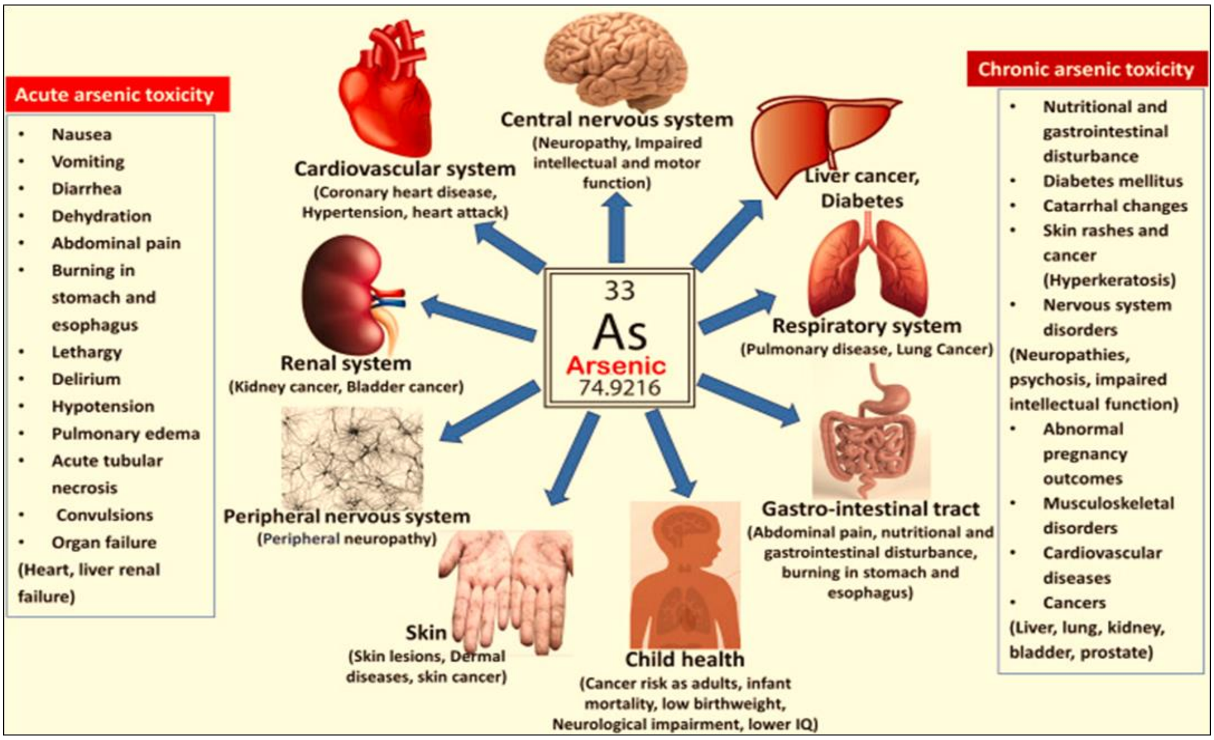


Fig. 7. Acute and chronic exposure caused due to arsenic toxicity

1.5.2. Biomarkers of arsenic

1.5.2.1.Acute exposure (Urine)

Due to the fact that the majority of As species are mostly excreted in urine, the total urine As concentration has frequently been employed as a measure of recent exposure (Buchet et al., 1981; Vahter et al., 1994). In human individuals, inorganic As has a half-life of around 4 days. The total As concentration in urine does not, however, reveal the kind of As that was absorbed. Some foods, especially those with a marine origin, frequently contain significant levels of As, primarily in the form of arsenobetaine, which is promptly eliminated in the urine despite not being digested by the body (Vahter et al., 1994). This means that intake of these items causes a sharp rise in the amount of total As present in the urine, invalidating urinary As as a measure of exposure to inorganic As. Comparatively, levels of 5–50 µg/L are discovered in the urine of individuals who consume no seafood that contains As or who are exposed excessively to inorganic As in drinking water or at work.

The fact that iAs (As V and As III) is more hazardous than organic As is crucial to emphasize at this point. In the human body, As undergoes methylation to form the distinct species of MMA and DMA (monomethyl arsenic acid and dimethylarsinic acid), which convert inorganic As to organic As (Vahter, 1999). The capacity of inorganic toxic As to methylate As in the body is significantly reduced (Tseng, 2009). According to Torres-Sánchez et al. (2016), higher levels of iAs diminish the methylation capability of As, which leads to larger levels of iAs in urine. Arsenic metabolism in human body is influenced by a variety of environments (Bozack et al., 2018; Torres-Sánchez et al., 2016).

1.5.2.2.Chronic exposure (Hair and Nail)

Keratin, a scleroprotein that is the only component of hair and nail tissues, is abundant in cysteine deposits with sulfhydryl clusters, which allow As to be readily bonded to them (Gault et al., 2008). Keratin proteins are the best indicator of metal (As) exposure in a human body (Khan and Muhammad, 2020; Kumar et al., 2021).

Chapter Two

Aims and Objectives

The objectives of the research study are as follows: -

- Groundwater quality indexing for drinking purposes from arsenic affected blocks of West Bengal: a health risk assessment study
- Contamination scenario and risk assessment of arsenic in deep tube-wells: a comparative study from two severely arsenic-affected blocks
- Food chain contamination scenario with respect to arsenic distribution and accumulation in whole paddy plant along with rice grain from arsenic prone block, West Bengal
- Different levels of arsenic exposure through cooked rice and its associated benefit-risk assessment from rural and urban populations of West Bengal, India: a probabilistic approach with sensitivity analysis
- Health exposure to arsenic toxicity through drinking water with special reference to rice grain contamination in arsenic affected blocks from West Bengal, India
- Appraisal of health exposure and perception of risk on the populaces exposed to varying arsenic levels through drinking water and dietary foodstuffs from four villages of arsenic endemic block
- Health exposure and risk assessment of a sub-population due to arsenic toxicity from an arsenic-prone zone
- Evaluating exposure level of arsenic and risk assessment of a mother-infant populace from a severely arsenic prone block, North 24 Parganas, West Bengal
- Exposure and health risk assessment of different aged children due to groundwater arsenic contamination from a severely exposed block, West Bengal, India
- Appraisal of acute and chronic health exposure due to arsenic toxicity on school children from exposed and apparently control areas of West Bengal, India
- A longitudinal health effect study to assess the impact of treated drinking water on chronic arsenic patients along with continuous intake of contaminated dietary foodstuffs from arsenic prone area, West Bengal, India
- Searching ways to remediate accumulation of arsenic in cooked rice during cooking process using different methodologies

Chapter Three

3.1. ARSENIC CONTAMINATION SCENARIO IN GROUNDWATER

Arsenic which is being considered as a naturally occurring heavy and toxic metalloid has been categorized under the group I human cancer-causing agent (Arain et al., 2009; WHO, 1981). The river basin of GMB is under threat due to high As in groundwater (Chakraborti et al., 2013; Goswami et al., 2020). Environmental As pollution is most prevalent in Bangladesh and Bengal, India, because of higher As concentrations in groundwater sources (Chakraborti et al., 2018; Chowdhury et al., 2000).

From the Bengal delta, several hypotheses have been proposed concerning the resources of As and the processes of movements in groundwater (Polya and Charlet, 2009). The overview of DOC into underground aquifers causes the lowering or solubilisation of Fe oxyhydroxide, accompanied by the discharge of coupled As in groundwater (Harvey et al., 2002). It was also detected that anaerobic metal-reducing microorganisms might play an important role in the redeployment of As in deposits from the Bengal basin (Islam et al., 2004).

Arsenic contamination in drinking water is a recurring issue in today's society. The groundwater contamination by As and its negative health consequences have been confirmed ever since centuries from various areas of India, Bangladesh, and worldwide (Chakraborti et al., 2015; Chowdhury et al., 2000; Kumar et al., 2019; Phan et al., 2010). Pure groundwater As-contamination is a long-term, irreversible risk to the Ganga Meghna Brahmaputra (GMB) plain's populace, especially in India (Chakraborti et al., 2018; Goswami et al., 2020). Arsenic poisoning exceeding the WHO suggested value (10 µg/L) in drinking water has been confirmed in nine districts in West Bengal (Chakraborti et al., 2009).

3.2. FOOD CHAIN CONTAMINATION WITH SPECIAL EMPHASIS ON RICE, RICE BY-PRODUCTS, AND VEGETABLES

To address the serious As downturn among populaces exposed in As-prone zones, various awareness initiatives and remediation technologies such as surface-water treatment, profound tube-well installation, and As eradication plants have been implemented. However, states such as West Bengal are facing tremendous problems as a result of the utilization of As-contaminated underground water for agricultural uses, which allows As to enter crops and vegetables developed on polluted soils (Chowdhury et al., 2018a). The origin of As exposure for humans from vegetable consumption is determined by the soil-to-plant transfer rate (Khan et al., 2009;

Roychowdhury et al., 2005). Aside from consuming As-contaminated water, ingesting contaminated foodstuffs allows this toxic metalloid to enter the human body (Chowdhury et al., 2020a, b; Mandal et al., 2019). Rice grain, the chief crop, adds a significant quantity of As (mostly inorganic) to regular diet through ingestion of cooked rice as well as rice by-products, posing a significant risk to endemic as well as non-endemic populaces (Biswas et al., 2019; Chowdhury et al., 2018b; Kumarathilaka et al., 2019). Aside from drinking As-tainted water, residents are subjected to As through nutrient habits of leafy vegetables, particularly rice grain cultivated on contaminated fields in the area (Roychowdhury, 2010). Arsenic in rice grain poses a serious threat for human health (Sohn, 2014). Around different parts of the state, health quality degrades depending on the long standing As exposure through intake of contaminated food crops (Bhattacharya et al., 2010; Santra et al., 2013). One of the prime sources of As exposure in human in recent times is rice and rice-based products whereas As concentrations in other pulses, cereals, vegetables also contribute to human health risk when consumed at a daily rate (Bhattacharya et al., 2010, Biswas et al., 2012, Roychowdhury et al., 2002b, Upadhyay et al., 2020). Samal et al. (2021) signified rice as a hyper accumulator depending on its bio-accumulation value of As. As a result, not only ingestion of contaminated drinking water, but also As contaminated rice and vegetables plays a vital role in increasing individuals health hazard (Bhattacharya et al., 2010). Biswas et al. (2019) highlighted that rice-based diet poses substantial risk to inhabitants living in both endemic and non-endemic areas. Arsenic in rice grain varies with cultivation season, background water and soil characteristics, rice cultivars etc. (Chowdhury et al., 2018a; 2020a). A maximum As concentration of 200 µg/kg has been suggested for inorganic As in polished rice by Codex Alimentarius, formed by FAO (Food and Agriculture Organization) of United Nations and WHO (Codex Alimentarius Commission, 2014). Although, Meharg et al., (2006) briefed that rice with iAs concentration over 100 µg/kg starts to impose cancer risk in As affected countries. Parboiling of sunned rice with As tainted water or cooking of rice grain with As contaminated water creates an additional burden (Chowdhury et al., 2018b, 2020a).

Inorganic As, a well-known carcinogen and potent toxin, is primarily found in drinking water and rice grain (IARC, 2012; NRC, 2001). Aside from As polluted drinking water, contamination from regular dietary exposure is a real concern for people living in endemic areas (Das et al., 2021; Mandal et al., 2019). Arsenic makes its pathway to the food chain through the usage of As-contaminated groundwater during irrigational practices and followed by cooking procedure (Chowdhury et al., 2018, 2020). Intake of As-contaminated food products has been linked to As exposure in individuals who consume safe drinking water from endemic areas. Numerous hydrogeochemical aspects in the Bengal basin are responsible for providing As-exposed inhabitants with safe drinking water (Biswas et al., 2012; Biswas et al., 2014a, b).

3.3. HEALTH EXPOSURE

A substantial number of individuals in West Bengal's nine districts have been exposed to arsenical health risks as a result of drinking As-contaminated water (Chakraborti et al., 2009; Rahaman et al., 2013). Arsenic is well-known as an environmental pollutant which is toxic as well as carcinogenic in nature. Globally, As is recognized as a class I carcinogen for causing cancer due to its long-term exposure (ATSDR, 2007) International Agency for Research on Cancer (IARC, 2012). Human exposure to toxic heavy metals has the tendency to occur for a lifetime, due to long-term exposure through water, food consumption, soil, and air (EFSA, 2009; Carlin et al., 2016; Rebelo and Caldas, 2016). For a long time, masses of individuals have been exposed to As toxicity through drinking of contaminated water (Chakraborti et al., 2009, 2013). As being a slow poison, it increases the toxicity burden in the human body through consumption of contaminated foodstuffs (Roychowdhury et al., 2002; Roychowdhury, 2010). The use of As-contaminated groundwater paved the way for As to enter the food chain during agricultural practices and food preparation (Zhao et al., 2010; Halder et al., 2014). Adults are more prone to As toxicity than children (Goswami et al., 2020). Children (aged between 12 and 15 years) are sub-clinically affected by As toxicity. Various studies have shown the possibility of maternal to fetal contaminant (As) transfer (Vahter, 2009; Gürbay et al., 2012). Starting from an early stage, exposure to toxic metals through consumption of contaminated water and foodstuffs is continued throughout life (Rebelo and Caldas, 2016). Depending on the rate of exposure worldwide, the presence of toxic metals has been categorized in human milk (Chao et al., 2014; Ettinger et al., 2014; Rebelo and Caldas, 2016).

Apart from long-term drinking of As-contaminated water, contaminated fruits and vegetables are also liable for triggering serious arsenical potential human health risks (Mandal et al., 1998; Roychowdhury et al., 2002, 2003). Groundwater is recognized as a critical source (97%)of fresh water that plays an important role in sustaining life (Frappart, 2013). The scenario of groundwater As contamination is a long-term, irreversible risk to the people of the GMB (Ganga Meghna Brahmaputra) plain, particularly West Bengal, India. Numerous reports have been noted for As contamination of natural groundwater and its detrimental health impacts over the years (Chakraborti et al., 2015; Santra et al., 2013). Arsenic is widely recognized as a human carcinogen because of its prolonged time of exposure (ATSDR, 2007; IARC, 2012). Noxious heavy metal exposure in humans happens over an entire lifespan as a result of long-term exposure through tainted water (EFSA, 2014). For many years, millions of people have indeed been exposed to significant As toxicity as a result of drinking contaminated water. (Chakraborti et al., 2009, 2013) Using As-contaminated groundwater (farming techniques and domestic scale cooking) opened the door for contamination of the food chain. (Roychowdhury, 2008; Zhao et al., 2010).

The total dietary intake of inorganic As per day is in the lower threshold on the standard dose for 0.5% enhanced lung cancer incidence ($BMDL_{0.5}$), as estimated 3.0 µg/kg bw/day, ranged from 2 to 7 µg/kg bw/day (WHO, 2011b). The benchmark range i.e. 10^{-6} to 10^{-4} is considered for all-time carcinogenic threat (Kazi et al., 2016; USEPA, 2011). Whenever the hazard quotient (HQ) value is more than one, the threat of any non-cancerous disorders from As-contaminated drinking water and food products is indicated (Das et al., 2020; USEPA, 2005). Arsenic concentrations in urine, nails and hair are indicators of lethality in our body. The rate of toxic metal exposure begins early in life and continues throughout life through drinking of contaminated water and nutritional foodstuffs (Rebelo and Caldas, 2016). Aside from drinkable water, As poisoning from ingestion is a serious problem for children in endemic areas. The acute toxicity of As through contamination of drinking water poses a serious health threat to kids living in exposed areas (Baig et al., 2016; Brahman et al., 2016; Singh and Ghosh, 2012). Even at a low level of As exposure, there exists health threats in children with contagious diseases (Biswas et al., 2018; Farzan et al., 2013). Due to absence of arsenical symptoms, such as skin lesions, diagnosing As toxicity in children becomes difficult. As a result, tracking children's health status is critical for analyzing future risk, as they incur from sub-clinical toxic effects. Children from an As-endemic block (Gaighata) have indeed been recognized as sub-clinically impacted and are at risk of developing cancer in the future. Short-term exposure to As toxicity induces abdominal pain, diarrhea, and other symptoms, whereas prolonged exposure causes massive manifestations. (Rahman et al., 2009; Ratnaike, 2003). Several research reports have demonstrated that consuming contaminated water poses significant health risks and has an impact on children's development and levels of intelligence (Rahman et al., 2001; Wasserman et al., 2015). Methylation of toxic As in our body and excretion elimination of the toxic element through urine is one method of removing it. The methylation process is slower in children, giving rise in developmental disorders (Chowdhury et al., 2003). Malnutrition among kids in underdeveloped and developing countries is impacted by As toxicity, resulting in a deterioration of their health status (Calderon et al., 2001; Milton et al., 2004). Long term exposure to As and its serious health consequences are impacting people of all ages, despite the fact that therapeutic options are limited. As a result, As, an ecologic carcinogen, must be eliminated from the drinking water and nutritional foodstuffs, ensuring the health of the next generation.

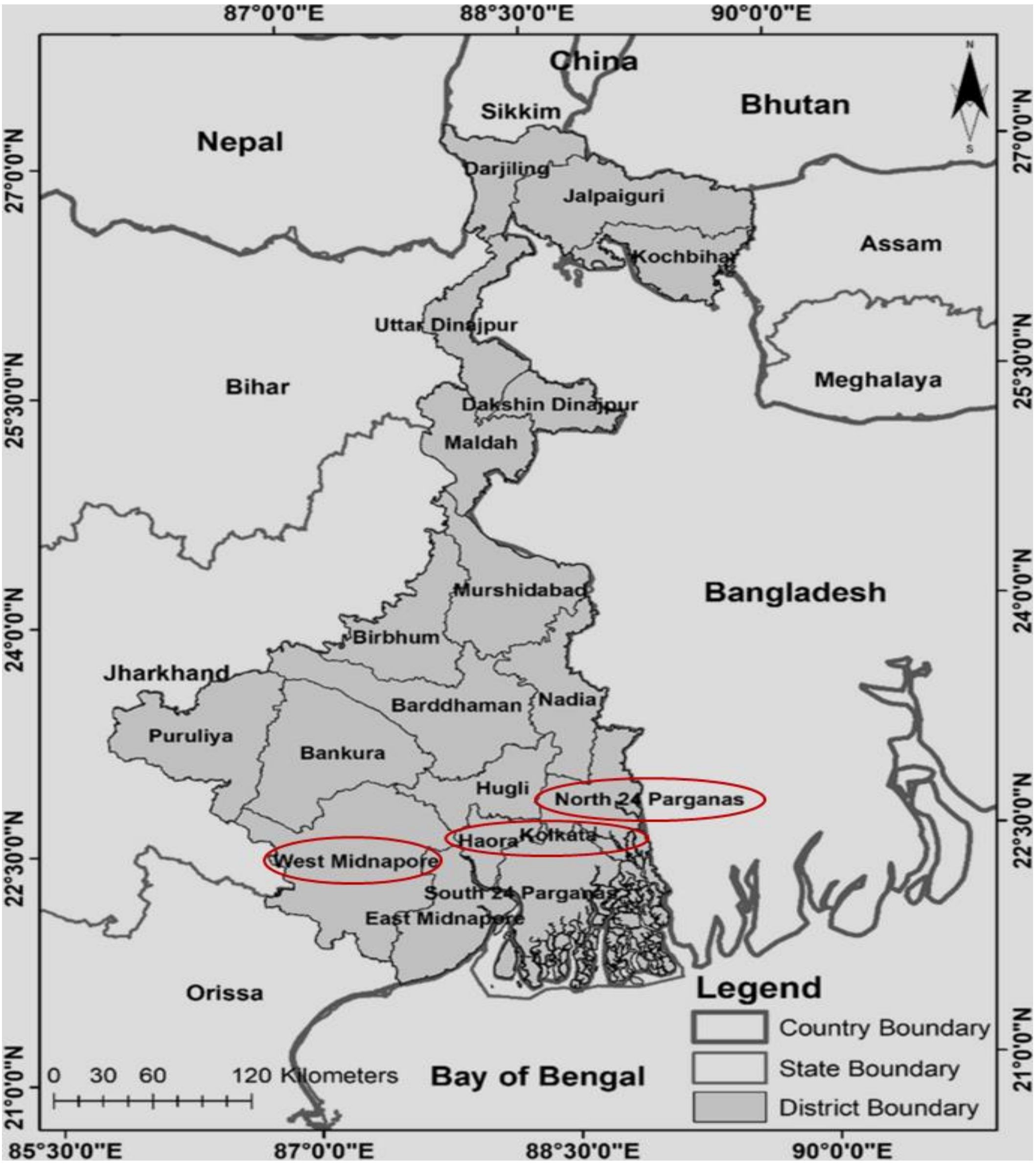
Health sensitivity due to acute and long-term toxicity has been seen in a variety of ages from exposed individuals (Bae et al., 2017; Rasheed et al., 2019). The drastic arsenical skin symptoms have determined prolonged As exposure among the populaces exposed (Maity et al., 2012). Persistent toxicity has been linked to a number of neurotoxic diseases in adults, as well as high risk of cancer, hyperkeratosis, black-foot disease, melanosis, gangrene, cardiovascular, kidney, and skin diseases (Bae et al., 2017; Prakash, 2016). Several researches have shown that the impact of As is reliant on doses in cancer cases involving the lung, kidney, skin, and bladder (Farzan et al., 2013; Wasserman et al., 2014). Individuals as well as exposed populaces differ in their ability to methylate As (Bozack et al., 2018). Several studies have found that an individual's methylation of a heavy metal like As is effected by its intake, type, medium of exposure, and nutritional intake (Chowdhury et al., 2003; Goswami et al.,2020). Long-term As noxiousness and other health risks have been noted among the residents of the endemic blocks (Rahman et al., 2003; Roychowdhury, 2010). Even though the total populace of the affected areas is not yet directly impacted, a large portion of the local populace lives on the edge of health hazard due to a lack of access to As-safe drinking water and an absence of adequate knowledge about As poisoning. The varying arsenical skin symptoms in a populace determine the degree of prolonged As exposure (Maity et al., 2012; Mandal et al., 1998). Innumerable epidemiological studies on the health impacts of sub-chronic As exposure among children, primarily through drinking water, have been carried in developing nations. The consequence of As-contaminated drinking water on children poses a significant risk (Baig et al., 2016; Singh and Ghosh, 2012). Aside from drinking contaminated water, As poisoning from ingestion of contaminated diet is a serious issue for kids in endemic areas. Even with lower concentrations of As exposure, it poses a danger of several infectious diseases (Biswas et al., 2018; Farzan et al., 2013). Even during late 1970s, studies of Chilean school kids revealed chronic pulmonary impacts after positive examination of the body for keratosis (Borgono et al., 1977).

Arsenic, as a metalloid, is widely regarded as a peripheral neuro-toxicant, causing extreme neuropathy in school children due to its acute toxicity (Wright et al., 2006).). Drinking water has posed a severe health hazard to children's development, mortality, and level of intelligence in Bangladesh (Rahman et al., 2013; Wasserman et al., 2015). Arsenic toxicity was found in children living in rural areas of Bangladesh and West Bengal, India, even after its concentration in drinkable water was reduced and fresh deeper tube-wells were equipped. This abnormality was then credited to As in food as well as public ignorance of the importance of using proper tube-wells for obtaining water (Kippler et al., 2016). Many instances revealed similar patterns in children from West Bengal's South 24 Parganas district (Mandal et al., 1998; Rahman et al., 2001). Numerous studies and researches have said that there is a clear link between As levels in the body and a decrease in cognitive capabilities in children after chronic exposure. Long term exposure of As and its detrimental consequences have crippled people of all ages, and remediation options are limited As a result, As, a powerful neurotoxin as well as a carcinogen, must be eliminated as much as doable from water supplies and food crops to ensure that future new generation have an improved standard of living in terms of both economic and educational and physical well-being. Arsenic toxicity is difficult to diagnose in children due to the absence of symptoms, such as skin lesions. As kids suffer from sub-clinical toxic effects, evaluating their medical status is more crucial for future hazard.

Arsenic contamination of drinking water and rice causes both acute and chronic health problems (Melkonian et al., 2013; Rasheed et al., 2017). The body burden (state of toxicity) of the toxicant is determined by examining human tissues (hair and nails) and urine (Goswami et al., 2020). Long-term As toxicity has been linked to serious skin symptoms (melanosis, keratosis, and pigmentation), cancer types, mental and neurological consequences, and cardiovascular disease (Martinez et al., 2011; Steinmaus et al., 2013). Because of their prolonged exposure rate, residents with drastic arsenical skin expressions are identified as arsenicosis patients among As-exposed communities (Mandal et al., 1998; Roychowdhury, 2010). Cancers of the bladder, kidney, liver, lungs, and skin are caused by As toxicity (Chakraborti et al., 2015; Rehman et al., 2020). Arsenic methylation is primarily determined by the dose, type, and medium of exposure, as well as the dietary background of the exposed person (Goswami et al., 2020).

Growing public awareness of As contamination in the groundwater in rural Bengal has prompted the development of many mitigation actions, including the drilling of deep tube-wells and the construction of As eradication plants (ARP) and surface water treatment facilities (SWTP) to provide As-safe drinking water. However, because of its limited availability, residential shallow tube-well water, which is mostly tainted with As, continues to be used for cooking and, in some cases, drinking, in addition to other household purposes such as washing, bathing. Furthermore, the utilization of As-contaminated groundwater for agriculture exacerbates the problem by allowing As into the food chain (Chowdhury et al., 2018). As a result, this study will examine the impact of awareness campaigns on serious As calamity, as well as the pattern of arsenical body burden in inhabitants who have been subjected to controlled drinking water for the past years.

Chapter Four



Study areas

Natural groundwater As contamination has been a foremost issue in West Bengal, India. Investigations in West Bengal showed groundwater from enormous areas are contaminated with As above the considerable value of As in drinking water (10 µg/L) (Bhowmick et al., 2018). Analysing groundwater samples from the districts and depending on their respective As concentration has divided West Bengal in different contaminated areas like highly contaminated, mild contaminated, uncontaminated etc. (Chakraborti et al., 2009). Nine districts namely North 24 Parganas, Murshidabad, South 24 Parganas, Malda, Nadia, Hooghly, Purba Bardhaman, Howrah, and Kolkata located on the eastern part of Bhagirathi River showed As levels in numerous domestic tube-wells above 300 µg/L and had been categorized under highly contaminated areas (Chakraborti et al., 2018). Among the 9 districts, North-24-Parganas, Murshidabad, Nadia are extensively affected (95% of blocks) having As concentration greater than 50 µg/L (Bhowmick et al., 2018). Five districts namely, East Medinipur and West Medinipur, Bankura, Birbhum, Purulia are unaffected with As in groundwater i.e. below 3 µg/L. The severity of the problem is determined by human exposure, with an estimated 26 million people in West Bengal potentially at danger from drinking water with an As concentration of more than 10 µg/L. (Chakraborti et al., 2009). North 24 Parganas extends in the tropical zone of West Bengal, India, which is mainly bounded by Nadia (northern side), Bangladesh (north and east side), South 24 Parganas & Kolkata (southern side) and Kolkata, Howrah & Hooghly (west side), respectively. This is a popular district in West Bengal, where the groundwater is extensively contaminated with As (Chakraborti et al., 2001). Groundwater is mostly As affected in several blocks like Gaighata, Swarupnagar, Deganga (Chakraborti et al., 2009; Chowdhury et al., 2018; Roychowdhury, 2010). Gaighata block has a total populace of 330,287, where, approximately 80.4 % populace is rural (Census, 2011).

The Global Positioning System information with proper latitudes and longitudes has been taken for precise detection of the water samples. The location of the respective study areas has been identified using GPS meter (Model: GARMIN Etrex 30x GPS).

4.1. North 24 Parganas district

The present study area includes three severely As-affected blocks located in North 24 Parganas district, West Bengal which is a portion in the Gangetic-delta, lying eastern side of the Hooghly River (Chakraborti et al., 2001 Roychowdhury, 2010). Equally Deganga block is already reported as severely As-contaminated sited in West Bengal, India (Chowdhury et al., 2018a, b). The three As-affected blocks are namely: Gaighata (Latitude: 22º93′48.21″ N and Longitude:

88º73′07.54″ E), Swarupnagar (Latitude: 22.8333°N and Longitude: 88.8667°E) and Deganga (Latitude: 22º41′36″ N and Longitude: 88º40′41″ N). The research study has carried out work on three As exposed blocks of this district i.e. Gaighata, Swarupnagar and Deganga.

Gaighata block: This block is stated as one of the severely As affected, out of 22 blocks in North 24 Parganas district of West Bengal, India (Chakraborti et al., 2009; Rahman et al., 2003). It has been found that groundwater samples (n = 3061) is As-contaminated above 10 µg/L, in 107 mouzas over 13 gram panchayats of Gaighata block with a mean As concentration of 113 µg/L, ranging from 10–900 µg/L (Roychowdhury, 2010). Not only domestic shallow tube-wells (30.5 m), but also groundwater from deep tube-wells (121.92-182.88m) mainly installed by the local government is also As-contaminated (Roychowdhury, 2010).

Four differently exposed villages from Sutia and Ichapur II-gram panchayat have been targeted as study areas namely Mathpara (22º54´11.17´´ N, 88º47´30.97´´ E), Eithbhata (22º54´19.13´´N, 88º47´51.12´´E), Madhusudankati (22º53´53.18´´N, 88º46´38.55´´E) and Jamdani (22º53´54.18´´N, 88º46´03.37´´E) depending on the current scenario of groundwater As-contamination placed in one of the severely As prone Gaighata block of North 24 Parganas district, West Bengal, India.

Swarupnagar block: This is recognized as a community development block, which forms an administrative separation in Basirhat sub-division of North 24 Parganas district, West Bengal, India. According to 2001 census, Swarupnagar has a total populace of 226,333 out of which 115,630 were male inhabitants and 110,703 were female inhabitants (Census, 2001). In accordance with Census of India, Swarupnagar CD Block consists of 256,075 (total populace), out of which rural is 251,715 and urban is 4,360 (Census, 2011). From the Swarupnagar block (n=3366) tube-wells were analysed for As. Analytical outcomes showed that 51.7% of the tube-wells had As higher than 50µg/L in Swarupnagar block (Hossain et al., 2006). Recently, Biswas et al. (2021) surveyed that about 95% of the tube-wells linked with As removal plants (ARP) in Swarupnagar block were having As concentration more than 50µg/L.

Deganga block: This is a community block situated 20 km from Barasat Sadar sub division in North 24 Parganas district of West Bengal, India and is a portion of the Gangetic delta, lying on the east side of Hooghly River. The aforementioned area is already well-known to be As-contaminated (Chakraborti et al., 2001; Mandal et al., 1996). According to Census of India, Deganga CD Block consists of 319,213 (total populace), out of which rural populace is 309,550 and urban is 9,663 (Census, 2011). Previously, Deganga has been testified to be one of the severely As-affected block of West Bengal by various investigators (Mandal et al., 1996; Chakraborti et al., 2001; Roychowdhury et al., 2002; Sarkar et al., 2013). In Deganga, soil As concentration was observed to be in the range of 17,400-30,900 µg/kg (Ghosh et al., 2004; Stroud et al., 2011).

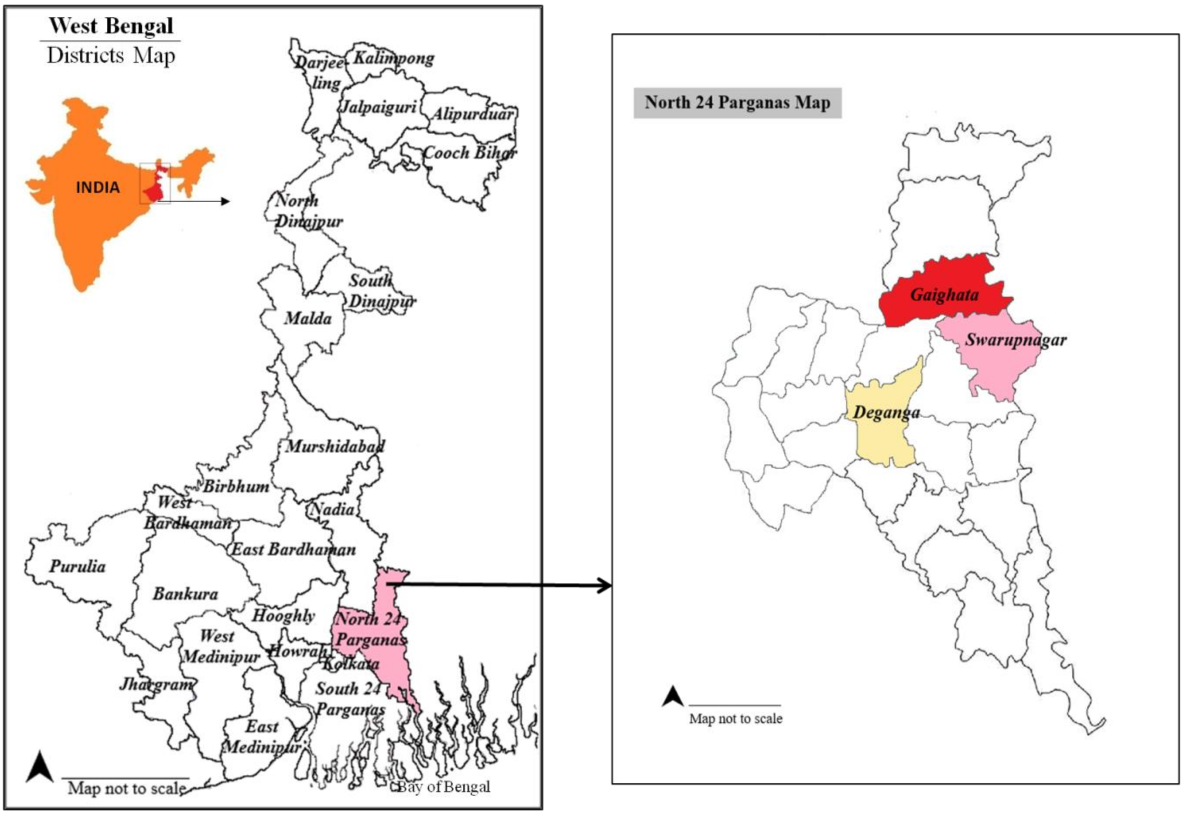


Fig. 8. Arsenic exposed district showing the studied blocks (Gaighata, Deganga and Swarupnagar)

4.2. Kolkata district

The Kolkata Municipal Corporation (KMC) is the largest Municipal Corporation located in West Bengal, India with a populace of 4,496,694 and covering an area of 185 km^2. In 1993, Arsenic was discovered in the groundwater of Kolkata city (Chakraborti et al., 2018). Recent research study analyzed water samples (n=262) from all 144 wards of KMC and testified that 100 wards are having alarming level of groundwater As contamination (Malakar et al., 2016). Out of 144 wards, 51 wards (35.4%) have been found As level above 50 µg/L, 49 wards have As between

11 and 50 µg/L and only 44 wards (30%) showed As below 10 µg/L in groundwater (Malakar et al., 2016).

The Kolkata Metropolitan Area (KMA) encompasses three municipal corporations (KMC, Howrah and Chandhannagore), which is the oldest as well as third major urban agglomerate (UA) in India covers over 1851 km^2 with a populace of 14,112,536 (Census, 2011). In accordance with 2011 census report, KMC is considered as the 5th densest city in India (24,252 person per km^2). For administrative purpose, the city is consisting of 141 wards; presently the administrative division of KMC is 144 wards since 2013. Ward in an administrative division of a city that classically elects and is represented by a counselor. Kolkata has been selected as an apparently As-contaminated area for this study (Biswas et al., 2019). Supply of As-safe water through treatment of Ganges water is accessible among the populace in KMC and its neighboring areas (greater Kolkata) (Biswas et al., 2019). Groundwater has been testified as As-contaminated mainly in the southern parts of the city, compared to its northern and central parts (Chakraborti et al., 2009, 2017; Malakar et al., 2016). Transportation of As-contaminated food crops (rice and vegetables) to Kolkata markets from agricultural fields of As exposed areas and its subsequent dietary intake leads to health threats for the populace residing in this zone (Biswas et al., 2019).

4.3. Medinipur district

East and West Medinipur districts of West Bengal has no indication of groundwater As-contamination (Chakraborti et al., 2009; Chowdhury et al., 2020).

Pingla block: Madhyabar, is an agricultural-based village (Latitude: 22°14'47.76” N, Longitude: 87°32'50.83” E) of Pingla block, West Medinipur district has been selected as control site for this research study.

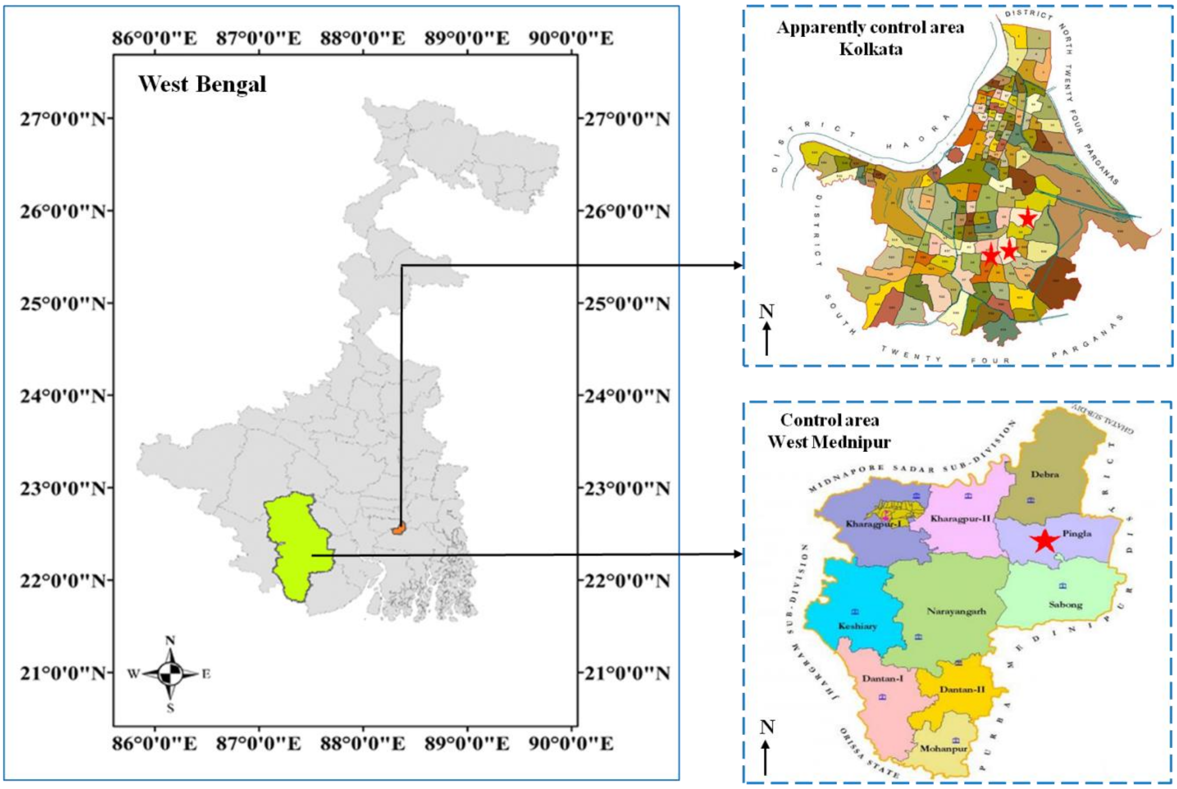


Fig. 9. Apparently control (Kolkata district) and control (Medinipur district)

4.4. Study areas

The research studies have been carried out from different areas of West Bengal, India categorized as, exposed (Gaighata), apparently control (Kolkata), and control (Pingla) with respect to groundwater As contamination scenario. Map of the study area has been shown in Fig. 10. A block named Gaighata is severely As affected situated in a district well known as North 24 Parganas, West Bengal, where groundwater is highly As contaminated (Roychowdhury, 2010). Several studies reported that in some parts of Kolkata district, groundwater is As contaminated and the other parts as uncontaminated (Chakraborti et al., 2017), and the contamination scenario is higher in the southern part compared to the northern, &central area (Malakar et al., 2016). Chakraborti et al. (2017) found that about 14.2 and 5.2% of the groundwater (n=4210) samples from Kolkata district were contaminated with As greater than 10 and 50 µg/L, respectively. However, because of pipeline supply of treated Ganges River by the KMC, a widespread Kolkata populace has the access to use As free drinking water. So, it is preferred to describe Kolkata as the apparently control area in the study. From the western part of Bengal, as there is no evidence of groundwater As contamination, West Medinipur district has been considered as the control site (Das et al., 2021a).

The study areas of my research comprises of groundwater quality indexing from different severely As affected, apparently control and control areas along with health risk evaluation. The work has been carried out further on pre-monsoonal and post-monsoonal groundwater quality evaluation and indexing from Gaighata block, North 24 Parganas district. Investigation on the food chain contamination scenario for different age groups mainly collected from the three studied areas; Along with studies on acute and chronic health exposure of different aged individuals from the As affected zones, followed by apparently control and control areas. Differently exposed villages, school children, arsenicosis patients, mother-child and families across Gaighata, have been selected for health exposure study through their various daily dietary intakes.

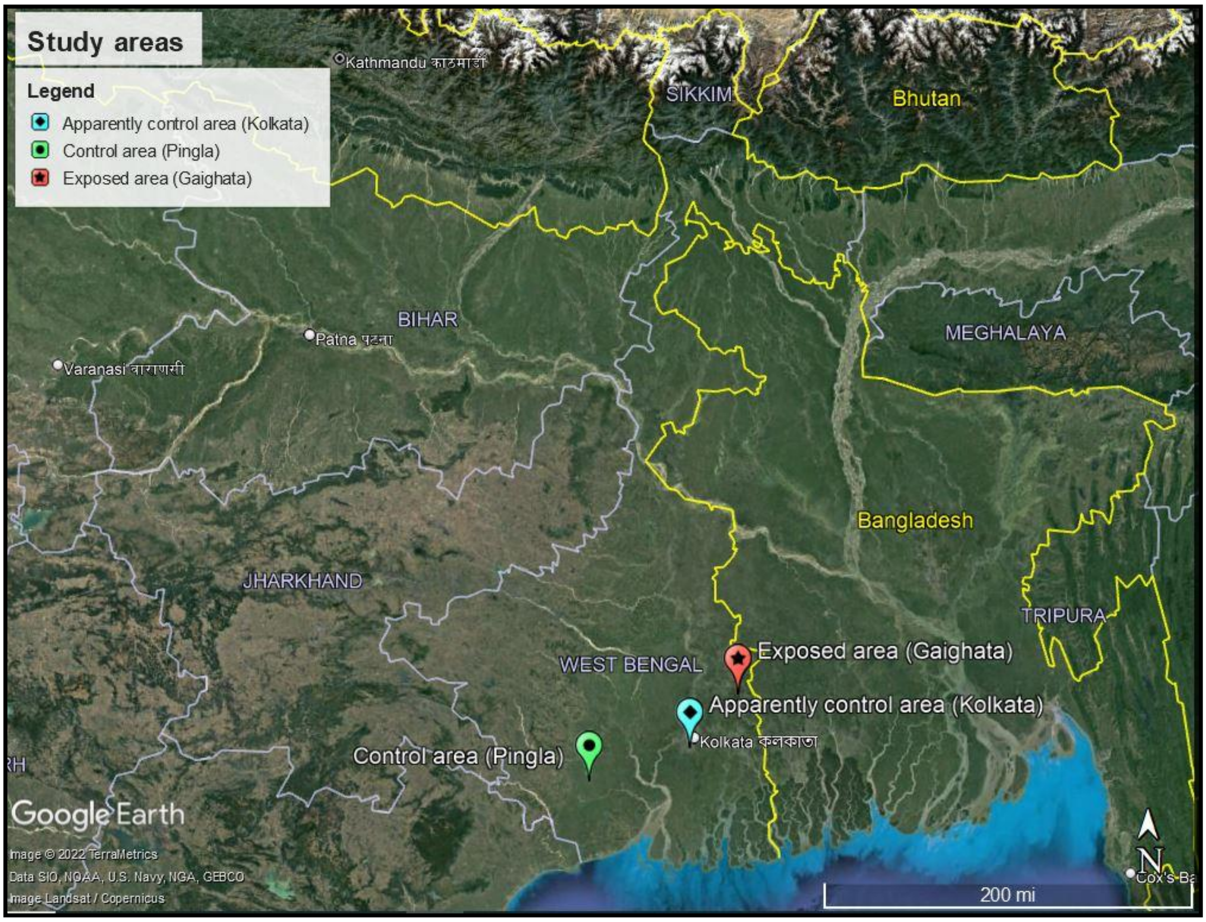


Fig. 10. Study area categorized as, exposed (Gaighata), apparently control (Kolkata), and control (Pingla) with respect to groundwater As contamination scenario.

Chapter Five

5.1. Study populations

Different study populaces have been selected for individual research studies.

- Three age-groups i.e. adult male, adult female and children has been targeted from different villages, located in an As endemic (Gaighata) block of North 24 Parganas district. The studied villages are Mathpara, Eithbhata, Madhusudankati and Jamdani which have been distinguished as extreme high, highly, moderate and mild exposed areas, respectively, mainly depending on the groundwater As contamination scenario of the area.

- Different families from the wards of the Gobordanga Municipality situated in Gaighata block.

- A group of mothers (aged between 23 and 31 years old) and infants (aged between 7 months and 4 years old) was selected from an As-exposed (Madhusudankati village) area, located in Sutia (gram panchayat) of Gaighata block.

- A group of school children aged between 5-12 years (class I–VI) has been selected from As-exposed and apparently control area. ‘Madhusudankati Free Primary School’ (Latitude: 22° 53′ 53.82″ N, Longitude: 88° 46′ 38.33″ E) is sited in Madhusudankati village, Sutia (gram panchayat) of Gaighata block has been considered as the exposed school. Similarly, ‘Purba Kalikata Odia High School’ (Latitude: 22° 34′ 53.39″ N, Longitude: 88° 23′ 36.50″ E) was selected as apparently control school placed in the northern side of Kolkata district.

- A group of arsenicosis patients aged between 42–75 years, which includes 17 males and 7 females from two severely As exposed villages namely ‘Bishnupur (Mathpara)’ and ‘Teghoria (Eithbhata)’ located in Sutia (gram panchayat), Gaighata block has been targeted for one-year (2018–2019) health exposure study. Arsenicosis patients have been exposed to treated drinking water from the year 2016 supplied through a surface water treatment plant which has been executed in the year 2014 and maintained by a local non-Government organization (Madhusudankati Krishak Kalyan Samity) collaborating with ‘Sulabh International Social Service Organization’ located in Madhusudankati village.

5.2. Collection of sample its preservation and preparation

5.2.1. Groundwater (drinking, cooking, household, irrigational purposes)

Different sources of groundwater were collected from the domestic shallow tube-wells, deep tube-wells which are mainly used for cooking, drinking, and other household purposes, and agricultural shallow tube-wells used for irrigational purposes. Approximately 30% of the groundwater samples have been collected in duplicate from the different sources of the studied populaces. The above-mentioned water samples have been collected from the families, arsenicosis patients or inhabitants of the study areas. The raw groundwater samples collected in sterilized polyethylene containers (15-30 ml) adding 0.1% (v/v) concentrated nitric acid solution. The above-mentioned collected water samples are ‘acidified water’, which are mainly used to analyze As and iron concentration. In a similar way, raw groundwater samples were collected as ‘non-acidified water’ in sterilized polyethylene containers (200-250 ml) without addition of any preservative are used to analyze all other water quality parameters namely pH, conductance, turbidity, total hardness, total dissolve solids (TDS) & total suspended solids (TSS), total alkalinity, calcium hardness, magnesium hardness, chloride, fluoride, nitrate, sulphate, and sodium. At the time of transportation, all the water samples have been placed in a cooled ice-box and preserved at 4ºC in the laboratory refrigerator before As estimation.

5.2.2. Whole paddy plant, raw rice grain, cooked rice, rice by-products, and vegetables

Whole paddy plant has been collected from the agricultural field of Madhusudankati village of Gaighata block. The final or ripening phase of the paddy plant has been collectd from both the pre-monsoonal and post-monsoonal season. Samples were methodically, systematically and scientifically collected from agricultural fields to assure statistical significance of the observed values. Daily dietary foodstuffs like raw rice grain (parboiled and sunned), cooked rice (parboiled and sunned), wheat flour, rice by-products (parched rice, puffed rice, and beaten rice), raw vegetables (leafy and non-leafy), cooked vegetable (curry of mixed raw vegetables) and mid-day meal have been targeted for our study. The above-mentioned dietary foodstuffs were collected from the families, arsenicosis patients or inhabitants of the different studied areas. In our study, the rice grain (paddy) and different vegetables consumed by the populace on a daily basis are mainly locally grown or cultivated in rural (As-endemic and non-endemic) areas. Different rice grain, rice by-products and wheat flour has been collected individually in labelled zip-lock packets and well-preserved at room temperature. The vegetables (leafy and non-leafy) were washed with distilled water, subsequently double distilled water using a magnetic stirrer (Model 2 ML, REMI Elektrotechnik Ltd, India) to eliminate the externally attached soil particles on its surface then dried overnight (50°C) in a hot air oven. During school hours, the mid-day meal samples were collected in labelled zip-lock packets from the school premises. Water sample (drinking and cooking), uncooked rice (parboiled) along with its respective cooked rice & total discarded water (TDW) were collected from the inhabitants (field level) maintaining the domestic scale cooking ratio of 1:3 from the studied areas. The uncooked and cooked rice were collected in sterilized zip-lock packets which are directly processed for acid digestion. Total discarded water (TDW) samples were collected in sterilized polyethylene containers; 2 mL of the sample was directly used for acid digestion followed by As estimation. Finally, the digested samples were evaporated for 1 h at 90°C and made up to a final volume of 5-10 mL with Milli-Q water and filtered using a suction filter (millipore 0.45 μm). These filtered solutions were finally used for As and micronutrients estimation. The details of sample collection, preservation and preparation have been described in Chowdhury et al. (2020).

5.2.3. Baby food products, milk (infants)

Along with different dietary foodstuffs, baby food products (commercial and homemade) and milk (breast and cow) samples consumed on a daily basis by infants (aged between 7 months and 4 years old) were collected from ten mother-infant's families. Baby food products like commercial baby food (Cerelac) and homemade mixtures has been collected in sterile zip-lock packets & stored at room temperature before processed for acid digestion for As analysis. No preservative has been added to the sterile containers during the collection of different milk samples. All milk samples were kept in an ice cooled box at the time of transportation and preserved at 4ºC prior to As estimation.

5.2.4. Biomarkers of arsenic

Investigating the arsenical body burden of the different populaces depending on its acute and chronic toxicity level, human biological samples such as urine, sweat, scalp hair, nail, body hair and skin scales has been collected from the individuals of respective age groups i.e. adult male, adult female, children, arsenicosis patients. The comparison investigation among the differently exposed populaces determines the arsenical body burden in the individuals because of chronic As toxicity.

5.2.5. Urine, sweat

Spot urine samples has been directly collected in sterilized polyethylene containers, kept in a cooled ice-box at the time of transportation and placed at -20ºC in the laboratory refrigerator. No chemical has been added in the urine samples for preservation. To remove colloidal elements and reduce matrix effects, all the urine samples were diluted in the ratio (1:1) using double distilled water and filtered before As estimation. Likewise, sweat samples has been collected without addition of any preservative and stored directly into 20 ml sterile polyethylene containers (Genuis et al., 2011; Sheng et al., 2016). During transportation, these samples were kept in an ice-cooled box and placed in the laboratory refrigerator (at 4ºC) prior to As analysis.

5.2.6. Scalp hair, nail, body hair and skin scales

Human biological tissue samples (scalp hair and nail) have been collected individually from the age-groups from all the different studied populaces, specifically, for the arsenicosis patients sampling collection was carried out for a span of 12 months, respectively, with one-month interval. Body hairs i.e. hand and leg hair, skin scales have been collected from limited individuals (arsenicosis patients) due to its non-availability for a one-month interval from the studied exposed area. All scalp hair, body hairs, finger nail clippings, and skin scales tissue samples were directly taken from the individuals with the help of stainless-steel scissors & ceramic blade, respectively. All the different biological tissue samples were stored individually in labelled polyethylene zip-lock packets at room temperature prior to acid-digestion followed by As estimation. The biological tissue samples have been washed thoroughly using double distilled water, then followed by acetone using a magnetic stirrer (Model 2 ML, REMI Elektrotechnik Ltd, India) to eradicate the external As on the surface of the respective samples. All the washed biological tissue samples were finally placed in individual beakers and allowed to dry overnight at 50°C in a hot air oven. The detailed facts of collection, preservation, storage and processing of solid and liquid samples has been described in (Chowdhury et al., 2018a, b; Das et al., 2020a; Roychowdhury, 2010).

5.3. Chemicals and reagents

Throughout the research activities, analytical-grade chemicals and reagents have been used. For the duration of the analytical phase of the study, double distilled water was employed. A standard stock solution of arsenate (1000 mg/L) from Merck, Darmstadt, Germany was used to estimate the total amount of As. The solid samples were acid digested using reagents such as concentrated nitric acid (HNO_3; 69%) and hydrogen peroxide (30% v/v). Utilizing the Hydride Generation-Atomic Absorption Spectrometry (HG-AAS) method, a solution of 0.6% sodium borohydride ($NaBH_4$) in 0.5% sodium hydroxide pellets (NaOH) and 5-10 M concentrated hydrochloric acid (HCl) from Merck, Mumbai, India, was used to estimate the total amount of As. During sample preparation, 5-10 ml of concentrated HCl solution and 10% of KI solution (from 10% aqueous solution) were added. The combined solution was then given 45 minutes to settle before being used for As measurement (Chowdhury et al., 2020). The analytical investigations have made extensive use of standard stock solutions of 1000 mg/L for nitrate (as nitrogen, Orion 920707, Thermo Scientific, USA), fluoride (as fluoride, Orion 940907, Thermo Scientific, USA), and iron (NIST, $Fe(NO_3)^3$ in HNO_3 0.5 mol/L). Previously, it has been discussed the approach, tools, and chemicals used to calculate each water quality metric in detail (Das et al., 2020).

5.4. Digestion

No digestion procedure has been followed prior to As estimation for urine and water samples, respectively. All different types of solid samples namely, foodstuffs (rice grain, rice by-products and vegetables), biological tissues (scalp hair and nail) were digested in a Teflon-bomb using a solution of concentrated nitric acid (2 mL) and hydrogen peroxide (1 mL) placing it at temperature of 120 ºC for 6 h inside a hot air oven. The total sample volume was evaporated on the hot plate at 90 °C for 1 h. The final evaporated solutions were made up to a volume of 2 mL (biological tissues) and 4-5 mL (foodstuffs) using double distilled water, respectively. The final volume of digested sample is filtered using a suction filter of millipore size (0.45 µm) and the filtered solutions were preserved in sterile containers before total As estimation. The detailed methods of digestion have been mentioned in Das et al. (2021a).

5.5. Analysis

5.5.1. Total As

Total As estimation has been carried out using AAS: Atomic Absorption Spectrophotometer of Model: Varian AA140, USA with software version 5.1 coupled with Vapor Generation Accessory (VGA-77, Agilent Technologies, Malaysia). All the liquid (water and urine) and digested solid samples has been analyzed for As using HG-AAS i.e. Hydride Generation-Atomic Absorption Spectrometry methodology.

5.5.2. Arsenic speciation: extraction and instrumentation

Arsenic species extraction has been performed using a diluted solution of 1% nitric acid. The analytical procedure for extraction of As species mainly inorganic As, MMA and DMA have been mentioned in earlier publication (Signes-Pastor et al., 2016). For analyzing As species in rice, HPLC i.e. High Performance Liquid Chromatography coupled with ICP-MS i.e. Inductively Coupled Plasma-Mass Spectrometry has been used for analysis of As species in rice (Islam et al., 2017b**)**. Arsenic species was analyzed from the Global Centre for Environmental Remediation (GCER), The University of Newcastle, Australia.

5.5.3. Estimation of micronutrients

The concentrations of micronutrients like selenium (Se), and zinc (Zn) were measured using ICP-OES: Inductively Coupled Plasma Optical Emission Spectrometry (Perkin Elmer, Avio 200, USA). Analytical graded chemicals, reagents, Milli-Q water of 18.2 MΩ cm (Merck, IQ700) and double distilled water were used throughout the experimental process.

5.5.4. Physico-chemical water quality parameters

Different physico-chemical parameters namely pH, Electrical Conductivity (EC) & tempertaure, Iron (Fe), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Arsenic (As), Total Hardness (TH), Total Alkalinity (TA), Chloride (Cl^-), Sulphate (SO_4^{2-}), Nitrate (NO_3^-), and Fluoride (F^-) present in the groundwater samples were quantified. The physico-chemical water quality parameters were analyzed using individual digital instruments, reagents and methodology as follows (APHA 1998, 2005; Das et al., 2020; Fries et al. 1977):

- **pH**

Instrument: pH meter CL 46+, Toshcon Industries Pvt. Ltd.

Reagents: Standard buffer capsules of pH 4.0, 7.0 and 9.2, respectively.

Methodology: pH metric estimation.

- **EC (Electrical Conductivity) (µS/CM) and Temperature (°C)**

Instrument: Conductivity meter-306 with temperature sensor (Systronics)

Reagents: Standard KCl solution

Methodology: Potentiometric estimation

- **TDS: Total Dissolved Solids and TSS: Total Suspended Solids**

Instrument: Fine balance (METTLER AE240)

Methodology: Gravimetric estimation

- **Turbidity (NTU)**

Instrument: Digital turbidity meter, model 331 E

Reagents: Hydrazine sulfate ($N_2H_6SO_4$), Hexa-methylenetetramine $(CH_2)_6N_4$

Methodology: Nephelometric turbidity method

- **Iron (mg/L)**

Instrument: UV-Vis Spectrophotometer (wavelength: λ=510 nm): ORION AQUAMATE 8000, made in USA;

Reagents: Iron standard stock solution (1000 mg/L) (traceable to SRM from NIST, $Fe(NO_3)_3$ in HNO_3 0.5 moL/l): Merck, Germany.

1. A solution of sodium acetate-acetic acid (CH_3COONa-CH_3COOH) buffer of pH 4–5;
2. 10% hydroxylamine hydrochloride or $HONH_2$ used for reducing ferric to ferrous solution)
3. 0.25% of 1,10-phenanthroline solution: Merck, Mumbai, India

Methodology: Spectrophotometric estimation

- **Total Hardness as $CaCO_3$ (mg/L)**

Reagents: (M/100) Ethylene di-amine tetra acetic acid (EDTA) or (M/100) disodium-EDTA (Na_2EDTA) solution, ammonium hydroxide-ammonium chloride (NH_4OH-NH_4Cl) buffer, Eriochrome Black T (EBT) indicator.

Methodology: Complexometric titration method

- **Calcium Hardness as $CaCO_3$ (mg/L) / Ca-Hardness**

Reagents: (M/100) disodium-EDTA (Na_2EDTA) solution, 10 % NaOH buffer solution and murexide indicator

Methodology: Complexometric titration method

Magnesium hardness (mg/L) / Mg-Hardness

Theoretically calculation: (Total hardness - Calcium hardness)

- **Calcium (mg/L)**

Theoretical calculation: From calcium hardness; $[Ca^{2+}]$ = Ca-Hardness/2.50

- **Magnesium (mg/L)**

Theoretical calculation: From magnesium hardness; $[Mg^{2+}]$ = Mg-Hardness/4.11

The conversion factors 4.11 and 2.50 are obtained from the total hardness (water) that consists of both Mg and Ca hardness which is measured as $CaCO_3$ (MW = 100) **(**Das and Nag 2015, Todd 1980).

- **Total alkalinity (TA) (mg/L)**

Reagents: (N/50) sulfuric acid or H_2SO_4solution, (N/50) sodium carbonate or Na_2CO_3 solution, methyl orange indicator.

Methodology: Acid-base titration method

- **Fluoride (mg/L)**

Instrument: ISE: Ion Selective Electrode meter of Thermo scientific Orion Star A214 combined with fluoride electrode (Orion ISE: Model no. 9609BNWP).

Reagents: Fluoride stock solution of 100 mg/L (Orion 940, 911: Thermo Scientific, USA), buffer-grade solution, TISAB-III (Total Ionic Strength Adjusting Buffer) concentrate with CDTA (Thermo Fisher Scientific, USA: Orion 940911).

Methodology: Electrode method.

- **Nitrate (mg/L)**

Instrument: ISE meter of Thermo Scientific (Orion Star A214) coupled with nitrate electrode (SW1-02217) and reference electrode (RS1-11546).

Reagents: Nitrate as Nitrogen standard 1000 ppm solution, Orion 920707, Thermo Scientific, USA, Nitrate interference suppressor solution, Orion 930710, Thermo Scientific, USA

Methodology: Electrode method

- **Sulphate (mg/L)**

Instrument: UV-Vis Spectrophotometer (ORION AQUAMATE 8000) (at λ= 420 nm); Reagents: Sodium sulphate (Na_2SO_4) stock solution, Conditioning reagent comprising of glycerol, HCl, 95 % ethyl alcohol (C_2H_5OH), NaCl or sodium chloride salt and barium chloride or $BaCl_2$ salt

Methodology: Nephelometric turbidity method through spectrophotometry

- **Chloride (mg/L)**

Reagents: Silver nitrate or $AgNO_3$ (secondary standard), Potassium chromate (K_2CrO_4) indicator, (M/100) sodium (NaCl) chloride

Methodology: Argentometric Titration method

The details of information on the analytical methodologies used for evaluation of the different ions (cations and anions) in the groundwater samples have been mentioned earlier (Das et al. 2020).

5.6. Quality assurance and quality control

Analyzing blank, digesting Standard Reference Materials (SRM) like a) Rice flour 1568a (Source: NBS, Gaithersburg, MD, USA), b) Tomato leaves 1573a (Source: NIST, Gaithersburg, MD, USA), and c) Human hair ERM-DB001 (Source: European Commission, JRC, IRMM, Retieseweg, Geel, Belgium) using Teflon-bomb digestion methodology has been used to preserve quality control and assurance of the systematic work. To sustain the quality control and quality assurance of the analytical procedure in research study, around 30% of the samples (solid) were digested with the help of hot plate digestion methodology. To validate the analytical data, As concentration in Standard Reference Materials (SRM) were detected using both the Teflon-bomb and hot-plate digestion practices. Using Teflon-bomb digestion protocol, successive analysis of As in SRM samples revealed 95%, 114%, and 104% recovery against their respective certified values (0.29, 0.112, and 0.044 µg/g), where, hot plate digestion showed 85%, 88% and 87% recovery, respectively. Quality control tests were carried out by analyzing duplicate samples (± 5% variation) and evaluating the recovery percentage (92-104%) of spiked digested samples.

5.7. Statistical analysis

Statistical interpretations like histogram plot, regression analysis, Pearson correlation matrix, Single-factor analysis of variance (one-way ANOVA: Tukey test), Two-tailed paired‘t-test’, and statistical modelling have been executed with the help of Microsoft Office Excel 2017, Microsoft Office Professional Plus 2016, Origin software 2016 and ‘R version 4.1.2’ (2021-1-01). The 2D Kernel density plot is non-parametric method for probability density functions, which is preferred to recognize the distribution of groundwater concentrations through a colour density representation of scatter plot (Duong 2007). Multivariate analysis through Principal Component Analysis (PCA) has been made to comprehend the inter-dependence of the water quality parameters, considering the depth as observational levels (Fang et al. 2012). Origin 2018 software has been used to perform the 2D Kernel density and PCA. Statistical modelling has been performed using “lmerTest” package (Version 3.3.3) (Kuznetsova et al., 2017), “lme4” (Version 1.1–27.1) (Bates et al., 2015) in ‘R version 3.6.3’ (Team, 2020). Following, the USEPA (United States Environmental Protection Agency) risk model, human health risk assessment (HHRA) has been evaluated (USEPA, 2005). Evaluation of probabilistic health risk has been performed using ‘Crystal Ball of Fusion edition version 11.1.1.1.00’ (De et al., 2021; Lonati and Zanoni, 2012).

5.8. Data interpretation and analysis

5.8.1. Fe/As ratio: Fe/As ratio is considered as a vital factor in case of the iron-based adsorbent technologies mainly required for As removal. Co-precipitation process helps to remove dissolved As with the help of naturally occurring Fe (Mamtaz and Bache, 2001). On the other hand, higher value of Fe/As is essential to achieve As-safe drinking water (Banerji and Chaudhari, 2017; Schmidt et al., 2016). Arsenic removal percentage in an alkaline leaching solution apparently increases with increasing ratio of Fe/As (Wang et al., 2019).

5.8.2. Single factor pollution index: This evaluation (Ii) has been performed to estimate the contamination in groundwater with special reference to As and Fe using the equation as mentioned in Zhang et al. (2018).

The equation is as follows: Ii = Ci/Co …. (i)

Where,

Ii = Specific indices;

Ci = Concentration of the toxic element present in groundwater;

Co = Allowable concentration of the contaminant established by the standard guidelines. (As = 10 µg/L and Fe = 0.3 mg/L in drinking water (BIS, 2012; WHO, 2011a).

Contamination factors in groundwater has been classified under 4 groups as follows: Low contamination (Ii < 1.0), Moderate contamination (1.0 ≤ Ii <3.0), Considerable contamination (3.0 ≤ Ii < 6.0) and High contamination (Ii ≥ 6.0) (Hakanson, 1980; Rehman et al., 2018).

5.8.3. Potential ecological risk assessment: This assessment assesses the probable impact of heavy metals on the ecosystem (Egbueri, 2020 a, b). Hakanson (1980) specified that the ecological risk is mainly dependent on the heavy metal concentration of any system, kind of the contaminant and its nature/strength of toxicity.

It is measured following the equation: Er=Tr × I …. (ii)

Where, Er = Ecological risk;

Tr = Toxicity response coefficient;

I = Contamination factor;

For a toxic metal/metalloid like As, the toxicity coefficient is considered as 10.

Quantitative valuation of ecological risk is characterized under 5 different classes: Low risk ($Er<40$), Moderate risk ($40 \leq Er<80$), Considerable risk ($80 \leq Er<160$), High risk ($160 \leq Er<320$) and Very high risk ($Er \geq 320$) (Hakanson 1980).

5.8.4. Water quality indexing (WQI)

WQI is an evaluation measure that highlights the overall quality of groundwater mainly for drinking purposes from the studied areas (Gupta and Misra 2018; Lumb et al., 2011, Meng et al., 2016, Xiao et al., 2014). WQI imitates the composite effect of different water quality parameters in this study. According to the assigned 'weight' of the parameters, the 'relative weight' (W_i) was evaluated.

The 'relative weight' (W_i) was calculated using the subsequent equation:

W_i (Relative Weight) = $w_i / (\sum^{n}_{i=1} (w_i))$ …. (iii)

Where, w_i = Weight of each parameter;

n= Number of parameters.

Quality rating scale (q_i) for each parameter is obtained by the succeeding equation:

q_i (Quality Rating) = $(C_i / S_i) \times 100$ …. (iv)

Where, C_i = Concentration of each chemical parameter in respective water sample (mg/L);

S_i = Indian drinking water standard for each chemical parameter according to the guidelines of the BIS (2012).

WQI was evaluated using the following equation:

SI_i (sub index of ith parameter) = $(W_i \times q_i)$ …. (v)

WQI = $\sum SI_i$ …. (vi)

Where, qi = Rating based on concentrate of i^{th} parameter (Das et al. 2020).

The calculated WQI values are categorized to determine the quality of water as: "excellent" (value < 50), "good" (range = 50–100), "poor" (range = 100–200), "very poor" (range = 200–300), and "inappropriate for drinking" (value > 300).

5.8.5. Daily dietary intake rate of As

Daily dietary intake of As (µg/kg bw/day) mainly through drinking water and foodstuffs like parboiled rice and vegetables has been assessed using the subsequent equations:

Total content $_{\text{arsenic}}$ (TC_{As}) = Concentration x Daily consumption rate of a individual …. (vii)

Daily dietary intake of arsenic (DDI) = TC_{As} / Bodyweight of the individual …. (viii)

Where,

Concentration (C) = Arsenic in drinking water (µg/L) and foodstuffs (µg/kg);

Daily consumption rate of an individual = Drinking water (l); Parboiled rice (kg); Vegetables (kg);

Average bodyweight of an individual in kg;

5.8.6. Dietary intake of As and Margin of Exposure (MoE)

The contribution of As (µg/kg bw/day) through the dietary intake of cooked rice and water on a daily basis by the three different exposed populaces has been calculated using the following equations **(**Islam et al., 2017b; Menon et al., 2020**)**:

$TC_{As} = (C_{As} \times DCR)$ .... (ix)

$DDI_{As} = TC_{As} / BW$.... (x)

$EWI_{As} = (TC_{As} \times 7) / BW$.... (xi)

Where, TC_{As}= Total content of As;

C_{As} = Concentration of As in water (µg/L) and cooked rice (µg/kg);

DCR= Daily consumption rate of water (l) and cooked rice (kg);

DDI_{As}= Daily dietary intake of As (µg);

EWI_{As}= Estimated weekly intake of As (µg);

BW= Average bodyweight in (kg) of an adult male, adult female, and children respectively, from the differently exposed areas.

The MoE was evaluated using the following equation (Guillod-Magnin et al., 2018; Jallad, 2019; Rintala et al., 2014):

$\text{MoE} = \text{BMDL}_{0.1}/\text{DDI}_{\text{As}}$.... (xii)

Where, $\text{BMDL}_{0.1}$ = Benchmark Dose Lower Confidence Limit = 0.0003 mg/kg/day for 0.1% increased incidence of various cancers (EFSA, 2009) which is placed as RfD value in HQ calculation. In summarizing, the calculated HQ values are the inverse of MoE values (i.e. HQ value < 1 and MoE value > 1 to avoid health risks (Menon et al., 2020).

5.8.7. SAMOE: Risk Thermometer

The Swedish National Food Agency demonstrated the 'risk thermometer' for establishing a novel practice on risk characterization (Sand et al., 2015a, b). Health risk characterization using risk thermometer focuses on the exposure level of a toxicant in food comparing it with the (TDI, Tolerable Daily Intake) material's health-based reference value. The risk class along with its corresponding concern level of exposure for the individuals was assessed through consumption of daily dietary intakes on a daily basis following the equation described by Sand et al. (2015a, b).

Severity Adjusted Margin of Exposure (SAMOE) = $\text{TDI} / (\text{AF}_{\text{BMR}} \times \text{AF} \times \text{SF} \times \text{E})$ …. (xiii)

Where, Tolerable Daily Intake (TDI) = 3.0 μg/kg bw/day, the recommended value for intake of inorganic As in human based on the range of 2–7 μg/kg body wt/day for the assessed total dietary exposure (WHO, 2011b);

AF_{BMR} (BMR - Benchmark response) = 1/10, when a substance's effect is assumed to be nonlinear relation in the dose range $\text{BMD}_{0.5} - \text{BMD}_{10}$ (BMD = benchmark dose);

AF (Assessment factor) = A factor 10 (conservative assessment considering human as sensitive individual under As exposure) (Sand et al., 2015a, b);

SF (Severity factor) = 100 (For cancerous effect, the most severe category) (WHO, 2011b);

E = Different exposure factors (the exposure level to any toxicant in food material is compared);

5.8.8. Probabilistic health risk assessment

Average Daily Dose (ADD)

Human health risk characterization has been executed to assess the lifetime cancerous and non-cancerous risk of human based on the average daily dose (ADD) of the toxic pollutant, following the equation adapted from USEPA (2005) model.

Average Daily Dose (ADD) = $[C \times IR \times ED \times EF] / [BW \times AT]$ …. (xiv)

Where, C = Concentration of As in daily dietary intakes (µg/L or µg/kg);

IR = Ingestion rate per day depending on the type of intake (l or kg);

ED = Exposure duration (years);

EF = Exposure frequency (365 days/year);

BW = Body weight (kg);

AT = Average lifetime in days (Chattopadhyay et al., 2020);

Cancerous and non-cancerous health risk has been assessed following the equations as mentioned in Chattopadhyay et al. (2020).

The Lifetime Cancerous Risk (CR) was measured to evaluate the cancerous risk level associated with consumption of As among the individuals:

Lifetime Cancerous Risk (CR) = ADD × CSF …. (xv)

Where,

CSF (cancer slope factor) of As = 1.5 per mg/kg bw/day (USEPA, 2005). According to the USEPA (2005), exceeding the LCR value of 1×10^{-6} may pose health risks.

Hazard quotient (HQ) was calculated to determine the non-cancerous risk in the individuals:

Hazard quotient (HQ) = (ADD / RfD) …. (xvi)

Where,

'Reference Dose' (RfD) value represents the chronic oral exposure dose for the toxic elements as follows, i.e., As (0.0003 mg/kg/day) (USEPA 2005), nitrate (1.6 mg/kg/day) and fluoride (0.06 mg/kg/day), respectively, as mentioned in several studies (Rasool et al. 2015, Su et al. 2013, Narsimha and Rajitha 2018). Hazard quotient is unitless, and when the value is 1, it indicates the existence of potential non-cancerous health risks due to the toxic contaminant (USEPA, 2011; Kazi et al. 2016).

Probabilistic risk (cancerous and non-cancerous) along with uncertainty and sensitivity analysis among the populace has been evaluated using software named “Crystal Ball: Fusion edition version 11.1.1.1.00" (De et al., 2021). In probabilistic risk analysis, the probability distribution function of the variables was selected based on goodness of fit tests (Rausand, 2011). Uncertainty analysis is considered a vital measure to assess the level of inferences, precision and limitations of the acquired data using health risk assessment (HRA) (Mukherjee et al., 2020; Zhang et al., 2019). During these simulations, the degree of accuracy level has been attained through 10,000 trials and health risks were assessed using the 5th, 50th and 95th percentile values of the model results (Baytak et al., 2008; Sohrabi et al., 2021).

Chapter Six

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DRINKING WATER

6.1. Groundwater quality indexing for drinking purpose from arsenic affected blocks of West Bengal: a health risk assessment study

The main objective of our study is to highlight the groundwater quality of two different sources (domestic shallow and deep tube-well) mainly used for drinking purposes from two As-affected blocks of West Bengal. The suitability of groundwater is determined mainly depending on the physico-chemical parameters along with the Water Quality Index (WQI). A statistical interpretation has been performed to evaluate the relation between As and Fe present in groundwater. Principal Component Analysis has been carried out to comprehend the interdependence of the groundwater quality parameters, considering the depth as observational levels. The study investigates the quality of groundwater from domestic shallow and deep tube-well for human consumption, based on the human health risk assessment (cancer and non-cancer). As a result, highlighting the human health impact due to groundwater As-contamination will lead to awareness among the exposed populaces and suitable mitigation strategies. From environmental health perception, it is of paramount important to determine groundwater (especially for drinking purposes) As concentration along with various other water quality parameters and subsequent human health risks. To the best of our knowledge, this is a first comparative study carried out on domestic shallow and deep tube-well groundwater quality from two As-affected blocks in Bengal delta to evaluate the As level and associated human health risks.

The two As-affected blocks are namely: Gaighata (Latitude: 22º55′ 48″ N and Longitude: 88º 43′ 48″ N) and Deganga (Latitude: 22º 41′ 36″ N and Longitude: 88º 40′ 41″ N) has been selected as the study areas.

6.1.1. Water quality parameters of domestic shallow and deep tube-wells

The overall groundwater quality of the domestic shallow and deep tube-well has been evaluated through analysis of the physical and chemical parameters. The statistical presentation of all the water quality parameters from the studied two blocks has been shown in Table 1. In Gaighata block, the respective mean value of pH for domestic shallow (n = 14) and deep tube-well (n = 14) groundwater samples are 7.28 and 7.41, respectively, which signifies that the groundwater is alkaline in character. The alkaline nature is confirmed observing the mean value of total alkalinity for the groundwater samples, i.e., 468 and 464 mg/L, respectively, which is higher than the Indian Standard value of drinking water (BIS 2012). The mean value of temperature observed for the groundwater samples of Gaighata block varies between 25.1–27.6ºC. The mean values of conductance and TDS of the domestic shallow and deep tube-well groundwater samples are 0.89 mS/cm, 164 mg/L and 0.97 mS/cm, 60.7 mg/L, respectively. The TDS observed in the drinking water samples is within the permissible limit (500 mg/L), which signifies that the presence of inorganic salts and minerals is lesser in this studied area. The mean chloride value observed for groundwater samples of domestic shallow (88.8 mg/L) and deep (82.2 mg/L) is within the recommended value (250 mg/L). The presence of chloride ions in water samples is influenced by TDS, which means that the taste (salinity) of groundwater is suitable for drinking purpose (Balakrishnan et al., 2011). The mean As concentrations observed for groundwater samples from domestic shallow and deep tube-well are 0.042 mg/L (range = 0.01–0.08 mg/L) and 0.008 mg/L (range = 0.003–0.04 mg/L), respectively. The observed mean iron concentrations for domestic shallow (7.65 mg/L) and deep tube-well (1.48 mg/L) water samples are higher than the recommended value (0.3 mg/L), which indicated that the groundwater is enriched with iron. The mean value of Total Hardness (TH) measured for both the domestic shallow and deep tube-well drinking water samples is higher than its permissible value (200 mg/L) in drinking water. The higher mean concentration of TH in water samples signifies that the feature of groundwater is relatively hard. The presence of calcium, magnesium, and iron ions denotes the hardness of drinking water. The mean calcium ion concentration observed for both domestic shallow (122 mg/L) and deep (75.8 mg/L) is higher than mean magnesium ion of domestic shallow (41.8 mg/L) and deep (49.1 mg/L), respectively. For domestic shallow water samples, the observed mean concentrations of nitrate, fluoride and sulphate ions are 4.52 mg/L (range = 0.49–20.1 mg/L), 0.13 mg/L (range=0.07-0.23 mg/L) and 51.4 mg/L (range = 0.1–433 mg/L), respectively. Likewise, for the deep water samples, the mean concentrations observed are as follows for nitrate (mean = 1.39 mg/L; range = 1.02–2.44 mg/L), fluoride (mean = 0.30 mg/L; range = 0.15–0.38 mg/L), and sulphate (mean = 1.82 mg/L; range = 0.1–7.54 mg/L). These observed concentrations of nitrate, fluoride and sulphate ions for both domestic shallow and deep water samples of the studied Gaighata block are lower than the recommended values 45, 1.5 and 200 mg/L, respectively. Overall, the mean anionic concentration of the water samples from the studied block showed the order of the ions as chloride > sulphate > nitrate which justifies the water quality of Gaighata block as basic in nature. In a similar way, for Deganga block, the respective mean value of pH for domestic shallow (n = 20) and deep (n = 20) tube-well groundwater samples are 7.35 and 7.66, respectively, which signifies that the groundwater is alkaline in character. The alkaline nature is confirmed observing the mean value of total alkalinity for the groundwater samples, i.e., 473 and 443 mg/L, respectively, which is higher than the recommended Indian Standard value. The mean value of temperature observed for the groundwater samples of Deganga block varies from 31.6–32.1ºC. The mean values of conductance and TDS of the domestic shallow and deep tube-well groundwater samples are 0.11 mS/cm, 3050 mg/L and 0.10 mS/cm, 1250 mg/L, respectively. The TDS observed in the drinking water samples is much higher than the permissible limit which signifies the presence of inorganic salts and minerals in the studied area. The mean chloride value observed for groundwater samples of domestic shallow (61.4 mg/L) and deep (52.6 mg/L) is within the recommended value. The mean As concentration observed for groundwater samples from domestic shallow and deep tube-wells are 0.661 mg/L (range: 0.07–2.84 mg/L), and 0.023 mg/L (range: 0.003–1.53 mg/L), respectively. The observed mean iron concentration for domestic shallow (5.79 mg/L) and deep (3.08 mg/L) water samples is higher than the recommended value, indicating that the groundwater is iron enriched. The mean value of Total Hardness (TH) measured for both the domestic shallow (369 mg/L) and deep (314 mg/L) tube-well water samples is higher than the permissible limit. The higher mean concentration of TH in water samples signifies that the feature of groundwater is relatively hard. The presence of calcium, magnesium, and iron ions denotes the hardness of drinking water. The mean calcium ion concentration observed for both domestic shallow (90.5 mg/L), deep (76.5 mg/L) is higher than mean magnesium ion of domestic shallow (34.9 mg/L) and deep (29.9 mg/L), respectively. For domestic shallow water samples, the observed mean concentrations of nitrate, fluoride and sulphate ions are 1.98 mg/L (range = 0.87–5.58 mg/L), 0.18 mg/L (range = 0.11–0.37 mg/L) and 9.03 mg/L (range = 0.4–39.1 mg/L), respectively. Likewise, for the deep water samples, the mean concentrations observed are as follows for nitrate (mean = 1.98 mg/L; range = 0.69–6.63 mg/L), fluoride (mean = 0.21 mg/L; range = 0.079–0.28 mg/L), and sulphate (mean = 5.03 mg/L; range = 1.3–10.9 mg/L). These observed concentrations of nitrate, fluoride and sulphate ions for both domestic shallow and deep water samples of the studied Deganga block are lower than the recommended values 45, 1.5 and 200 mg/L, respectively. Overall, the mean anionic concentration of the water samples from the studied block showed the order of the ions as chloride > sulphate > nitrate, which justifies that the water quality of Deganga block is basic in nature.

Table 1: Different water quality parameters of domestic shallow and deep tube-wells from two studied blocks a) Gaighata and b) Deganga

a) Gaighata block		**Statistical parameters**				
Category	**Water quality parameters**	**Mean**	**SD**	**Median**	**Min**	**Max**
Domestic shallow tube-well (n=14)	pH	7.28	0.33	7.25	6.9	7.9
	Temperature (˚C)	26.3	0.45	26.2	25.9	27.6
	Conductance (ms/cm)	0.89	0.19	0.85	0.64	1.4
	TDS (mg/l)	164	79.5	150	50	300
	Total hardness (mg/l)	464	126	480	250	680
	Alkalinity (mg/l)	468	56.5	460	400	560
	Sulphate (mg/l)	51.4	114	11.8	0.1	433
	Chloride (mg/l)	88.8	24.8	79.9	49.7	134
	Arsenic (mg/l)	0.042	0.02	0.04	0.01	0.08
	Iron (mg/l)	7.65	2.39	8.22	2.61	11.3
	Fluoride (mg/l)	0.13	0.047	0.13	0.07	0.23
	Nitrate (mg/l)	4.52	5.34	2.48	0.49	20.1
	Calcium (mg/l)	186	50.3	192	100	272
	Magnesium (mg/l)	113	30.6	117	60.8	165
Deep tube-well (n=14)	pH	7.41	0.19	7.4	7.1	7.8
	Temperature (˚C)	25.3	0.32	25.1	25.1	26.1
	Conductance (ms/cm)	0.97	0.08	0.95	0.87	1.09
	TDS (mg/l)	60.7	21.3	50	50	100
	Total hardness (mg/l)	391	54.1	400	300	510
	Alkalinity (mg/l)	464	56.1	460	370	600
	Sulphate (mg/l)	1.82	2.72	0.1	0.1	7.54
	Chloride (mg/l)	82.2	30.8	81.7	28.4	142
	Arsenic (mg/l)	0.008	0.01	0.003	0.003	0.04
	Iron (mg/l)	1.48	0.75	1.745	0.19	2.82
	Fluoride (mg/l)	0.30	0.06	0.325	0.15	0.38
	Nitrate (mg/l)	1.39	0.43	1.22	1.018	2.44
	Calcium (mg/l)	156	21.6	160	120	204
	Magnesium (mg/l)	95.1	13.2	97.3	72.9	124

b) Deganga block		**Statistical parameters**				
Category	**Water quality parameters**	**Mean**	**SD**	**Median**	**Min**	**Max**
Domestic shallow tube-well (n=20)	pH	7.35	0.097	7.36	7.18	7.52
	Temperature (˚C)	31.8	0.16	31.8	31.6	32.1
	Conductance (ms/cm)	0.11	0.02	0.1	0.083	0.152
	TDS (mg/l)	3050	3605	1500	200	14000

	Total hardness (mg/l)	369	81.2	346	268	600
	Alkalinity (mg/l)	473	43.1	469	377	614
	Sulphate (mg/l)	9.03	9.31	6.2	0.4	39.1
	Chloride (mg/l)	61.4	29.3	58.9	20.8	135
	Arsenic (mg/l)	0.661	0.73	0.39	0.07	2.84
	Iron (mg/l)	5.79	3.04	6.09	0.41	11.4
	Fluoride (mg/l)	0.18	0.06	0.17	0.11	0.37
	Nitrate (mg/l)	1.98	1.34	1.41	0.87	5.58
	Calcium (mg/l)	148	32.5	138	107	240
	Magnesium (mg/l)	89.9	19.8	84.2	65.2	146
Deep tube-well (n=20)	pH	7.66	0.14	7.66	7.49	8.05
	Temperature (˚C)	31.8	0.12	31.8	31.6	32.1
	Conductance (ms/cm)	0.10	0.06	0.09	0.07	0.36
	TDS (mg/l)	1250	1606	600	200	6800
	Total hardness (mg/l)	314	55.8	322	140	380
	Alkalinity (mg/l)	443	62.7	443	316	525
	Sulphate (mg/l)	5.03	2.62	4.7	1.3	10.9
	Chloride (mg/l)	52.6	135	24.2	6.9	626.5
	Arsenic (mg/l)	0.023	0.04	0.008	0.003	0.153
	Iron (mg/l)	3.08	4.04	1.5	0.75	16.9
	Fluoride (mg/l)	0.21	0.04	0.215	0.079	0.28
	Nitrate (mg/l)	1.98	1.30	1.97	0.69	6.63
	Calcium (mg/l)	126	22.3	129	56	152
	Magnesium (mg/l)	76.4	13.6	78.3	34.1	92.5

6.1.2. Distribution of As and Fe in groundwater with depth

To understand the distributions of both the As and Fe concentrations in groundwater collected from domestic shallow and deep tube-wells, 2D-Kernel Density plot has been shown with depth range variation from the two studied blocks (Fig. 11). In Gaighata block, major presence of As in domestic shallow and deep tube-well groundwater is confined at a depth range of 50–100 ft and 580–780 ft, respectively (Fig. 11a, b). According to the density plot, the Fe concentration greater than 0.3 mg/L is scattered proportionally with the depth range of both domestic shallow and deep tube-wells. Likewise, in Deganga block, major presence of As as well as Fe in domestic shallow and deep tube-well groundwater is confined at a depth range of 80–130 ft and 500–800 ft, respectively (Fig. 11c, d). Approximately 78.5 and 70% of the deep tube-well groundwater samples from the respective Gaighata (n = 14, depth = 580–780 ft) and Deganga (n = 20, depth = 500–800 ft) block has been observed with As less than the WHO recommended value in drinking water, i.e., 10 µg/L (WHO 2011). Groundwater from the domestic shallow tube-wells (depth = 50–130 ft) in both the studied blocks shows high As concentration compared to the deep aquifer. About 28% of the groundwater samples in the depth range of < 110 ft were found as As contaminated above 50 µg/L in West Bengal, India (Chowdhury et al., 1999). As a result, consumption of As through groundwater from domestic shallow tube-wells poses severe health risk to the populaces residing in the As-affected blocks.

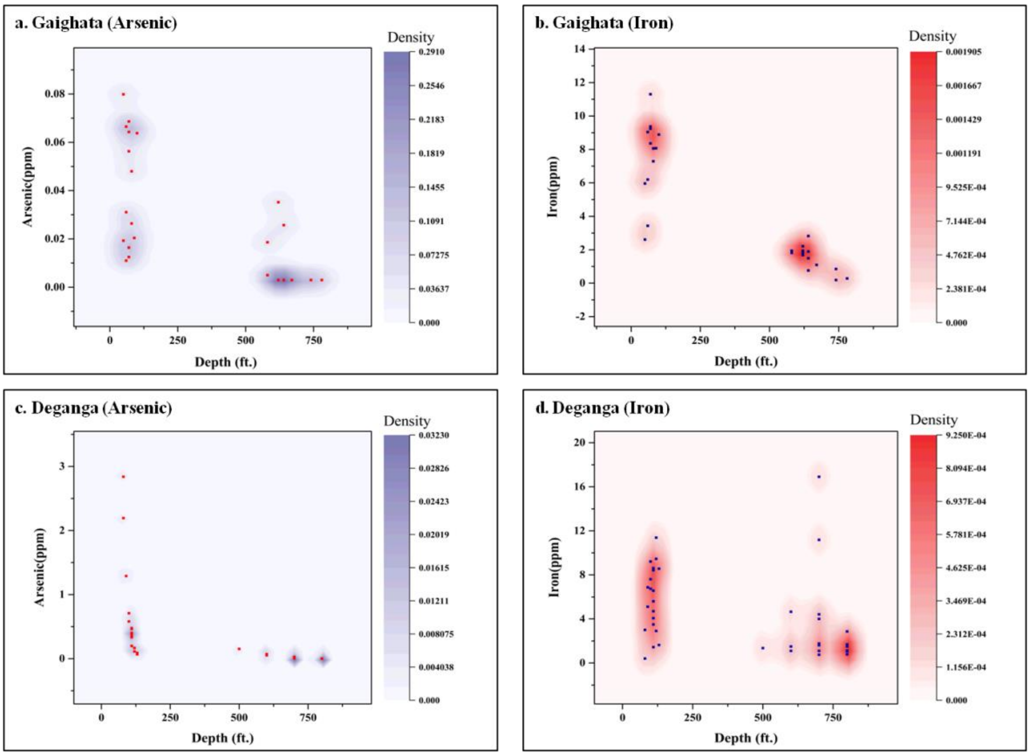


Fig. 11. Kernel Density plot of As and Fe from the two studied blocks.

6.1.3. Statistical distribution of toxic elements (As, NO_3^-, and F^-)

Arsenic, nitrate and fluoride are categorized as toxic elements present in groundwater. The statistical distribution of the three toxic elements in the studied blocks has been shown Fig. 12. The mean As concentration in domestic shallow tube-well groundwater of the respective Gaighata and Deganga block is 4.2 and 5.25 and 28.7 times higher than the mean As of deep tube-well groundwater of Gaighata and Deganga block, respectively. Exposure to high As concentration in drinking water leads to severe human health risks like arsenicosis, skin pigmentation, cancer (skin, lung and bladder), etc. (Abdul et al. 2015, Bhowmick et al. 2018, Roychowdhury 2008, 2010). The fluoride as well as nitrate concentration in the domestic shallow and deep tube-wells groundwater from the studied blocks is within the permissible limit of drinking water. The recommended value of fluoride and nitrate in drinking water is 1.5 and 45 mg/L, respectively (BIS 2012, WHO 2011). Consumption of high fluoride containing drinking water results in decaying of bones, dental and skeletal fluorosis in children and adults (Narsimha and Rajitha 2018). Globally, nitrate is the most considerable chemical toxin in groundwater. Exposure of nitrate through drinking water causes health risk in infants (Fan and Steinberg 1996).

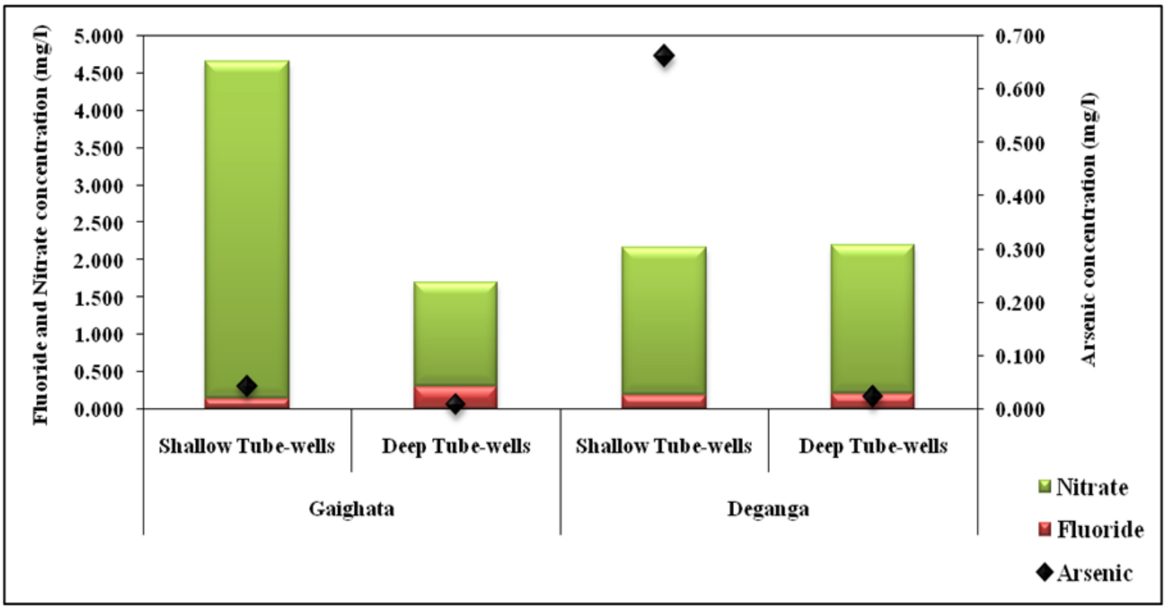


Fig. 12. Stacked plot showing the distribution of toxic elements

6.1.4. Correlation and Principal Component Analysis of the water quality parameters

The correlation among the water quality parameters has been depicted in Table 2. In Gaighata block, for both domestic shallow and deep tube-well, a moderate positive relation has been observed between pH and alkalinity (0.48, 0.59) compared to the Deganga block groundwater samples. This suggests that the water quality of Gaighata and Deganga block is alkaline in nature, which is confirmed by the mean concentration of pH and alkalinity in groundwater samples. The TDS and EC for the groundwater samples showed no significant variations. A strong positive correlation between EC and chloride was observed for both the types of groundwater samples. The interdependence of the water quality parameters depicts that the quality of domestic shallow groundwater is hard in nature compared to deep tube-well groundwater. The different water quality parameters from the two studied blocks have been plotted through Principal Component Analysis (PCA) (Fig. 13). PCA provides information on the water quality parameters, which depict the entire data elucidation, and reduction followed by summarizing the statistical correlation among them with least loss of original information (Helena et al. 2000). The biplot was plotted for both domestic shallow and deep tube-well groundwater with depth as observational levels and eleven variables (pH, conductance, TDS, total hardness, alkalinity, sulphate, chloride, As, Fe, fluoride, and nitrate). In Gaighata block, for domestic shallow tube-well groundwater, the two Principal Components cumulatively showed 52.6% of the total variation, where contribution of PC1 (26.98%) and PC2 (25.62%), respectively. The Group 1 in PCA biplot was formed between As, nitrate, pH, Fe and alkalinity. Among the distinctly placed parameters (total hardness, TDS, conductance, chloride, sulphate and fluoride), conductance has strong relation with chloride. Similarly, for deep tube-well groundwater, the cumulative two Principal Components showed 51.17% of the total variation, where PC1 and PC2 contributed 30.71% and 20.46%, respectively. The PCA biplot showed the dependence among the parameters as Group 1 (As and Fe), Group 2 (total hardness, nitrate, pH and alkalinity) and Group 3 (TDS, sulphate, chloride, conductance, and fluoride).

Likewise, in Deganga block, domestic shallow tube-well groundwater showed two Principal Components cumulatively as 49.81% of the total variation, where contribution of PC1 (30.84%) and PC2 (18.97%), respectively. The interdependence relation among the water parameters has been observed as Group 1 (Fe and sulphate), Group 2 (alkalinity, chloride, conductance), Group 3 (As, pH, TDS, fluoride) and Group 4 (total hardness and nitrate). In a similar way, the deep tube-well groundwater showed 60.45% of the total variation as cumulative two Principal Components, where PC1 and PC2 contributed 37.56% and 22.89%, respectively. The PCA biplot showed inter-relation among the parameters as Group 1 (alkalinity, chloride, conductance, TDS, nitrate and pH), and Group 2 (sulphate, fluoride) and total hardness as well as As was placed distinctly. Overall, in the domestic shallow aquifer samples of Gaighata block, the high ionic electrical conductivity resembles the high chloride concentration. The presence of total hardness has caused the high value of alkalinity, whereas the Deganga domestic shallow water samples showed a good correlation between electrical conductivity and chloride, alkalinity, and total hardness. The water quality parameters of the domestic shallow water samples are distributed throughout the hyper-plane of the PC1 and PC2. In case of deep tube-wells, the water quality parameters are mainly distributed throughout the hyper-plane of the PC2, except As and Fe (Gaighata block) and only As (Deganga block) falls under PC1. The varied distribution pattern of the parameters might be due to different geographical position of the aquifers from the studied blocks.

Table 2: Correlation matrixes of the physico-chemical parameters (Domestic Shallow and Deep tube-wells)

Gaighata **a) Domestic shallow tube-wells**	pH	EC	TDS	TH	Alkalinity	Sulphate	Chloride	Arsenic	Iron	Fluoride	Nitrate	Calcium	Magnesium
pH	1												
EC	-0.22	1											
TDS	-0.60	0.17	1.00										
TH	-0.59	0.81	0.35	1									
Alkalinity	0.48	0.33	-0.62	0.04	1								
Sulphate	0.03	-0.02	-0.20	0.21	0.25	1							
Chloride	0.03	0.70	0.04	0.43	0.36	-0.49	1						
Arsenic	0.22	-0.34	-0.09	-0.46	-0.13	-0.31	-0.06	1					
Iron	0.08	0.28	-0.37	-0.07	0.51	-0.05	0.15	0.31	1				
Fluoride	-0.16	-0.26	0.22	-0.06	-0.24	0.61	-0.68	-0.32	-0.16	1			
Nitrate	0.15	-0.15	-0.19	-0.22	0.15	-0.06	-0.18	0.28	0.24	-0.05	1		
Calcium	-0.59	0.81	0.35	1	0.04	0.21	0.43	-0.46	-0.07	-0.06	-0.22	1	
Magnesium	-0.59	0.81	0.35	1	0.04	0.21	0.43	-0.46	-0.07	-0.06	-0.22	1	1

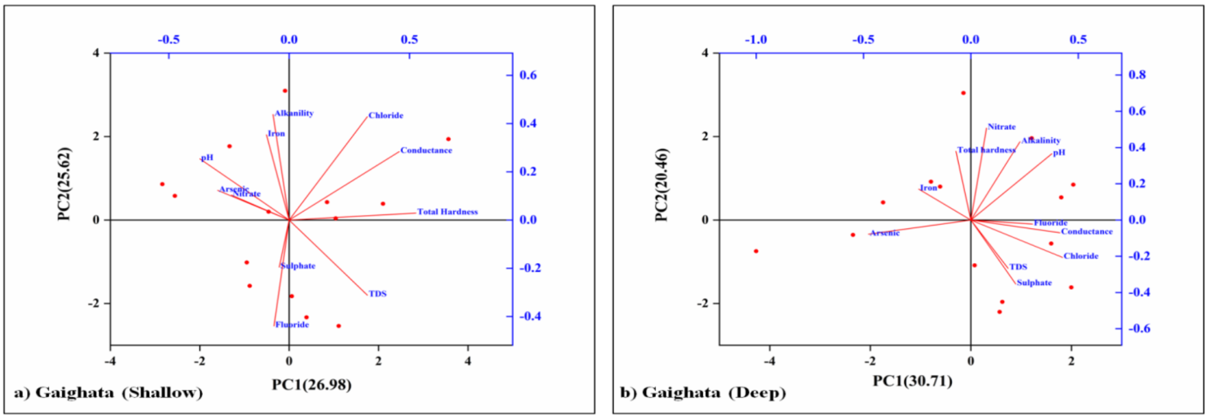
Gaighata **b) Deep tube-wells**	pH	EC	TDS	TH	Alkalinity	Sulphate	Chloride	Arsenic	Iron	Fluoride	Nitrate	Calcium	Magnesium
pH	1												
EC	0.35	1											
TDS	0.26	-0.10	1										
TH	0.00	-0.09	-0.34	1									
Alkalinity	0.59	0.19	-0.20	0.32	1								
Sulphate	-0.08	0.21	0.44	-0.18	-0.11	1							
Chloride	0.26	0.86	0.12	-0.11	0.13	0.35	1						
Arsenic	-0.68	-0.52	-0.27	0.06	-0.34	-0.28	-0.49	1					
Iron	-0.18	-0.37	-0.30	0.22	-0.35	-0.03	-0.56	0.12	1				
Fluoride	0.23	0.25	0.12	0.05	-0.04	0.34	0.23	-0.79	0.26	1			
Nitrate	0.60	-0.02	-0.01	0.24	0.37	-0.20	-0.18	-0.14	0.26	0.00	1		
Calcium	0.00	-0.09	-0.34	1	0.32	-0.18	-0.11	0.06	0.22	0.05	0.24	1	
Magnesium	0.00	-0.09	-0.34	1	0.32	-0.18	-0.11	0.06	0.22	0.05	0.24	1	1

Deganga **c) Domestic shallow tube-wells**	pH	EC	TDS	TH	Alkalinity	Sulphate	Chloride	Arsenic	Iron	Fluoride	Nitrate	Calcium	Magnesium
pH	1												
EC	-0.10	1											

TDS	0.21	-0.28	1										
TH	0.02	0.48	-0.09	1									
Alkalinity	0.01	0.79	-0.05	0.69	1								
Sulphate	0.10	0.36	-0.16	-0.13	0.20	1							
Chloride	-0.09	0.82	0.04	0.50	0.57	0.33	1						
Arsenic	0.42	-0.25	0.16	-0.12	-0.09	-0.06	-0.35	1					
Iron	-0.34	-0.04	-0.12	-0.09	0.06	0.40	-0.16	-0.41	1				
Fluoride	0.20	0.10	0.09	0.21	0.15	-0.32	0.10	-0.17	-0.37	1			
Nitrate	0.01	0.15	0.10	0.73	0.33	-0.10	0.38	-0.27	0.00	-0.06	1		
Calcium	0.02	0.48	-0.09	1	0.69	-0.13	0.50	-0.12	-0.09	0.21	0.73	1	
Magnesium	0.02	0.48	-0.09	1	0.69	-0.13	0.50	-0.12	-0.09	0.21	0.73	1	1

Deganga

d) Deep tube-wells	pH	EC	TDS	TH	Alkalinity	Sulphate	Chloride	Arsenic	Iron	Fluoride	Nitrate	Calcium	Magnesium
pH	1												
EC	0.66	1											
TDS	-0.06	0.02	1										
TH	-0.62	-0.62	0.05	1									
Alkalinity	0.27	0.47	0.07	0.28	1								
Sulphate	0.08	0.20	-0.41	0.06	0.28	1							
Chloride	0.65	0.98	0.04	-0.75	0.29	0.13	1						
Arsenic	-0.31	-0.20	-0.09	-0.19	-0.55	-0.15	-0.08	1					
Iron	-0.09	-0.10	-0.15	0.42	0.29	-0.01	-0.13	-0.11	1				
Fluoride	0.02	0.11	0.01	0.26	0.55	0.20	-0.02	-0.78	-0.12	1			
Nitrate	0.70	0.89	-0.04	-0.42	0.53	0.19	0.85	-0.25	0.23	0.02	1		
Calcium	-0.62	-0.62	0.05	1	0.28	0.06	-0.75	-0.19	0.42	0.26	-0.42	1	
Magnesium	-0.62	-0.62	0.05	1	0.28	0.06	-0.75	-0.19	0.42	0.26	-0.42	1	1



a) Gaighata (Shallow)

b) Gaighata (Deep)

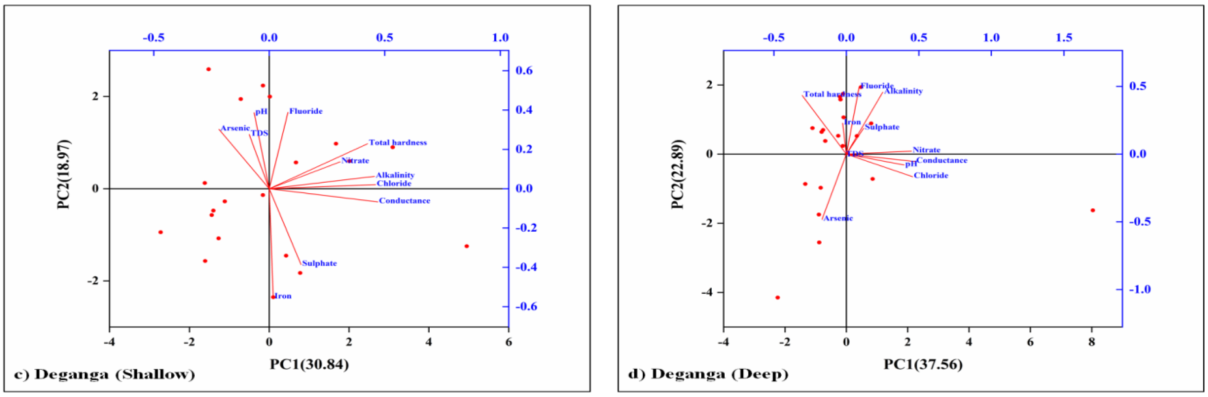


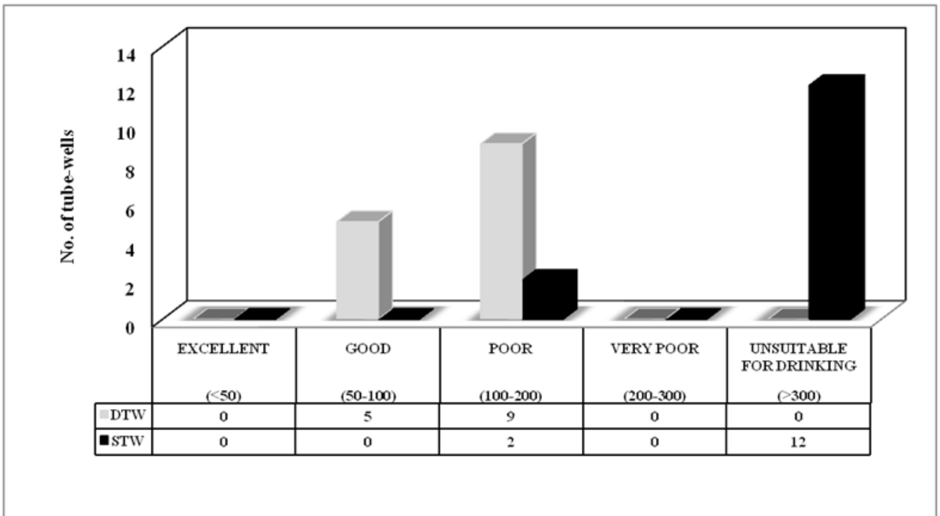
Fig. 13. PCA showing the scores of the first two principal components (PC1 and PC2) of the total variance.

6.1.5. Assessment of Water Quality Index (WQI)

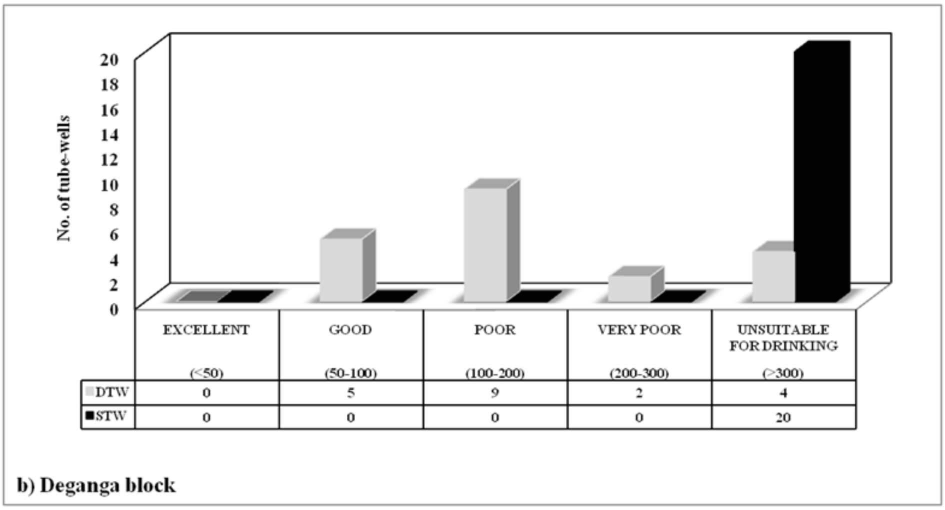
Ten significant physico-chemical parameters were considered according to their significant weight (w_i) with respect to the overall water quality for drinking purposes. For the toxic element, i.e., As, the highest weight of 5 has been considered depending on its potential harmful nature. In case of fluoride and nitrate, a weight of 4 was taken as it plays an important role in groundwater pollution. The physico-chemical parameters along with their respective calculated relative weights and Indian Standards in drinking water has been shown in Table 3. The Water Quality Index (WQI) has been evaluated for both the domestic shallow and deep tube-wells from the two studied blocks using the equations as described earlier. The respective range of WQI categorizes the water quality for drinking purpose. Water Quality classification of domestic shallow and deep groundwater based on WQI assessment has been shown in Fig. 14. About 14% and 86% of the domestic shallow tube-well groundwater (n =14) samples from Gaighata block are estimated as ‘poor’, and ‘unsuitable for drinking’, respectively, whereas 100% of the domestic shallow tube-well groundwater (n =20) samples from Deganga block are considered as ‘unsuitable for drinking’. In case of deep tube-well groundwater (n =14) samples collected from Gaighata block, about 36% and 64% are categorized under ‘good’ and ‘poor’ drinking water, respectively. Likewise, in Deganga block, it was observed about 25, 45, 10, and 20% of the deep tube-well groundwater (n =20) samples are under the categories ‘good’, ‘poor’, ‘very poor’, and ‘unsuitable for drinking’ respectively. Hence, Water Quality Index (WQI) showed that approximately 36% and 25% of deep tube-well water samples are categorized under ‘good water quality’, whereas 86% and 100% of the domestic shallow tube-well water samples are not recommended for drinking purpose in Gaighata and Deganga, respectively. As a whole, the domestic shallow tube-well water quality is mainly ‘unsuitable for drinking’ from both the studied blocks. On the other hand, the deep tube-well groundwater from the studied areas is safer compared to shallow level; however, it needs to evaluate the quality before use for domestic purposes.

Table 3: Relative weight of physico-chemical parameters in groundwater

Parameters	**Weight (w_i)**	**Relative weight (W_i)**	**Indian Standards (mg/l, except pH) (BIS, 2012, WHO, 2011a)**
Arsenic	5	0.167	0.01
Iron	3	0.1	0.3
Ph	3	0.1	6.5-8.5
TDS	2	0.067	500-2000
Total Hardness	2	0.067	200-600
Alkalinity	2	0.067	200-600
Fluoride	4	0.133	1.0-1.5
Nitrate	4	0.133	45
Sulphate	2	0.067	200-400
Chloride	3	0.1	250-1000
	$\sum = 30$	**$\sum = 1$**	



a) Gaighata block



b) Deganga block

Fig. 14. Water Quality classification based on WQI assessment

6.1.6. Human health risk assessment through consumption of toxic contaminants present in groundwater (As, NO_3^-, F^-)

The human health carcinogenic and non-carcinogenic risk has been evaluated based on the equations as mentioned earlier. Cancer as well as non-cancer risk assessment has been performed for As, a group I toxic and carcinogenic pollutant (ATSDR 2007, IARC 2012, USEPA 2006). Only non-cancer risk assessment (Hazard Quotient) has been performed for nitrate and fluoride (Adimalla et al. 2018, Das et al. 2020, Narsimha and Rajitha 2018). The health risk assessment (both cancer and non-cancer) of the populaces through these toxic contaminants present in groundwater has been shown in Table 4.The potential carcinogenic and non-carcinogenic risk due to As toxicity has been observed higher among the populaces of Deganga through domestic shallow tube-wells (3.54×10^{-2} and 78.6) and deep tube-wells (1.21×10^{-3} and 2.68), compared to the Gaighata populaces (domestic shallow tube-wells: 2.24×10^{-3} and 4.97) and (deep tube-wells: 4.38×10^{-4} and 0.97), respectively. The standard As level for lifetime carcinogenic risk is 1×10^{-6} (USEPA 2005). The observed range of HQ value greater than 1 for As is a serious matter of concern for the studied two populaces who have been consuming As-contaminated groundwater for a prolonged time, which might be responsible for severe health hazards in near future. The range of cancer risk through intake of domestic shallow and deep tube-well groundwater is much higher than its threshold level.

For both the studied blocks, the risk through domestic shallow tube-well groundwater is higher than the deep tube-well groundwater. This study indicates that the exposure of drinking water from domestic shallow tube-well has a greater potential to cause serious health problems including lung, liver, urinary or skin cancer (Alam et al. 2016). The studied populaces from the two blocks have been already exposed to As toxicity through consumption of As-contaminated drinking water and foodstuffs (rice grains and vegetables) being cultivated by using As contaminated irrigation water and soil (Chowdhury et al. 2018a, b, Roychowdhury 2010). Rice grain is the main staple crop, which contributes a considerable amount of inorganic As through daily diet that poses severe health risk, due to As toxicity, for the populace (Roychowdhury 2008, 2010). Therefore, it is important to take necessary steps for improvement of drinking water quality as it is related with the health issues of the local populace. The calculated mean value of non-cancer risk (HQ) for nitrate and fluoride found in Gaighata block are 0.0009, 0.024 for domestic shallow and 0.0002, 0.005 for deep tube-well groundwater samples, respectively. Likewise, Deganga block showed nitrate and fluoride HQ value of 0.015, 0.39 through domestic shallow and 0.0005, 0.013 for deep tube-well groundwater samples, respectively. The acceptable level of risk (non-cancerous diseases) for each element is unity, i.e., when the HQ value is greater than 1, then an unacceptable non-carcinogenic risk exists (Das et al. 2020, USEPA 2005). The evaluated non-cancer risk (HQ value) for both nitrate and fluoride present in groundwater is less than the tolerable level of risk for non-cancerous diseases. As a result, there is no human health risk from nitrate and fluoride at present through intake of groundwater from both the studied Gaighata and Deganga blocks.

Table 4: Health risk assessment (cancer and non-cancer) for the studied populations through consumption of the toxic elements

			Cancer risk		**Non-cancer risk**	
Studied block	**Sources (Tube-well)**	**Toxic contaminants**	**Mean**	**Range**	**Mean**	**Range**
Gaighata	**Deep**	Arsenic	4.38x10^{-4}	1x10^{-4} - 1.8x10^{-3}	0.97	0.36-4.19
		Fluoride	-	-	0.005	0.001-0.021
		Nitrate	-	-	0.0002	0.00006-0.0007
	Domestic shallow	Arsenic	2.24x10^{-3}	5x10^{-4} - 4x10^{-3}	4.97	1.31-9.51
		Fluoride	-	-	0.024	0.006-0.047
		Nitrate	-	-	0.0009	0.0002-0.002
Deganga	**Deep**	Arsenic	1.2x10^{-3}	2x10^{-4} - 8.2x10^{-3}	2.68	0.35-18.2
		Fluoride	-	-	0.013	0.002-0.09
		Nitrate	-	-	0.0005	0.00006-0.003
	Domestic shallow	Arsenic	3.54x10^{-2}	4x10^{-3} - 0.152	78.7	8.09-337
		Fluoride	-	-	0.39	0.04-1.68
		Nitrate	-	-	0.15	0.002-0.06

Overall groundwater quality of the domestic shallow and deep tube-wells from two As-affected blocks has been categorized as alkaline and hard in nature. About 78.5 and 70% of the deep tube-well groundwater samples from Gaighata (depth = 580–780 ft) and Deganga (depth = 500–800 ft) block, respectively, have been identified with As concentration less than 10 µg/L. The mean As concentration of domestic shallow tube-well is 5.25 and 28.7 fold higher than the mean As of deep tube-well from Gaighata and Deganga block, respectively. Presence of other toxic elements like nitrate and fluoride in groundwater does not play any significant role, as the values are within the permissible limit. So, it can be concluded that there is no human health risk from nitrate and fluoride through intake of groundwater from both the studied blocks. The groundwater quality index (WQI value) showed that 36% and 25% of deep tube-well water samples are characterized under ‘good water quality’, recommended for drinking purpose in Gaighata and Deganga, respectively. The domestic shallow tube-well water quality indexing clearly indicates that the water is ‘unsuitable for drinking’ from both the studied blocks. As a result, the groundwater from deep aquifer is comparatively safer with respect to shallow aquifer for drinking, cooking and other household purposes; however, continuous monitoring of water quality is required. The potential carcinogenic and non-carcinogenic risk due to severe As exposure through drinking water is high from domestic shallow tube-well compared to deep tube-well among the studied blocks.

6.2. Contamination scenario and risk assessment of arsenic in deep tube-wells: a comparative study from two severely arsenic-affected blocks

The present study investigates the As-contamination scenario in deep tube-wells from all the gram panchayats of Gaighata and Swarupnagar blocks located in North 24 Parganas district through As distribution, depths and associated Fe concentrations. Deep tube-wells water quality has been evaluated using different pollution index studies mainly based on As and Fe concentrations along with an ecological risk assessment. Simultaneously, a comprehensive health risk assessment (cancerous and non-cancerous) for the populace has been evaluated through consumption of water from deep tube-wells. This work essentially examines the present scenario in rural Bengal after installation of deep tube-wells as one of the mitigation strategies to provide As-safe water.

6.2.1. Gaighata block: Concentrations of As and Fe in deep tube-wells situated in 13 gram panchayats (GP) of Gaighata block (Table 5). Deep tube-wells water samples mainly used by the populaces have been collected from 13 gram panchayats namely Chandpara (n=18), Duma (n=21), Jaleswar I (n=20), Jaleswar II (n=9), Ichapur I (n=10), Ichapur II (n=17), Dharampur I (n=12), Dharampur II (n=22), Sutia (n=28), Jhaudanga (n=16), Shimulpur (n=22), Ramnagar (n=19), Fulsara (n=21). Research reports have highlighted groundwater is containing As above 10 µg/L in 107 mouzas and above 50 µg/L in 91 mouzas over 13 gram-panchayats. Nearly 59.2 and 40.3% of the tube-well water was As-contaminated above 10 µg/L and 50 µg/L, respectively **(Roychowdhury, 2010).**

In this study, the observed As concentrations of the deep tube-well (depth range: 500-800 ft.) water samples are as follows: Chandpara (mean = 42.7µg/L; range = 7.63-83.2 µg/L), Duma (mean = 16µg/L; range = 3-61.6 µg/L), Jaleswar I (mean = 65.1µg/L; range = 3.93-88.9 µg/L), Jaleswar II (mean = 51.8µg/L; range = 1.83-142 µg/L), Ichapur I (mean = 120µg/L; range = 19.2-249 µg/L), Ichapur II (mean = 73.9 µg/L; range = 0.5-229 µg/L), Dharampur I (mean = 57.5µg/L; range = 3-119 µg/L), Dharampur II (mean = 46.5µg/L; range = 3-175 µg/L), Sutia (mean = 19.8µg/L; range = 3-175 µg/L), Jhaudanga (mean = 11.6µg/L; range = 3-67.2 µg/L), Shimulpur (mean = 10.6µg/L; range = 3-87.9 µg/L), Ramnagar (mean = 10.5µg/L; range = 3-80 µg/L), Fulsara (mean = 56.9µg/L; range = 6-154 µg/L).

In a similar way, the observed Fe concentrations of the respective gram panchayats of the block are as: Chandpara (mean = 3.95 mg/L; range = 1.24-14.7 mg/L), Duma (mean = 0.91 mg/L; range = 0.43-1.58 mg/L), Jaleswar I (mean = 3.4 mg/L; range = 2.03-4.94 mg/L), Jaleswar II (mean = 4.62 mg/L; range = 1.88-11.3 mg/L), Ichapur I (mean = 2.94 mg/L; range = 0.43-7.22 mg/L), Ichapur II (mean = 3.41 mg/L; range = 0.94-9.87 mg/L), Dharampur I (mean = 0.26 mg/L; range = 0.01-1.02 mg/L), Dharampur II (mean = 0.22 mg/L; range = 0.03-0.92 mg/L), Sutia (mean = 2.47 mg/L; range = 0.94-9.36 mg/L), Jhaudanga (mean = 1.1 mg/L; range = 0.64-2.49 mg/L), Shimulpur (mean = 2.38 mg/L; range = 0.26-7.57 mg/L), Ramnagar (mean = 1.20 mg/L; range = 0.68-3.41 mg/L), Fulsara (mean = 4.29 mg/L; range = 1.17-24.3 mg/L).

6.2.2. Swarupnagar block: Concentrations of As and Fe in deep tube-wells observed in 13 gram panchayats (GP) of Swarupnagar block (Table 6). Deep tube-wells water samples mainly used by the populaces have been collected from 9 gram panchayats namely Bithari (n=22), Banglani (n=25), Balti (n=20), Charghat (n=32), Jhakra-Gokulpur (n=29), Khejuri (n=25), Shaguna (n=31), Sarapul (n=23), Tepul (n=25). This block is also well recognized as As-contaminated since ages (Roychowdhury, 2010).

In this study, the observed As concentrations of the deep tube-well (depth range: 500-900 ft.) water samples are as follows: Balti (mean = 44.6 µg/L; range = 3-300 µg/L), Banglani (mean = 66 µg/L; range = 3-394 µg/L), Bithari (mean = 15.3 µg/L; range = 4.23-57.8 µg/L), Charghat (mean = 41.6 µg/L; range = 3-341 µg/L), Jhakra-Gokulpur (mean = 65.4 µg/L; range = 3--355 µg/L), Khejuri (mean = 53.1 µg/L; range = 3-398 µg/L), Shaguna (mean = 75.7 µg/L; range = 3-431 µg/L), Sarapul (mean = 65.8 µg/L; range = 3-527 µg/L), Tepul (mean = 56.8 µg/L; range = 3-393 µg/L).

In a similar way, the observed Fe concentrations of the respective gram panchayats of the block are as: Balti (mean = 0.46 mg/L; range = 0.05-1.71 mg/L), Banglani (mean = 2.2 mg/L; range = 0.05-27.2 mg/L), Bithari (mean = 0.16 mg/L; range = 0.05-0.59 mg/L), Charghat (mean = 1.55 mg/L; range = 0.15-22.3 mg/L), Jhakra-Gokulpur (mean = 5.27 mg/L; range = 0.13-25.6 mg/L), Khejuri (mean = 1.06 mg/L; range = 0.19-6.62 mg/L), Shaguna (mean = 0.93 mg/L; range = 0.05-6.01 mg/L), Sarapul (mean = 1.13 mg/L; range = 0.05-6.68 mg/L), Tepul (mean = 0.96 mg/L; range = 0.05-5.6 mg/L).

Table 5: Concentrations of As and Fe in deep tube-wells situated in 13 gram panchayats (GP) of Gaighata block

No.	GP: CHANDPARA	Depth (ft.)	GPS	Arsenic (µg/L)	Iron (mg/L)
1	Simuliapara S.S.K	600	N:22º58´44.49´´ E:88º46´28.02´´	83.2	3.16
2	Simuliaparasreepalli I.C.D.N	600	N:22º58´36.49´´ E:88º46´21.40´´	80.2	1.29
3	Parbati Mandal	500	N:22º58´37.83´´ E:88º46´08.18´´	58.5	1.82
4	Mandirtala	600	N:22º58´29.35´´ E:88º46´31.44´´	66.5	1.39
5	F.P.School	600	N:22º58´34.92´´ E:88º46´39.00´´	61.7	1.82
6	Sub Health Centre (Sanapara)	600	N:22º58´38.97´´ E:88º46´42.00´´	41.9	4.83
7	Debayan Sangha	600	N:22º48´47.96´´ E:88º46´42.86´´	45.7	1.93
8	Deep tube-well (B.D.O)	700	N:22º58´34.69´´ E:88º46´52.52´´	26	1.39
9	KalimandirChadapara	600	N:22º58´24.16´´ E:88º46´50.82´´	39.5	1.24
10	Mandalpara Market	600	N:22º59´14.38´´ E:88º47´15.53´´	23.6	14.3
11	Dhakapara I.C.D.S	600	N:22º59´52.93´´ E:88º46´55.78´´	33.3	2.51
12	Dhakapara Child Education	500	N:23º00´00.29´´ E:88º46´41.48´´	23.5	14.7
13	Dhakapara F.P. School	500	N:22º00´03.55´´ E:88º46´46.84´´	24.3	2.28
14	Jogachia star club	700	N:23º00´10.79´´ E:88º47´13.81´´	27.1	5.71
15	Sub Health Centre(Dhakapara)	700	N:23º00´09.21´´ E:88º47´22.73´´	36.2	4.61
16	JogachiaBastola	800	N:23º00´06.17´´ E:88º47´28.58´´	33.9	2.53
17	Jogachia Market	600	N:23º00´01.74´´ E:88º47´49.40´´	56.6	1.88
18	MandalparaHigh School	500	N:22º59´28.00´´ E:88º47´20.45´´	7.63	3.79
	MEAN	606		42.7	3.95
	SD	80.2		21	4.05
	MIN	500		7.63	1.24
	MAX	800		83.2	14.7

No.	GP: DUMA	Depth (ft.)	GPS	Arsenic (µg/L)	Iron (mg/L)
1	Koipukuria R.P.School ARP		N:22º57´11.55´´	21.4	1.12

			E:88º49´30.78´´		
2	Koipukuria primary School	100	N:22º57´11.55´´	3	0.81
			E:88º49´30.78´´		
3	Ganesh Mandal	600	-	3	0.75
4	Rail gate(chotoseyana)	600	N:22º58´56.95´´	61.6	1.58
			E:88º47´38.72´´		
5	Bottola(chotoseyana)	700	N:22º58´57.84´´	61.3	1.49
			E:88º47´52.04´´		
6	Madhusudan Mandal (chotoseyana)	700	N:22º58´52.03´´	46.1	1.26
			E:88º48´02.91´´		
7	Primary School(boroseyana) ARP	NA	N:22º59´04.73´´	28.7	1.1
			E:88º48´15.93´´		
8	B.M. Palli-7478 (boroseyana)	600	N:22º59´10.80´´	25.4	1.19
			E:88º48´23.06´´		
9	Kobi Sukanta smriti primary school (jhikhira)	700	N:22º57´11.55´´	12.9	0.99
			E:88º48´54.72´´		
10	Shyamal Baidya (jhikhira)	700	N:22º59´23.63´´	3	0.51
			E:88º48´57.06´´		
11	Kalitala primary school(jhikira)	900	N:22º59´18.34´´	3	0.61
			E:88º49´10.04´´		
12	Sub health centre (Sahebdanga)	600	N:22º58´49.18´´	3	0.57
			E:88º49´30.85´´		
13	Saruipur Battola	800	N:22º58´20.26´´	3	0.66
			E:88º49´22.02´´		
14	Saruipur choumatha	800	N:22º57´56.62´´	3	0.74
			E:88º49´19.36´´		
15	Mathapara kanimandir deoful	700	N:22º57´30.81´´	3	0.81
			E:88º48´59.53´´		
16	A.R.P(Deoful)		-	38.8	1.48
17	Adrani Primary School (Deoful)	600	N:22º57´16.57´´	3	0.56
			E:88º48´52.56´´		
18	Santosh Bachar (Deoful)	500	N:22º57´11.00´´	3	0.67
			E:88º48´54.42´´		
19	Child Education(Malaypur)	300	N:22º56´57.89´´	3	0.71
			E:88º48´53.96´´		
20	Mathpara (Malaypur)	800	N:22º56´54.02´´	3	1.1
			E:88º48´59.81´´		
21	Ajit Goldar(Beldanga)	700	-	3	0.43
	MEAN	633		16	0.91
	SD	188		20.1	0.35
	MIN	100		3	0.43
	MAX	900		61.6	1.58

No.	**GP: FULSARA**	**Depth (ft.)**	**GPS**	**Arsenic (µg/L)**	**Iron (mg/L)**
1	Katakhalikhal	100	N:22º56´56.79´´	17.7	2.03
			E:88º46´02.08´´		
2	Katakhalikhal Tapas	600	N:22º57´01.71´´	6	14.4

	Mandal		E:88º45´57.70´´		
3	Dilip Pal (Bakchara)	500	N:22°57´21.36´´ E:88°45´52.46´´	26.4	1.17
4	(Market) Battola (Bakchara)	600	N:22º57´26.32´´ E:88º45´47.73´´	19.6	2.53
5	Area Office (Bakchara)	600	N:22º57´27.85´´ E:88º45´45.21´´	42.1	1.24
6	Katakhali R.P. School	700	N:22º57´27.85´´ E:88º45´45.21´´	18.5	4.94
7	Chougacha High School	800	N:22º57´32.85´´ E:88º45´39.38´´	39.3	2.18
8	Chougacha Kalitala	800	N:22º56´47.96´´ E:88º45´22.80´´	66.1	1.32
9	Chougachi Prajati Sangha	800	N:22º57´52.59´´ E:88º45´20.97´´	73.5	1.69
10	Chougacha F.P. School	600	N:22º57´53.96´´ E:88º45´15.82´´	35.2	4.25
11	Kishor Sarkar (kharer math)	100	N:22º58´33.01´´ E:88º44´55.13´´	154	7.19
12	Harish Chandra Sarkar	600	N:22º58´35.08´´ E:88º44´58.43´´	60.3	2.03
13	Jofrajapur R.P. Primary school	600	N:22º58´45.76´´ E:88º44´54.73´´	86.5	24.3
14	Jofrajapur Kalitala	600	N:22º58´53.17´´ E:88º44´23.09´´	16.6	4.25
15	Kharer Math (Kalitala)	600	N:22º58´43.33´´ E:88º45´08.70´´	50.8	1.65
16	Kharer Math Sajal Sarkar	800	N:22º58´45.18´´ E:88º45´14.67´´	127	2.81
17	Kharer Math Khaldhar Kalitala	700	N:22º58´46.71´´ E:88º45´22.67´´	55.1	2.46
18	Jiten Mallik (kharer math)	700	N:22º58´46.44´´ E:88º45´32.29´´	135	1.95
19	Ganesh Mandal (Fulsara)	700	N:22º58´39.18´´ E:88º45´52.30´´	63.8	1.93
20	Primary School (Fulsara)	600	N:22º58´41.02´´ E:88º46´06.47´´	53.1	4.08
21	Primary School (Back-side: Fulsara)	300	N:22º58´41.02´´ E:88º46´06.47´´	49.2	1.69
	MEAN	590		56.9	4.29
	SD	200		40.2	5.45
	MIN	100		6	1.17
	MAX	800		154	24.3

No.	**GP: JALESHWAR-I**	**Depth (ft.)**	**GPS**	**Arsenic (µg/L)**	**Iron (mg/L)**
1	Shivnath Mondal	600	N:22º54´23.61´´ E:88º43´28.02´´	56.4	2.24

2	Bagna Bridge	700	N:22º54´38.33´´ E:88º43´25.60´´	84.4	4.94
3	Saburali Park	800	N:22º54´40.91´´ E:88º43´24.39´´	83	3.18
4	Jayanta Mondal	700	N:22º54´46.16´´ E:88º43´23.16´´	73.8	2.38
5	S.Bagna FP Schol	600	N:22º54´53.52´´ E:88º43´19.09´´	73.6	2.69
6	Bhudev Mondal	700	N:22º54´54.35´´ E:88º43´15.63´´	88.9	4.25
7	Jaleswar crossing	650	N:22º55´04.36´´ E:88º43´12.84´´	69.5	3.19
8	Jaleswar High school	650	N:22º55´40.38´´ E:88º42´47.77´´	75.3	2.03
9	Jaleswar Shiv Temple	700	N:22º55´42.15´´ E:88º42´42.25´´	81.2	4.3
10	Bidhan Biswas	800	N:22º55´52.60´´ E:88º42´53.63´´	75.3	4.25
11	ARP: Jaleswar	ARP	N:22º55´52.89´´ E:88º42´50.68´´	3.93	2.65
12	Samir kabiraj	700	N:22º56´02.61´´ E:88º42´46.36´´	44	2.81
13	Chandigar FP	700	N:22º56´25.39´´ E:88º42´47.09´´	51.9	2.46
14	ARP: Chandigar	ARP	N:22º56´24.30´´ E:88º43´06.59´´	6.3	3.65
15	Govindo Dutta	650	N:22º56´18.87´´ E:88º43´19.35´´	84.5	4.93
16	FP School: Narkela	750	N:22º56´01.70´´ E:88º43´27.53´´	63.8	4.08
17	NRSS: Narkela	750	N:22º55´57.20´´ E:88º43´37.33´´	78.3	3.39
18	ARP: Narkela	ARP	N:22º55´54.46´´ E:88º43´44.69´´	55.8	3.97
19	Sanjib Debnath	700	N:22º55´41.77´´ E:88º43´55.29´´	74.9	3.4
20	Premananda Debnath	650	N:22º55´40.95´´ E:88º43´54.87´´	77.3	3.71
	MEAN	694		65.1	3.4
	SD	58.3		23.7	0.9
	MIN	600		3.93	2.03
	MAX	800		88.9	4.94

No.	**GP: JALESHWAR-II**		**Depth (ft.)**	**GPS**	**Arsenic (µg/L)**	**Iron (mg/L)**
1	Rampur kg School	Rampur	700	N:22º56´39.15´´ E:88º44´12.51´´	53.3	7.36
2	Kharer Math	Rampur	600	N:22º57´09.12´´	1.83	1.88

	Kali Mandir			E:88º44´11.57´´		
3	Manab Haldar	Rampur	500	N:22º57´26.83´´	50.4	2.565
				E:88º44´13.47´´		
4	VaibonBottola	Rampur	500	N:22º57´20.72´´	5.3	3.595
				E:88º44´48.46´´		
5	Purborampur F.P	Rampur	100	N:22º57´18.05´´	2.8	2.345
				E:88º44´45.98´´		
6	AmraKajan Club	Rampur	100	N:22º56´36.51´´	100	7.995
				E:88º44´40.32´´		
7	PriyoNir	Rampur	400	N:22º56´40.63´´	23.9	11.295
				E:88º44´20.56´´		
8	Aarti Ghosh	Rampur	800	N:22º56´31.00´´	87.1	2.03
				E:88º44´10.03´´		
9	Binapani Ghosh	Rampur	600	N:22º56´17.60´´	142	2.495
				E:88º44´10.06´´		
	MEAN		478		51.8	4.62
	SD		244		49.4	3.40
	MIN		100		1.83	1.88
	MAX		800		142	11.3

No.	GP: ICHHAPUR-I		Depth (ft.)	GPS	Arsenic (µg/L)	Iron (mg/L)
1	Gourab Mondal	Kemia	700	N:22º50´04.80´´	152	1.65
				E:88º84´41.98´´		
2	Kemia FP (ARP)	Kemia		N:22º54´42.82´´	55.6	1.01
				E:88º44´48.07´´		
3	Kemia FP (ARP)	Kemia	40	N:22º54´42.82´´	181	3.32
				E:88º44´48.07´´		
4	Jutika Sarkar	-	100	N:22º53´49.81´´	19.2	5.67
				E:88º44´11.05´´		
5	Ichhapur Primary School	Ichhapur	400	N:22º53´58.20´´	153	3.79
				E:88º44´09.08´´		
6	Friends Club(ARP)	Ichhapur		N:22º54´00.21´´	53.7	0.43
				E:88º44´08.82´´		
7	ARP	Amkola		N:22º55´41.16´´	152	1.98
				E:88º44´10.41´´		
8	Sanat Sarkar	Amkola	600	N:22º55´33.65´´	132	1.32
				E:88º44´08.83´´		
9	Ichhapur Sanimandir Matikumra FP	Matikumra	700	N:22º54´51.57´´	53.6	7.22
				E:88º43´54.94´´		
10	IchhapurSani mandir	Matikumra	600	N:22º53´35.56´´	249	2.96
				E:88º44´47.08´´		
	MEAN		449		120	2.94
	SD		278		72.1	2.16
	MIN		40		19.2	0.43
	MAX		700		249	7.22

No.	GP: JHAUDANGA		Depth (ft.)	GPS	Arsenic (µg/L)	Iron (mg/L)
1	Basudev Haldar	Jhaudanga	70	N:22º56´40.41´´ E:88º51´17.83´´	3	0.78
2	Ratan Sarkar	Jhaudanga	900	N:22º56´50.56´´ E:88º51´18.37´´	3	0.85
3	Gopal Ghosh	Jhaudanga	60	N:22º56´52.24´´ E:88º51´08.10´´	3	0.92
4	KolniR.P.School	ARP		N:22º56´55.98´´ E:88º51´15.92´´	48.2	1.61
5	Volanath Das	Jhaudanga	700	N:22º57´08.98´´ E:88º50´53.43´´	3	0.64
6	MahuaIcecream	Jhaudanga	600	N:22º57´11.49´´ E:88º50´45.43´´	3	0.77
7	Sabaipur High School	Sabaipur	700	N:22º57´14.32´´ E:88º50´30.51´´	3	0.89
8	ShibdurgaMnadir	Sabaipur	500	N:22º57´10.55´´ E:88º50´27.18´´	3	0.91
9	Kanan Das	Sabaipur	700	N:22º57´09.26´´ E:88º50´36.57´´	3	0.82
10	Poritos Das	Sabaipur	700	N:22º57´09.50´´ E:88º50´30.88´´	3	1.1
11	Sakti Sangha	Goyalbakhan	700	N:22º57´01.33´´ E:88º50´08.67´´	67.2	2.49
12	Vola Sarkar	Goyalbakhan	800	N:22º56´59.02´´ E:88º50´03.14´´	3	0.88
13	NaniTarafdar	Goyalbakhan	600	N:22º56´52.79´´ E:88º50´05.69´´	3	0.76
14	Goyalbaban FP	Goyalbakhan	400	N:22º57´07.25´´ E:88º49´56.64´´	30.8	1.64
15	DulalBasak	Goyalbakhan	800	N:22º57´09.04´´ E:88º49´49.51´´	3	0.99
16	Gari Roy	Goyalbakhan	600	N:22º57´23.97´´ E:88º49´49.55´´	3	0.91
	MEAN		589		11.6	1.1
	SD		245		19.6	0.5
	MIN		60		3	0.64
	MAX		900		67.2	2.49

No.	GP: SHIMULPUR	Depth (ft.)	GPS	Arsenic (µg/L)	Iron (mg/L)
1	Bhabo Mondol	70	N:22º54´54.41´´ E:88º46´52.00´´	87.9	7.57
2	Horolaal Barui	400	N:22º55´00.30´´ E:88º47´01.52´´	83.3	6.53
3	Kishore Samiti	600	N:22º55´01.34´´ E:88º47´03.18´´	3	1.72
4	Shimulpur Kalitola	600	N:22º55´05.17´´ E:88º47´08.73´´	3	6.98
5	Kishnapada Biswas	700	N:22º55´10.12´´ E:88º47´16.42´´	3	1.67
6	Hari Battola	600	N:22º55´13.93´´ E:88º47´22.00´´	3	0.78
7	Anil Majumder	700	N:22º55´19.55´´	18.3	5.93

			E:88º47´30.94´´		
8	Chaumatha	700	N:22º55´22.22´´ E:88º47´33.60´´	3	2.43
9	Hirendranath Ghosh	400	N:22º55´31.00´´ E:88º47´32.37´´	3	1.42
10	Friends Club	700	N:22º55´34.13´´ E:88º47´32.00´´	20.3	7.14
11	Khathal Tola	600	N:22º55´31.23´´ E:88º47´48.93´´	3	2.05
12	Subhash Parlor	700	N:22º55´35.85´´ E:88º47´57.34´´	3	2.91
13	Deshpara FP School	400	N:22º55´83.96´´ E:88º48´09.47´´	3	0.51
14	ARP	ARP	N:22º55´51.77´´ E:88º48´49.67´´	3	3.52
15	ARP	ARP	N:22º55´51.77´´ E:88º48´49.67´´	3	0.26
16	ITI College Gate	600	N:22º55´57.65´´ E:88º48´55.02´´	3	3.1
17	Bazar	600	N:22º56´03.28´´ E:88º49´05.44´´	3	0.94
18	Ashok Kalimandir	500	N:22º56´00.16´´ E:88º49´08.10´´	3	1.09
19	Chaumatha	ARP	N:22º55´51.66´´ E:88º49´58.94´´	3	0.68
20	Hirendranath Ghosh	600	N:22º55´50.69´´ E:88º50´07.18´´	3	0.64
21	Friends Club	700	N:22º55´50.44´´ E:88º50´20.14´´	3	0.68
22	Khathal Tola	ARP	N:22º55´47.05´´ E:88º50´49.17´´	3	0.64
	MEAN	565		10.6	2.38
	SD	162		22.5	2.39
	MIN	70		3	0.26
	MAX	700		87.9	7.57

No.	**GP: RAMNAGAR**	**Depth (ft.)**	**GPS**	**Arsenic (µg/L)**	**Iron (mg/L)**
1	Purnandapur das para club	600	N:22º54´21.60´´ E:88º52´38.28´´	3	0.97
2	Purnandapur purachandra bala	200	N:22º54´18.48´´ E:88º52´39.84´´	80	3.41
3	Purnandapur santanu bazaar	700	N:22º54´13.17´´ E:88º52´53.95´´	3	0.91
4	Subitpur masjid	600	N:22º54´02.87´´ E:88º53´00.18´´	3	0.76
5	Subitpur muslim para	700	N:22º54´34.92´´ E:88º46´39.00´´	3	0.86
6	Subitpur radhamadhav tala	700	N:22º54´38.97´´ E:88º52´42.00´´	3	0.94
7	Kalachi primary school	700	N:22º54´47.96´´ E:88º52´42.86´´	14.7	1.27

8	Kalachi primary school ARP	ARP	N:22º54´34.69´´	32.2	1.99
			E:88º52´52.52´´		
9	Kalachi shantigopal mondol	600	N:22º54´24.16´´	23.6	1.81
			E:88º52´50.82´´		
10	Kalachi kalitola	600	N:22º54´14.38´´	7.13	2.38
			E:88º52´15.53´´		
11	Kalachi uttarpara	700	N:22º54´52.93´´	3	0.83
			E:88º52´55.78´´		
12	Subitpur primary school	800	N:22º54´00.29´´	3	0.95
			E:88º52´41.48´´		
13	Subitpur netaji sishu sikha Kendra	700	N:22º54´03.55´´	3	0.69
			E:88º52´46.84´´		
14	Beri free primary scholl	600	N:22º54´10.79´´	3	0.81
			E:88º52´13.81´´		
15	Beri mondol kumar bagh	900	N:22º54´09.21´´	3	0.99
			E:88º52´22.73´´		
16	Beri govimdo das	700	N:22º54´06.17´´	3	0.79
			E:88º52´28.58´´		
17	Beri uttarpara primary school	800	N:22º54´01.74´´	3	0.83
			E:88º52´49.40´´		
18	Gopalpur bustand	600	N:22º54´28.00´´	3	0.68
			E:88º52´20.45´´		
19	Bilchaturiya (tetulberiya)	700	N:22º54´28.00´´	3	0.9
			E:88º52´20.45´´		
	MEAN	661		10.5	1.20
	SD	142		18.7	0.71
	MIN	200		3	0.68
	MAX	900		80	3.41

No.	**GP: SUTIA**	**Arsenic (µg/L)**	**Iron (mg/L)**
1	NagbariKutipara F.P	3	3.55
2	SutiaKutipara (nagbari) I.C.D.S.	3.2	1.34
3	Madhyam Barasat (NatuKayasta)	3	1.64
4	Samir Das (5 years-800ft)	3	1.74
5	Madhyam Barasat F.P.	3	1.49
6	ZiaulMondal (Madhyam Barasat)(6years)	8.1	1.56
7	Krishnapada Ghosh (PurbaBarasat)	11.4	3.68
8	Swadesh Ghosh (4 years) (PurbaBarasat)	3	1.83
9	PurbaBarasat I.C.D.S (only for cooking purpose)	16.2	4.85
10	PradipSarkar (Pabna Para)(2 years)(540 ft)	3	1.19
11	Pabna Para I.C.D.S.(PurbaBarasat)	3	3.39
12	PanchpataBharadanga High School(Cooking purpose)	144	4.95
13	PanchpataBharadanga High School(Drinking water)	112	3.64
14	PanchpataPurbapara F.P	9	9.36
15	RamkrishnaBiswas (Panchpata)	3	1.36
16	Pally Kalyan School (Bharadanga)(J.R.Basic)	14.1	1.49
17	BharaDangaBattala (Gaur NitaiBiswas)	3	1.5
18	Panchpata R.I office	3	1.41
19	Panchpata F.P	3	1.43
20	PurbaBarasat F.P	6.5	1.68
21	PaschimBarasat F.P 1	3	3.39
22	PaschimBarasat F.P 2	3	1.83
23	Jadavpur F.P	3	0.94

24	SutiaParuipara I.C.D.S.	175	1.45
25	SutiaBarasat Pally Unnyan High School(H.S) (Cooking)	3	1.01
26	SutiaBarasat Pally Unnyan High School(H.S) (Drinking)	3	1.82
27	Sutia F.P (1)	3	1.54
28	Sutia F.P (2)	3	4.22
	MEAN	19.8	2.47
	SD	44.7	1.80
	MIN	3	0.94
	MAX	175	9.36

No.	**GP: ICHAPUR II**			**Depth(ft.)**	**Arsenic (µg/L)**	**Iron (mg/L)**
1	BuroKashopy	Shimulpur	Shimulpur	600	1.3	1.63
2	Suman Chatterjee	Bara	Ichapur II	640	0.5	2.57
3	Bora High School	Bara	Ichapur II	200	124	6.74
4	Bora High School (Plant)	Bara	Ichapur II		0.7	0.94
5	BikashMondol	Krishnanagar,Bara	Ichapur II	260	7.9	9.87
6	Nikhil Halder	Krishnanagar,Bara	Ichapur II	520	1.8	2.3
7	Mandir	Krishnanagar,Bara	Ichapur II	600	0.8	1.48
8	Manoj Biswas	Krishnanagar,Bara	Ichapur II	700	23.8	3.95
9	PachiHalder	Krishnanagar,Bara	Ichapur II	500	2.3	1.81
10	Ajit Ghosh	Jamdani	Ichapur II	600	141	1.77
11	Bot-tola	Jamdani	Ichapur II	600	229	4.31
12	Primary School (Infront of school field)	Jamdani	Ichapur II	800	215	6.79
13	Gauri Mondol	Karola	Ichapur II	600	89	1.63
14	Primary School (Infront of school-beside the roadside)	Gutri	Ichapur II	640	126	2.3
15	Primary School	Madhusudankati	Sutia	120	92	4.91
16	Kalitola	Madhusudankati	Sutia	680	5.5	2.03
17	SanjoyMondol	Ward Number 17	Gobordanga Municipality	480	195	2.97
	MEAN			534	73.9	3.41
	SD			187	83.7	2.43
	MIN			120	0.5	0.94
	MAX			800	229	9.87

No.	**GP: DHARAMPUR II**			**Depth (ft.)**	**Arsenic (µg/L)**	**Iron (mg/L)**
1	SwapanMondol	Kuljhuti	Dharampur	600	52.3	0.10
2	SwaifulloMondol	Amonkandi	Dharampur II	120	3	0.30
3	UddayanSanga	Amonkandi	Dharampur II	700	15.6	0.10
4	Jaitara F.P.	Jaitara	Dharampur II	700	64.2	0.22
5	BasudevSarkar	Jaitara	Dharampur II	600	42	0.03
6	Ray-para ICDS	Jaitara	Dharampur II	700	59.8	0.05
7	Nolkura FP	Nolkura	Dharampur II	580	36.9	0.15
8	TaposhSarkar	Nolkura	Dharampur II	500	4.56	0.11
9	AamboilaSashtoh-kendra	Aamboila	Dharampur II	700	53.4	0.10
10	Susil De	Aamboila	Dharampur II	600	47.4	0.44
11	NaliniParui	Gopalpur	Dharampur II	700	42.1	0.31
12	Binapanishongo	Simulia	Dharampur II	700	42.6	0.09

13	Haran Chandra Baidhyo	Simulia	Dharampur II	400	101	0.18
14	Abul Kalam Mondol	Simulia	Dharampur II	600	39.6	0.17
15	Gopal F.P.	Gopal	Dharampur II	700	38.1	0.92
16	Jaitara bazar	Jaitara	Dharampur II	540	4.81	0.13
17	Maina F.P.	Maina	Dharampur II	600	34.2	0.10
18	NoyonMondol	Sripur	Dharampur II	560	60.9	0.12
19	Manoshatola	Sripur	Dharampur II	700	57.4	0.28
20	Kuljhuti F.P.	Kuljhuti	Dharampur II	700	3.32	0.60
21	Moralbhanga F.P.	Moralbhanga	Dharampur II	700	44.1	0.10
22	Masjid	Moralbhanga	Dharampur II	400	175	0.32
			MEAN	595	46.5	0.22
			SD	142	37.2	0.21
			MIN	120	3	0.03
			MAX	700	175	0.92

No.	**GP: DHARAMPUR I**			**Depth (ft.)**	**Arsenic (μg/L)**	**Iron (mg/L)**
1	BagobanBiswas	Dharampur	Dharampur I	600	57.6	0.05
2	Dharampurpartho F.P.	Dharampur	Dharampur I	700	54.8	0.17
3	Gonodipayan F.P	Notogram	Dharampur I	280	65.6	0.58
4	SathyadhamBedanto Ashram	Notogram	Dharampur I	600	3	0.10
5	Gopal Das	Patabuko	Dharampur I	700	62	1.02
6	Bharoti Dutta	Patabuko	Dharampur I	600	22.2	0.26
7	Thakur tola	Patabuko	Dharampur I	540	119	0.03
8	Milan shongo	Patabuko	Dharampur I	650	37.8	0.12
9	Dharampur Samiti	Dharampur	Dharampur I	600	52.9	0.10
10	Choruigachi I.C.D.S	Choruigachi	Dharampur I	100	115	0.62
11	Jubokshongo	Choruigachi	Dharampur I	600	51.8	0.01
12	Gopalpur F.P.	Gopalpur	Dharampur I	600	48	0.11
			MEAN	548	57.5	0.26
			SD	177	32.9	0.31
			MIN	100	3	0.01
			MAX	700	119	1.02

Table 6: Concentrations of As and Fe in deep tube-wells (depth: 500-800 ft.) available in 9 gram panchayats of Swarupnagar block

	BALTI - NITYANADA KATHI		
	(Depth range: 500-900ft)		
S.No.	**Location**	**Arsenic (µg/L)**	**Iron (mg/L)**
1	Balti bazaar	4.3	0.34
2	Balti Bus-stand	3.86	0.05
3	Balti High school	3	0.79
4	Balti primary school	3	0.41
5	Balti mandir	3	0.16
6	Nityananda kathi (road crossing)	3	0.18
7	Nityanandakathi Sujit Dhar	6.16	0.27
8	Nityanandakathi Ajay Mallik	4	0.07
9	Hakimpur high school	4.44	0.23
10	Hakimpur colony	3.64	0.05
11	Hakimpur milansangha	4	0.29
12	Hakimpur health centre	3.34	0.27
13	Hakimpur Mansa tala	3	0.56
14	Hakimpur horitala	8.18	0.05
15	Hakimpur no.2 colony	4.68	0.25
16	Nityananda kathi primary school	257	1.71
17	Nityananda horitola kalimandir	263	1.67
18	Bayar ghata Bus Stand	300	1.26
19	Bayar ghatabiswaspara	5.26	0.29
20	Bayar ghata bazar	4.46	0.25
	MEAN	**44.6**	**0.46**
	SD	**98.9**	**0.51**
	MIN	**3**	**0.05**
	MAX	**300**	**1.71**

	TEPUL : MIRZAPUR AREA		
	(Depth range: 500-900ft)		
S.No.	**Location**	**Arsenic (µg/L)**	**Iron (mg/L)**
1	Tepul FP	393	1.27
2	Tepul Kalitala	5.3	0.05
3	Parui Masjid	29.3	0.22
4	Nimtala ICDS	6.54	0.05
5	Purbali Bottala	240	5.13
6	Purbali FP School	35.7	0.2
7	ChotoMirzapurSisusikha	287	5.19
8	Media 1 No. Primary School	3	0.05
9	Media 3 No. Shiv Mandir	19.3	0.25
10	Media 7 No. Soni Mandir	26.5	5.6
11	Media 24 No. Colony Para	6.42	0.05
12	Media 18 No. High School	5.6	0.22
13	TepulMirzapurAnchal Office	10.8	0.05
14	Media 20 No. Colony Para	11.1	0.05
15	Media 6 No. Nilay Biswas	207	4.55
16	Media 9 No. NGO	6.96	0.05
17	Media Bastu Hara School	3	0.2
18	Boro Mirzapur Kanai Mondol	6.32	0.05
19	Nimtala Majher Para	5.86	0.05
20	Nimtala Deep Tube-Well	35.26	0.2
21	Media 5 No. Colony	14.28	0.05
22	Damhati Masjid	13.7	0.05
23	Salua Bazar	15.4	0.33
24	Kachdaha Bazar	16.6	0.055
25	Anchal Office	14.9	0.05
	MEAN	**56.8**	**0.96**
	SD	**105**	**1.87**
	MIN	**3**	**0.05**
	MAX	**393**	**5.6**

	BANGLANI		
	(Depth range: 500-900ft)		
S.No.	**Location**	**Arsenic (µg/L)**	**Iron (mg/L)**
1	Swarunagar bazar	29.1	1.02
2	Swarunagar BDO Office	3	0.89
3	Swarunagar health centre	3	0.32
4	Swarunagarthana	3	0.18
5	Swarunagarchorpara	370	6.01
6	Tetulia bazar	18.9	0.18
7	Tetulia gas office	3	0.69
8	Tetulia BSF camp	31.3	0.47
9	Ramchandrapur bazar	3	0.99
10	Ramchandrapur itvata	25.9	0.92
11	Ramchandrapur kheyaghat	301	6.01
12	Ramchandrapurbottala	3.84	0.72
13	Khashpur more	3	0.84
14	Khashpur primary school	3	0.25
15	Khashpursmashan	3	0.37
16	Hotatgonj bazar	394	2.03
17	Hotatgonj more	3	0.84
18	Hotatgonj masjid	13.6	0.27
19	Hotatgonj das para	344	1.83
20	Hotatgonj shiv mandir	37.2	0.72
21	SwarupnagarDhalipara	3.72	0.05
22	amchandrapurSomobaySan	3.18	0.74
23	AtaliyoSmashan	39.6	27.2
24	Ataliyo ICDS	4.5	1.21
25	AtaliyoSurjoSangho	3.74	0.35
	MEAN	**66**	**2.2**
	SD	**129**	**5.43**
	MIN	**3**	**0.05**
	MAX	**394**	**27.2**

	BITHARI		
	(Depth range: 500-900ft)		
S.No.	**Location**	**Arsenic (µg/L)**	**Iron (mg/L)**
1	Balki ByabsayiSamiti	8.34	0.07
2	Balki UdaySangha	4.26	0.25
3	Balki Library	4.92	0.05
4	Balki Bottala	4.5	0.11
5	Bithari More	4.56	0.07
6	Bithari DokanTola	9.24	0.23
7	Bithari School More	55.8	0.05
8	Bithari Primary School	57.8	0.38
9	Tarali Mombar House	5.07	0.14
10	Tarali Talikhola	4.86	0.05
11	Tarali Manicktala	4.23	0.59
12	Tarali Play Ground	55.2	0.2
13	Swarupdaha High School	4.83	0.09
14	Swarupdaha Colony	5.76	0.11
15	Swarupdaha Bijoy Moncha	4.41	0.11
16	Swarupdaha Uttor Para	8.88	0.16
17	Nilkuthi	8.16	0.16
18	Kalanchi Play Ground	7.92	0.07
19	Kalanchi Park	10.6	0.27
20	Kalanchi Ricemill	6.48	0.16
21	Kalanchi Mandir	4.23	0.14
22	Kalanchi Thakur Bari	57.4	0.05
	MEAN	**15.3**	**0.16**
	SD	**20**	**0.13**
	MIN	**4.23**	**0.05**
	MAX	**57.8**	**0.59**

	JHAKRA GOKULPUR		
	(Depth range: 500-900ft)		
.No.	**Location**	**Arsenic (µg/L)**	**Iron (mg/L)**
1	Jhakra bazar	65.9	24.5
2	JhakraAjarmonda	257	5.13
3	JhakraMondir	43.3	19.9
4	North Jhakradoltala	230	5.74
5	North Jhakra Primary School	3.82	0.68
6	Golda bazar	52.2	1.26
7	Golda Bottala	3.3	0.4
8	Aturiya bazar	3	0.2
9	AturiyaSamiti	42.8	0.83
10	KatiyaMondirtala	3	0.46
11	Katiya ICDS	3	1.13
12	Sonapur ICDS	3	0.23
13	Near Akhil Nandi's house	57.5	25.6
14	Vaduriya Masjid	3	1.18
15	VaduriyaDaspara	305	5.33
16	Vaduriya North Primary School	45.5	0.43
17	Vaduriya South Sishu SikshaNiketan	7.42	0.63
18	Amudiya Bazar Samiti	3	0.13
19	Amudiya ICDS	3	0.58
20	Amudiya BSF Camp	3	0.18
21	Nayabastia primary school	32.4	25.3
22	Boro jhakra kalitala	12.7	0.76
23	Boro jhakra high school	355	5.51
24	Boro jhakra majher para	5.3	0.23
25	Boro jhakra shiv mandir	5.42	0.48
26	Galda high school	3	0.13
27	Gokulpur mela	3	0.61
28	Gokulpur play ground	282	5.23
29	Gokulpurmathpara	60.1	20.2
	MEAN	**65.4**	**5.27**
	SD	**106**	**8.55**
	MIN	**3**	**0.13**
	MAX	**355**	**25.6**

	KHEJURI		
	(Depth range: 500-900ft)		
S.No.	**Location**	**Arsenic (µg/L)**	**Iron (mg/L**
1	Gabadyabazar	37.3	0.63
2	Gabadya primary school	40.8	0.76
3	Gabadya Anil mondol	45.1	0.4
4	Gabadya sambay samiti	7.06	0.2
5	Dobilasuryasangha	45.4	0.68
6	Dobila PHE	3	0.76
7	Dobilamanashatala	3	0.23
8	Gachcha ICDS	3	0.38
9	Gachchamajher para	15.8	0.81
10	GachchaBinay Das	3	0.18
11	Sonarpur hut	3	0.78
12	Sonarpur chamber	22	0.18
13	Sonarpursabujsangha	22.2	0.86
14	Saestanagar das para	23.5	0.25
15	Saestanagarmohilasamiti	23.9	0.68
16	kalbazarbaybshaesamiti	16.6	0.83
17	kalbazaroilmill	3	0.23
18	Loknathmandir	374	6.62
19	Calbazar post office	398	6.57
20	Chiturikalibari	3	0.63
21	Chituriabhisekhmondol	5.78	0.78
22	Chiturisishusikshya	217	0.91
23	Mallickpurhathkhola	3	0.76
24	Mallickpur High school	6.88	0.23
25	Mallickpurnabarunsangha	3	1.18
	MEAN	**53.1**	**1.06**
	SD	**109**	**1.69**
	MIN	**3**	**0.18**
	MAX	**398**	**6.62**

	SHAGUNA		
	(Depth range: 500-900ft)		
S.No.	Location	Arsenic (µg/L)	Iron (mg/L)
1	West Polta FP	15.87	0.27
2	West Polta Bazar	6.96	0.95
3	West PoltaTapan Mondol	180	1.02
4	Laban Gola More	7.86	1.24
5	Laban Gola Bottala	5.58	0.32
6	Laban Gola Mathpara	19.4	0.05
7	Baghghata Bazar	5.61	0.65
8	Baghghata ICDS	5.22	0.69
9	Baghghata Purba Para	348	2.28
10	Baghghata School Para	347	1.63
11	Mominpur More	9.33	0.35
12	Mominpur Thakur Bari	212	1.56
13	Mominpur Itvata	3	0.89
14	Mominpur Hut	3	0.27
15	Vekutia ICDS	3	0.1
16	Vekutia Club	7.02	0.84
17	Vekutia Bottala	3	0.74
18	Vekutia Library	9.36	0.37
19	Srinathpur Kheya Ghat	3	0.47
20	Srinathpur Bazar	3	0.79
21	Srinathpur Ashok Roy	53.4	0.55
22	Srinathpur Smashan	3	0.25
23	Keutali Jele Para	25.56	0.27
24	Keutali Masjid	26.28	0.72
25	Keutali Kalitala	3	0.79
26	Keutali TetulTala	23.91	0.15
27	Saguna Anchal Office	29.58	0.72
28	Saguna Bazar	3	0.57
29	Saguna Shilpi Sangha	431	6.01
30	Saguna Play Ground	326	1.91
31	Saguna ICDS	226	1.37
	MEAN	**75.7**	**0.93**
	SD	**128**	**1.09**
	MIN	**3**	**0.05**
	MAX	**431**	**6.01**

	CHARGHAT		
	(Depth range: 500-900ft)		
S.No.	Location	Arsenic (µg/L)	Iron (mg/L)
1	Charghat bazar	23.8	22.3
2	Charghat girl's school	192	1.56
3	Charghat primary	6.48	0.35
4	Polta Nimai Mondol	3	0.18
5	Pantua Primary School	24.2	0.89
6	Pantua Bazar para	3	1.16
7	Pantua ICDS	172	0.62
8	Poltakonitola	3	1.07
9	Polta Primary	3	1.07
10	Kapileswar Purbirha Bose	3	1.09
11	Ghola Primary school	5.92	0.3
12	GholaThakurbari	36.5	0.89
13	Tipi kalitatal	3	0.97
14	Tipi Park	3	0.55
15	Serampore bazar	3	0.25
16	Serampore Primary school	38.1	0.97
17	Seramporebottola	5.74	0.92
18	Gopalpurghat	3	0.27
19	GopalpurSishusikshya	3	0.15
20	Shakdah bazar	6.36	0.99
21	Sakdaha FP school	37.4	0.57
22	Poltarakhal Mondol	3	0.3
23	Polta ICDS	341	6.53
24	Poltakalitala	295	1.63
25	Bekutia bazar	3	0.79
26	Saluo bazar	33	0.45
27	Saluo FP	16.1	0.79
28	Saluomadhyam	14.5	0.77
29	Kotalbere post office	18.3	0.15
30	Kotalbere kali bari	15.7	0.15
31	Kotalbere masjid	8.06	0.69
32	Kotalbere rathtala	4.04	0.2
	MEAN	**41.6**	**1.55**
	SD	**84.7**	**3.95**
	MIN	**3**	**0.15**
	MAX	**341**	**22.3**

	SARAPUL NIRMAN		
	(Depth range: 500-900ft)		
S.No.	Location	Arsenic (µg/L)	Iron (mg/L)
1	SarapulBazar	6.84	5.74
2	SarapulPrimary School	3	0.05
3	Sarapul Heath Centre	19.9	0.05
4	Sarapul Masjid	527	6.68
5	NirmanMajherpara	14.8	0.45
6	NirmanJagarani Club	9.82	0.05
7	NirmanTin Rastar More	3	0.05
8	NirmanDakshin Para	3	0.05
9	NirmanBottola	45.9	0.42
10	Nirman ICDS	45.8	0.05
11	Duttapara Upasasthya Kendra	3	0.05
12	Duttapara School More	3	0.05
13	Duttapara Ghoshpara	3	0.05
14	Duttapara North	319	5.6
15	Duttapara Taltala	10.32	0.05
16	Dak Bunglow More	3	0.05
17	Dak Bunglow High School	3	0.05
18	Dak Bunglow Library	18.08	0.28
19	Dak Bunglow Upasathya Kendra	3	0.05
20	Burning ghat uttarpara	3	0.05
21	Burning ghat Ghoshpara	42.5	0.09
22	Burning ghat sishusiksha	356	5.96
23	Burning ghat Milan Debnath	67.2	0.17
	MEAN	**65.8**	**1.13**
	SD	**138**	**2.29**
	MIN	**3**	**0.05**
	MAX	**527**	**6.68**

Assessment of pollution index and potential ecological risk factor from the deep tube-wells from 13 gram panchayats of Gaighata block (Table 7) and 9 gram panchayats of Swarupnagar block (Table 8).

6.2.3. Fe/As ratio

6.2.3.1. Gaighata block: The Fe/As ratio of the deep tube-wells were found to be higher for all the gram panchayats. Among all the gram panchayats, the highest Fe/As ratio has been observed in Ichapur II (803) compared to the lowest 7.25 observed in Dharampur I. the order of Fe/As ratio of the block based on the distribution of all the gram panchayats is as follows – Dharampur I (7.25) < Dharampur II (18.8) < Sutia (51.6) < Ichapur I (54.5) < Jaleswar I (106) < Chandpara (151) < Duma (157) < Fulsara (194) < Jhaudanga and Ramnagar (241) < Jaleswar II (368) < Shimulpur (524) < Ichapur II (803).

6.2.3.2. Swarupnagar block: The highest Fe/As ratio of the deep tube-wells from the block is 163 obtained from Jhakra-Gokulpur gram panchayat. Among all the 9 gram panchayats of the block, the lowest Fe/As ratio has been observed in Tepul. Considering all the gram panchayats the order of Fe/As ratio is as follows – Tepul (20.9) < Bithari (23.8) < Sarapul (49) < Balti (63) < Shaguna (82.8) < Khejuri (88) < Charghat (137) < Banglani (138) < Jhakra-Gokulpur (163).

Comparatively, the Fe/As ratio for deep tube-wells form the Gaighata block showed higher value compared to Swarupnagar block of North 24 Parganas district. The plausible explanation might be due to the geographical location of the two blocks or geogenic source of the contaminant from a severely As affected district.

6.2.4. Single factor pollution index

6.2.4.1. Gaighata block: For As, gram panchayat categorized under high contamination factor are (Fulsara, Jaleswar I, Ichapur I, Ichapur II), considerable contamination (Chandpara, Jaleswar II, Dharampur I, Dharampur II) and moderate contamination (Duma, Jhaudanga, Shimulpur, Ramnagar, Sutia). In case of Fe, gram panchayat categorized under high contamination factor are (Chandpara, Fulsara, Jaleswar I, Jaleswar II, Ichapur I, Shimulpur, Sutia, Ichapur II), considerable contamination (Duna, Jhaudanga, Ramnagar) and low contamination (Dharampur I and Dharampur II).

6.2.4.2. Swarupnagar block: For As, gram panchayats categorized under high contamination factor (Banglani, Jhakra, Shaguna, Sarapul), considerable contamination (Balti, Charghat, Khejuri, Tepul) and moderate contamination (Bithari). In case of Fe, gram panchayats categorized under high contamination (Banglani, Jhakra), considerable contamination (Charghat, Khejuri, Shaguna, Sarapul, Tepul) and moderate (Balti) and low (Bithari).

6.2.5. Ecological risk analysis

Among 13 gram panchayats from Gaighata block, 8 gram panchayats showed very high categorization of ecological risk through deep tube-well water sources. Two of them namely Duma and Sutia showed high ecological risk, whereas, the remaining three gram panchayats (Jhaudanga, Shimulpur, Ramnagar) showed considerable ecological risk factor through deep tube-well water sources. Out of 9 gram panchayats from Swarupnagar block, 8 gram panchayats showed very high ecological risk factor through deep tube-well water sources, whereas, only Bithari gram panchayat showed considerable risk factor.

Table 7: Assessment of pollution index and potential ecological risk factor from the deep tube-wells from 13 gram panchayats of Gaighata block

			Gaighata			
S.No	**Gram Panchayat**	**No. of deep tube-wells**	**Fe/As ratio**	**Single factor pollution index (Ii= Ci/Co)**		**Er = Tr x I**
				As	**Fe**	**As**
1.	Chandpara	18	151 (16.1-626)	4 (considerable)	13 (high)	427 (very high)
2.	Duma	21	157 (24.3-367)	2 (moderate)	3 (considerable)	160 (high)
3.	Fulsara	21	194 (14.4-2400)	6 (high)	14 (high)	569 (very high)
4.	Jaleswar I	20	106 (26.9-674)	6.51 (high)	11.4 (high)	651 (very high)
5.	Jaleswar II	9	368 (17.5-1027)	5.18 (considerable)	15.3 (high)	518 (very high)
6.	Ichapur I	10	54.5 (8-295)	12 (high)	9.7 (high)	1201 (very high)
7.	Jhaudanga	16	241 (33.4-366)	1.15 (moderate)	3.53 (considerable)	116 (considerable)
8.	Simulpur	22	524 (78.3-2326)	1.19 (moderate)	8.97 (high)	120 (considerable)
9.	Ramnagar	19	241 (42.6-334)	1.05 (moderate)	3.99 (considerable)	105 (considerable)
10.	Sutia	28	51.6 (8.28-1407)	1.97 (moderate)	8.24 (high)	197 (high)
11.	Dharampur I	12	7.25 (0.17-33)	5.74 (considerable)	0.87 (low)	574 (very high)
12.	Dharampur II	22	18.8 (0.76-181)	4.64 (considerable)	0.74 (low)	464 (very high)
13.	Ichapur II	17	803 (12.5-5140)	7.38 (high)	11.3 (high)	738 (very high)
	Total (average)			**4.52** **(considerable)**	**8.00** **(high)**	**449** **(very high)**

Table 8: Assessment of pollution index and potential ecological risk factor from the deep tube-wells from 9 gram panchayats of Swarupnagar block

Swarupnagar						
S.No	**Gram Panchayat**	**No. of deep tube-wells**	**Fe/As ratio**	**Contamination Scenario ($I_i = C_i/C_o$)**		**$E_r = T_r$ x I**
				As	**Fe**	**As**
1.	Balti	20	63 (4.2-263)	4 (considerable)	2 (moderate)	446 (very high)
2.	Banglani	25	138 (5.15-687)	7 (high)	7 (high)	660 (very high)
3.	Bithari	22	23.8 (0.9-139)	1.5 (moderate)	0.5 (low)	153 (considerable)
4.	Charghat	32	137 (4-937)	4 (considerable)	5 (considerable)	416 (very high)
5.	Jhakra - Gokulpur	29	163 (9.45-781)	6.4 (high)	17.6 (high)	654 (very high)
6.	Khejuri	25	88 (4.19-393)	5 (considerable)	4 (considerable)	531 (very high)
7.	Shaguna	31	82.8 (2.57-296)	7.5 (high)	3.1 (considerable)	757 (very high)
8.	Sarapul	23	49 (1.09-839)	7 (high)	4 (considerable)	658 (very high)
9.	Tepul	25	20.9 (3.23-211)	5.7 (considerable)	3.2 (considerable)	567 (very high)
	Total (average)			**5.34 (considerable)**	**5.15 (considerable)**	**538 (very high)**

Overall, Swarupnagar block, comprising 9 gram panchayats showed both As and Fe categorized under considerable contamination scenario. Whereas, quantitative estimation of ecological risk has been categorized under very high risk class considering all the gram panchayats of the block. Likewise, Gaighata block, consisting of 13 gram panchayats showed considerable As contamination and high Fe contamination of the deep tube-well water sources. Whereas, quantitative estimation of ecological risk factor is under very high risk class.

6.2.6. Health risk assessment

The cancerous and non-cancerous risk assessment of the populaces from Gaighata and Swarupnagar block has been placed in Table 9 and 10, respectively. Health risk persists among the populaces from all the gram panchayats of the two studied blocks through consumption of deep tube-well water, as the cancer risk values are higher than the recommended value i.e. $1x10^{-6}$. Likewise, probability of non-cancerous diseases exists among the populace of the two studied blocks, where the HQ value > 1. Exceptionally, populaces residing in Sutia gram panchayat from Gaighata block and Balti gram panchayat from Swarupnagar block show no probability of non-cancerous risk. Overall, it can be said that inhabitants residing in Gaighata block are more prone to severe health risk compared to Swarupnagar block.

Table 9: Cancer and non-cancer risk of 13 gram panchayats of Gaighata block

Gaighata block			
S.No.	**Gram panchayat**	**Cancer risk**	**Non-cancer risk**
1.	Chandpara	3.2×10^{-3} (5.7×10^{-4} - 6.2×10^{-3})	7.12 (1.27-13.8)
2.	Duma	1.2×10^{-3} (2.2×10^{-4} – 4.6×10^{-3})	2.66 (0.5-10.2)
3.	Fulsara	3.2×10^{-3} (4.5×10^{-4} – 6.4×10^{-3})	7.22 (1-14.4)
4.	Jaleswar I	4.8×10^{-3} (2.9×10^{-4} - 6.6×10^{-3})	10.8 (0.65-14.8)
5.	Jaleswar II	2.4×10^{-3} (1.3×10^{-4} - 6.5×10^{-3})	5.34 (0.31-14.5)
6.	Ichapur I	3.4×10^{-3} (1.4×10^{-4} - 4.2×10^{-3})	7.58 (3.2-9.26)
7.	Ichapur II	1.5×10^{-3} (3.7×10^{-5} - 6.9×10^{-3})	3.41 (0.08-15.3)
8.	Jhaudanga	8.6×10^{-4} (2.2×10^{-4} - 5.1×10^{-3})	1.92 (0.5-11.2)
9.	Shimulpur	8.9×10^{-4} (2.2×10^{-4} - 6.5×10^{-3})	1.99 (0.5-14.6)
10.	Ramnagar	7.8×10^{-4} (2.2×10^{-4} - 6.1×10^{-3})	1.75 (0.5-13.3)
11.	Sutia	3.6×10^{-4} (2.2×10^{-4} - 1.2×10^{-3})	0.81 (0.5-2.7)
12.	Dharampur I	3.4×10^{-3} (2.2×10^{-4} – 4.9×10^{-3})	7.59 (0.5-10.9)
13.	Dharampur II	2.8×10^{-3} (2.2×10^{-4} – 4.8×10^{-3})	6.21 (0.5-10.7)

Table 10: Cancer and non-cancer risk of 13 gram panchayats of Swarupnagar block

Swarupnagar block			
S.No.	**Gram panchayat**	**Cancer risk**	**Non-cancer risk**
1.	Balti	3.1×10^{-4} (2.2×10^{-4} - 6.1×10^{-4})	0.69 (0.5-1.36)
2.	Banglani	8.6×10^{-4} (2.2×10^{-4} – 2.9×10^{-3})	1.92 (0.5-6.66)
3.	Bithari	4.6×10^{-4} (3.2×10^{-4} – 7.9×10^{-4})	1.03 (0.7-1.76)
4.	Charghat	8.8×10^{-4} (2.2×10^{-4} – 2.8×10^{-3})	1.96 (0.5-6.35)
5.	Jhakra-Gokulpur	8.6×10^{-4} (2.2×10^{-4} – 3.4×10^{-3})	1.93 (0.5-6.35)
6.	Khejuri	1.2×10^{-3} (2.2×10^{-4} – 3.4×10^{-3})	2.57 (0.5-7.56)
7.	Shaguna	7.3×10^{-4} (2.3×10^{-4} – 2.2×10^{-3})	1.63 (0.5-4.93)
8.	Sarapul	9.6×10^{-4} (2.2×10^{-4} – 3.4×10^{-3})	2.14 (0.5-7.65)
9.	Tepul	1.1×10^{-3} (2.3×10^{-4} – 2.6×10^{-3})	2.31 (0.5-5.95)

FOOD CHAIN CONTAMINATION

Agricultural shallow groundwater → Cultivation practices → Whole paddy plant

6.3. Food chain contamination with respect to arsenic distribution and accumulation

Rice is the staple crop in Bengal and inhabitants largely consume rice grown on the As contaminated fields (Williams et al., 2005; Mondal and Polya, 2008). Accumulation rate of As in rice differ widely from different topographical areas and rice cultivar or variety. Thus, guideline of As standard in rice is quite challenging (Schmidt, 2015). Developing countries like India and Bangladesh that receive temperate rainfall follows two processes of paddy cultivation: one is Boro (the pre-monsoon cultivation, irrigated with groundwater) and second is Aman (the monsoon cultivation, which sometimes involve ground water due to insufficient rain). Pre-monsoon (Boro) cultivation and irrigation with the help of groundwater have increased since ages in Bengal delta (Harvey et al., 2005). Numerous studies have shed light on the effect of irrigation with As contaminated groundwater and its subsequent As burden in paddy. During pre-monsoon season, Minikit variety of rice is mainly irrigated but the cultivars differ generally, like White Minikit, Jaya, Gangakaberi, Banskati, Gosai-minikit etc. Subsequently in monsoonal season all the plant samples with variety of cultivars.

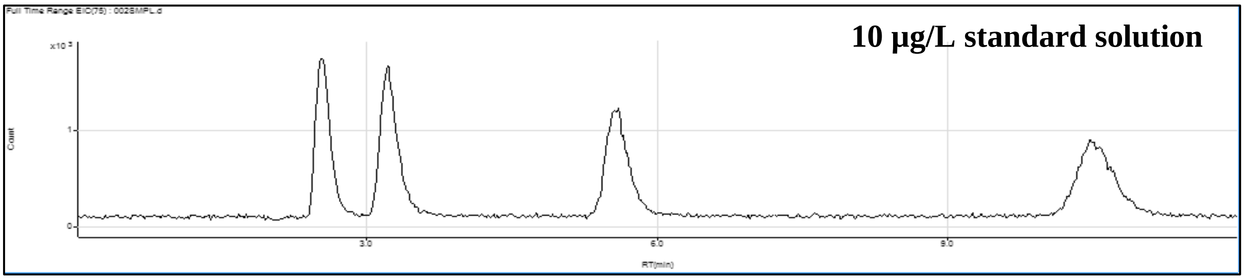
6.3.1. Whole paddy plant along with rice grain

The final or ripening phase of the whole paddy plant has been targeted from As-exposed field of Madhusudankati village, Gaighata block. Minikit and Maharaj variety of paddy has been collected from pre-monsoonal and post-monsoonal season, respectively. The different fractions analyzed of the whole paddy plant are root, stem, leaf, rice husk and rice grain. Arsenic species distribution in rice grain, rice husk, leaf, stem and root of pre-monsoonal and post-monsoonal season paddy plant collected from Gaighata block has been shown in Table 11. During pre-monsoonal season, the As concentrations in different fractions of the whole paddy plant is observed as root (35575 µg/kg), stem (2181 µg/kg), leaf (1467 µg/kg), rice husk (521 µg/kg), rice grain (135 µg/kg). Similarly, in post-monsoonal season, the As concentrations in different fractions of the whole paddy plant is observed as root (23302 µg/kg), stem (2840 µg/kg), leaf (1174 µg/kg), rice husk (246 µg/kg), rice grain (112 µg/kg). Root accumulates the highest As compared to other parts of the paddy plant. The translocation of the As accumulation for both the seasonal paddy plant follows the order as root > stem > leaf > rice husk > rice grain. This corroborates with the findings of Chowdhury et al., (2018a; 2020b). During monsoonal cultivation (Singh et al., 2014), due to seasonal flooding the topsoil As concentration decreases with temporal variability. This causes diffusion of As into floodwater, followed by lateral removal with receding water and the As movement increases to the deeper soil layers by infiltration (Shrivastava et al., 2017). Arsenic behaviour in paddy fields and its accumulation in rice grain varieties during both the summer and monsoon cultivation periods have been reported in several studies (Asada and Matsumoto, 2009; Shrivastava et al., 2017; Takahashi et al., 2004). Intermittent irrigation practices with a combination of aerobic and anaerobic irrigation resulted in lesser As mobility and accumulation in rice grains and better rice productivity (Shrivastava et al., 2020).

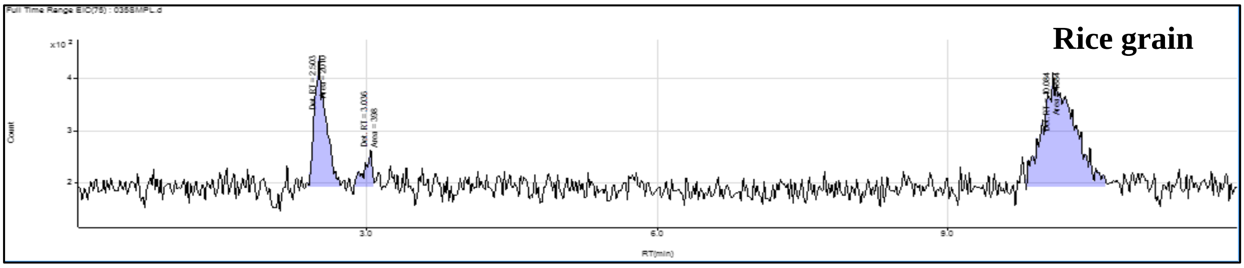
The chromatograph showing the As species distribution in different parts of a whole paddy plant of pre-monsoon and post-monsoon season from a As exposed area has been shown in Fig. 15. Interestingly, the As V species follows the translocation trend of total As accumulation in different paddy parts. Overall, the percentage (%) distribution of iAs (inorganic As: As III + As V) in different parts of the pre-monsoonal paddy is observed as 94.4, 95.8, 95.3, 82, and 99.8% in rice grain, rice husk, leaf, stem, and root, respectively. Whereas, 89, 915, 87.6, 97.4, and 99.5% of iAs distribution has been in post-monsoonal rice grain, rice husk, leaf, stem, and root, respectively. The total rice grain As concentrations from pre-monsoon and post-monsoon season cultivated in the As exposed fields are 135 and 112 µg/kg. This corroborates with the main findings of Chowdhury et al., (2020b) that paddy cultivated during post monsoonal season are comparatively safer for consumption than the pre-monsoonal rice. The rice husk As accumulation is higher in pre-monsoon (521 µg/kg) than post-monsoon (246 µg/kg) season. The plausible explanation might be agricultural water As, rice cultivar and soil As concentration. In rice grains, the contribution of inorganic As (iAs) from total As is observed as 94.4% and 89% in pre-monsoon and post-monsoon season respectively. The findings are in good agreement with Halder et al., (2013), (2014); Laparra et al., (2005); Meharg et al., (2009); Mondal and Polya, (2008); Signes-Pastoret al., (2008). They have also found that the iAs As species of rice grain is toxic and carcinogenic, it contributes nearly 80% of total As content. MMA is not found in rice grain, as it is evident that iAs mainly dominates grain As concentration with presence of less amount of DMA (Halder et al., 2014).

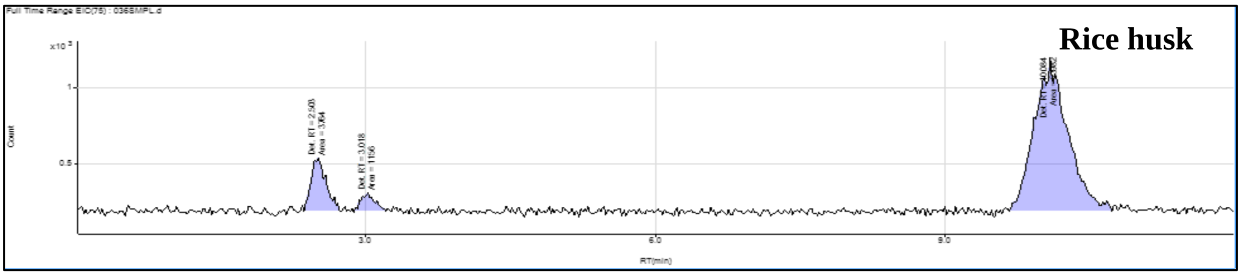
Table 11. Arsenic species distribution in rice grain, rice husk, leaf, stem and root of a) pre-monsoonal and b) post-monsoonal season paddy plant collected from Gaighata block

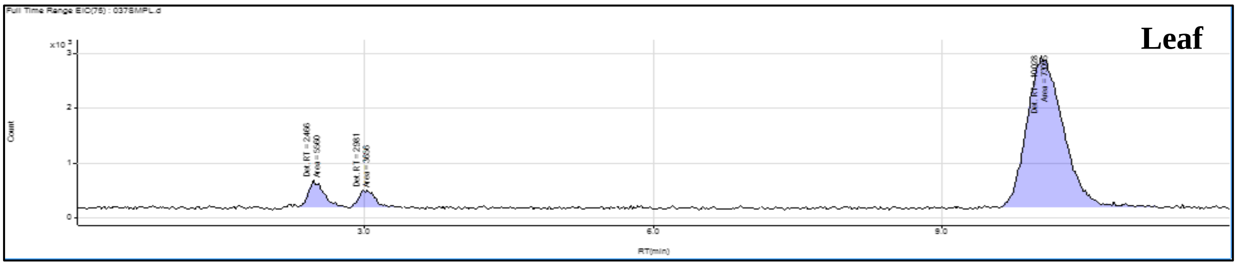
S no.	Sample	As III	DMA	MMA	As V	Total As	% of Inorganic As (As III + As V)
a. Pre-monsoon season: Exposed area - Gaighata, Minikit variety							
1	Rice grain	41.6	7.6	0	85.7	135	94.4
2	Rice husk	77.8	22.0	0	421	521	95.8
3	Leaf	115	69.5	0	1282	1467	95.3
4	Stem	76.8	129	264	1711	2181	82
5	Root	192	77.3	0	35305	35575	99.8
b. Post-monsoon season: Exposed area - Gaighata, Maharaj variety							
6	Rice grain	21.4	12.4	0	78.1	112	89
7	Rice husk	28.3	21.0	0	197	246	91.5
8	Leaf	136	123	21.9	893	1174	87.6
9	Stem	296	74.9	0	2469	2840	97.4
10	Root	16.1	55.2	65.7	23165	23302	99.5

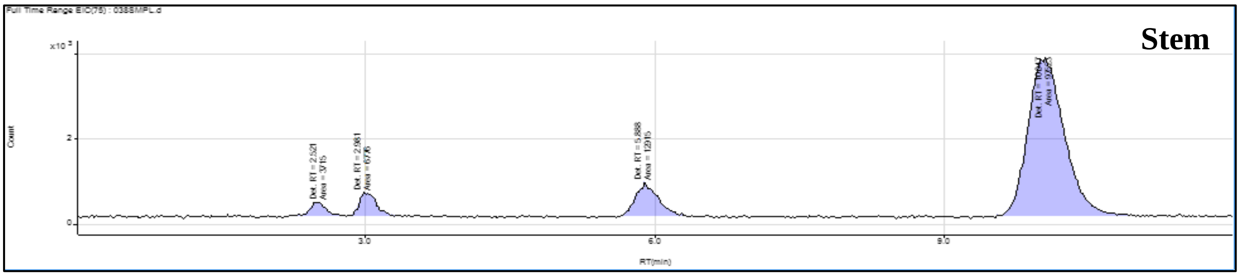


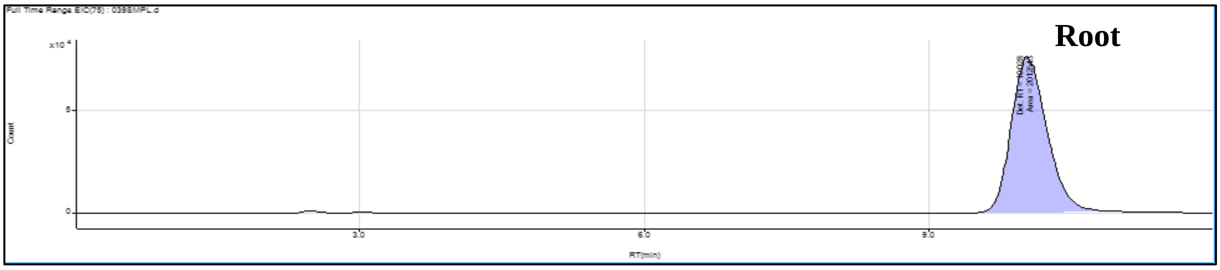
a. Pre-monsoon season



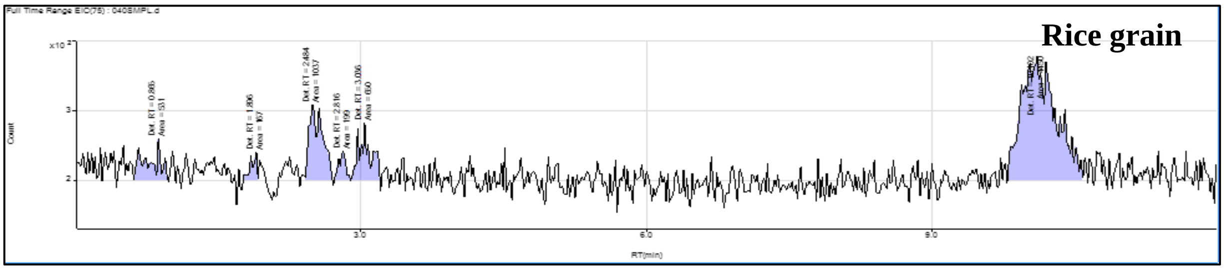


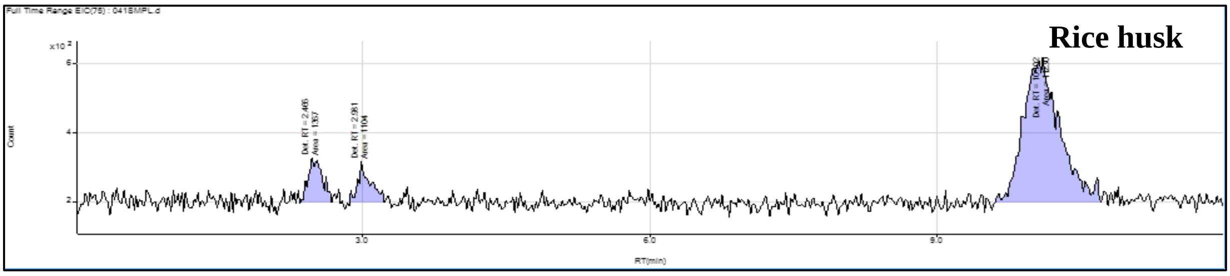


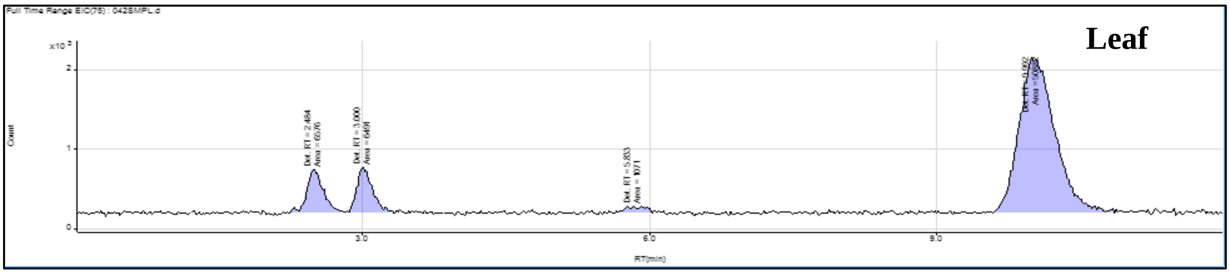




b. Post-monsoon season







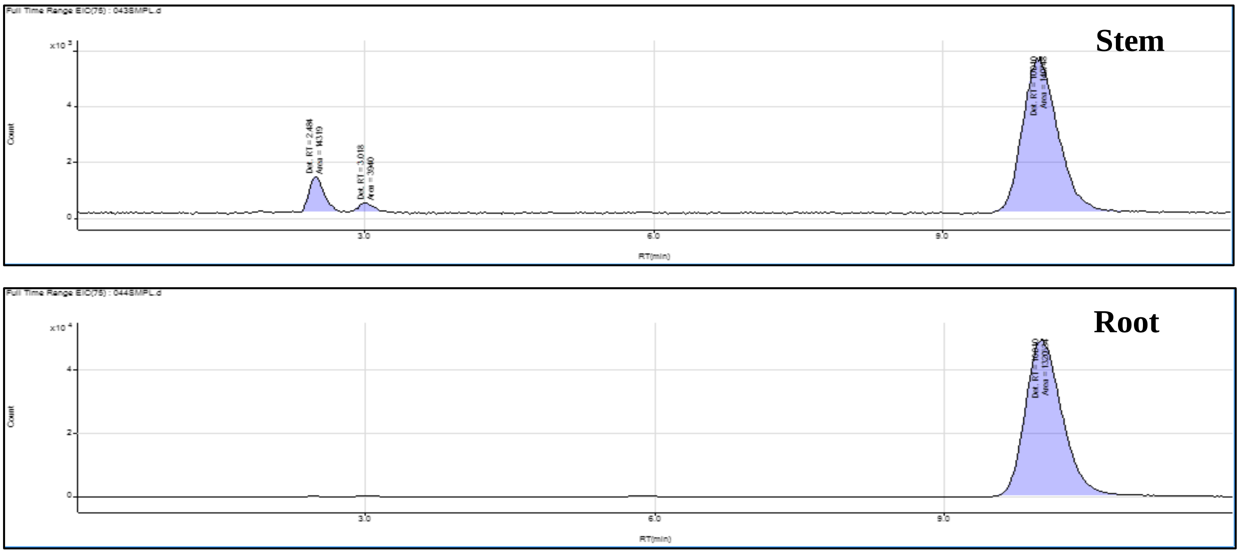


Fig. 15. HPLC chromatograph showing the As species distribution in Standard 10 µg/L and different parts of a whole paddy plant from (a) Pre-monsoon season, (b) Post-monsoon season from a As exposed area

6.3.2. Rice milling fractions

One of the most significant cereal food crops and a reliable source of food for humans in most Asian nations is rice (*Oryza sativa*), which is a member of the Poaceae or Gramineae family (Saleh et al., 2019). A common food and a significant source of dietary glycaemic load is rice (Rathna et al., 2019). China, India, Indonesia, and Thailand are the top rice-producing countries. India comes in second place behind China in terms of global rice output, producing 24.5% of the world's total (Malabadi et al., 2022). Rice is not only known for being the source of nutrients, but also of the toxic elements worldwide (Jo and Todorov, 2019).

6.3.2.1. Processing of rice

After harvest, rice grain is processed through stages that include drying, milling, and packing to make it convenient for human consumption. For human use, paddy rice, which is the harvested unprocessed rice, must be milled. The protective hull of the rice is taken off during processing, leaving only the actual rice kernel, often known as brown rice. The outer bran layer with a typically brown hue is removed from the complete rice grain or paddy in the first phase of the milling process to produce the whole brown rice grain. To achieve polished or white rice, the second stage involves removing the outer bran layer.

Pericarp, aleurone, subaleurone layer, and germ make up the layers of bran, which are rich in nutrients and bioactive substances (Zahra et al., 2020). However, the removal of the outer bran layers during polishing or milling produced polished grain or flour that had fewer nutrients and bioactive substances. Whole grain cereals like brown rice are recognised to be good for people's health. Consuming whole grains can lower your chance of developing metabolic problems, cardiovascular illnesses, and several forms of cancer, according to recent epidemiological research (Saleh et al., 2019).

6.3.2.2. Nutritional value and health benefits of Brown rice

Brown rice may become white rice when the bran layer is exposed of in the milling process (Malabadi et al., 2022; Zahra et al., 2020). By using a threshing method, rough rice may be divided into husk and brown rice. The endosperm (approximately 90%), an embryo (about 2.3%), and bran layers (6-7%) make up brown rice that has been hulled from whole rice grain. Brown rice can also be processed into polished rice, often known as white rice, by removing the bran (Saleh et al., 2019). Rice milling process can be used to distinguish between brown and white rice. The starchy endosperm makes up the majority of white rice. The nutrients are lost when rice bran is removed. About 85% of the fat, 15% of the protein, 75% of the phosphorus, 90% of the calcium, and 70% of the B vitamins (B1, B2, and B3) are eliminated during milling process (Chaudhari et al., 2018).

6.3.2.3. Arsenic concentrations in rice milling fractions

Rice milling fractions (whole rice grain, unpolished/brown rice, rice husk, polished/white rice, rice bran) has been collected from different rice cultivars of both the pre-monsoonal and post-monsoonal season. Different rice cultivars from pre-monsoon season are namely Minikit, Baskati, Super-minikit, Par-minikit, Satabdi minikit, Suphala minikit, Suphala, Jeerakati minikit, Satabdi, Sankar, Ganga and Suphala minikit collected from Gaighata and Swarupnagar areas. Whereas, rice cultivars from post-monsoon season are namely Nayanmoni, Ranjit, Satabdi, Par-minikit, Super-minikit, Satabdi minikit, Ganga, Parash minikit, Pan minikit, Maharaj and Narendra.

Table 12. Arsenic conceentrations (µg/kg) in rice milling fractions from a) Pre-monsoon season and b) Post monsoon season

a. Pre-monsoon	**As accumulation (µg/kg) in rice milling fractions**				
Rice cultivar	**Whole rice grain (WRG)**	**Unpolished / Brown rice**	**Polished / White rice**	**Rice husk**	**Rice bran**
Minikit	317	194	118	541	457
Baskati	325	205	196	822	590
Super minikit	305	220	143	825	328
Par minikit	248	209	156	620	363

Satabdi minikit	224	215	198	261	216
Suphala minikit	283	206	142	356	244
Suphala	332	320	187	571	283
Jeerakati minikit	328	191	128	291	299
Satabdi	314	301	212	817	334
Sankar	303	168	170	340	265
Ganga	263	196	159	727	378
Suphala minikit	204	156	146	470	254
b. Post-monsoon	**Rice milling fractions (μg/kg)**				
Rice cultivar	**Whole rice grain (WRG)**	**Unpolished / Brown rice**	**Polished / White rice**	**Rice husk**	**Rice bran**
Nayanmoni	164	126	87.6	224	163
Ranjit	140	77.1	72.2	218	192
Satabdi	127	121	100	235	139
Par-minikit	178	96.1	62.3	394	341
Super minikit	141	110	118	165	123
Satabdi minikit	192	184	144	138	122
Ganga	120	116	105	217	173
Parash minikit	180	165	151	196	283
Pan minikit	206	132	140	388	180
Maharaj	127	114	112	326	236
Narendra	327	97.1	97.5	162	226

Arsenic distributions in different rice cultivars from pre-monsoon and post monsoon season (Fig. 16). For pre-monsoonal season, the observed mean As concentrations for all the different rice cultivars (n=12) are 287 ± 42.9, 215 ± 48.3, 553 ± 212, 163 ± 29.8, 334 ± 105 μg/kg for whole rice grain, unpolished/brown rice, rice husk, polished/white rice, rice bran, respectively. Likewise, rice cultivars (n=11) of post-monsoonal season showed the observed mean As concentrations are 170 ± 58.7, 122 ± 30.6, 242 ± 88.5, 108 ± 28.7, 242 ± 47 μg/kg for whole rice grain, unpolished/brown rice, rice husk, polished/white rice, rice bran, respectively.

The mean decreased percentages from whole rice grain to unpolished rice and whole rice grain to polished rice has been observed as 24.5% (3.61-44.6%) and 41.9% (11.6-62.8%) respectively for pre-monsoonal rice cultivars. Whereas, the post-monsoonal rice cultivars, showed a mean decreased percentage of 24.8% (3.33-70.3%) and 33.2% (11.8-70.2%) from whole rice grain to unpolished rice as well as whole rice grain to polished rice, respectively. A stacked bar diagram showing As concentrations in rice milling fractions different rice cultivars of pre-monsoon and post monsoon season has been shown in Fig. 17. Highest amount of As has been found in brown rice due to the thin outer layer of the rice kernels which accumulate large amount of As and gives brown rice its colour and is removed to produce white rice (Meharg et al., 2008).

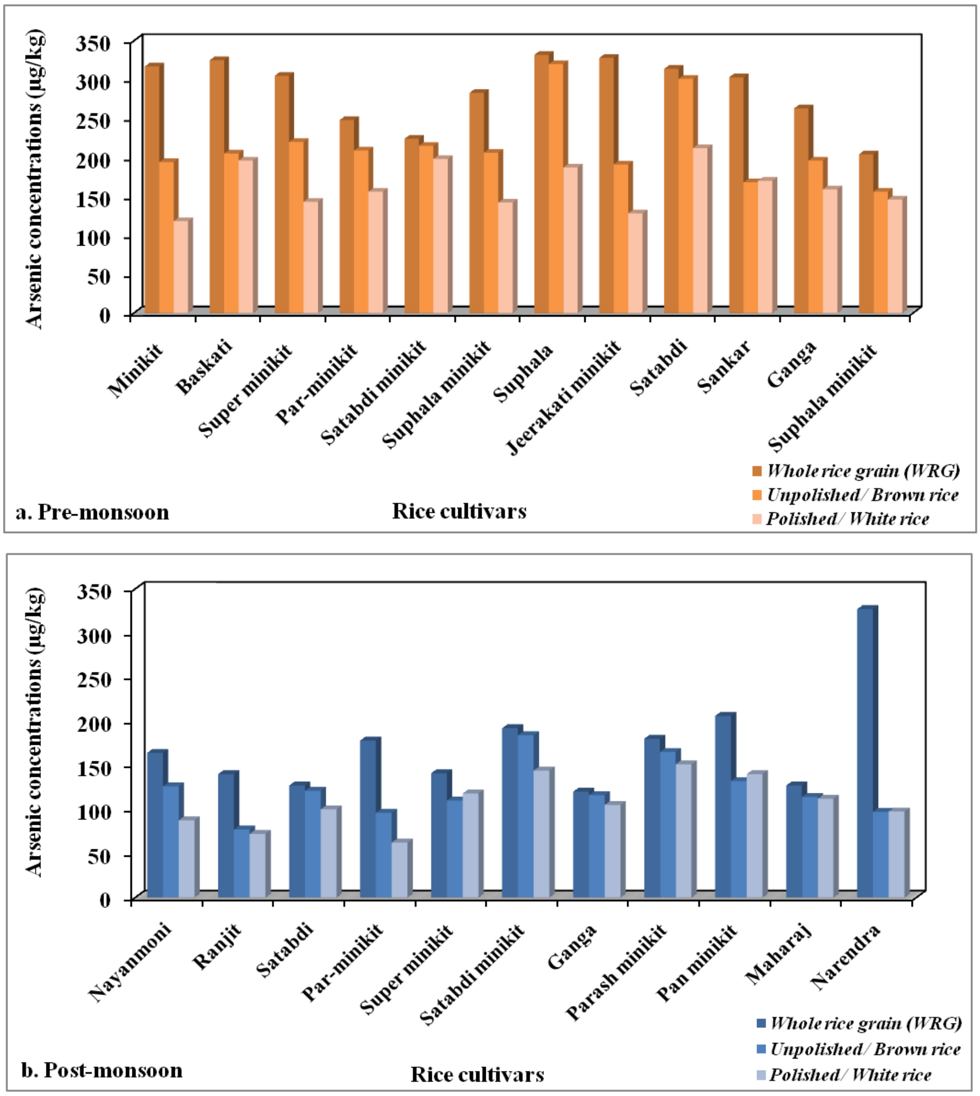
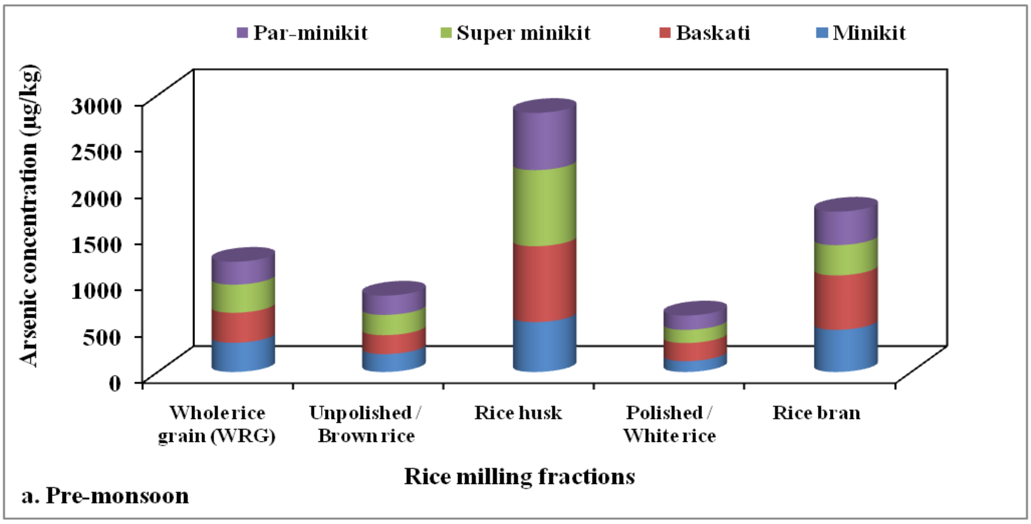


Fig. 16. Arsenic distributions in different rice cultivars of a) Pre-monsoon season and b) Post-monsoon season



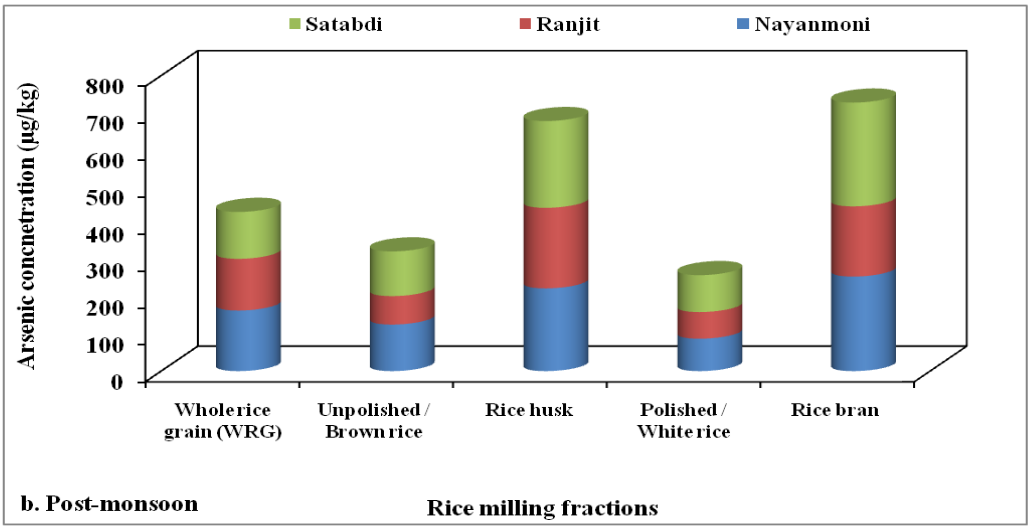


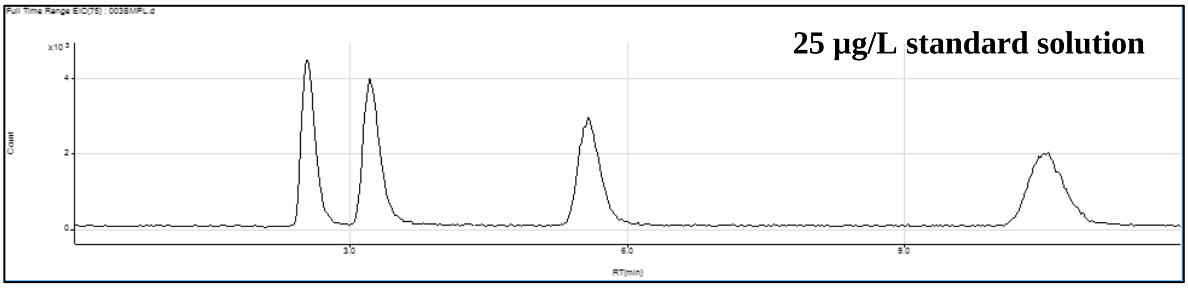
Fig. 17. Stacked bar diagram showing As concentrations in rice milling fractions different rice cultivars of a) Pre-monsoon season and b) Post monsoon season

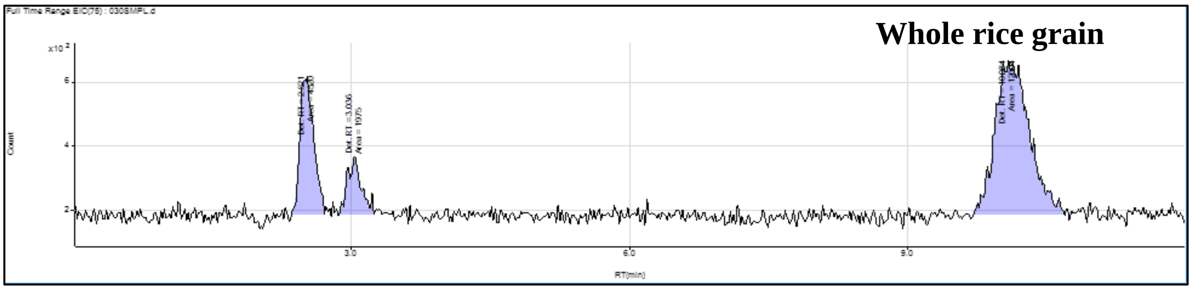
6.3.2.4. Arsenic species distribution in rice milling fractions

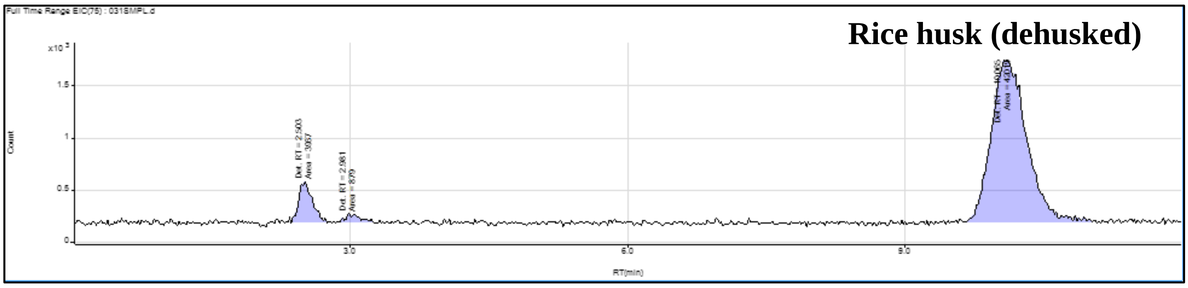
Pre-monsoonal season (Minikit variety) of rice milling samples from Madhusudankati village, Gaighata block has been targeted for As species analysis (Table 13). The different fractions analyzed of the rice milling samples are whole rice grain, rice husk (dehusked), brown rice, rice bran, and white rice. The HPLC chromatograph showing the As species distribution different parts of a whole paddy plant from pre monsoon and post monsoon season (Fig. 18). The observed As concentrations in different fractions of the rice milling samples are whole rice grain (354 µg/kg), rice husk (dehusked) (836 µg/kg), brown rice (289 µg/kg), rice bran (920 µg/kg), and white rice (238 µg/kg). Rice husk (after de-husking) and rice bran contains the higher amount of As compared to rice. The As accumulation follows the trend in an order as whole rice grain > brown rice > white rice. This corroborates with the findings of Chowdhury et al., (2018a; 2020b). Interestingly, the concentration of As V species is higher than As III species. MMA is not observed in all the fractions of rice milling including brown and white rice, as, it is evident that iAs mainly dominates grain As concentration with presence of less amount of DMA (Halder et al., 2014). Overall, the percentage (%) distribution of iAs in different parts of the rice milling samples is observed as 87.1, 98, 89.2, 98.7 and 85.5% in whole rice grain, rice husk (dehusked), brown rice, rice bran and white rice respectively. The total As concentration is higher for brown rice compared to white rice. This corroborates with the main findings of Chowdhury et al., (2020b) that white rice or polished rice accumulates lesser As compared to brown rice or unpolished rice. Several researches have showed that the iAs As species of rice grain is toxic and carcinogenic, it contributes nearly 80% of total As content Halder et al., 2013; Meharg et al., 2009; Mondal and Polya, 2008; Signes-Pastoret al., 2008.

Table 13: Arsenic species distributions in rice milling fractions of Minikit rice cultivar from pre-monsoon season

Rice Milling (Pre-monsoon season, Exposed area - Gaighata: Minikit variety)							
No.	**Sample**	**As III**	**DMA**	**MMA**	**As V**	**Total As**	**% of Inorganic As (As III + As V)**
1	Whole rice grain	109	45.5	0	199	354	87.1
2	Rice husk (Dehusked)	82	16.7	0	737	836	98.0
3	Brown rice	106	31.2	0	152	289	89.2
4	Rice bran	103	11.9	0	805	920	98.7
5	White rice	99	34.6	0	104	238	85.5







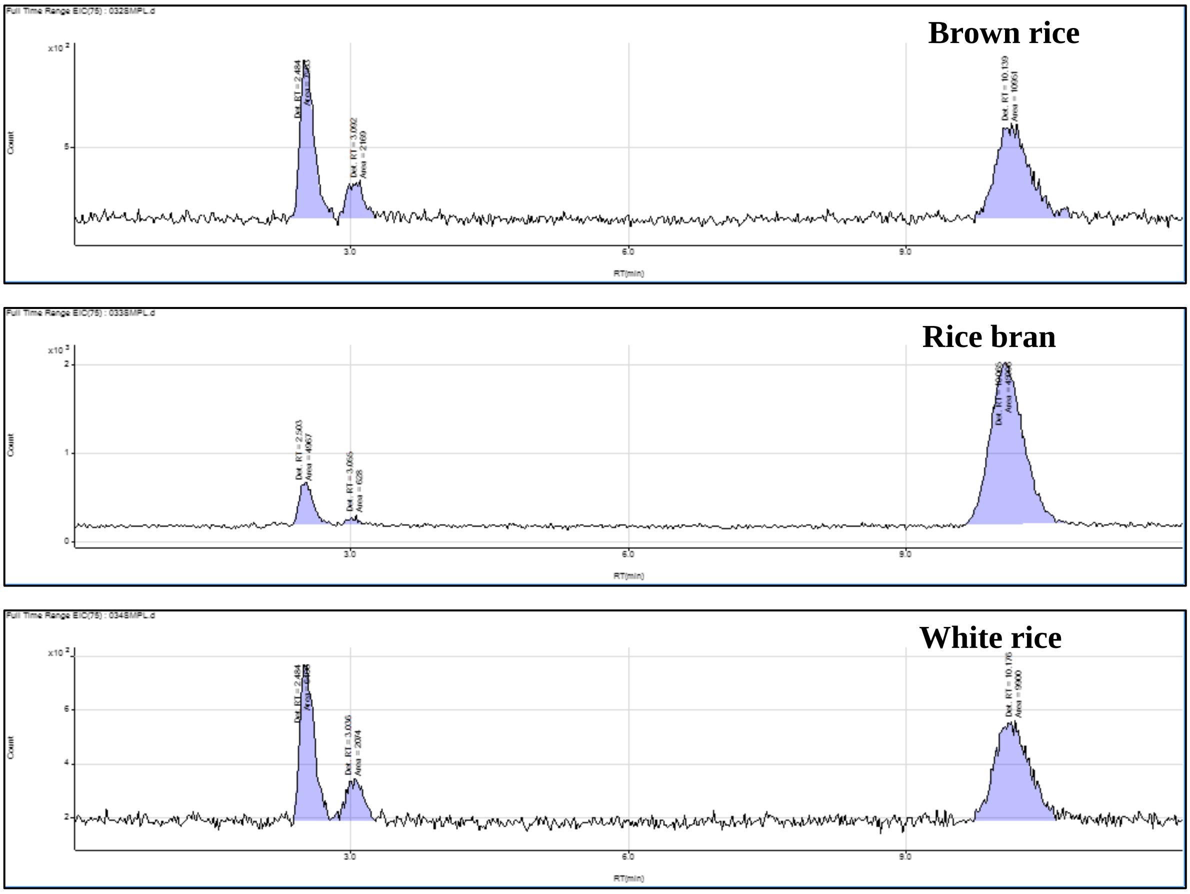


Fig. 18. HPLC chromatograph showing the As species distribution in Standard 25 µg/L and different parts of a whole paddy plant from (A) Pre monsoon season (B) Post monsoon season from a As exposed area

6.3.2.5. Health risk assessment

Cancer and non-cancer risk has been evaluated through consumption of unpolished/brown rice and polished/white rice for adults and child populace from the exposed area.

6.3.2.5.1. Pre-monsoon rice cultivars

Polished/white rice is mainly consumed by the adult and child populace. The observed mean cancer and non-cancer risk through polished rice for the adult populace are 1.73×10^{-3} (range: 1.25×10^{-3}-2.24×10^{-3}) and 3.84 (range: 2.77-4.99), respectively. Likewise, child populace showed 4.87×10^{-4} (range: 3.53×10^{-4}-6.34×10^{-4}) and 1.08 (0.78-1.41) of cancer and non-cancer risk through intake of polished rice on a daily basis.

6.3.2.5.2. Post-monsoon rice cultivars

Polished/white rice is mainly consumed by the adult and child populace. The observed mean cancer and non-cancer risk through polished rice for the adult populace are 1.15×10^{-3} (6.6×10^{-4}-1.6×10^{-3}) and 2.54 (1.47-3.55), respectively. Likewise, child populace showed 3.24×10^{-4} (1.86×10^{-4}-4.52×10^{-4}) and 0.72 (0.41-1) of cancer and non-cancer risk through intake of polished rice on a daily basis.

Our findings clearly showed that risk through post-monsoonal rice cultivars is lower compared to pre-monsoonal rice cultivars. Moreover, the health risks through unpolished rice are higher compared to the polished rice cultivars.

Table 14: Health risk assessment of adults and child groups based on As consumption through brown (unpolished) and white (polished) rice

	Season	**Adults**		**Child**	
		Unpolished / Brown rice	**Polished / White rice**	**Unpolished / Brown rice**	**Polished / White rice**
Cancer risk	Pre-monsoon	$2.27x10^{-3}$	$1.73x10^{-3}$	$6.44x10^{-4}$	$4.87x10^{-4}$
	Post- monsoon	$1.28x10^{-3}$	$1.15x10^{-3}$	$3.64x10^{-4}$	$3.24x10^{-4}$
Non-cancer risk	Pre-monsoon	5.06	3.84	1.43	1.08
	Post- monsoon	2.86	2.54	0.81	0.72

6.4. Different levels of arsenic exposure through cooked rice and its associated benefit-risk assessment from rural and urban populations of West Bengal, India: a probabilistic approach with sensitivity analysis

The present study attempts to evaluate the potential probabilistic health risk mainly associated with cooked rice As (cooking of As-contaminated uncooked rice using As-safe water) considering the three differently exposed populaces of West Bengal, India. On a subjective note, this study assesses the cumulative exposure of As toxicity among different age groups, (adult male, adult female, and children) through As-safe water (primarily used for drinking and cooking), uncooked rice, and its respective cooked rice from exposed (Gaighata), apparently control (Kolkata), and control (Pingla, Medinipur) areas. The study also reflects the distribution of different As species (inorganic As, DMA, and MMA) in uncooked rice and their respective cooked rice in accordance with the total concentration of As from the studied areas. The risk class and its concern level of As were assessed through the application of SAMOE value through daily dietary intakes. Cancerous and non-cancerous risk assessments along with the uncertainty and sensitivity analysis for the different age groups were investigated. Along with As distribution pattern, essential micronutrients like selenium (Se) and zinc (Zn) have been estimated to assess the protective nature against As-induced toxicity. Benefit-risk assessment has been performed on the populace groups based on the actual intake and their respective recommended dietary intake or potential tolerable dietary intake. To our knowledge, this is the first benefit-risk assessment through cooked rice from three different areas which quantifies the health impact along with the importance of dietary intake to control and prevent the level of toxicity.

The study was carried out from different areas of West Bengal, India like exposed (Gaighata: 22º54´14.51´´N, 88º46´25.36´´E), apparently control (Kolkata: 22º29´44.22´´N, 88º22´15.31´´E), and control (Pingla:22º14´47.76´´N, 87º32´50.83´´E) with respect to groundwater As contamination scenario. The source of the uncooked rice from exposed (Gaighata) and control (Pingla) area were locally cultivated, whereas, for apparently control (Kolkata) area, the uncooked rice is mainly transported from other parts of the state, especially from the As exposed areas (Table 15).

Table 15: Surveyed information on sampling area, source of uncooked rice and rice cultivars

Areas	Locations	Population	Source of uncooked rice	Rice cultivars
Exposed	Gaighata North 24 Parganas	Rural	Locally grown or cultivated	Minikit, Satabdi minikit, Maharaaj, Laal minikit, Basmati, Ganga, Swarna.
Apparently control	Kolkata	Urban	Market availability, Transported from exposed and control areas	Sitashal, Nidhi, Dudhesor, Lalbaba minikit, Sadho Basmati, Minikit, Lakhan sal, Lakshibhog, Debeshor.
Control	Pingla Medinipur	Rural	Locally grown or cultivated	IR-64, Tay gold, Superlala, Uaifali, Sankar, Nativo.

6.4.1. Survey questionnaire

Questionnaires were prepared to collect the required data from the different age groups of the studied populaces. In this study, the exposure duration (years), body weight (kg), ingestion rate (amount) of drinking water (litres) and cooked rice (g) of the studied three age groups (adult male, adult female and children) from exposed, apparently control and control populaces have been surveyed from the individuals (Table 16). The average values of the surveyed data have been considered for evaluations of health risk. The average amount of water consumed by an adult male, adult female, and children are (4.33, 3.67, and 1.83 l), (3.58, 2.83, and 1.75 l), and (3.33, 3.25, and 1.33 l) from exposed, apparently control and control area, respectively. Similarly, three age groups from exposed, apparently control and control areas consumed (1355, 1043 and 688 g), (593, 368 and 188 g) and (1250, 938 and 543 g) of cooked rice, respectively on a daily basis.

6.4.2. Arsenic concentration in dietary intakes

6.4.2.1. Water (drinking and cooking)

Water samples used for both drinking and cooking purposes have been analyzed from the studied areas. The observed mean water As concentrations for exposed (n=27), apparently control (n=22) and control (n=26) populaces are 8.93 (range: <3-31.9 µg/L), 3.27 (range: <3-5.35 µg/L) and <3 µg/L, respectively (Table 17). The observed values of As in water are within the WHO permissible limit (10 µg/L) for all the studied populaces. The presence of lower As concentration in water from exposed areas is due to effective awareness programs on As calamity, which resulted in the consumption of As-safe (treated) drinking water for rural populace.

Table 16: Exposure duration, body weight and ingestion rate of water, uncooked rice, cooked rice of the studied adult male, adult female and children from three different areas

		Exposure Duration (ED)*		**Body weight (BW)***		**Ingestion rate (IR)***					
Areas	Category	Age (years)	Age Range (years)	Average BW (kg)	BW Range (kg)	Average amount of drinking water consumed (l)	Drinking water Range (l)	Average amount of uncooked rice consumed (g)	Uncooked rice Range (g)	Average amount of cooked rice consumed (g)	Cooked rice Range (g)
Exposed (Gaighata)	Adult Male	45	32-64	58.7	52-71	4.33	4-4.5	542	400-600	1355	1000-1500
	Adult Female	44	22-59	46.7	38-58	3.67	3-4	417	300-450	1043	750-1125
	Children	11	5-16	25.6	12-42	1.83	1.5-2	275	150-300	688	375-750
Apparently control (Kolkata)	Adult Male	44	26-64	63.5	56-74	3.58	3-4	237	200-300	593	500-750
	Adult Female	44	26-58	53.5	50-58	2.83	2.5-3	147	100-240	368	250-600
	Children	10	5-18	26.5	19-44	1.75	1.5-2	75	45-160	188	113-400
Control (Pingla)	Adult Male	41	20-59	64.8	48-78	3.33	3-3.5	500	450-600	1250	1125-1500
	Adult Female	41	22-52	52.3	46-59	3.25	3-3.5	375	300-450	938	750-1125
	Children	11	6-16	32.5	24-40	1.33	1-1.5	217	200-300	543	500-750

**Surveyed for daily food habit.*

Table 17: Arsenic concentration in water (µg/L) and rice (µg/kg) used in cooked rice preparation from the studied areas

		Arsenic concentration (µg/L or µg/kg)		
Components	**No. of samples (n)**	**Mean**	**SD**	**Range**
Exposed area: Gaighata				
Water (Drinking & Cooking)	27	8.93	7.38	<3-31.9
Uncooked rice(UCR)	27	338	216	92.1-895
Cooked rice (CR)	27	92.3	83.9	23.3-365
Total discarded water (TDW)	27	53.6	45.3	6.6-231
Supernatant	27	37.6	16.5	12.8-69.8
% I/D from UCR to CR*	27	73.8	10.3	52.5-87.8
Apparently control area: Kolkata				
Water (Drinking & Cooking)	22	3.27	0.59	<3-5.35
Uncooked rice(UCR)	22	162	64.1	59.6-306
Cooked rice (CR)	22	32.4	12.6	19.3-62.8

Total discarded water (TDW)	22	27.3	10.6	10.9-57.1
Supernatant	22	23.3	12.6	7.66-56.5
% I/D from UCR to CR*	22	78.5	7.55	59.2-88.6
Control area: Pingla				
Water (Drinking &Cooking)	26	<3	0	-
Uncooked rice(UCR)	26	85.7	55.9	38.8-246
Cooked rice (CR)	26	28.2	12.3	12.2-55
Total discarded water (TDW)	26	21.3	9.88	10.5-56.1
Supernatant	26	13.8	7.66	4.23-36.4
% I/D from UCR to CR*	26	61.3	17.3	19.7-83.5

*Increase or decrease percentage from uncooked (UCR) to cooked rice (CR)

6.4.2.2. Uncooked rice and its respective cooked rice

Status of As accumulation in uncooked rice and its respective cooked rice (µg/kg) collected from the three different areas has been shown in Table 17. West Bengal is well-recognized for being the largest rice-producing state in India (Signes-Pastor et al., 2008). In rural Bengal, parboiled rice which is mostly used for cooked rice preparation typically accumulates more As than sunned rice (Chowdhury et al., 2018b, 2020b). In our study, the mean As concentration of uncooked rice showed 338± 216 µg/kg (range: 92.1-895 µg/kg, n=27), 162 ± 64.1 µg/kg (range: 59.6-306 µg/kg, n=22) and 85.7 ± 55.9 µg/kg (range: 38.8-246 µg/kg, n=26) collected from exposed, apparently control, and control areas, respectively. The EU Commission Regulation has declared a threshold limit value of 100µg/kg in rice for infants, young children and 200µg/kg for adults (EFSA, 2014; Islam et al., 2017b). Consumption of rice is considered the major source of As-exposure to the populaces of Bengal delta consuming As-safe drinking water. Parboiled (uncooked) rice collected in the Kolkata (urban) area had mean As accumulation of 105 µg/kg (range: 46-199 µg/kg, n=30) and 352 µg/kg (range: 234-653 µg/kg, n=32), respectively (Biswas et al., 2019). Likewise, Pingla (rural area) has reported mean rice As accumulation of 106 µg/kg (n=5), ranging from 50 to 135 µg/kg (Chowdhury et al., 2020a). A research study in Bangladesh has also reported that variation in rice As concentration depends on different geographical areas of cultivation (Islam et al., 2017c).

Consumption of As through cooked rice which is mainly prepared using locally cultivated rice, poses a major health risk to the populaces of the Bengal delta (Mandal et al., 2019). The observed mean As concentration in cooked rice collected from exposed, apparently control, and control areas was 92.3 ± 83.9 µg/kg (range: 23.3-365 µg/kg, n=27), 32.4 ± 12.6 µg/kg (range: 19.3-62.8

µg/kg, n=22) and 28.2 ± 12.3 µg/kg (range: 12.2-55 µg/kg, n=26), respectively. Several researches showed the presence of inorganic As in uncooked and cooked rice from the Bengal delta and other parts of the world (Chowdhury et al., 2020b; Meharg et al., 2009). Also, for the populaces using As-safe water, rice might be responsible for one of the main dietary sources of As, due to the transportation of As-contaminated rice from As-exposed to unexposed areas (Biswas et al., 2019; Chatterjee et al., 2010).

In this study, the mean decreased percentages of As from uncooked rice to cooked rice are 73.8% (range: 52.5-87.8%),78.5% (range:59.2-88.6%) and 61.3% (range:19.7-83.5%) for exposed, apparently control, and control areas, respectively. In the endemic area, a household-based study found that cooking with As-contaminated water increases As concentration in cooked rice by 56%, whereas, cooking with As-safe water decreasesconcentration by 78% in cooked rice compared to uncooked rice (Mandal et al., 2019). TDW is the additional starch water that remains after the cooked rice preparation, i.e. mainly discarded (Kumarathilaka et al., 2019). TDW showed mean As concentration of 53.6 ± 45.3 µg/kg (range: 6.6-231 µg/kg, n=27), 27.3 ± 10.6 µg/kg (range: 10.9-57.1 µg/kg, n=22) and 21.3 ± 9.88 µg/kg (range: 10.5-56.1 µg/kg, n=26) from the three studied areas, respectively. Chowdhury et al. (2020b) reported that reduction of Asin cooked rice was due to the release of As during cooking from uncooked rice to TDW (starchy solution) using As-safe water and the rate of As reduction was found high for parboiled rice compared to sunned rice when cooked with low As-contaminated water. As a result, the use of As-safe water during cooking resulted in a high decreased percentage of As concentration in cooked rice irrespective of the studied populaces.

6.4.3. Daily dietary intake (DDI) rate of As and MoE

Assessment on daily and weekly dietary intake of As along with its MoE through water and cooked rice from three differently exposed populaces have been shown in Table 18. DDI for the studied exposed populace through water and cooked rice is ranging from 0.21-2.51 and 0.52-9.80µg/kg bw/day, respectively. The European Food Safety Authority's Panel on Contaminants in the Food Chain determined a standard $BMDL_{0.1}$ ranging from 0.3 to 8 µg/kg bw/day of As intake for an elevated risk of cancer (lung, skin and bladder), and skin lesions (EFSA, 2009). Likewise, DDI_{water} of the age groups from apparently control (range: 0.16-0.35 µg/kg bw/day) and control (range: 0.12-0.15 µg/kg bw/day) areas are lower than the recommended range. Whereas, in the case of $DDI_{cooked\ rice}$ from the apparently control area (range: 0.14-0.58 µg/kg bw/day)is at a level of marginal riskcompared to that of control area (range: 0.20-1.06 µg/kg bw/day).The range of EWI values of cooked rice consumption for the exposed populace (4.38-68.6 µg/kg bw/week)is much higher than the $BMDL_{0.1}$range.In a recent study on EWI,Asexposure through different varieties of rice consumption for the male and female groups ranges from 0.82-7.34 µg/kg bw/week(Kukusamude et al., 2021).In rural Bengal, consumption of contaminated daily dietary foodstuffsmight lead to an additional entry of the toxicant posing a future health risk to the populace, considering intake of As-safe water for a period of time(Halder et al., 2013).

MoE values have been evaluated for a better indication of the level of concern or margin of risk posed by As among the different age groups (Brandon et al., 2014). The calculated MoE values are < 1 for all the agegroups of the exposed populace. Similarly, for the apparently control populace; the MoE values are > 1, which ideally avoids health risks. Likewise, the control populace showed MoE_{water}> 1 and $MoE_{cooked\ rice}$< 1 which signifies the existence of health risks through cooked rice consumption compared to water for the different age groups. Several worldwide researchesalso showed the MoEof Asthrough rice consumption. Menon et al. (2020) reported MoE values for adult male (12.86); adult female (10.80) and infant (1.38) of UK populace based on their recent per capital ingestion rate of rice. A study on French populace has reported MoE range from 0.4-1.3 for adults and children due to As exposure at 95th percentile (Arnich et al., 2012). Rintala et al. (2014) also reported MoE values < 1 through rice consumption for different age groups of men, women and children in Finland.

Table 18: Assessment on intake of inorganic arsenic through water and cooked rice on studied populations from three different exposed areas

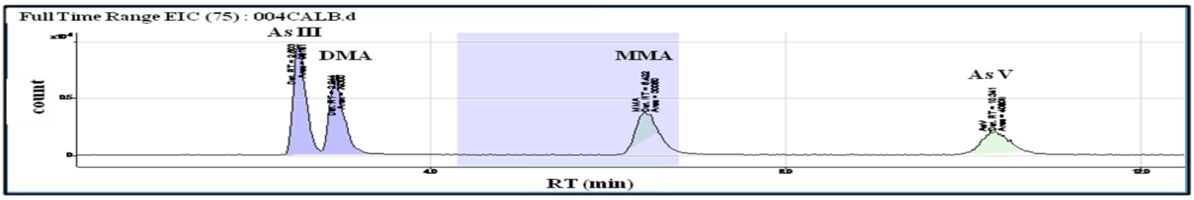
Populations	**Category**	**TC_{As}**		**DDI_{As}**		**EWI_{As}**		**MoE**	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
		a) Water (Drinking &Cooking)							
Exposed	Adult male	38.7	12.9-138	0.66	0.22-2.35	4.61	1.54-16.5	0.80	0.13-1.36
	Adult female	32.8	11-117	0.70	0.24-2.51	4.91	1.65-17.5	0.75	0.12-1.27
	Children	16.3	5.49-58.4	0.64	0.21-2.28	4.46	1.50-15.9	0.82	0.13-1.39
Apparently control	Adult male	11.7	10.7-19.2	0.18	0.16-0.30	1.29	1.18-2.11	1.66	0.99-1.77
	Adult female	9.27	8.49-15.1	0.17	0.16-0.28	1.21	1.11-1.98	1.77	1.06-1.89
	Children	5.73	5.25-9.36	0.22	0.19-0.35	1.51	1.38-2.47	1.42	0.84-1.51
	Adult male	9.99	-	0.15	-	1.08	-	1.94	-

Control	Adult female	9.75	-	0.19	-	1.30	-	1.61	-
	Children	3.99	-	0.12	-	0.86	-	2.44	-
b) Cooked rice									
Exposed	Adult male	125	31-495	2.13	0.53-8.42	15.1	3.76-58.9	0.24	0.03-0.55
	Adult female	96	24.3-381	2.06	0.52-8.15	14.4	3.64-57.1	0.25	0.03-0.57
	Children	63.5	16-251	2.48	0.62-9.80	17.4	4.38-68.6	0.21	0.03-0.47
Apparently control	Adult male	19.2	11.4-37.2	0.30	0.18-0.58	2.12	1.26-4.11	1.12	0.51-1.66
	Adult female	12.5	7.44-24.2	0.23	0.14-0.45	1.64	0.97-3.17	1.44	0.66-2.15
	Children	6.09	3.63-11.8	0.23	0.14-0.44	1.61	0.95-3.12	1.46	0.67-2.19
Control	Adult male	35.3	15.2-68.7	0.54	0.24-1.06	3.81	1.64-7.42	0.64	0.28-1.27
	Adult female	26.5	11.4-51.6	0.51	0.22-0.98	3.54	1.53-6.90	0.69	0.30-1.37
	Children	15.3	6.62-29.8	0.47	0.20-0.92	3.30	1.42-6.43	0.75	0.33-1.47

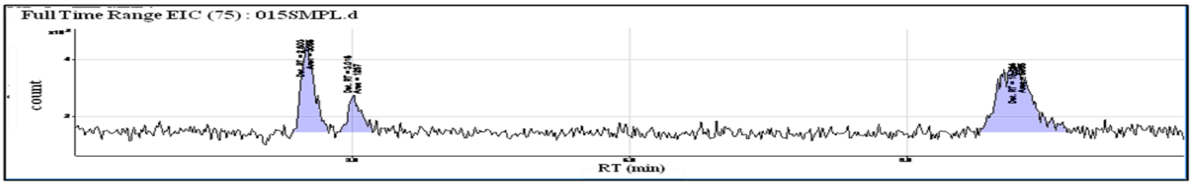
6.4.4. Variation of As species in uncooked rice and its respective cooked rice

In this study, an attempt has been taken to quantify the distribution of As species in uncooked and cooked rice, when mainly cooked usingAs-safe water. The HPLC chromatogram of 50 µg/L standard As solution of arsenite (As III), dimethylarsinic acid **(**DMA), monomethylarsonic acid (MMA)and arsenate (As V) along with the presence of different As species in uncooked and cooked rice from the studied areas has been shown in Fig. 19. The different concentrations of As species in uncooked and cooked rice from the studied areas have been shown in Table 19. In our study, uncooked rice and cooked rice from the exposed populace showed the presence of 96.6 and 92.2% of inorganic As (iAs = AsIII + AsV). Previously, a study showed that iAs contributed 100% and 93.8% in uncooked rice and cooked rice, respectively while cooking with low-As contaminated water (Chowdhury et al., 2020b). The distributions of iAs in uncooked and cooked rice from the apparently control area were observed as 195 and 101 µg/kg, respectively. iAs contributed 94.7% and 90.2%in uncooked and cooked rice, whereas,5.24% and 9.19% were contributed by DMA species, respectively. It is significant to state the presence of iAs in uncooked rice might be due to the transportation of As-contaminated rice grain from exposed to unexposed areas (Biswas et al., 2019). Another plausible explanation might be geographical variations, combination of As contaminated and uncontaminated rice before marketing, as a result even the populace from the unexposed areas are getting exposed to As. For the control area (Pingla, Medinipur), the extracted iAsspecies were observed as 94.9 and 50.5 µg/kg, respectively in uncooked rice (locally cultivated) and cooked rice. It is important to mention that organic As species (DMA and MMA) were not detected in raw rice; however, approximately5.63% was contributed by DMA (3.02 µg/kg) in cooked rice. These findings are in good agreement with the observations in Halder et al., 2014.From apparently control and control areas, it is visible that the presence of iAs is mostly dominated by raw rice As concentration along with the existence of a smaller amount of DMA in cooked rice, which corroborates with the findings by Chowdhury et al. (2020b) and Zavala et al. (2008). The most important As species in rice (both uncooked and cooked) is mainly inorganic, which is highly toxic and carcinogenic. iAs mainly contributed more than 80% of total As in rice, which has also been reported in earlier studies (Halder et al., 2013, 2014; Meharg et al., 2009; Roychowdhury, 2008; Signes-Pastor et al., 2008). During cooking with As-safe water, the decreased percentages of total As concentration from uncooked to cooked rice were observed as 59.3, 48.2 and 46.7% for exposed, apparently control and control areas, respectively. A similar decreasing trend of As was reported in cooked rice when less-As contaminated water was used during cooked rice preparation (Halder et al., 2014). There is no definite recommended level to assess the health risk due to consumption of iAs through dietary sources (Ahmed et al., 2016). It is reported by US Environmental Protection Agency (EPA) that there is no "safe" amount of inorganic As exposure (Islam et al., 2017b). Moreover, Islam et al. (2017c) reported that exposure to iAs through As-contaminated rice poses potential cancerous and non-cancerous health risks. As a result, the contribution of iAs in cooked rice might lead to potential health risks for all the different studied age groups in near future.

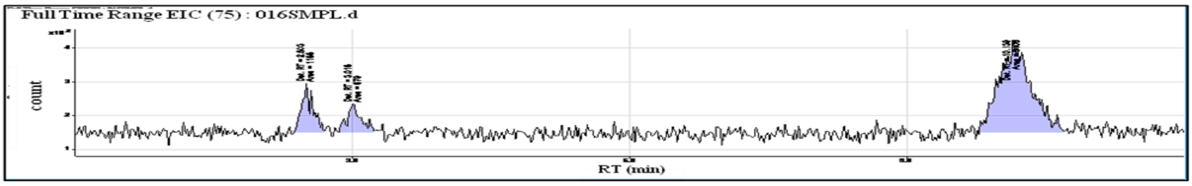
a. Standard 50 µg/l



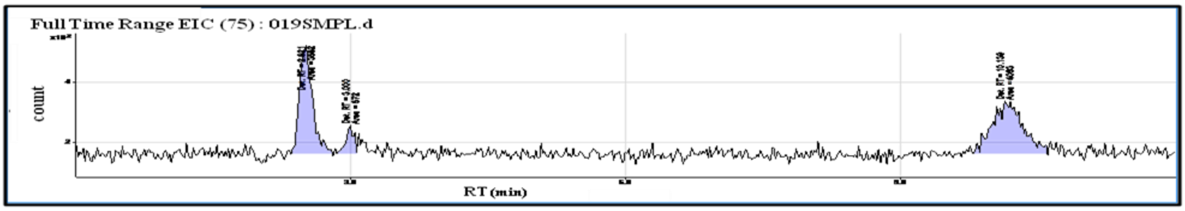
b. Exposed (Gaighata): Uncooked rice



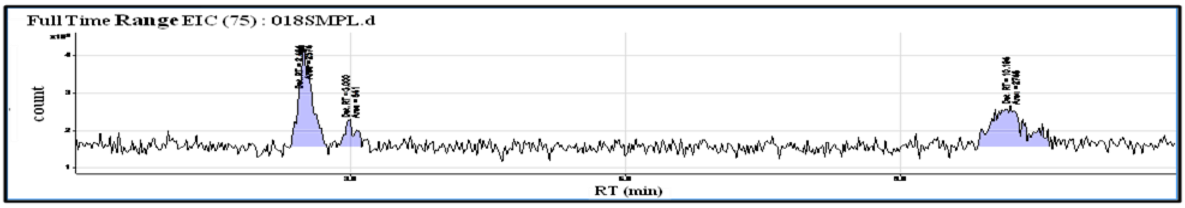
c. Exposed (Gaighata): Cooked rice



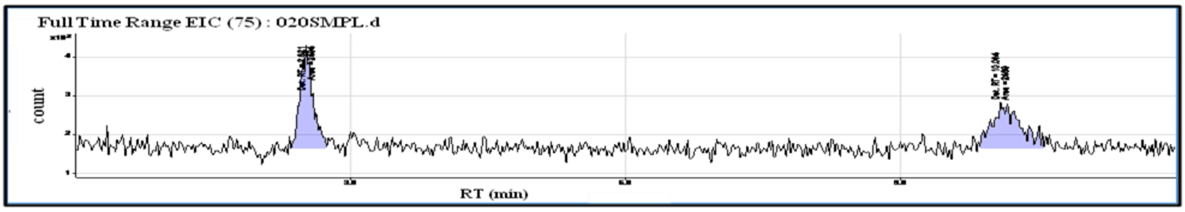
d. Apparently control (Kolkata): Uncooked rice



e. Apparently control (Kolkata): Cooked rice



f. Control (Pingla): Uncooked rice



g. Control (Pingla): Cooked rice

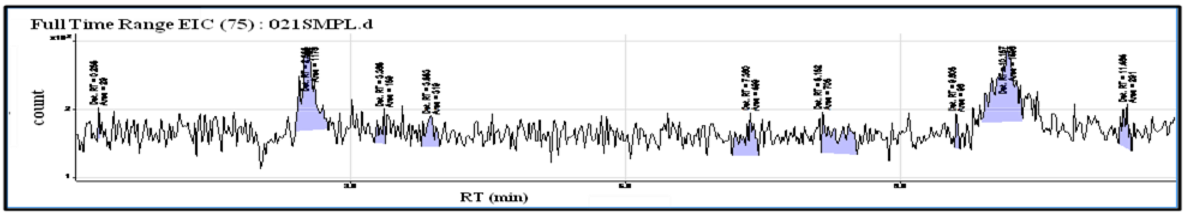


Fig. 19. HPLC chromatogram of As species in a. Standard 50 µg/L, b. Exposed (Gaighata): Uncooked rice, c. Exposed (Gaighata): Cooked rice, d. Apparently control (Kolkata): Uncooked rice, e. Apparently control (Kolkata): Cooked rice, f. Control (Pingla): Uncooked rice and g. Control (Pingla): Cooked rice

Table 19: Distribution of As species in uncooked rice and cooked rice from three studied areas

Areas	Category	Inorganic As (As III + As V)	DMA	MMA `	Total As (µg/kg)	Inorganic As (%)
Exposed (Gaighata)	Uncooked rice	290	10.1	0	300	96.6
	Cooked rice	118	9.52	0	128	92.2
Apparently control (Kolkata)	Uncooked rice	195	10.8	0	206	94.7
	Cooked rice	101	10.3	0	112	90.2
Control (Pingla)	Uncooked rice	94.9	0	0	94.9	100
	Cooked rice	50.5	3.02	0	53.6	94.2

6.4.5. SAMOE: Risk Thermometer

Using risk thermometer, the SAMOE values denoted the risk class and their respective concern level of As toxicity through consumption of water and cooked rice of the three differently exposed populaces (Table 20). Different class of risk and concern level has been observed for adult male, adult female and children in the studied areas through water, uncooked and cooked rice (Fig. 20). The water used for both drinking and cooking purposes for the exposed populace showed a moderate-high concern level with risk class 4, whereas the apparently control and control populaces showed low-moderate concern level with risk class 3. Considering, uncooked rice(parboiled), a high concern level with risk class 5 has been observed for all the three differently exposed populaces. Likewise, cooked rice (parboiled) from the exposed populace resulted in showing a moderate-high concern level (risk class 4), compared to the apparently control and control populaces (risk class 3: low-moderate concern level). Consequently, the risk of suffering from As toxicity is high for the exposed populace through intake of water and cooked rice compared to the apparently control and control populaces. Our findings are in good agreement with the observations described in Chowdhury et al. (2020b).

Table 20: SAMOE values categorizing the risk class along with its respective concern level for the three differently exposed populations

Area	Source	Adult Male		Adult Female		Children	
		SAMOE value	Risk class	SAMOE value	Risk class	SAMOE value	Risk class
Exposed (Gaighata)	Water	0.08	Class 4	0.08	Class 4	0.08	Class 4
	Uncooked rice	0.01	Class 4	0.01	Class 4	0.01	Class 4
	Cooked rice	0.02	Class 4	0.02	Class 4	0.02	Class 4
Apparently control (Kolkata)	Water	0.17	Class 3	0.18	Class 3	0.14	Class 3
	Uncooked rice	0.06	Class 4	0.08	Class 4	0.08	Class 4
	Cooked rice	0.11	Class 3	0.15	Class 3	0.15	Class 3
Control (Pingla)	Water	0.19	Class 3	0.16	Class 3	0.24	Class 3
	Uncooked rice	0.06	Class 4	0.06	Class 4	0.07	Class 4
	Cooked rice	0.10	Class 3	0.10	Class 3	0.10	Class 3

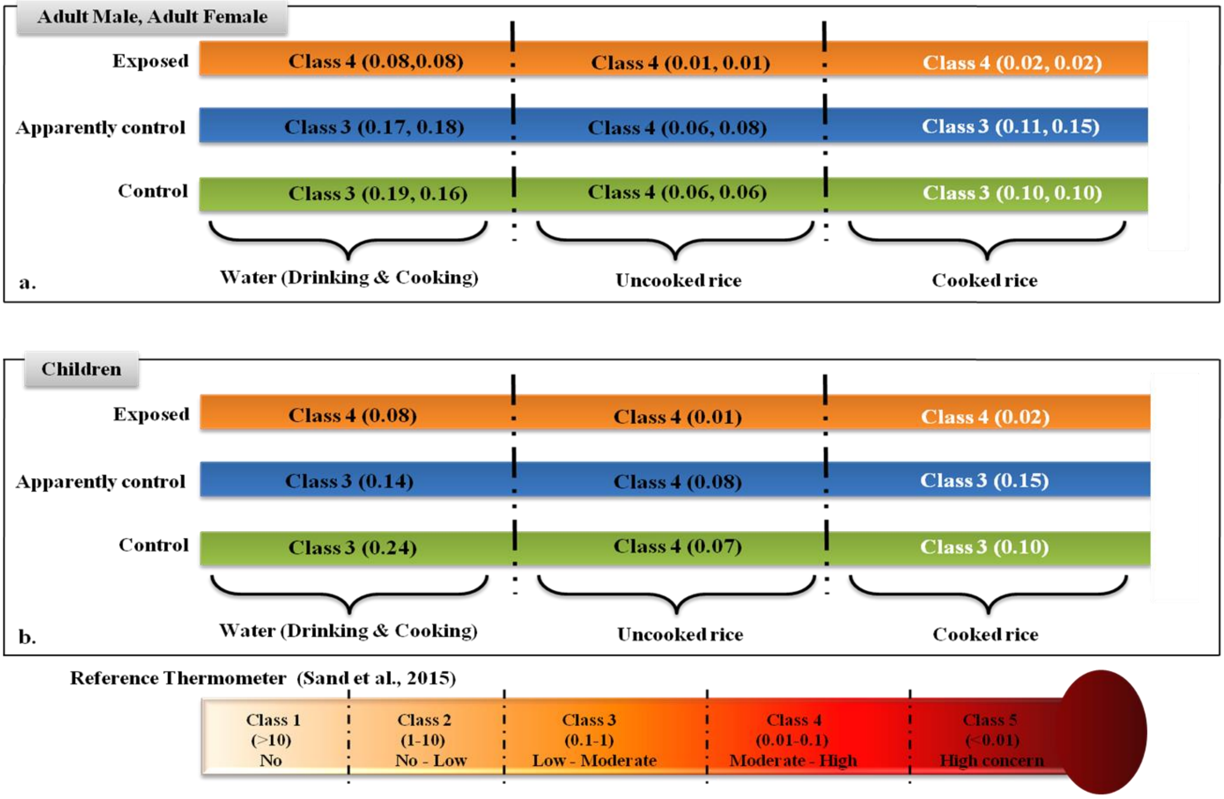


Fig. 20. SAMOE values of water (drinking & cooking), uncooked rice & cooked rice using Risk Thermometer

6.4.6. Arsenic attributable LCR and HQ: Probabilistic health risk

Health risk evaluation showed the possibility of LCR and HQ (non-cancer risk) through dietary intakes of different aged individuals from exposed, apparently control and control populaces, respectively. Cancer and non-cancer risk for an adult male, adult female and children through ingestion of water and cooked rice from the three different exposed populaces are shown in Table 21. Both cancer and non-cancer risk through intake of water is high for different agegroups of the exposed populace compared to apparently control and control populace. The plausible explanation might be due to greater amount of ingestion rate of drinking water for the studied exposed populace. The cancer risk value for exposed populace through cooked rice ($LCR_{Adult\ male} = 2.1 \times 10^{-3}$, $LCR_{Adultfemale} = 1.9 \times 10^{-3}$ and $LCR_{Children} = 5.8 \times 10^{-4}$) is higher than the recommended value i.e. 1×10^{-6} (USEPA, 2005). Similarly, the $HQ_{Adult\ male} = 4.55$ and $HQ_{Adult\ female} = 4.31$for the exposedpopulace are higher and exceeds the threshold limit i.e. 1 (USEPA, 2005) compared to the $HQ_{Children} = 1.29$. The cancer risk value is observed to be higher for apparently control ($LCR_{Adult\ male} = 2.8 \times 10^{-4}$, $LCR_{Adult\ female} = 2.1 \times 10^{-4}$) and control ($LCR_{Adult\ male} = 4.7 \times 10^{-4}$, $LCR_{Adult\ female} = 4.4 \times 10^{-4}$) populaces through cooked rice consumption. Whereas, non-cancerous risk through cooked rice is within the threshold limit for apparently control ($HQ_{Adult\ male}$ = 0.63 and $HQ_{Adult\ female}$ = 0.47); however, nearly at a marginal level for control ($HQ_{Adult\ male}$ = 1.06 and $HQ_{Adult\ female}$ = 0.99) populaces. This is due to the higher ingestion rate of cooked rice by the control populace from rural area compared to the apparently control populace from urban area (Table 2). Similarly, children from apparently control ($LCR_{Children}$= 4.9 x 10^{-5}) and control ($LCR_{Children}$= 1.1 x 10^{-4}) populaces showed lower health risk compared to the adults. However, $HQ_{cookedrice}$for apparently control and control children denotesthat there is no existing future non-cancerous risk. LCR and HQ values showed that adult male and adult female are more susceptible age group to As exposure compared to children, due of their high ingestionrate and long exposure duration. These results agreewith the findings of Mridhaet al. (2022b). The calculated values signifythat surveyed populaces are at an elevated exposurerisk of As due to intake of cooked rice on a daily basis. It is significant that with long exposure duration, the LCR assessment on different agegroups is higher. The evaluated risk implies cooking of rice with As-safe water considerably decreases Asin cooked rice; however, daily intake of cooked rice is a potential route to As exposure for the rural populace. Our findings stand by the observations of Halder et al. (2014). Wang et al. (2020) also showed that adult groups are more susceptible to the potential risk of As through consumption of cooked rice compared to the children. Overall, the distribution pattern of total As, iAs along with the risk class categorization and associated health risk through uncooked and cooked rice from differently exposed areas has been shown in Fig. 21.

Table 21: Probabilistic health risk assessment categorizing the LCR and HQ among the three differently exposed populations

		LCR			**HQ**		
		Water	**Uncooked rice**	**Cooked rice**	**Water**	**Uncooked rice**	**Cooked rice**
Exposed (Gaighata)	Adult male	6.3×10^{-4}	3.0×10^{-3}	2.1×10^{-3}	1.41	6.67	4.55
	Adult female	6.6×10^{-4}	2.8×10^{-3}	1.9×10^{-3}	1.46	6.30	4.31
	Children	1.5×10^{-4}	8.5×10^{-4}	5.8×10^{-4}	0.33	1.89	1.29
Apparently control (Kolkata)	Adult male	1.7×10^{-4}	5.7×10^{-4}	2.8×10^{-4}	0.38	1.26	0.63
	Adult female	1.6×10^{-4}	4.2×10^{-4}	2.1×10^{-4}	0.36	0.93	0.47
	Children	4.6×10^{-5}	9.8×10^{-5}	4.9×10^{-5}	0.10	0.21	0.11
Control (Pingla)	Adult male	1.4×10^{-4}	5.8×10^{-4}	4.7×10^{-4}	0.30	1.28	1.06
	Adult female	1.6×10^{-4}	5.4×10^{-4}	4.4×10^{-4}	0.36	1.19	0.99
	Children	2.9×10^{-5}	1.3×10^{-4}	1.1×10^{-4}	0.06	0.29	0.24

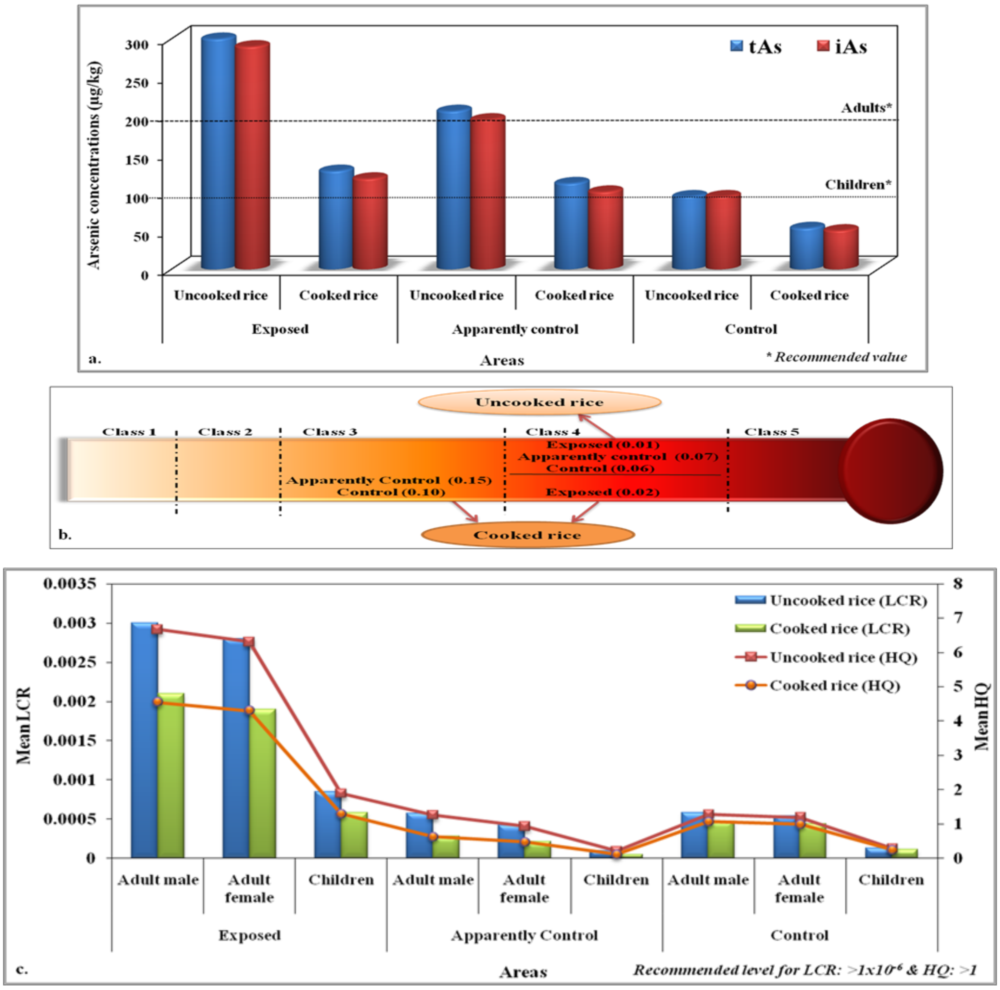


Fig. 21. a. Distribution pattern of tAs and iAs in uncooked and cooked rice from the studied areas, b. Risk thermometer showing the SAMOE values of uncooked and cooked rice, c. Bar-diagram showing the LCR and HQ through uncooked and cooked rice for all age-groups from the studied areas

6.4.7. Distribution pattern and association with health risk

Linear Model (LM) has been implemented to estimate the association of health risk (LCR and HQ) for all the studied populaces due to consumption of water and cooked rice with the areas of interest. The statistical modelling has been performed on exposed and apparently control areas with respect to the control area. The analysis identified that there exists a significant association of $HQ_{\text{cooked rice}}$ and $LCR_{\text{cooked rice}}$ with that of HQ_{water} and LCR_{water}, respectively. This association of HQ_{water} and LCR_{water} on $HQ_{\text{cooked rice}}$ and $LCR_{\text{cooked rice}}$; however, is independent of studied areas. The health risk (HQ and LCR) associated with cooked rice is found to be dependent on a higher exposure toAs in the exposed area, Gaighata (P=0.00228) compared to the control area (Pingla). There is no significant association between apparently control area (P=0.8923) with that of control area.

Box-plot shows significantly higher HQ values from water and cooked rice of the studied exposed populace. This might be due to the higher ingestion rate of the exposed populace compared to the control and apparently control populaces. The box plot (Fig. 22a, b) shows an area-wise significant association of HQ, LCR of water and cooked rice in the exposed area, compared to the control and apparently control area where no significant difference exists. Likewise, the scatter plot shows the association between HQ and LCR of cooked rice with water (Fig. 22c, d). Studies showed that there always exists an association between water, raw rice as well as cooked rice depending on the cooking process (Mondal et al., 2010).

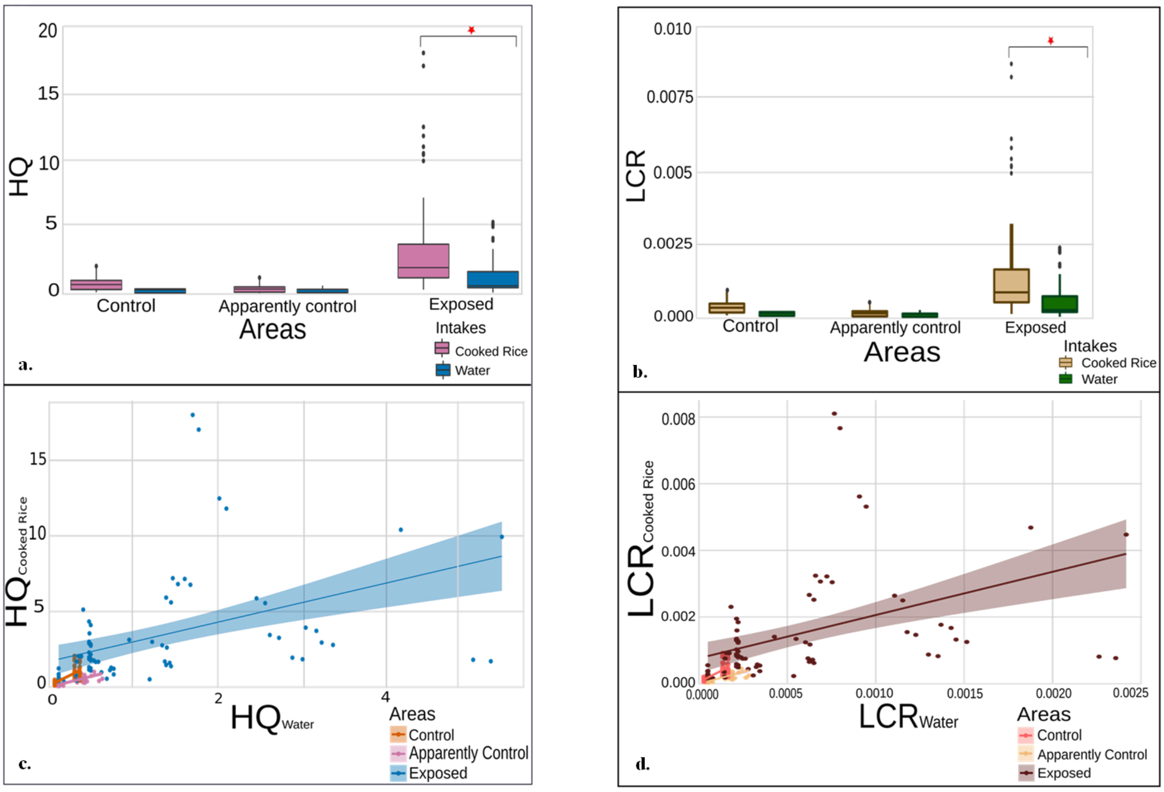


Fig. 22. a. Area-wise HQ box plot, b. Scatter-plot showing association of HQ $_{\text{cooked rice}}$ with HQ $_{\text{water}}$, c. Area-wise LCR box plot and d. Scatter plot showing association of LCR $_{\text{cooked rice}}$ with LCR $_{\text{water}}$ of the studied areas

6.4.8. Uncertainty analysis: To quantify the uncertainties observed in HRA, simulations have been performed on the normal statistical distribution of the input parameters. During the probabilistic healthrisk evaluation, the uncertainty bounds i.e. upper (P95), mean (P50) and lower (P5) of LCR and HQ of As through consumption of cooked rice of three different agegroups from the studied populaces has been shown in Table 22 and Fig. 23a, b, respectively.

All the observations are higher than the USEPA threshold value (1 x 10^{-6}) of LCR which may lead to potential health risks. At all uncertainty boundaries, the HQ values for all age groups from exposed populaces are greater than 1, resulting in non-carcinogenic health risk. In contrast, all values for apparently control populaces are within the tolerable limit (i.e., HQ 1), compared to control area where exceptionally adult male populaces are in the risk zone when P50 and P95 percentile values are considered. The HQ values that are less than 1 at P5, P50, and P95 bounds for all the age groups specify that the exposure level of the toxicant does not pose a significant non-carcinogenic health risk to the populace.

Thus, the results reveal that the exposed populace is surviving in the most vulnerable situation followed by the control and apparently control populace due to As toxicity. Taking into account the uncertainty value showed the LCR and HQ risk from cooked rice in an order of adult male > adult female > children for all studied populaces. As a result, prolonged As exposure will lead to severe carcinogenic and non-carcinogenic health risks among the populaces. Several research studies have also reported inhabitants face chronic health hazards depending on their area of living and exposure level through their daily dietary intakes (Das et al., 2021a; Mondal and Polya, 2008; Mridha et al., 2022b). Moreover, this study also specifically addressed the influential parameters through sensitivity analysis.

Table 22: Percentile values (P5, P50 and P95) of cooked rice consumption

Area		Exposed			Apparently Control			Control		
Category		Cooked rice			Cooked rice			Cooked rice		
Parameters		ADD	HQ	LCR	ADD	HQ	LCR	ADD	HQ	LCR
P5	**Adult Male**	$8.94*10^{-4}$	2.91	$1.34*10^{-3}$	$1.24*10^{-4}$	$4.04*10^{-1}$	$1.86*10^{-4}$	$2.08*10^{-4}$	$6.77*10^{-1}$	$3.12*10^{-4}$
	Adult Female	$8.44*10^{-4}$	2.74	$1.26*10^{-3}$	$9.14*10^{-5}$	$2.97*10^{-1}$	$1.37*10^{-4}$	$1.93*10^{-4}$	$6.27*10^{-1}$	$2.89*10^{-4}$
	Children	$2.54*10^{-5}$	$8.32*10^{-1}$	$3.81*10^{-4}$	$2.14*10^{-5}$	$7.01*10^{-2}$	$3.21*10^{-5}$	$4.83*10^{-5}$	$1.58*10^{-1}$	$7.24*10^{-5}$
P50	**Adult Male**	$1.35*10^{-3}$	4.52	$2.03*10^{-3}$	$1.88*10^{-4}$	$6.28*10^{-1}$	$2.83*10^{-4}$	$3.15*10^{-4}$	1.05	$4.72*10^{-4}$
	Adult Female	$1.27*10^{-3}$	4.26	$1.92*10^{-3}$	$1.38*10^{-4}$	$4.61*10^{-1}$	$2.07*10^{-4}$	$2.92*10^{-4}$	$9.74*10^{-1}$	$4.38*10^{-4}$
	Children	$3.84*10^{-4}$	1.28	$5.76*10^{-4}$	$3.25*10^{-5}$	$1.08*10^{-1}$	$4.87*10^{-5}$	$7.30*10^{-5}$	$2.44*10^{-2}$	$1.09*10^{-4}$
P95	**Adult Male**	$2.01*10^{-3}$	6.9	$3.02*10^{-3}$	$2.80*10^{-4}$	$9.59*10^{-1}$	$4.21*10^{-4}$	$4.69*10^{-4}$	1.61	$7.04*10^{-4}$
	Adult Female	$1.90*10^{-3}$	6.59	$2.85*10^{-3}$	$2.06*10^{-4}$	$7.14*10^{-1}$	$3.09*10^{-4}$	$4.35*10^{-4}$	1.51	$6.53*10^{-4}$
	Children	$5.77*10^{-4}$	2	$8.65*10^{-4}$	$4.84*10^{-5}$	$1.68*10^{-1}$	$7.30*10^{-5}$	$1.09*10^{-4}$	$3.80*10^{-1}$	$1.64*10^{-4}$

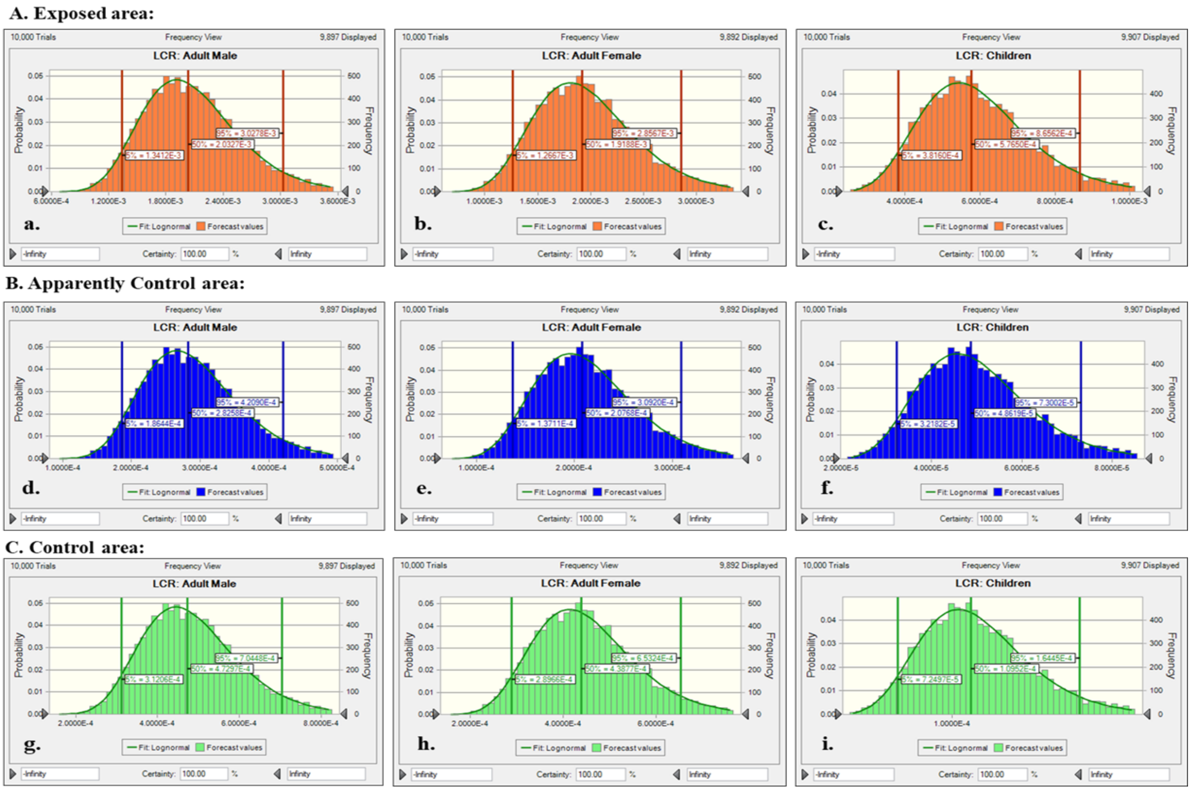


Fig. 23a. Uncertainty analysis based on LCR through consumption of cooked rice for adult male, adult female and children from A. Exposed, B. Apparently control, and C. Control area, respectively

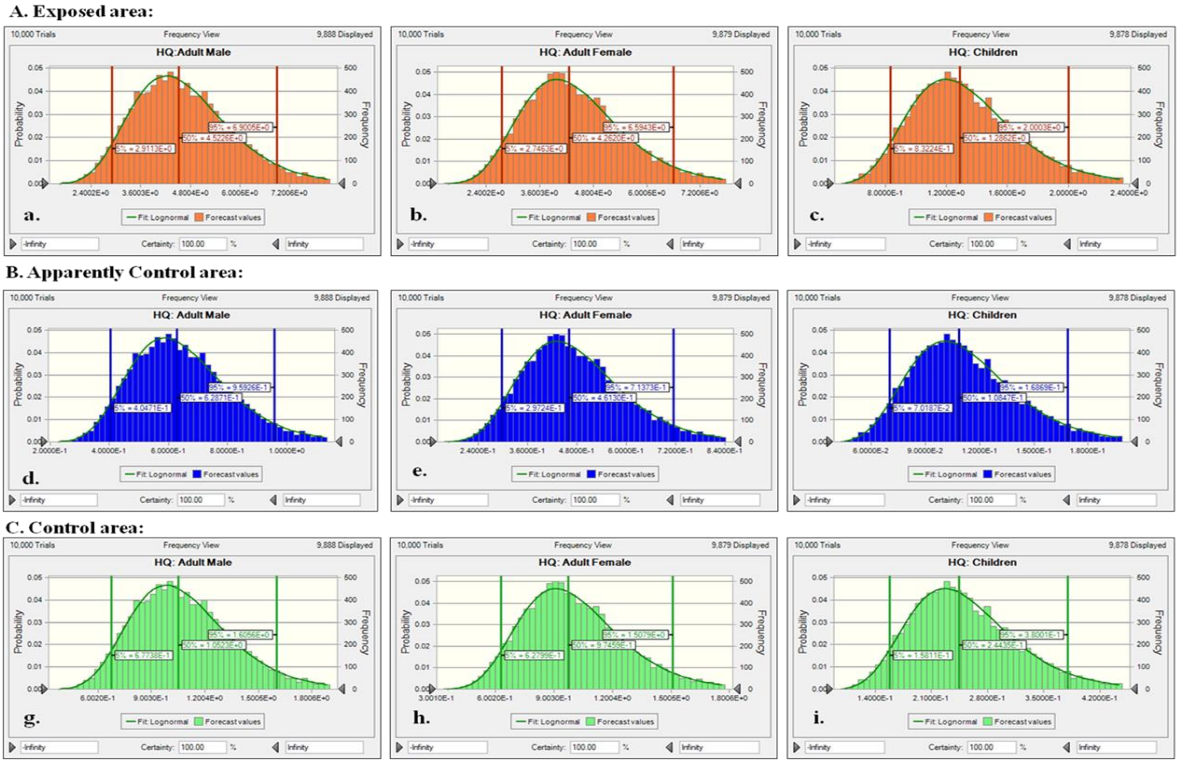


Fig. 23b. Uncertainty analysis based on HQ through consumption of cooked rice for adult male, adult female and children from A. Exposed, B. Apparently control, and C. Control area, respectively

6.4.9. Sensitivity analysis: The sensitivity analysis was performed to classify the major contribution of the input assumptions (IR, C and BW) for the probabilistic risk evaluation through water and cooked rice consumption. IR and C have been recognized as major factors influencing the sensitivity analysis of the three differently exposed populaces from rural and urban areas, respectively. The BW is the third significant factor (negative influencer) for sensitivity analysis. In our study, during water consumption, IR is responsible as the significant influencing factor for adult male and adult female from all the studied areas, whereas, children group showed C as a positive influencer (Fig. 24a). Islam et al. (2017c) reported that several factors like age, sex, bodyweight and IR influence the level of health risk among studied males and females. Saha and Rahman (2020) also showed that for children group, the concentration of the toxicant acts as a high influencing parameter. In our study, adult male and adult female inhabitants from the rural (exposed and control) and urban (apparently control) populaces showed IR as their influencing factor due to As exposure through cooked rice (Fig. 24b). Likewise, children from rural populaces indicated C as their influencing variable compared to children from the urban populace, where, IR proved to be a positive influencer towards As in cooked rice. In the case of cooked rice consumption, the plausible explanation might be children always has the lowest body weight compared to adults (Mukherjee et al., 2020), and also the amount of intake rate is considerably high for rural populaces than urban. Overall, this study highlighted that the different studied populaces are at a high risk of cancer as well as non-cancer for adults compared to children depending mainly on the IR and C factors, respectively.

Fig. 24a. Sensitivity analysis based on ADD through consumption of water for adult male, adult female and children from A. Exposed, B. Apparently control, and C. Control area, respectively

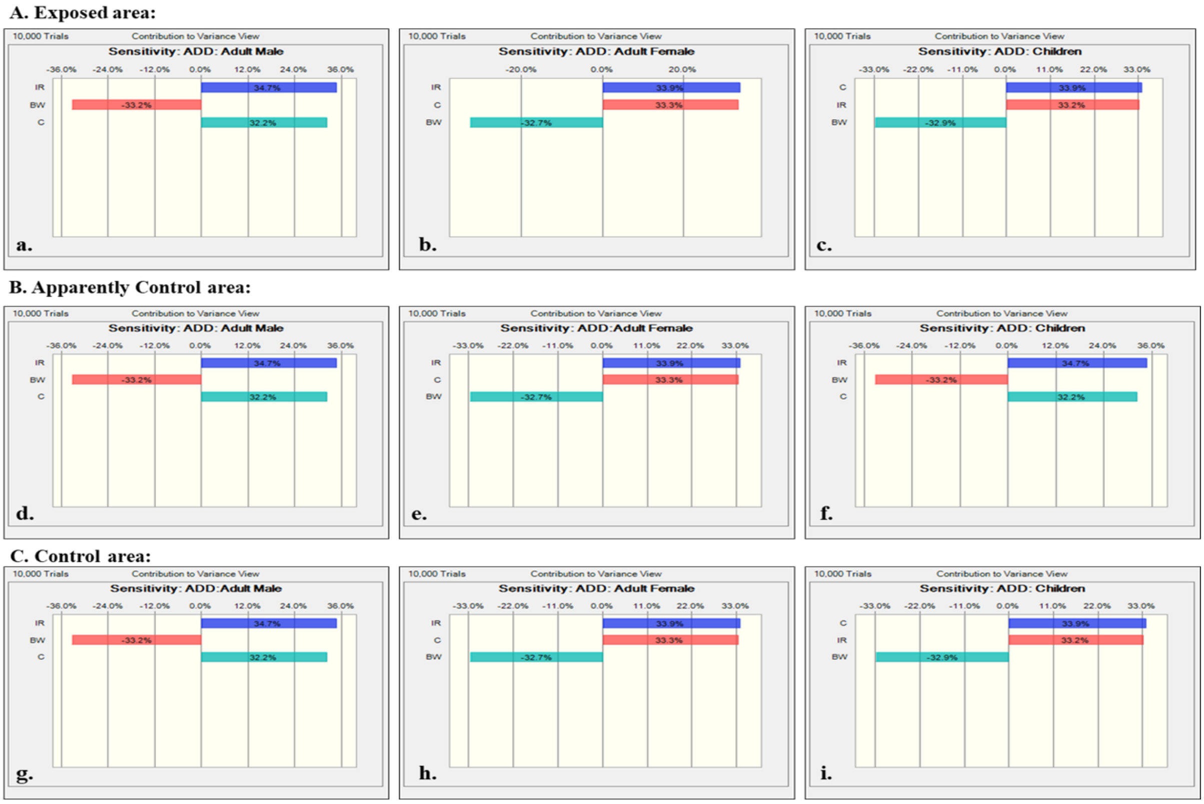


Fig. 24b. Sensitivity analysis based on ADD through cooked rice for adult male, adult female and children from A. Exposed, B. Apparently control, and C. Control area, respectively

6.4.10. Distribution of micronutrients (Se and Zn)

Zn and Se are two essential nutrients for humans and it is well reported as having a reducing potent against As-toxicity (Plum et al., 2010). The distribution of Zn and Se concentrations in uncooked and cooked rice from all the studied areas along with their As concentration have been shown in Table 23. The mean concentrations of Zn in uncooked and cooked rice are 6200, 3088 µg/kg; 6960, 3302 µg/kg; and 6446, 2464 µg/kg from exposed, apparently control and control areas, respectively. Likewise, mean Se concentrations in uncooked and cooked rice from exposed, apparently control and control areas are observed as 65, 52.5 µg/kg, 1122, 360 µg/kg and 972, 228 µg/kg, respectively. From the above observations, it can be stated that the mean concentration of Zn is higher compared to that of Se for both uncooked and cooked rice and Se concentration is comparatively lower in both the forms of rice from exposed area than apparently control and control areas. The mean concentrations of Se and Zn of 66.2, 52.3 µg/kg; and 9690, 6620 µg/kg were reported in rice grain from other severely As-affected blocks namely Domkol and Jalangi located in Murshidabad district of West Bengal, respectively (Roychowdhury et al., 2003). Halder et al. (2020) showed a mean accumulation of essential elements like Zn (9790 µg/kg) and Se (280 µg/kg) in rice from Bengal basin.

Table 23: Distribution of As, Zn and Se concentrations in uncooked and cooked rice from exposed, apparently control, and control areas of West Bengal, India

		Concentration (µg/kg)					
Area	**Source**	**As**		**Zn**		**Se**	
		Mean	**Range**	**Mean**	**Range**	**Mean**	**Range**
Exposed (rural)	Uncooked rice	338	92.1-895	6200	5940-6460	65	50-80
	Cooked rice	92.3	23.3-365	3088	2899-3278	52.5	35-70
Apparently control (urban)	Uncooked rice	162	59.6-306	6960	6917-7002	1122	1109-1134
	Cooked rice	32.4	19.3-62.8	3302	3160-3444	360	348-372
Control (rural)	Uncooked rice	85.7	38.8-246	6446	6070-6798	972	735-1152
	Cooked rice	28.2	12.2-55	2464	1592-3156	228	165-354

Fig. 25 shows the contribution of micronutrients i.e. Zn and Se (µg/day) along with DDI of As (µg/kg bw/day) through cooked rice. The intake amount of Se for adult male, adult female, and children from exposed area has been observed as 71.1, 54.7, and 36.1 µg/day, respectively. In the case of apparently control and control area, the different age groups showed Se intake as 213, 138, 67.7 and 285, 214, 124 µg/day, respectively. Contrastingly, the intake amount of Zn for adult male, adult female and children has been observed as 4184, 3221 and 2124 µg/day, respectively from exposed area. For the apparently control and control age groups, Zn intake has been observed as 1958, 1274, 621 µg/day, and 3080, 2311, 1337 µg/day, respectively. Several factors like age, gender and also pregnancy affect the most favourable consumption rate of Se (Kuria et al., 2020). The recommended dietary intake (RDI) value for Se is 60 µg/day (Zhang et al., 2020a), while that for Zn is 15000 and 12000 µg/day for adult male and female, respectively (Rubio et al., 2009). Hurst et al. (2013) reported that the allowable ranges of Se for different age groups were 40-85 µg/day(adult male) and 30-70 µg/day(adult female). In this study, the observed dietary intake rate of Se (µg/day) through cooked rice for adult female and children from the exposed populace is lower than the RDI value; whereas, slightly higher for adult male. Wang et al. (2018) estimated the dietary Se intake of consumers through agro-foods as 44.6 µg/day, which was less than the RDI value. As, there is no definite recommended level of Zn in rice (Kukusamude et al., 2021), the permissible value for Zn in food standard i.e. 50000 µg/kg has been considered (Jha, 2016). In this study, the level of Zn in cooked rice is lower than the permissible limit of Zn in food standard for the studied populaces. Kukusamude et al. (2021) showedthatthe average Zn concentrations (25180, 25470, 19530, and 25310 µg/kg) in four different rice varieties from Thailand were much lower than the threshold limit. Another report from Guangdong Province, Southern China (Ma et al., 2017) showed a mean Zn concentration of 16400 µg/kg (range: 12000-25500 µg/kg, n=41) in rice, which was much lower than the threshold value). Zn is considered as one of the essential elements for metabolic processes; as a result, long-standing excessive intake of Zn can result in iron deficiency, and causes several disorders in humans (Saha et al., 2016). Overall, this study showed that the mean Se intake through cooked rice for all the age groups from the exposed area is much lower compared to the apparently control and control areas. Whereas, Zn consumption amount is higher in case of exposed populace (3176 µg/day) compared to apparently control (1284 µg/day) and control (2243 µg/day) populaces. The plausible explanation might be due to the variation in ingestion rate (amount) of cooked rice for the different studied areas. A similar study from rural Bengal also reported that rice consumption (amount) was a major source for fulfilment of essential elements in human body system for various physiological activities (Halder et al., 2020). The water As concentration plays a vital role in the distribution of micronutrients in cooked rice during its preparation (Table 23), which was corroborated by Chowdhury et al. (2020). Therefore, the water mainly usedduring cooked rice preparation regulates the distribution of As and other micronutrients. As per the observations, it can be stated that geographical area, IR, rice cultivars and cultivation procedure are the important factors for the distribution of essential elements in uncooked and its respective cooked rice. Difference in accumulation of essential and non-essential elements in rice was found dependent on irrigation practices, paddy soil, areaal variation and several other environmental factors (Ahmed et al., 2011; Halder et al., 2020; Norton et al., 2009). Half of the world's populace relies primarily on rice as a source of nourishment; as a result, deficiency of micronutrients in rice makes As-toxicity more susceptible (Duan et al., 2013) and is referred as "hidden hunger" (Deshpande et al., 2017). Thus, deficiency of Se in rice plays a vital role against As-toxicity for exposed populace in this study. So, a proper nutritional balanced diet needs to be maintained on a daily basis to sustain a healthy life.

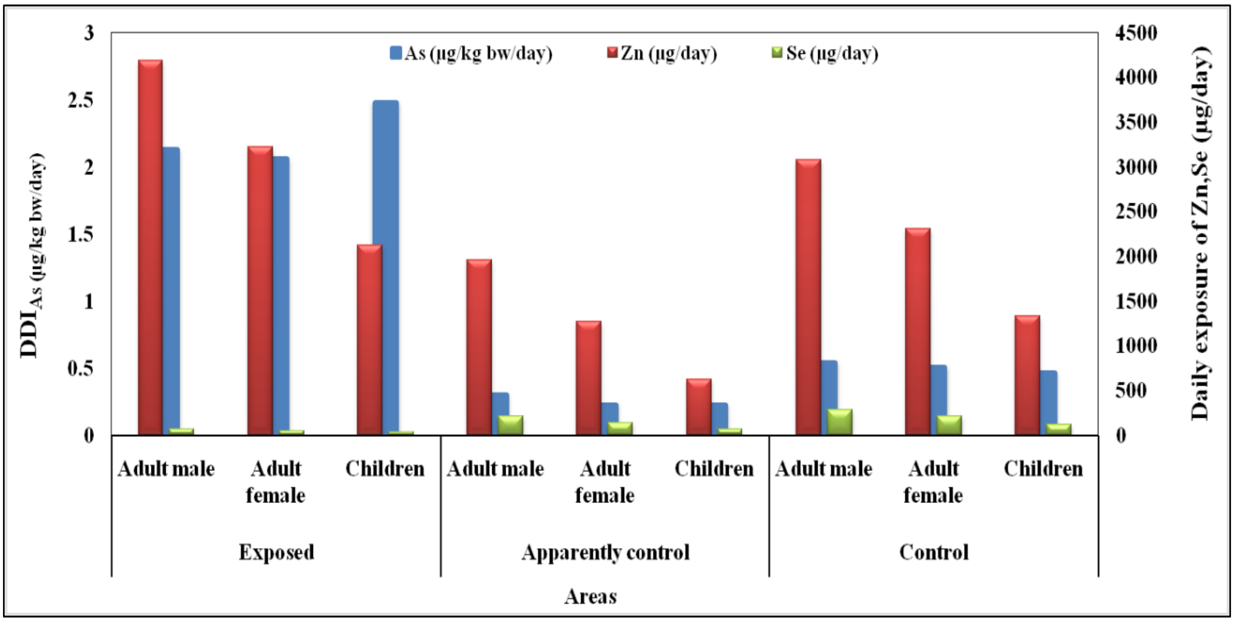


Fig. 25. Contribution of micronutrients (Zn and Se) along with DDI of As through cooked rice

6.4.11. Benefit-risk assessment of selenium, zinc associated with As

For benefit-risk calculation, the PTDI value of As has been considered as 3 µg/kg bw/day (WHO, 2011b) and the RDI value for Se is 60 µg/day (Zhang et al., 2020a). Table 24 showed the benefit-risk assessment (in percentage) of Se and Zn associated along with As through uncooked and cooked rice for all the studied groups. The observed AI/PTDI ratio associated with the toxicant

(As) for the exposed populace is higher than 100% through uncooked rice compared to cooked rice. In case of exposed populace, the observed ratio through cooked rice for adult male, adult female and children are 71, 68.7 and 82.6%, respectively, which signifies there exists risk of poisoning compared to apparently control (10.1, 7.42, and 7.66%) and control (18.1, 16.8, and 15.7%) populace. Fig. 26 showed the stacked distribution pattern of benefit-risk assessment through As, Se and Zn for all the studied groups from three different areas. The AI/RDI ratio of Se through cooked rice for the adult male, adult female, children are 356, 221, 113% and 475, 356, 206% from the apparently control and control populace, respectively. Comparatively, the AI/RDI values of Se are much higher than 100% for apparently control, control populaces compared to exposed populace. As a result, it symbolizes that the Se intake fulfils the physiological need of human body for the apparently control and control populaces compared to exposed populace. Likewise, for the exposed populace, the cooked rice Se ratio is 119, 91.2, and 60.2% for adult male, adult female and children respectively which is lower as well as signifies that the populace needs to increase the intake to meet the need of the body through Se-rich dietary foodstuffs. Considering different age-groups and gender, the tolerable dietary intake (TDI) level for Zn is considered as 40 mg/day as declared by Institute of Medicine (IOM) (Filippini et al., 2018; Razzaque et al., 2021). In case of Zn, as there is no specific RDI through rice (Kukusamude et al., 2021), considering the 40000 µg/day (TDI) value, it has been observed that the ratio is much lower for all the studied populace. A similar study by Zhang et al. (2020a) also showed that dietary intake of Zn through agro-foods by adults is lower than the TDI value. Overall, considering the benefit-risk assessment for the exposed populace, it has been observed that there exists risk of poisoning through cooked rice, as the value of As is at a marginal level and also their benefit (Se<100%) level is low. Moreover, the study also highlights that the benefit-risk assessment, considering As and Se for apparently control and control populace are at a good level to fight against the As toxicity. Increasing the consumption rate will make the actual intake (AI) for all the studied populace to fulfil their respective recommended daily intake (RDI) (Zhang et al., 2020a). In our study, benefit-risk evaluation supported that the Se-rich values in cooked rice are effective in avoiding the toxic effect and potential risk from the associated metal (As). This benefit-risk assessment is highly important to advice the dietary intake and related public health associated with diet for controlling and prevention of disease (Fang et al., 2021).

Table 24: Benefit-risk assessment (in percentage) of selenium and zinc associated along with As through a) Uncooked rice and b) Cooked rice for all the studied groups

a) Uncooked rice

Elements	Areas	Benefit-Risk assessment (%)		
		Adult male	Adult female	Children
Arsenic	Exposed	104	101	121
	Apparently control	20.2	14.8	15.3
	Control	22	20.5	19.1
Selenium	Exposed	58.7	45.2	29.8
	Apparently control	443	274	140
	Control	810	608	352
Zinc	Exposed	8.40	6.46	4.26
	Apparently control	4.12	2.55	1.31
	Control	8.06	6.04	3.49

b) Cooked rice

Elements	Areas	Benefit-Risk assessment (%)		
		Adult male	Adult female	Children
Arsenic	Exposed	71	68.7	82.6
	Apparently control	10.1	7.42	7.66
	Control	18.1	16.85	15.7
Selenium	Exposed	119	91.26	60.2
	Apparently control	356	221	113
	Control	475	356	206
Zinc	Exposed	10.46	8.05	5.31
	Apparently control	4.89	3.04	1.55
	Control	7.7	5.78	3.35

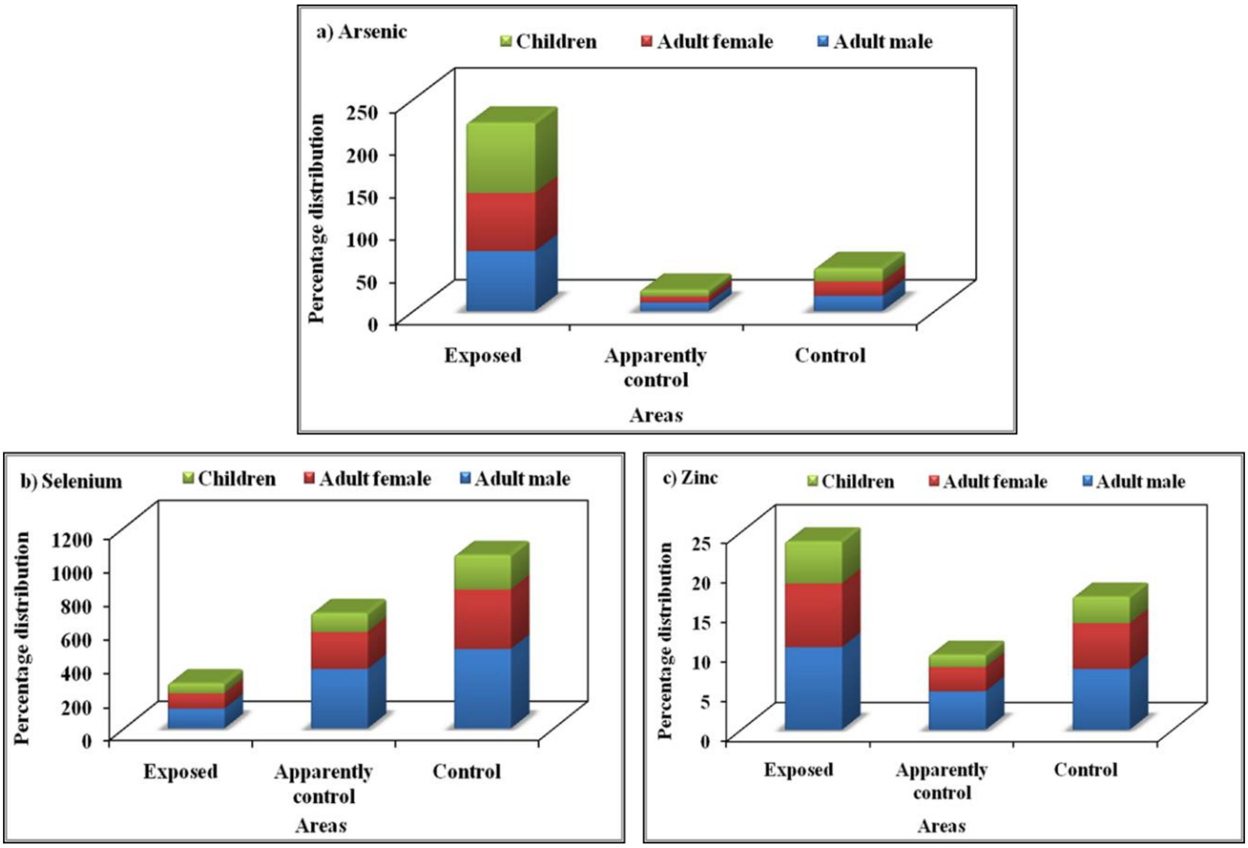
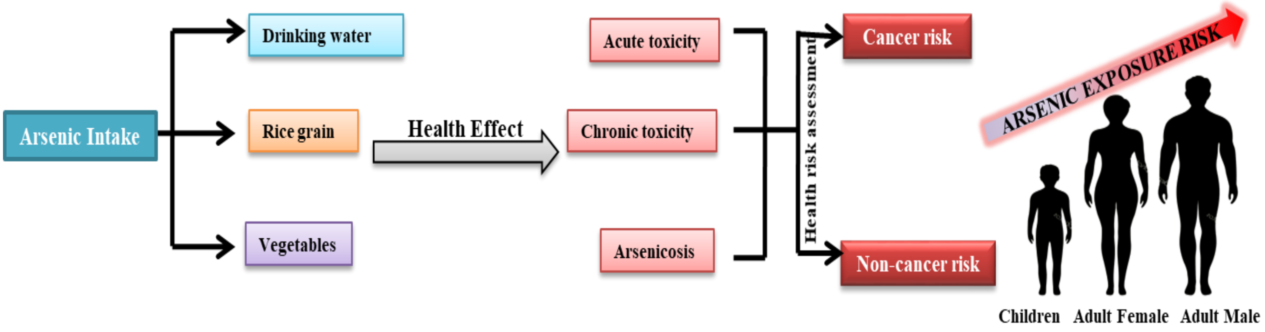


Fig. 26. Benefit-risk stacked distribution pattern for all the studied groups from three different areas through a) Arsenic, b) Selenium and c) Zinc

Overall, cooking practices at a domestic scale (1:3 ratio) with As-safe water reduce high As accumulation in cooked rice compared to uncooked rice, irrespective of their geographical area. The risk thermometer categorized cooked rice under risk class 4 for exposed (rural) and risk class 3 for apparently control and control populaces. Considering the probabilistic risk (uncertainty) analysis, the LCR and HQ through cooked rice follow the order as adult male > adult female > children for all the studied populaces. Overall, this study stated that the three differently studied populaces are at a high health risk through consumption of cooked rice for adults compared to children mainly depends on the IR and C factors. The study also highlighted that despite decreased As levels in cooked rice, the health risk of As exposure to both rural and urban populaces from cooked rice consumption remains substantial. Consumption of lower amount of Se through cooked rice showed that the exposed populace had less protective nature against As-toxicity compared to control and apparently control populace. Benefit-risk assessment also supported the fact that Se-rich values in cooked rice are effective in avoiding the toxic effect and potential health risk.



HEALTH EXPOSURE
&
ARSENICAL SKIN MANIFESTATIONS

6.5. Health exposure to arsenic toxicity through drinking water with special reference to rice grain contamination in arsenic affected blocks from West Bengal, India

The study mainly focuses on the contamination scenario of As in groundwater of the two affected blocks and put forward the As burden in raw rice grain, which is primarily cultivated using groundwater contaminated with As. Simultaneously, it will also give emphasis on future risk assessment of the studied populace on the basis of their dietary intake. The studied populace belongs from two blocks named Deganga and Gaighata situated on the east river bank of Hooghly in the district North 24 Parganas in West Bengal, which is a part of the lower Gangetic delta.

6.5.1. Level of As Contamination in drinking water of the studied areas

Our surveyed populace belongs from Deganga, which is considered as one of the severely As-endemic area in North 24 Parganas district (Chakraborti et al., 2009). Chakraborti et al., 2001 reported that the shallow tube-wells used for irrigational purposes in the agricultural fields of Deganga block showed As withdrawn rate of approximately 6.4 tons per annum and As got deposited on soil throughout the year. Mandal, 1998 highlighted about 96% of all shallow tube-wells used in agricultural field contains higher amount of As compared to the recommended value of WHO guideline of As level in drinking water, i.e. 10 μg/L. Roychowdhury 2010, reported that among the all water samples collected from the shallow tube-wells located in Gaighata block about 59.2% and 40.3% contained As concentration above 10 and 50 μg/L respectively. In the rural belts of West Bengal, drinking of As-contaminated groundwater is a common practice till today. Apart from drinking, the affected populace consumes As through their daily dietary foodstuffs which are being cultivated using groundwater from As-contaminated shallow tube-wells/which are being cultivated in agricultural fields irrigated by As-contaminated groundwater. The water samples from domestic tube-wells were collected from 6 inhabitant families in Deganga block and Gaighata block respectively showed that the populace usually consumes 10 times higher As than the permissible limit. In Deganga block, the As concentration in water samples ranged 168-1290 μg/L with a mean concentration of 774 ± 446 μg/L. Similarly, in Gaighata block, the As concentration in water samples ranged of 398-613 μg/L with a mean concentration of 506 ± 80 μg/L (Fig. 27).

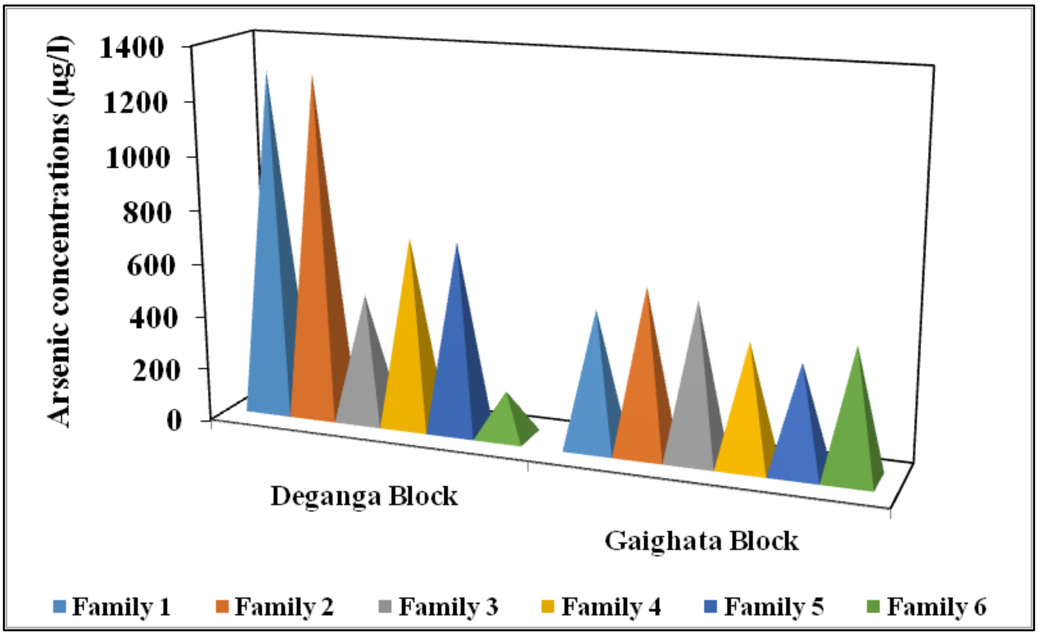


Fig. 27. Groundwater As concentrations in ground water samples collected from 6 inhabitant families of affected blocks

6.5.2. Status of As accumulation in rice grains of surveyed blocks

The successive study was performed with the rice grains which were collected from 6 inhabitant families belong to the two As-endemic blocks of the North 24 Parganas district. The rice grains are mainly cultivated using the As-contaminated groundwater, which also leads to accumulation of As in agricultural soil. When such contaminated soils are used during cultivation of plant crops like paddy, As naturally enters into our body system through the consumption of contaminated cereals (Zhao et al., 2010**).** Populaces dependent on a regular diet of rice and its derivatives are more prone to develop As related problems. Bring a staple crop, rice considered to be the main reason for the occurrence of health problems related to As toxicity in major As-affected areas throughout the world such as China, Africa, Taiwan, Bangladesh and India (Azam et al., 2016). In the rural belt of Bengal, rice is well-known as the staple food crop. Samal et al., 2011 stated that using of As-contaminated water during irrigation purposes; rice cultivation period leads to additional burden of As in the plant system making the situation more worst**.**

The rice grain samples collected from each family (n=6), showed a considerable amount of As concentration and all were with As-concentration higher than the recommended permissible limit of As in rice according to WHO. In Gaighata block, the rice grain samples showed a concentration range of 229-1970 µg/kg As with a mean concentration of 720 ± 634 µg/kg. Similarly, in Deganga block, the rice grain samples showed a concentration range of 78-341 µg/kg As with a mean concentration of 171 ± 97 µg/kg (Fig. 28).

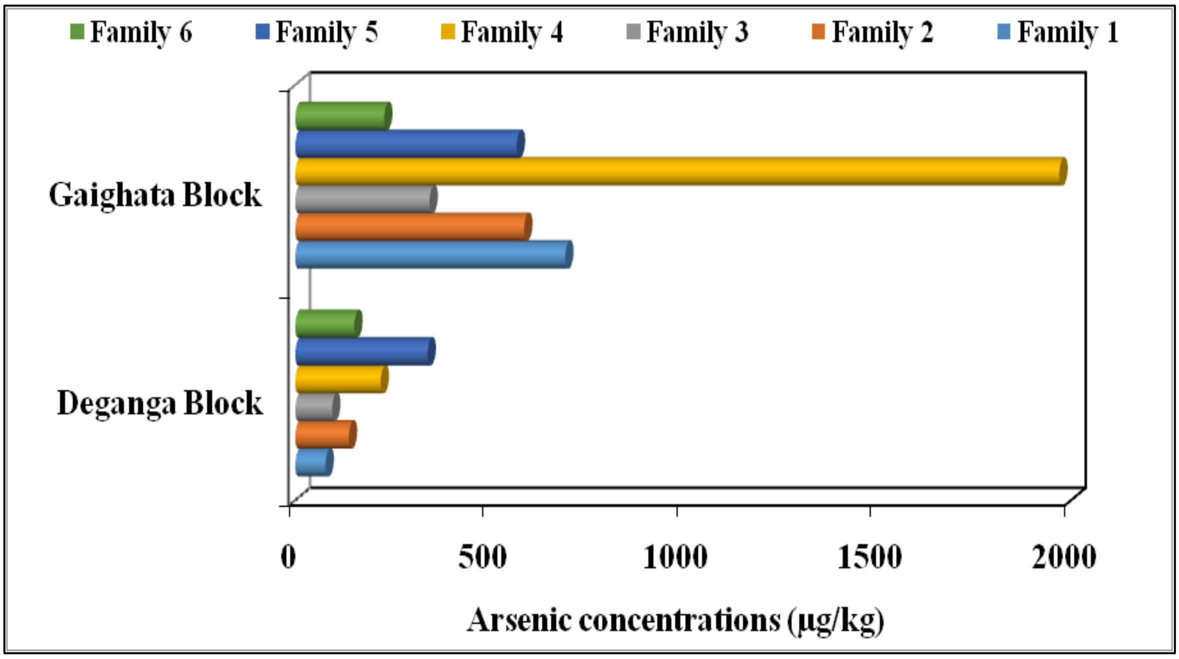
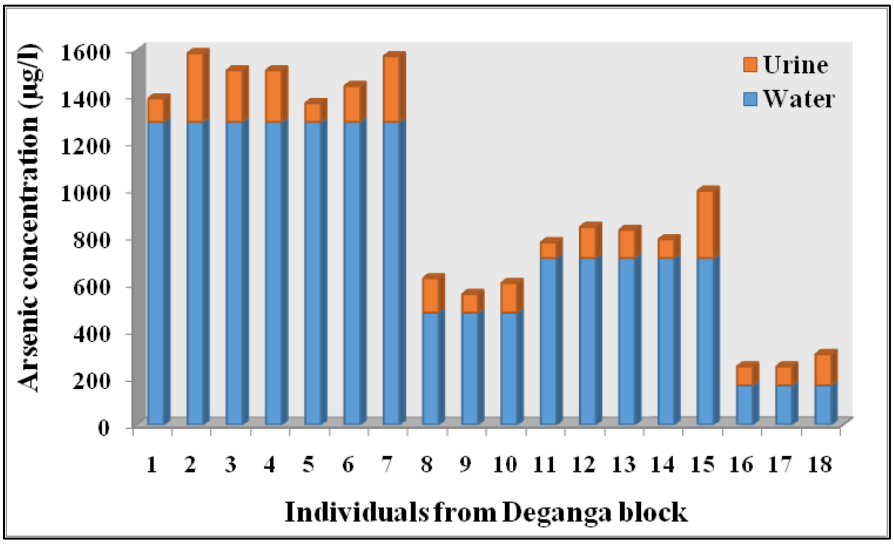


Fig. 28. Arsenic concentration in raw rice grains collected from 6 inhabitant families of studied endemic areas

6.5.3. Exposure of acute toxicity on individuals

Being a major route of excretion of most As species, the total urine As concentration has often been considered as an effective indicator of recent exposure level (Buchet et al., 1981; Vahter et al., 1994). The half-life of inorganic As is about 4 days in human body system. Das et al., 1996 reported that in West Bengal, higher urine As concentration has been observed for the populace living in exposed areas and consuming high level of As through drinking water. Roychowdhury 2010 reported about 83% and 68% of the collected urine samples from the affected individuals in Gaighata block contained As concentration above 10 and 20 µg/L respectively. Analyzing the concentration of As in urine samples determine the acute effect of As consumption in the internal body system. Our survey revealed that the populace from the two affected blocks is not drinking As free water, but they have prominent level of As in urine. So, it easily indicates that contaminated drinking water is solely not responsible for acute exposure but also other foodstuffs, which are being mainly, cultivated using As-contaminated irrigational water.

Urine samples collected Gaighata populace (n=17) showed an average concentration of 112 ± 176 µg/L, correspondingly, urine samples from Deganga populace (n=18) showed an average concentration of 148 ± 77 µg/L (Fig. 29) whereas the allowable limit of As concentration in urine is 3-26 μg/L.



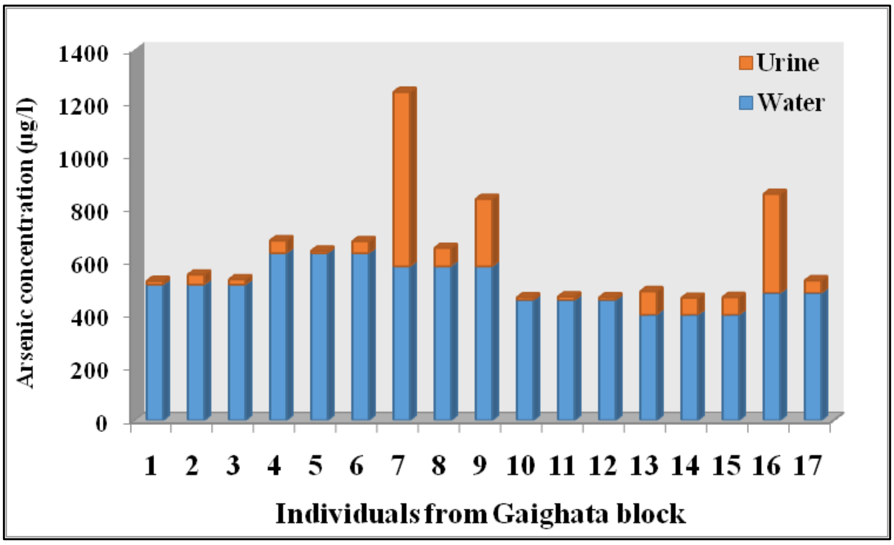


Fig. 29. Arsenic concentration in urine samples collected from the individuals of affected blocks

6.5.4. Exposure of chronic toxicity on individuals

The best biological samples used as indicators for prolonged As toxicity in human body system are hair and nail (Samanta et al.,2004). Shapiro et al., 1967 explained that the deposition rate of As is higher in hair and nail tissues from other body parts due to the presence of high amount of keratin protein. This elevated As-concentration in hair and nail samples strongly indicate that the individuals are consuming As-contaminated water for a long time throughout their lives. Das et al., 1996 reported that in West Bengal, 1810-31050 μg/kg As in hair for the populace who consume high level of As through drinking water and other foodstuffs. In Gaighata block, an average concentration of 2500 µg/kg in hair was observed for the exposed populace (Roychowdhury 2010). Likewise, 1470-52030 µg/kg have been reported in nail for the populace who consume high level of As through drinking water and other sources (Das et al., 1996). In Gaighata block, an average concentration of 6050 µg/kg in nail was observed for the exposed populace (Roychowdhury 2010). Both the observed reults are higher than the normal range of As in hair and nail, respectively.

The chronic exposure of As consumption for long period of time was also observed in the studied blocks situated in North 24 Parganas. The exposed hair samples collected from the populace of Deganga (n= 18) showed As concentration in the range of 1.54 to 11.43 µg/g with an average concentration of 5.65± 2.77 µg/g. Similarly, exposed hair samples of Gaighata populace (n=17) showed As concentration in the range of 0.23 to 13.3 µg/g with an average concentration of 5.93±3.19 µg/g, where the permissible limit of As in hair is 0.08-0.25µg/g. As concentration in the exposed hair samples of the Deganga populace (n=18) range from 1.21 to 10.9 µg/g with a mean concentration of ± µg/g. Likewise, exposed samples of hair from Gaighata populace (n=17) showed As concentration in the range of 3.64 to 23.5 µg/g with an average concentration of 9.84 ± 4.68 µg/g (Fig. 30), where the permissible limit of As in nail is 0.43-1.08 µg/g.

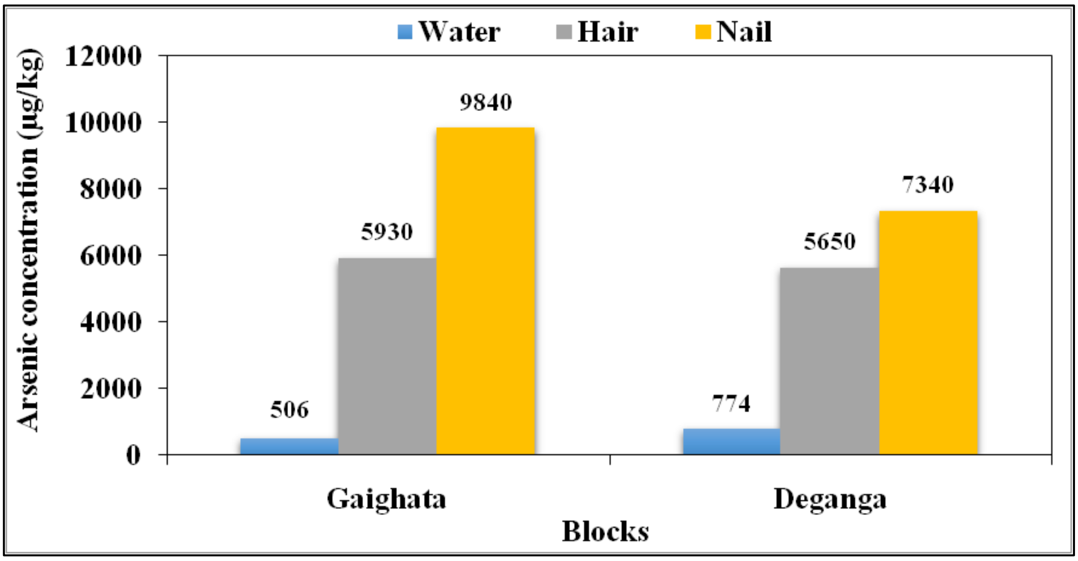


Fig. 30. Arsenic concentration in collected hair and nail samples from the affected individuals of studied blocks

Linear regressions showed a good correlation between the As content in drinking water samples vs. hair and nail samples which were collected from the populaces of both the affected blocks of North 24 Parganas (Fig. 31).

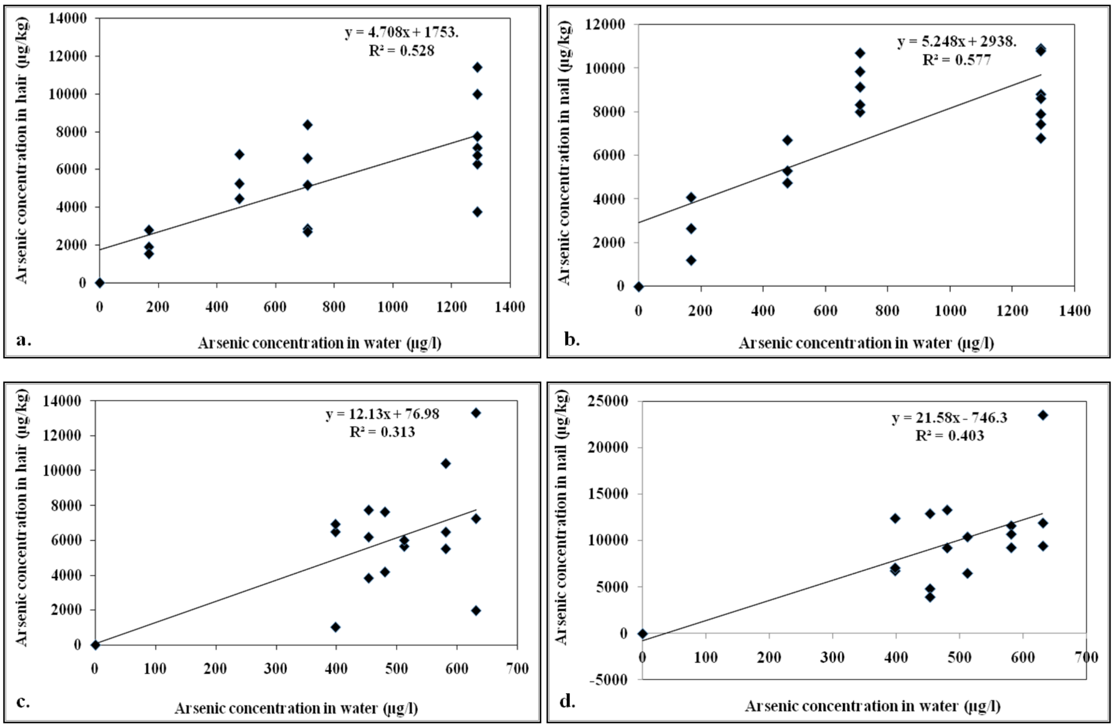


Fig. 31. Regression analysis between As concentrations in drinking water with a) Hair samples collected from Deganga population, b) Nail samples collected from Deganga population, c) Hair samples collected from Gaighata population, and d) Nail samples collected from Gaighata population

6.5.5. Risk Assessment on the studied population

An assessment on cancer risk factor was performed on affected populace of the two blocks of North 24 Parganas. The general formula used for assessing the intake rate of inorganic As was adapted from the USEPA policy (USEPA 2001). The result of our observations signified that the intake of As contaminated groundwater might be responsible for high risk of cancer.

The probability of individual exposure of As through the ingestion of contaminated drinking water was evaluated by using Health Risk Assessment. The risk of cancer upon exposure of inorganic As for the Male and Female from the studied areas has been shown in Fig. 32. Our study revealed that in case of both the affected populace the male individuals are prone to higher cancer risk compared to the female individuals. Similarly, in the non-cancerous risk assessment (through inorganic As), both male and female individuals showed the HQ value that is much higher than 1. So, there is a high possibility of occurrence of several other severe health issues in the studied populace as they are exposed to As not only through consuming As-contaminated water but also through contaminated foodstuffs found in the affected areas.

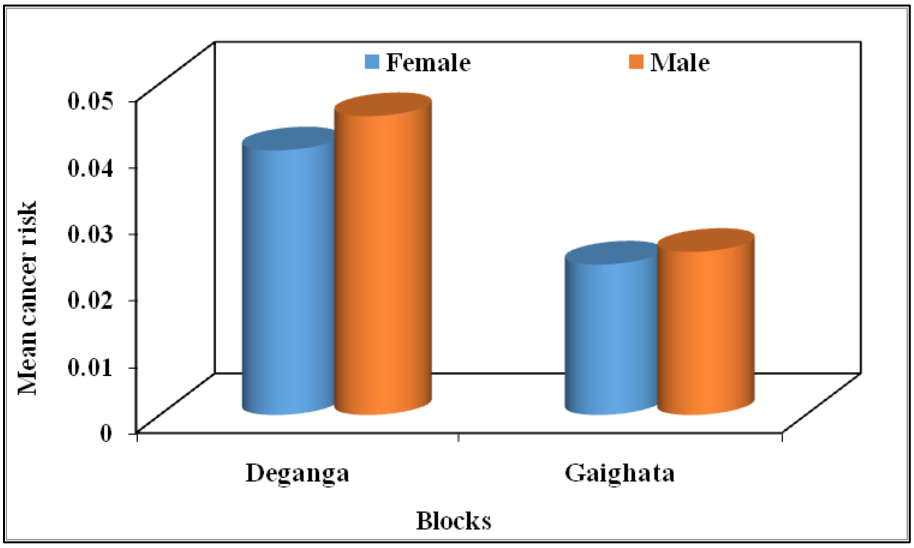


Fig. 32. Cancer risk assessment in male and female from the studied population

Our study revealed that in case of both the affected populace the male individuals are prone to higher cancer risk compared to the female individuals. Similarly, in the non-cancerous risk assessment (through inorganic As), both male and female individuals showed the HQ value that is much higher than 1. So, there is a high possibility of occurrence of several other severe health issues in the studied populace as they are exposed to As not only through consuming As-contaminated water but also through contaminated foodstuffs found in the affected areas.

6.6. Appraisal of health exposure and perception of risk on the populaces exposed to varying arsenic levels through drinking water and dietary foodstuffs from four villages of arsenic endemic block

Mathpara (Bishnupur), Eithbhata (Teghoria), Madhusudankati (Sutia gram panchayat), and Jamdani (Ichapur II-gram panchayat) were selected as study areas from a severely As-affected block Gaighata of North 24 Parganas district, West Bengal, India. The study was conducted on different aged-individuals from Mathpara (22º54´11.17´´N, 88º47´30.97´´E), Eithbhata (22º54´19.13´´N, 88º47´51.12´´E), Madhusudankati (22º53´53.18´´N, 88º46´38.55´´ E), and Jamdani (22º53´54.18´´N, 88º46´03.37´´E) that have been grouped under extravagantly moderate and meager As-affected areas, based on the current status of the As contamination of groundwater. Fig. 33 shows the map of the studied areas.

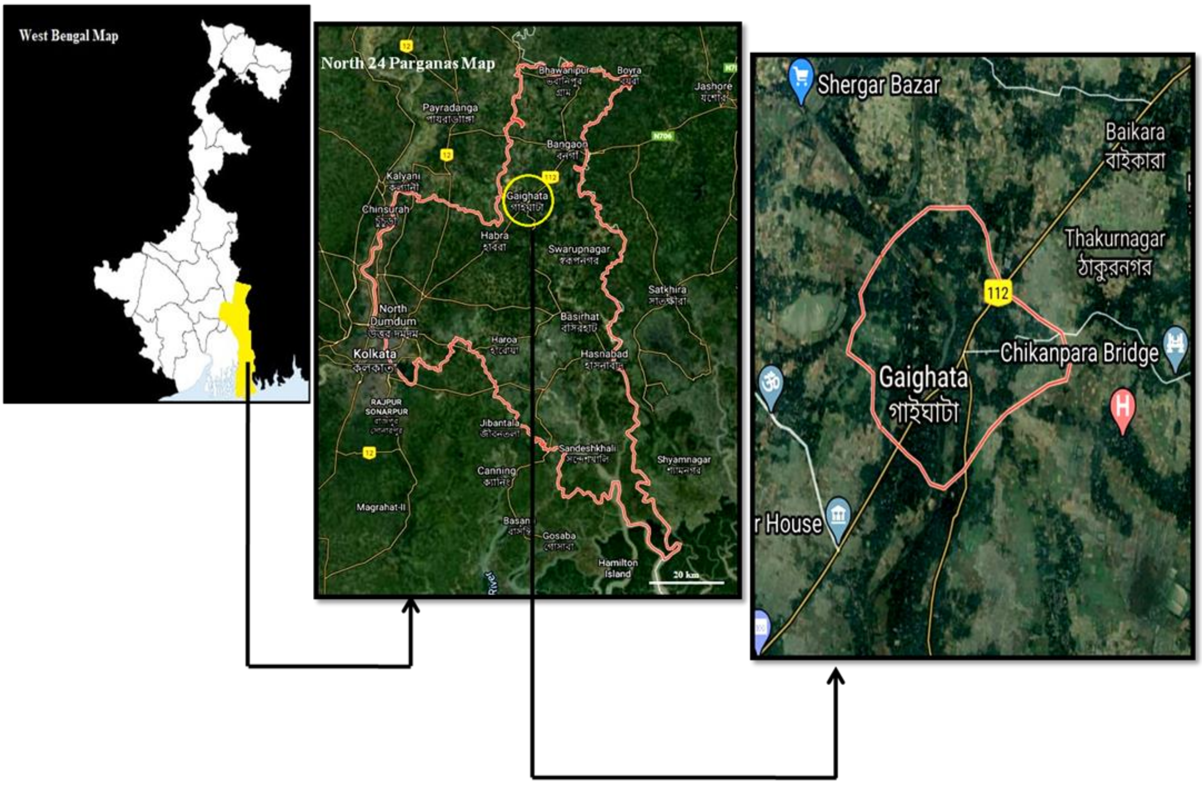


Fig. 33. Map of the As-affected area

Four populaces exposed to different groundwater As levels (drinking purpose) and daily dietary intakes (rice by-products, rice and vegetables) foodstuffs have been surveyed for a health risk evaluation study. Quantitative analysis of As in the biomarkers to measure the acute (urine) and chronic (biological tissues i.e. hair and nail) exposure among the different age groups. Statistical elucidation evaluated the inter-relation among drinking water and the arsenical biomarkers for the different populaces. SAMOE value categorized the class of risk and its concern level through intake of different As-concentrated drinking water, rice and vegetables among the different exposed populaces. The future health risk assessment study (carcinogenic and non-carcinogenic) through the daily intakes of the different aged individuals from all the exposed populaces was examined. To our knowledge, this study delivers an extensive view on the present health exposure and perception of risk scenario due to As toxicity of the populaces exposed with different groundwater As levels along with various dietary intakes from an As-affected block.

6.6.1. Groundwater As contamination

The current As in domestic tube-wells in the four diversely exposed villages disclosed that the populaces continue to be on the verge of drinking As-contaminated groundwater. The average As concentration in domestic tube-well water (n=12) samples taken from families living in an extremely high village was 615 µg/L (ranged from 433-966 µg/L). Water samples (n=15) drawn from highly vulnerable domestic tube-wells (Eithbhata) revealed an average concentration level of 301 µg/L (ranged from 29-829 µg/L). Water samples taken from residential tube-wells (n=15) of residents living in the moderate exposed (Madhusudankati) village revealed an average As concentration of 48 µg/L (ranged from 3-169 µg/L), whereas, tube-well water (n=10) samples from mild exposed village showed the average As concentration of 20 µg/L (ranged from:8.5-56 µg/L). With respect to the entire groundwater As-contamination situation, the average water As concentration (µg/L) made a significant contribution of 62, 31, 5, and 2% in incredibly highly, highly, moderate and mild villages, respectively, and it distinguishes the vulnerability rates of the inhabitants currently living in differently exposed parts. The dominant As species in underground water from West Bengal, India, and Bangladesh has been recognized as inorganic As (chiefly arsenite and arsenate) (Huq and Naidu, 2003; Tokunaga et al., 2005).

6.6.2. Arsenic in dietary foodstuffs

Table 25 represents the As accumulation in rice, rice by-products, wheat flour, and vegetables from all the exposed villages.

Rice grain: In Bengal and Bangladesh, apart from As-contaminated groundwater, rice grain is observed as the primary source of As for the local dwellers (Chowdhury et al.,2020a, b; Rahman et al., 2011). Bengal is very renowned for being one of India's foremost rice growing states (Signes-Pastor et al., 2008). Rice grain piles up a massive concentration of As in GMB plain due to the utilization of As-contaminated underground water during crop production (Chowdhury et al., 2018a; Sun et al., 2008) when contrasted to irrigational production (Das et al., 2004). The huge populace of India tends to depend on rice and its derivative products for sustenance (Chowdhury et al., 2018b; Rahman et al., 2008). In rural Bengal, partially cooked rice grain is largely used for regular cooked rice preparation, and it usually accumulates extra As than sun tanned rice grain (Chowdhury et al., 2018b). The inclusion of As to partially cooked rice grain is made possible by parboiling paddy grain in As-contaminated water. The average levels of As in parboiled rice assembled from the respective Mathpara, Eithbhata, Madhusudankati, and Jamdani villages were 792 µg/kg (ranged from: 229-1970 µg/kg, n=14), 487 µg/kg (ranged from: 172-1057 µg/kg, n=15), 588 µg/kg (ranged from: 105-2026 µg/kg, n=16), and 569 µg (ranged from: 283-895 µg/kg, n=10).

Consumption of iAs via cooked rice made from cultivated rice grain (staple crop) which is locally grown, poses a significant threat to the populaces of the Bengal delta (Chowdhury et al., 2020a; Halder et al., 2014; Mandal et al., 2019). The average As concentration in rice from Nadia and Murshidabad districts was 214 µg/kg (ranged from: 43-662 µg/kg, n=52) (Roychowdhury, 2008a). As per Chowdhury et al. (2018a), the average As accumulation in rice (n=10) nurtured in Deganga block was 1120 µg/kg (ranged from: 360-1560 µg/kg). The occurrence of increased levels of iAs in rice and cooked rice from the Bengal delta and worldwide has indeed been noted (Meharg et al., 2009; Williams et al., 2006). All of these observed values are consistent with the study's findings. In this report, the concentration of As in rice from the individual affected village (mean: 609 µg/kg, ranged from: 105-2026 µg/kg, n=55) was greater compared to the ingestion of rice with iAs value of 100 µg/kg, which displayed the least danger in As-affected nations (Meharg et al., 2006b), whereas, 200 µg/kg (European Commission, 2015) for adults in rice-based produces. The variation in concentration of As in rice grain is caused by numerous reasons, which include rice grain variety (Booth, 2008; Chowdhury et al., 2018a) and geographic area (Meharg et al., 2009; Schmidt, 2015). Rice is the primary nutritional source of As, for the inhabitants drinking As-safe water (Biswas et al., 2019; Chatterjee et al., 2010). As per our research results, the As concentration in rice grain was nearly equal in all 4 separately exposed parts. This might be because of the point that most of the raw rice grains and seasonal vegetables were cultivated locally (own agricultural lands) and as a result enters the local market.

Table 25: Status of As accumulation in rice grain, rice by-products, wheat flour, leafy, and non-leafy vegetables (µg/kg) collected from the exposed families in the studied areas

	Exposed populations											
Categories	**Mathpara**			**Eithbhata**			**Madhusudankati**			**Jamdani**		
	n	**Mean**	**Range**	**n**	**Mean**	**Range**	**n**	**Mean**	**Range**	**n**	**Mean**	**Range**
Rice grain (parboiled)	14	792	229 – 1970	15	487	172 - 1057	16	588	105 - 2026	10	569	283 - 895
Rice by-products												
Puffed rice	14	109	39.2 – 196	15	86.7	32.4 - 149	16	354	203 - 571	10	98.1	63.6 - 157
Parched rice	14	101	48.1 – 203	15	346	210 – 692	16	399	208 - 821	10	121	98 - 143
Beaten rice	14	110	7.33 – 639	15	273	188 – 492	16	324	151 - 828	10	98	54.2 - 146
Wheat flour	14	34	14.6 – 105	15	96.3	46.2 - 285	16	76.9	3 - 191	10	29.5	19.9 - 37.7
Raw Vegetables												
Red spinach (leafy)	13	1360	535 – 2801	13	552	55 – 882	14	989	311 - 2212	10	1318	431 - 2557
Puin leaf (leafy)	8	189	77.2 – 508	5	64.4	20 – 94	10	117	21.1 - 297	6	148	83.2 - 227
Arum leaf (leafy)	12	295	82.2 – 855	12	191	49 – 430	13	195	51.3 - 410	9	216	128 - 339
Coriander (leafy)	5	568	33.9 - 887	4	445	355 – 613	5	522	354 - 766	5	353	162 - 676
Lab Lab beans	11	162	73.2 – 454	13	115	9 – 207	11	74.5	5.02 - 121	9	164	76.7 - 383
Brinjal	9	144	59.7 – 228	7	157	49 – 277	10	209	50.6 - 294	7	199	58.7 - 349
Cauliflower	13	71.5	9.99 – 229	13	81.8	14 – 237	14	74.2	3 - 292	9	98.7	33 – 258
Radish	11	239	115 - 532	11	220	61 – 554	15	185	67.4 - 389	9	260	147 - 443
Arum	10	110	24.2 - 267	11	156	15 – 403	14	96.9	17.2 - 294	9	166	32.4 - 516
Turnip	7	99.8	41.1 – 202	1	46	46	3	88.1	58 - 126	5	147	68.1 - 267
Carrot	3	37.5	14.9 – 67	4	51.7	14 – 82	5	93	31.6 - 160	4	166	53.7 - 389
Potato outer skin	14	136	95.2 – 168	15	185	88.6 - 242	16	281	128 - 409	10	331	288 - 388
Potato inner flesh	14	50.8	32.3 - 71.4	15	49	28.4 - 127	16	79.7	29.9 - 162	10	56.5	34.1 - 120

Rice by-products and wheat flour: Puffed, parched and beaten rice locally known as muri, khoi, and chire are rice by-products which are mainly produced from parboiled rice grains and consumed for breakfast and dinner. In addition, along with the accessible rice by-products from the studied villages, wheat flour is as well used once in a day for a meal. The observed mean As in all the respective puffed, parched and beaten rice were 162 µg/kg (ranged from: 32.4-571 µg/kg; n=55), 236 µg/kg (ranged from:48.1-821 µg/kg; n=55), and 201 µg/kg (ranged from: 7.33-828 µg/kg; n=55) from the four differently exposed villages. A study from Deganga block of North 24 Parganas district, showed a high concentration of As in rice by-products like puffed (ranged from: 103-354 µg/kg), parched (ranged from: 128-743 µg/kg), and beaten (ranged from: 110-516 µg/kg) rice (Chowdhury et al., 2018b). Sun et al. (2009) also indicated that rice products bought from UK market showed high As levels compared to normal rice. The current investigation shows that among the four differentially exposed villages, the trend of As accumulation in rice by-products does not vary proportionally with the rate of As exposure. Because the rice by-products were made from locally grown parboiled rice grains that were cultivated in the exposed areas, resulting in high As buildup. The main emphasis of As exposure through food is a diet enriched in rice. However, the rural populace in the Bengal delta is consuming more wheat in their daily diet. The second most important crop for human consumption is wheat which provides a great source of protein, carbohydrates, and vitamins (USDA, 2015; Zhao et al., 2010). The wheat flour used in this study was procured from local markets, as it was not locally grown. In all the exposed villages, the mean As content in wheat flour was 59.2 µg /kg, with a range of 3-285 µg /kg (n=55). In a recent investigation, wheat flour samples from Bihar (an As-exposed state sited in the middle Gangetic plain of India) residents revealed considerable levels of As in the diet (mean: 49.8 µg /kg, range: 3.59–448 µg /kg, n=58) (Suman et al., 2020). In India's key wheat-producing states like Punjab or Bihar, wheat grain may be grown utilizing As-contaminated soil and water before being delivered to neighboring local markets. Thus, risk exists for the next generation due to exposure from consuming meals containing wheat.

Vegetables (leafy and non-leafy): The mean As accumulations of leafy vegetables (red spinach leaf, arum leaf, coriander leaf, and puin leaf) for Mathpara (n=38), Eithbhata (n=34), Madhusudankati (n=42), and Jamdani (n=30) populaces showed 603µg/kg (ranged from = 33.9-2801 µg/kg), 313 µg/kg (ranged from = 20-882 µg/kg),455 µg/kg (ranged from = 21.1-2212 µg/kg) and 508 µg/kg (ranged from = 83.2-2557 µg/kg), respectively. Contrastingly, for the non-leafy vegetables (turnip, radish, brinjal, lab lab beans, cauliflower, arum, and carrot) the mean

As accumulations were 123 µg/kg (n=64, ranged from: 9.99-532 µg/kg), 118µg/kg (n=60, ranged from: 9-554 µg/kg), 117 µg/kg (n=72, ranged from: 3-389 µg/kg), and 171 µg/kg (n=52, ranged from: 32.4-516 µg/kg), respectively. The concentration of As in agricultural soil, irrigation water utilization, time-period of cultivation, and the ability of the crop under cultivation to accumulate As are the key determinants of As content in produced vegetables (Roychowdhury et al., 2002, 2003). Similar findings included those non-leafy vegetables from the As-affected Nadia and Murshidabad districts in West Bengal had higher As accumulation than leafy vegetables (Roychowdhury, 2008a). In Bangladesh, the leafy vegetables contributed as much as 130-790 µg/kg of As (Williams et al., 2006). In comparison to the fleshy area of the potato (n=55, mean: 59 µg/kg; ranging from: 28.4-162 µg/kg), the As accumulation is significantly higher in the skin (n=55, mean: 233 µg/kg; 88.6-409 µg/kg). Previous publications have also documented similar kinds of observations (Mandal et al., 1998; Roychowdhury, 2008a). The pattern of As accumulation does not change depending on the rate of As exposure between the four analyzed villages because the vegetables are grown-up locally and were undoubtedly available in adjacent local markets.

6.6.3. Daily dietary intake of As

Daily dietary intake of As through the ingestion of contaminated water, rice and vegetables by the adult male and female, children (4-15 years old) from the four populaces has been shown in the Table 26. Fig. 34 represents a pie-chart with the contributions of As concentration (µg/kg) through dietary intakes including water and foodstuffs to the differently exposed inhabitants residing in four villages, respectively. For the differently exposed populaces, drinking water contributed respective 30, 17, 2, and 2% in accordance to the total As concentration through dietary intakes. The contributions of As concentrations through rice grain and its by-products were higher compared to the vegetables for all the exposed areas. Daily dietary intake of As for all the studied populaces are in a sequence of Mathpara > Eithbhata > Madhusudankati > Jamdani. DDI of As for adult male, adult female and children of Mathpara populace were 6.8, 5.9, and 5.6 folds greater than that of the Jamdani populace. Intake of water, rice and vegetables by the studied inhabitants in their daily foods has been measured as per maintaining the procedure of the former studies from rural Bengal (Brahman et al., 2016; Roychowdhury, 2010). From the differently exposed areas, the ingestion of As via water, rice, and vegetables in the day-to-day diet of the exposed adult male individuals is greater than the adult female individuals. This work noticeably specifies that the exposed children populace is also at great risk concerning

As toxicity.

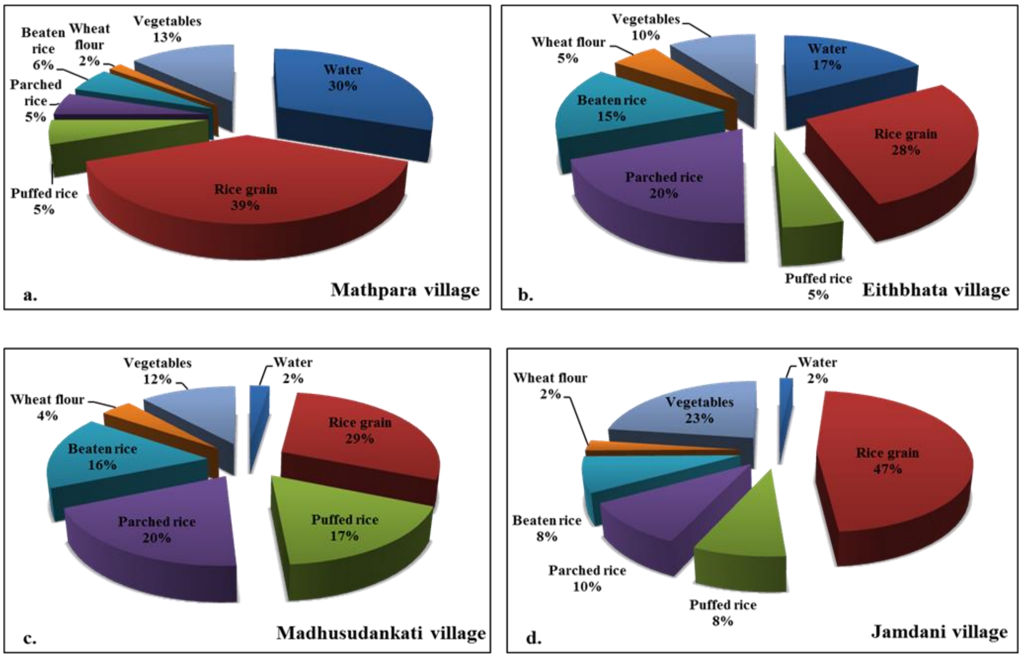


Fig. 34. Contributions of As concentration (μg/kg) through different dietary intakes to the four differently exposed populaces

6.6.4. Observed daily dietary intake rate of As

In this study, the DDI of As for adult male, adult female, and children from the differently exposed areas (Table 26) were much greater compared to the WHO suggested value 3.0 μg/kg bw/day. The observed mean values of DDI from all the studied populaces were 56, 28.7, 11.3 and 9.13 μg/kg bw/day in the respective Mathpara, Eithbhata, Madhusudankati and Jamdani, villages. So, the measured exposed populaces have been experienced with varied rate of As exposure through regular nutritional diet. The impact of As through drinking of contaminated water in extreme high and high exposed areas were around 81% and 78% of the total nutritive intakes, respectively, compared to moderate (31%) and mild (16%) exposed areas. 18, 21, 65, and 78% of the total day-to-day intakes was contributed by rice itself to the differently exposed populaces. So, this research study reveals the fact that the drinking of As-contaminated water is not solely accountable behind As exposure to the differently exposed populaces. Ingestion of As-contaminated food crops which are being cultivated in As prone areas plays a noteworthy role behind As toxicity. This paves an additional entry of As resulting in upcoming threat to the populaces living in both As endemic and non-endemic areas, even consuming As-safe drinking water. Drinking water and foodstuffs noticeably contributed significant amounts of iAs to the inhabitants which has been reported from countries like Northern Chile (Diaz et al., 2015) and

Pakistan (Rasheed et al., 2018) and is increasing the risk of As exposure. Furthermore, transportation of food crops from As endemic areas and subsequent intake leads to a great risk to the populace living in non-endemic areas (Biswas et al., 2019).

Table 26: Daily dietary intake rate of arsenic for adult male, adult female and children from the studied exposed areas

Source	Category	Daily consumption	Daily dietary intake of arsenic (µg/kg bw/day) (Drinking water (µg/l) and foodstuffs (µg/kg))											
			(a) Mathpara			(b) Eithbhata			(c) Madhusudankati			(d) Jamdani		
			Arsenic											
			Concentration	Total (µg)	Intake rate	Concentration	Total (µg)	Intake rate	Concentration	Total (µg)	Intake rate	Concentration	Total (µg)	Intake rate
Drinking water (Domestic)	Adult male	5 l	615	3075	51.3	301	1505	25.1	48	240	4	20	100	1.67
	Adult female	4 l		2460	44.7		1204	21.8		192	3.4		80	1.44
	Children	2 l		1230	41		602	20.1		96	3.2		40	1.33
Rice (Parboiled)	Adult male	0.712 kg	792	564	9.4	487	347	5.78	588	418	6.96	569	405	6.75
	Adult female	0.712 kg		564	10.2		347	6.3		418	7.6		405	7.36
	Children	0.380 kg		301	10		185	6.16		223	7.43		216	7.2
Vegetables	Adult male	0.100 kg	283	28.3	0.47	187	18.7	0.31	238	23.8	0.4	300	30	0.5
	Adult female	0.100 kg		28.3	0.52		18.7	0.34		23.8	0.43		30	0.54
	Children	0.060 kg		16.9	0.56		11.2	0.37		14.3	0.47		18	0.6
Total	Adult male			3667	61.2		1871	31.2		682	11.4		535	8.92
	Adult female			3052	55.4		1570	28.4		634	11.4		515	9.34
	Children			1548	51.5		798	26.6		333	11.1		274	9.13

6.6.5. Exposure and risk of suffering

6.6.5.1. Acute toxicity

Biomarker As concentration of the four exposed populaces of varying age groups are shown in Table 27. The foremost way for eliminating of urine As species, where the half-time of iAs is about 4 days in a human body, as it is less dependent on keratin (Goswami et al., 2020). To estimate the acute As exposure, the evaluation of urine As concentration is necessary (Vahter et al., 1994). The observed mean urine As concentrations for the individual considered age group from the extreme high, high, and moderate exposed populaces were higher than the normal urine As that ranged from 3-26 µg/L. The observed mean As in urine for all the considered age groups from the respective extreme high (n=35), high (n=41), and moderate (n=68) exposed populaces were 79.3 µg/L, ranged from 3-659 µg/L, 42.9 µg/L ranged from 11-147 µg/L, and 71.2 µg/L ranged from 13-407 µg/L. Presence of greater amount of As in urine clearly specifies that the studied inhabitants were suffering from acute As toxicity. Whereas, considering the mild exposed (n=39) populaces, the mean urine As is 4.69µg/L, ranging from 3-10.5 µg/L for all the considered age groups signify that the inhabitants was drinking As-safe water at the period of survey. Existence of high urine As concentration from the Gaighata block inhabitants was also reported in Roychowdhury (2010). All of these findings support our study results.

Table 27: Concentrations of As in biomarkers of the four differently exposed populations

Exposed Populations	**Group**	**Biomarkers of As**											
		Urine (µg/L)				**Hair (µg/kg)**				**Nail (µg/kg)**			
		n	**Mean**	**SD**	**Range**	**N**	**Mean**	**SD**	**Range**	**n**	**Mean**	**SD**	**Range**
Mathpara	**AM**	13	111	181	3-659	13	4880	2560	230-10400	13	7910	4270	2230-14400
	AF	14	84.2	130	7-400	14	6610	2740	1280-13300	14	10000	5980	1520-23500
	C	8	42.7	33	7-108	8	4780	2510	1020-9230	8	10100	3310	6160-13700
	Total	**35**	**79.3**	**75.2**	**3-659**	**35**	**5423**	**121**	**230-13300**	**35**	**9336**	**1352**	**1520-23500**
Eithbhata	**AM**	17	46.6	33.5	11-126	17	6580	5760	1090-20600	17	7510	5980	1500-22400
	AF	18	52.7	43.6	17-147	18	6270	4340	1340-16600	18	8760	5540	940-18500
	C	6	29.5	19.9	11-67	6	5530	2520	2410-8570	6	7370	3970	3160-12300
	Total	**41**	**42.9**	**11.9**	**11-147**	**41**	**6126**	**1624**	**1090-20600**	**41**	**7880**	**1057**	**940-22400**

Madhusudankati	**AM**	24	92.3	85.7	15-407	24	1520	1050	350-4050	24	1950	1110	380-5480
	AF	31	59.6	41.3	13-177	31	830	470	320-2260	31	1910	1190	50-5300
	C	13	61.7	26.8	21-98	13	1340	750	390-2830	13	1860	860	290-3200
	Total	**68**	**71.2**	**30.7**	**13-407**	**68**	**1230**	**290**	**320-4050**	**68**	**1906**	**172**	**50-5480**
Jamdani	**AM**	17	4.20	1.57	3-7.9	17	1080	870	20-2830	17	730	530	50-2440
	AF	20	3.08	0.29	3-4.3	20	740	670	10-2140	20	900	890	10-4030
	C	2	6.8	5.23	3-10.5	2	780	20	770-800	2	920	1000	560-1440
	Total	**39**	**4.69**	**2.56**	**3-10.5**	**39**	**867**	**444**	**10-2830**	**39**	**850**	**246**	**10-4030**

 # AM, AF, C stands for Adult Male, Adult Female and Children respectively.
Normal range of hair As content is 80 - 250 µg/kg, and > 1,000 µg/kg in hair shows toxic behavior (Arnold et al., 1990).
Normal range of nail As content is 430 - 1,080 µg/kg (Ioanid et al., 1961).
Normal range of urine As content is 3.33 - 26.7 µg/L (Farmer and Johnson, 1990).

Fig. 35 depicts a regression assessment of levels of As in water and urine collected from four village inhabitants. Water and urine As concentrations of inhabitants from Mathpara (n=22) and Eithbhata (n=21) villages have been discovered to have common conditions (R^2 = 0.539 and 0.532, respectively) (Fig. 35a, b). Increased concentrations of urine As (mean: 326 µg/L, ranged from: 208-659 µg/L, n=14) in incredibly high populaces exposed (Mathpara) plainly reveal that the majority of the communities were ingesting high As-contaminated water in the spectrum 480-828 µg/L. (Fig. 35a). Surprisingly, a marked reduction of urine As with water As accumulation has been noted in this scenario. This could be because, in a few cases, a small number of people as during survey have been drinking very little As-contaminated water from several other sources available in the village under study, other than their own residential tube-wells, resulting in lower As in urine (mean: 75 µg/L, ranged from: 31-132 µg/L, n=8). A reasonable correlation (R^2 = 0.511) was observed in the case of moderate populaces exposed (Madhusudankati village) (Fig. 35c). For the slightly exposed people (Jamdani village), however, a weak correlation (R^2=0.216) was noted (Fig. 35d). The evaluation of urine As revealed that peoples in extreme high, high, and moderate vulnerable villages were subjected to greater levels of As through drinking of water. The urine As of the slight (Jamdani) exposed group, on the other hand, revealed that the community was ingesting comparatively As-safe water in comparison to the other exposed people. The pattern of urine levels of As in several cases shows clearly that a small number of the populaces studied ingested both contaminated and treated water (As-safe) accessible at the respective residential and local level. Other research findings in As-affected districts of West Bengal and other parts of the world have found good correlations between water and urine As concentration levels of the residents (Maity et al., 2012; Rasheed et al., 2019; Roychowdhury, 2010).

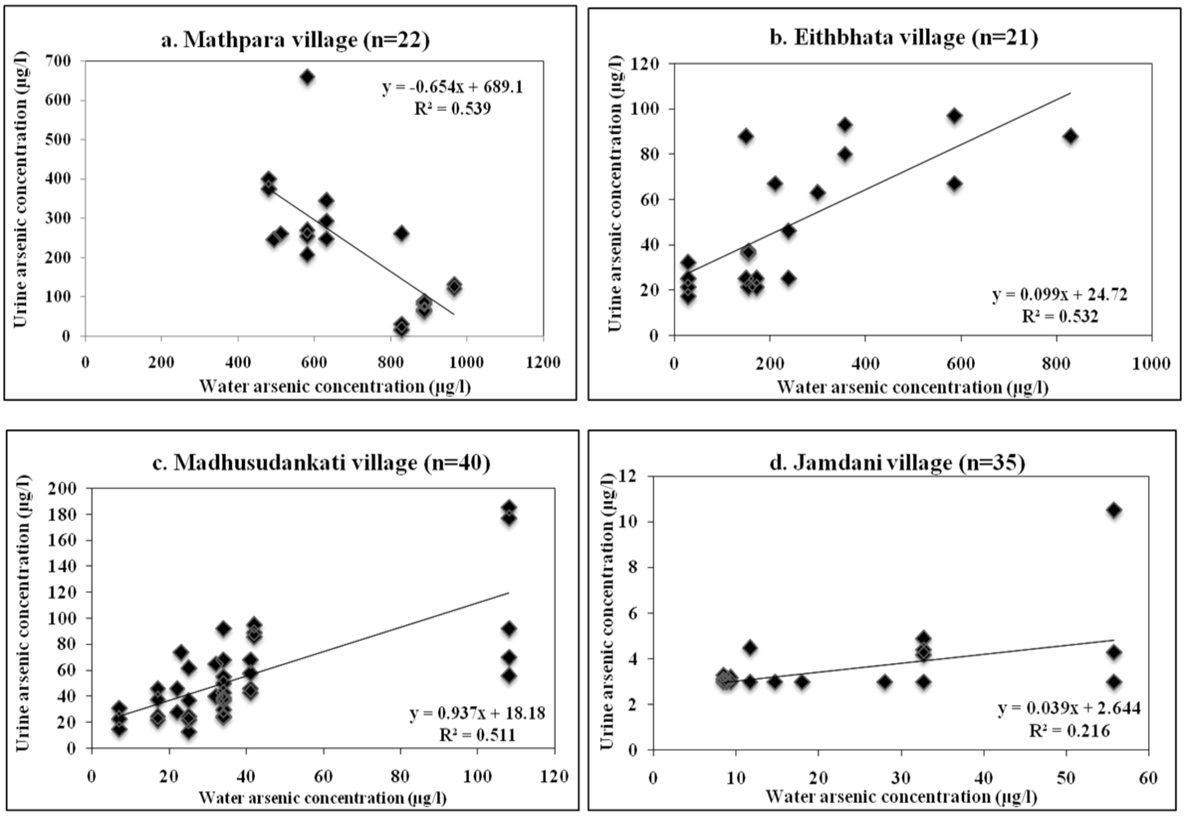


Fig. 35. Regression analysis between water and urine As concentrations collected from the four differently exposed populations

6.6.5.2. Effect of long term exposure rate (chronic toxicity)

Monitoring biomarkers helps as a diagnostic test to determine arsenical body burden in humans (RGI 2003). To determine the amount of persistent acute poisoning in the populaces studied, total As concentrations in nail and hair samples were evaluated. Hair and nail specimens have been noted to be the strong predictors of persistent As exposure time in the human body system, varying from 6 to 18 months (Pororinskaya and Karpenko, 2009). Arsenic levels in the scalp, hair, and nails expose a longer vulnerability rate to As poisoning because it piles up in these slowly expanding body tissues (Hall, 2006), while the deposition rate is quicker in the nails than in the hair (NRC, 1999). Because of the keratin protein in body tissues of hair and nail the deposition rate is higher (Shapiro, 1967). Chronic As toxicity was noticed because of higher levels of As deposition in hair as well as nail among adult males, adult females, and children in increasing order from mild to incredibly high exposed individuals (Table 27). A histogram plot depicts the thorough proportion of As in hair and nail specimens from people living in numerous As-exposed areas (Fig. 36, 37). Hair samples taken from residents of the high exposed Mathpara village (n=35) revealed an average concentration level of 5423 µg/kg, ranged from 230-13300 µg/kg (Fig. 36a). Correspondingly, the average concentration of As in nail specimens (n=35) was 9336 µg/kg, with a spectrum of 1520-23500 µg/kg (Fig. 36b). Likewise, hair as well as nail specimens gathered from individuals (n=41) living in the strongly vulnerable Eithbhata village revealed an average concentration level of 6126 µg/kg (ranged from: 1090-20600 µg/kg) and 7880 µg/kg (ranged from: 940-22400 µg/kg), respectively (Fig. 36c, d). The average hair and nail As levels in moderate (Madhusudankati, Fig. S3a, S3b) and lightly (Jamdani, Fig. 37c, d) vulnerable inhabitants were 4.4 and 4.9, and 6.2 and 10.9 folds lower, respectively, than in incredibly high exposed (Mathpara) individuals. High levels of As were found in hair (n=132, mean: 2500 µg/kg; ranged from: 170-5990 µg/kg) and nail specimens (n=116, mean: 6050 µg/kg; ranged from: 550-16700 µg/kg) from residents of Gaighata block (Roychowdhury, 2010). Arsenic amounts were discovered to be elevated in nail and hair samples from adult men, females, and kids in several other As-affected districts in Bengal (Chatterjee et al., 2018; Samanta et al., 2004). Globally, elevated concentrations of As buildup in biological tissues have been noted (Baig et al., 2016; Rasheed et al., 2019). All these results support our findings.

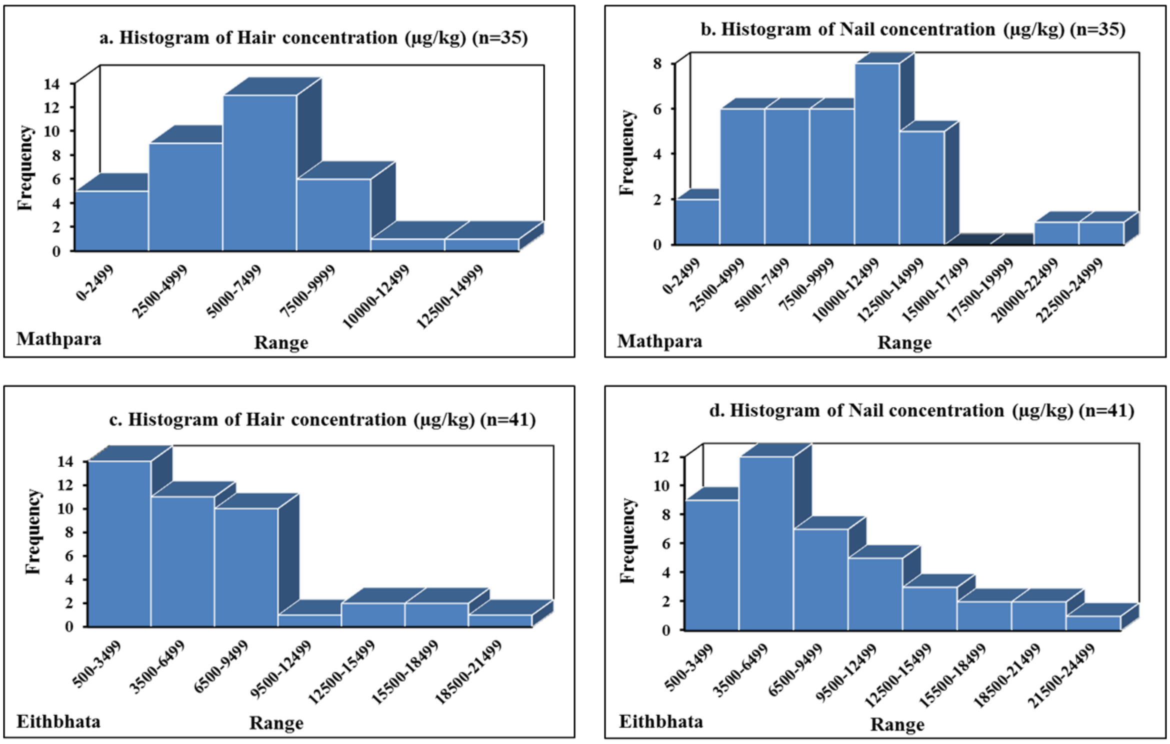


Fig. 36. Histogram plot showing the distribution of As concentration in hair and nail samples of the inhabitants from the extremely highly (Mathpara) and highly (Eithbhata) exposed studied areas

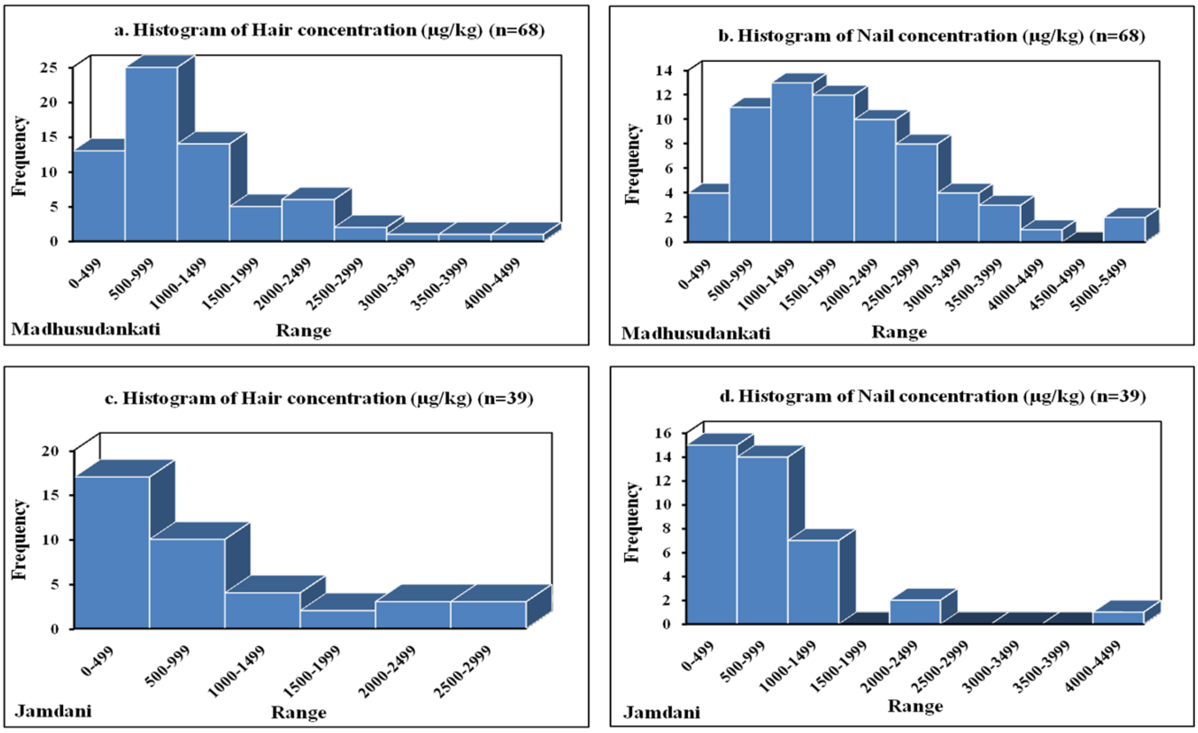


Fig. 37. Histogram plot showing the distribution of As concentration in hair and nail samples of the inhabitants from the moderate and mild exposed studied areas

6.6.6. Relation between water and biomarkers

A 95% confidence level analysis of the data was performed using "ANOVA: Single-factor analysis of variance" to evaluate the relationship between water and biological markers As for the respective adults and children from all the exposed villages. The independent and dependent variables are the As content in drinking water and the biomarkers, respectively. The null hypothesis (H_0) means 'no significant dependency of As in biomarkers with water As,' whereas the alternate hypothesis (H_1) means ‘significant dependency within the dependent and independent variables’. The respective F_{cal} value compared to the F_{critical} value along with the p value has been shown in Table 28.

As the respective F_{cal} values are greater than their respective F_{critical} values, alternate hypothesis (H_1) is recognized in case of adults and children living in the extreme high and high exposed villages. However, in case of moderate exposed populace, water As has no substantial relation with urine As. So, null hypothesis (H_0) is established for both adults and children in the moderate exposed village. On the other hand, in case of hair and nail As, null hypothesis (H_0) is rejected for this populace. In the same way, in the adults of the mild exposed village showed important relation within the variables accepting the alternate hypothesis (H_1) while the children rejected the alternate hypothesis (H_1). This influence exists because of the fact that intake of As through water did not truly contribute to the urine As, as the studied populaces from moderate and mild exposed areas consumed smaller As quantities through drinking water at domestic level as well As-safe water from different sources.

Table 28: Single-factor analysis of variance (ANOVA) evaluating relation between water with urine, hair and nail for adults and children from the differently exposed areas

Exposed Populations	**Category**	**Groups**	F_{cal}	***p* value***	$F_{critical}$	**Remarks (Alternate hypothesis**)**
Mathpara (Extremely highly)	**Adults**	Water-Urine	146	9.2×10^{-17}	4.0	Significant
		Water-Hair	94	2.9×10^{-13}		Significant
		Water-Nail	68.8	4.3×10^{-11}		Significant
	Children	Water-Urine	73.1	6.3×10^{-7}	4.6	Significant
		Water-Hair	21.7	0.0004		Significant
		Water-Nail	65.2	1.2×10^{-6}		Significant
Eithbhata (Highly)	**Adults**	Water-Urine	52.2	5.4×10^{-10}	3.9	Significant
		Water-Hair	52.4	5.1×10^{-10}		Significant
		Water-Nail	66.3	1.2×10^{-11}		Significant
	Children	Water-Urine	7.10	0.02	4.9	Significant
		Water-Hair	27.1	0.0004		Significant
		Water-Nail	19.7	0.0012		Significant
Madhusudankati (Moderate)	**Adults**	Water-Urine	0.29	0.59	3.9	Non-significant
		Water-Hair	70.5	4.1×10^{-13}		Significant
		Water-Nail	121	9.8×10^{-19}		Significant
	Children	Water-Urine	0.0003	0.98	4.4	Non-significant
		Water-Hair	26.4	4.9×10^{-5}		Significant
		Water-Nail	40.5	3.3×10^{-6}		Significant
Jamdani (Mild)	**Adults**	Water-Urine	48.2	1.4×10^{-9}	3.9	Significant
		Water-Hair	46.4	2.5×10^{-9}		Significant
		Water-Nail	39.6	2.1×10^{-8}		Significant
	Children	Water-Urine	1.12	0.40	18.5	Non-significant
		Water-Hair	3.82	0.19		Non-significant
		Water-Nail	4.82	0.16		Non-significant

** Significant at $\alpha = 0.05$; ** Alternate hypothesis (H_1) denotes "significant dependence within the groups"*

6.6.7. Factors dependable for risk analysis

6.6.7.1. Exposure and level of toxicity

Urine As clearly specifies that as they were exposed to As-contaminated drinking water, the extreme high, high and moderate exposed populaces were suffering from acute toxicity (Table 27), exceptionally the mild exposed populace was drinking relatively low As-contaminated water. The chronic consequence of As in the human body was established from the As deposition rate in the inhabitants scalp hair and nail samples from the four exposed populaces. The extreme high and high exposed inhabitants showed highest As accumulation in their body tissues compared to the moderate and mild exposed inhabitants (Table 27). It is noteworthy that in spite of the substantial As accumulation in hair and nails, the moderate and mild exposed populaces did not reveal arsenical skin symptoms, so they were measured as sub-clinically As affected. The high As deposition rate in the body of the individuals from the extreme high and high exposed populaces authenticates that they were exposed to arsenical symptoms. On the other hand, the moderate and mild populaces showed the As deposition rate and high probability of health risk exists if the inhabitants persist to ingest both contaminated water and rice. So, the populace consuming less As-contaminated water may be exposed to the toxic effect of As through nutritional intakes in long run.

A well socio-economic grade and healthier nutritive balance results in lesser arsenicosis human health risk (Milton et al., 2004; Sampson et al., 2008). Furthermore, it was stated that compared to the undernourished populace, those consuming healthy food would suffer less from As toxicity (Roychowdhury, 2010; Santra et al., 2013). Arsenic toxicity can be resisted due to presence of essential micronutrients like Zn and Se in regular diets (Chowdhury et al., 2020a; Roychowdhury et al., 2003). Rural populaces persevere under poor nourishment, so the probability of suffering from As toxicity might exist (Roychowdhury, 2010). In this study, as they were prone to insufficient healthier nutritional diet, the inhabitants were suffering from both the acute & chronic toxicity. Numerous reports indicated that the basic occurrence ratio between arsenicosis individuals with poor nutritive status was high than the healthy nutrition (Milton et al., 2010; Sarma et al., 2017). A worldwide comparative study has been shown in Table 29. In contrast to the other findings, this research study clearly specifies the severity of As toxicity, subsequent adverse health effects and risk of suffering for the studied populaces in accordance to the different exposure levels through nutritive intakes.

Table 29: Comparison study showing As scenario in four differently exposed zones in Gaighata block with other As-affected zones in West Bengal, India

District	**Studied area**	**Observations in the populations due to As toxicity**				**As affected patients**	**References**
		Water As	**Urine As**	**Hair As**	**Nail As**		
North 24 Parganas district, West Bengal	Deganga block	n=9949 % > 10 µg/L=57 % > 50 µg/L =37.3	n=4867 % > Normal level of As =86	n=1360 % > Normal level of As =48	n=1450 % > Normal level of As =78	Yes	Mandal et al. 1997
	Fakirpara village, Deganga	n=46 % > 10 µg/L=95.6 % > 50 µg/L =89.1	n=325 Mean=528 µg/L Range=319-2912 µg/L	n=260 Mean=3340 µg/kg Range=320-18500 µg/kg	n=285 Mean=8190 µg/kg Range=850-44900 µg/kg	Yes	Chowdhury et al. 2001
	Kolsur G.P, Deganga	n=2184 % > 10 µg/L=88.6 % > 50 µg/L =67.6	n=1433 % > Normal level of As =98	n=942 % > Normal level of As =87	n=1103 % > Normal level of As =95	Yes	Rahman et al. 2003
	Ambikanagar, Deganga	NA	Mean=250 µg/L	Mean=10840 µg/kg	Mean=36000 µg/kg	Yes	Rahman et al. 2003
	Bishnupur, Gaighata	NA	Mean=1095 µg/L	Mean=8890 µg/kg	Mean=17900 µg/kg	Yes	Rahman et al. 2003
	Sinderdaya, Gaighata	Mean=410 µg/L	NA	Mean=12500 µg/kg	Mean=30400 µg/kg	Yes	Rahman et al. 2003
	Gaighata block	n=3061 Mean=113 µg/L Range=10-900 µg/L	n=193 Mean=292 µg/L Range=8.35-1024 µg/L	n=132 Mean=2500 µg/kg Range=170-5990 µg/kg	n=116 Mean=6050 µg/kg Range=550-16700 µg/kg	Yes	Roychowdhury 2010
Murshidabad district, West Bengal	Rajapur village, Domkol block	n=336 % > 10 µg/L=82.7 % > 50 µg/L =54.8	n=50 Mean=420 µg/L Range=33-2353 µg/L	n=188 Mean=1930 µg/kg Range=530-8450 µg/kg	n=182 Mean=3140 µg/kg Range=850-9700 µg/kg	Yes	Rahman et al. 2005a
	Sagarpara G.P, Jalangi block	n=565 % > 10	n=176 Mean=271	n=301 Mean=2290	n=382 Mean=5070	Yes	Rahman et al. 2005b

		µg/L=86.2 % > 50 µg/L =58.8	µg/L Range=33-2420 µg/L	µg/kg Range=220-15000 µg/kg	µg/kg Range=610-27900 µg/kg		
Bhojpur District, Bihar	SemriaOjha Patti village	n=206 % > 10 µg/L=81.5 % > 50 µg/L =56.8	n=51 Mean=798 µg/L Range=24-3696 µg/L	n=59 Mean=2770 µg/kg Range=250-12400 µg/kg	n=38 Mean=6980 µg/kg Range=450-35700 µg/kg	Yes	Chakraborti et al. 2003
Ballia District, Uttar Pradesh	Chayanchapra village	n=55 % > 10 µg/L=100 % > 50 µg/L =96	n=80 Mean=1097 µg/L Range=23-4030 µg/L	n=94 Mean=2370 µg/kg Range=1370-10900 µg/kg	n=84 Mean=6370 µg/kg Range=760-19700 µg/kg	Yes	Ahamed et al. 2006a
Luxmipur, Bangladesh	Samta village, Jessore district	n=265 % > 10 µg/L=98.1 % > 50 µg/L =91.3	Mean=538 µg/L Range=24-3085 µg/L	Mean=2380 µg/kg Range=460-9480 µg/kg	Mean=7190 µg/kg Range=260-29600 µg/kg	Yes	Chowdhury et al. 2001
	Eruani village, Comilla	n=193 % > 10 µg/L=100 % > 50 µg/L =97.4	n=300 Range=26.7-1000 µg/L	n=283 Range=250-6000 µg/kg	n=242 Range=1080-8080 µg/kg	Yes	Ahamed et al. 2006b
Bangladesh	Ramganj block	n=2077 % > 10 µg/L=100 % > 50 µg/L =97.4	n=181 % > Normal level of As =100	n=25 % > Normal level of As =100	n=311 % > Normal level of As =97	Yes	Das et al. 2009
Patna District, Bihar, India	Five blocks	n=1365 Mean=1466 µg/L % > 10 µg/L=61 % > 50 µg/L =44	n=176 % > Normal level of As =100 Range=<100 µg/L	n=176 % > Normal level of As =100 Range=20-200 µg/kg	n=176 % > Normal level of As =100 Range=20500 µg/kg	Yes	Chakraborti et al. 2016a
Bihar, India	Shahpur Block, Bhojour District	n=4074 Mean=1805 µg/L % > 10	n=579 % > Normal level of As =91	n=579 % > Normal level of As =82	n=579 % > Normal level of As =89	Yes	Chakraborti et al. 2016b

		µg/L=40.3 % > 50 µg/L =21.1					
Assam, India	Majuli (river Island)	n=20 Mean=137 µg/L Range=5-386 µg/L	Mean=142 µg/L Range=43.1-305 µg/L	Mean=1738 µg/kg Range=220-5461 µg/kg	Mean=2792 µg/kg Range=426-11725 µg/kg	Yes	Goswami et al. 2020
North 24 Parganas, Gaighata block	Mathpara village	n=12 Mean=615 µg/L Range=433-966 µg/L	n=35 Mean=79.3 µg/L Range=3-659 µg/L	n=35 Mean=5423 µg/kg Range=230-13300 µg/kg	n=35 Mean=9336 µg/kg Range=1520-23500 µg/kg	Yes	**Present study**
	Eithbhata village	n=15 Mean=301 µg/L Range=29-829 µg/L	n=41 Mean=42.9 µg/L Range=11-147 µg/L	n=41 Mean=6126 µg/kg Range=1090-20600 µg/kg	n=41 Mean=7880 µg/kg Range=940-22400 µg/kg	Yes	**Present study**
	Madhusudankati village	n=15 Mean=48 µg/L Range=3-169 µg/L	n=68 Mean=71.2 µg/L Range=13-407 µg/L	n=68 Mean=1230 µg/kg Range=320-4050 µg/kg	n=68 Mean=1906 µg/kg Range=50-5480 µg/kg	No	**Present study**
	Jamdani village	n=10 Mean=20 µg/L Range=8.5-55.8 µg/L	n=39 Mean=4.69 µg/L Range=3-10.5 µg/L	n=39 Mean=867 µg/kg Range=10-2830 µg/kg	n=39 Mean=850 µg/kg Range=10-4030 µg/kg	No	**Present study**

6.6.8. Relation concerning As in dietary intakes and excretes

A statistical study was conducted at 95% level of confidence, "Two-tailed paired t-test," to rationalize the relationship between As ingestion and excretes among the four exposed populace. The research was carried out to investigate the relationship between As ingestion (independent variables) from water, rice, and vegetables and As excretes (dependent variable). The null hypothesis (H_0) states that there is 'no significant dependence of As excretes with As intakes,' while the alternate hypothesis (H_1) states that there is a 'significant dependency between the dependent and independent variables’. The respective t_{stat} value compared to the $t_{critical}$ value along with the ‘degrees of freedom’ (*df*) has been shown in Table 30.

Table 30: ‘Two-tailed paired t-test analysis’ showing the relation between the As intakes and excretes among the four differently exposed populations

Differently exposed populations	Arsenic excrete (Total)	n	Arsenic Intakes			df^{*}	Remarks (Alternate hypothesis**)
			Drinking water	Rice grain	Vegetables		
Extremely highly (Mathpara)	(Urine+Hair+Nail)	35	$t_{stat}(13.8)>t_{critical}(2.03)$	$t_{stat}(13.2)>t_{critical}(2.03)$	$t_{stat}(14.2)>t_{critical}(2.03)$	34	Accepted
Highly (Eithbhata)	(Urine+Hair+Nail)	41	$t_{stat}(9.69)>t_{critical}(2.02)$	$t_{stat}(9.51)>t_{critical}(2.02)$	$t_{stat}(9.64)>t_{critical}(2.02)$	40	Accepted
Moderate (Madhusudankati)	(Urine+Hair+Nail)	60	$t_{stat}(14.8)>t_{critical}(2.00)$	$t_{stat}(12.4)>t_{critical}(2.00)$	$t_{stat}(13.9)>t_{critical}(2.00)$	59	Accepted
Mild (Jamdani)	(Urine+Hair+Nail)	39	$t_{stat}(8.63)>t_{critical}(2.02)$	$t_{stat}(6.11)>t_{critical}(2.02)$	$t_{stat}(7.26)>t_{critical}(2.02)$	38	Accepted

** Significant at α = 0.05; ** Alternate hypothesis (H_1) denotes “significant dependence within the As intakes and excretes”*

In view of all the varying exposed populaces, a considerable inter-relation has been detected within the dependent (As excretes i.e. hair, nail and urine) and independent (As intakes i.e. rice, vegetables and water) variables. For all the exposed residents, the t_{stat} values are higher than the $t_{critical}$ values. Hence, for the four differently exposed villages the alternate hypothesis (H_1) is accepted. So, for the acute and chronic As exposure the food chain contamination is accountable. Henceforth, the interpretations validate that for the four differently exposed populaces the rate of As exposure in the human body is dependent on the various nutritive intakes. Consequently, on a regular basis the ingestion of As-contaminated foodstuffs as well as water are the essential sources of As toxicity among the exposed populaces.

6.6.9. Dermatological manifestations discriminating the As exposure rate

Here, in differently exposed villages the expression of carcinogenic effect among the inhabitants was not apparent. It is predominantly influenced by the time-period of exposure and also that long term exposure causes cancer (Chikkanna et al., 2019; Vazquez et al. 2016). In this study, the adult male inhabitants suffered more from arsenical symptoms compared to the adult female inhabitants living in the exposed areas. Children of 4-15 years of age did not show any arsenical skin symptoms, as they are measured as more susceptible to As effects than adults (Kippler et al., 2016; Roychowdhury, 2010). The detrimental health effect is dependent on As methylation which is mainly initiated by mode, dose and type of As along with the exposed inhabitants nutritive status (Chowdhury et al., 2003; Goswami et al., 2020), as a result, which leads to kidney, skin, lung, and bladder cancer (Farzan et al., 2013; Wasserman et al., 2014). Reports found that prolonged exposure of As resulting in different dermatological features in humans that rises with the hyperkeratosis (spotted or diffuse), whole body pigmentation (melanosis) to keratosis (Mandal et al., 1996; NRC, 2001). In rural Bengal, severe cases of cancer have been caused due to As toxicity as reported earlier (Chakraborti et al.,2018; Roychowdhury, 2010).

In this study, individuals from extreme high and high exposed areas showed the highest body burden in terms of As toxicity (Table 27). Fig. 38 depicted the As distribution in biological samples of all the age groups from the studied populaces groups with varying As intakes (data in logarithmic scale). The outcomes clearly elucidate that the body burden increased with increasing amounts of As through diet, and that it is placed in a sequence of Mathpara > Eithbhata > Madhusudankati > Jamdani. Arsenic in nail and hair samples from high exposed populaces was 5.5 and 6.2 times greater than in non-exposed populaces, respectively. Furthermore, Table 26 showed the body burden of As from exposed villages has been observed to be proportional to As exposure via nutritional intakes. Arsenic exposure via dietary intakes was 4.2 times higher in high exposed populaces than in moderate and mildly exposed populaces (Fig. 38 and Table 27). Consequently, documented patients with skin lesions have been recognized from extreme high and high exposed areas. In this survey, adults and children living in moderate and mild exposed areas showed no arsenical skin symptoms; however, significant quantities of As were found in their body tissues, that were distinctly higher than the standard values of As in hair. The mean As in hair and nail samples from the adult male (n=41), adult female (n=51) and children (n=15) living in moderate and mild exposed villages were 1300 µg/kg (ranged from: 20-4050 µg/kg), 1340 µg/kg (ranged from: 50-5480 µg/kg); 785 µg/kg (ranged from: 10-2260 µg/kg), 1405 µg/kg (ranged from: 10-5300 µg/kg) and 1060 µg/kg (ranged from: 390-2830 µg/kg), 1390 µg/kg (ranged from: 290-3200 µg/kg), respectively (Table 30). Likewise, the children (n=14) from extreme high and high exposed villages were exposed to higher As accumulation in hair (mean: 5155 µg/kg; ranged from: 1020-9230 µg/kg) and nail (mean: 8735 µg/kg; ranged from: 3160-13700 µg/kg), respectively. These values were 4.8 and 6.3 folds higher than the detected values of As in children's respective hair and nail from moderate and mild exposed villages. So, the respective exposed inhabitants were considered as sub-clinically affected with As. This investigation included a field camp lasting for 2-3 days with medical team, along with a concerned dermatologist for screening inhabitants with arsenical skin manifestations. Arsenical skin lesions of affected inhabitants from extremely high and high exposed areas have been shown in Fig. 39.

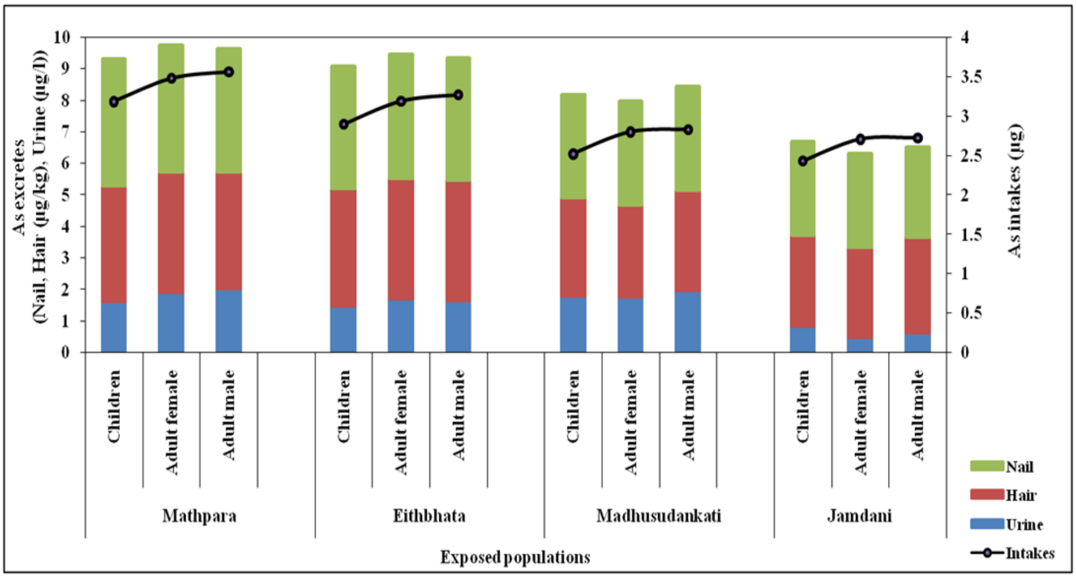


Fig. 38. Distribution of As concentrations in the biological samples of adult male, adult female and children with different dietary As intakes from the studied areas (data in logarithmic scale)


[redacted]

Spotted Palm Keratosis
Village: Mathpara

Bowen's
Village: Eithbhata

Rain drop pigmentation
Village: Mathpara

Whole body blackening
Village: Eithbhata

Bowen's
Village: Mathpara

Diffuse sole Keratosis
Village: Eithbhata

Fig. 39. Arsenical skin manifestations in few affected individuals from the extremely highly (Mathpara) and highly exposed areas (Eithbhata)

6.6.10. Risk thermometer based on the As toxicity exposure level

The "risk thermometer" identifies the risk class among studied based on regular diet (drinking water, rice and vegetables). As stated by SAMOE (Sand et al., 2015a), Fig. 40 plots the risk class and its level of concern via consumption of As-contaminated water and foodstuffs (rice and vegetables). The drinking water from the Mathpara and Eithbhata populaces was rated as high-risk class 5, whereas the drinking water for the Madhusudankati and Jamdani populaces was rated as moderate risk class 4. For rice grains, the thermometer for all populaces indicated a high level of concern (class 5). Correspondingly, vegetables from demonstrated a moderate risk of suffering (class 4) for all populaces. As a consequence, the Mathpara and Eithbhata individuals were at a greater risk of As poisoning from water and rice intake compared to vegetables. In correlation to water and vegetables, intake of rice was associated with a high risk for the Madhusudankati and Jamdani individuals.

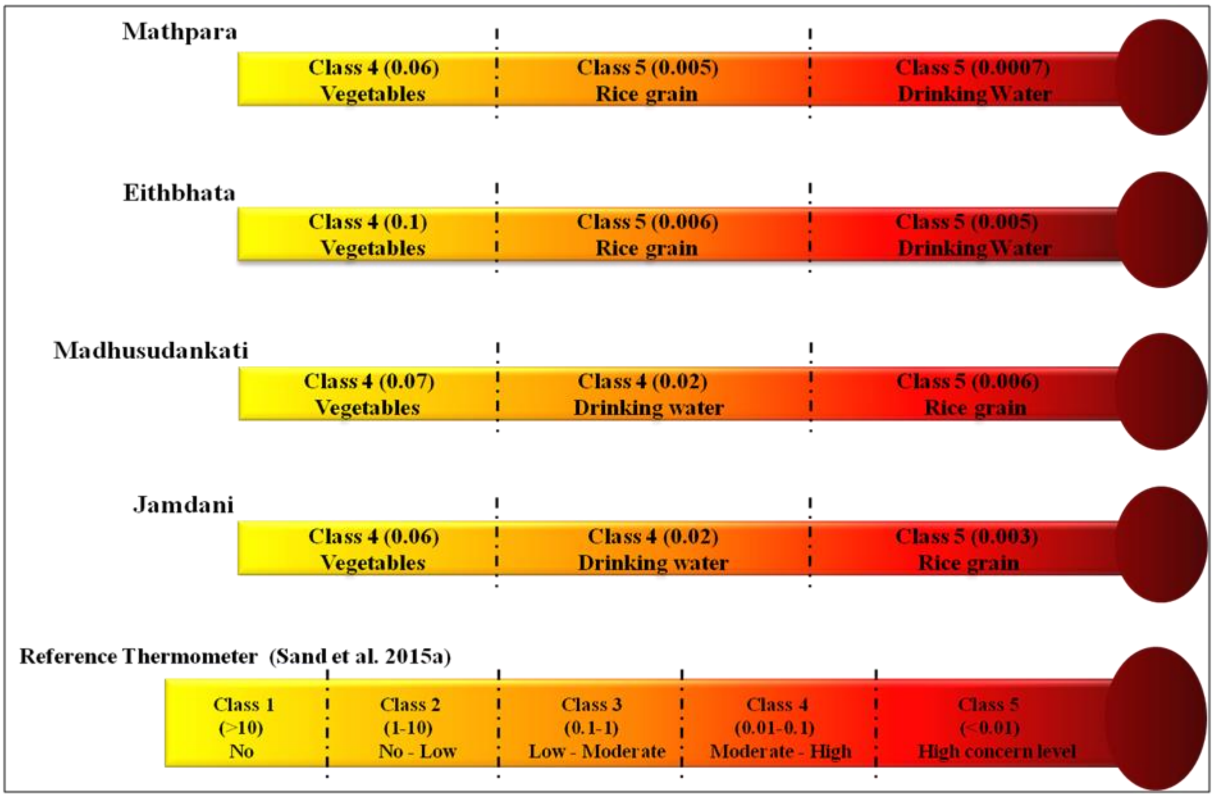


Fig. 40. Risk thermometer scale showing the class of As toxicity through consumption of As-contaminated drinking water, rice grain, and vegetables in the differently exposed populations

6.6.11. Health risk assessment of the studied populations in differently exposed areas

From the four exposed villages risk depiction was executed to calculate the cancerous as well as non-cancerous effect on different age groups. The evaluation indicated the prospect of cancerous risk in adult male, adult female and children’s groups who are exposed to As via dietary consumptions. In our study, the extreme high and high exposed populace showed high risk of cancer through the continuous intake of As-contaminated water than moderate and mild populaces. Assimilation of As-contaminated rice and vegetables might become a health hazard factor in the near future for individuals residing in As-contaminated villages.

Cancerous and non-cancerous risk in different age groups via dietary foodstuffs from the exposed inhabitants are placed in Table 31. The mean ILCR is high for the adult male, adult female and children via regular food intakes for all exposed areas. Fig. 41 depicted the distribution of cancerous risk in different age groups through all contaminated dietary stuffs. The measured value for each case is higher than the acceptable value (1×10^{-6}) (USEPA 2005). Adults (males & females) from Mathpara and Eithbhata showed risk through contaminated water is much greater compared to the adults from Madhusudankati and Jamdani. All the differently exposed areas, showed that the ingestion of contaminated rice and vegetables contributes risk of cancer in adults and children. Furthermore, the risk of cancer is greater through rice compared to drinking water for adults and children groups from moderate and mild areas. The risk of cancer through contaminated drinking water is maximum for the extreme high inhabitants than the mild exposed inhabitants (Table 31 and Fig. 41).

Cancer risk distribution via contaminated water (Table 31) is proportionate with the exposure level of exposed areas (Table 26). In extreme high and high exposed village, cancerous risk is maximum through drinking water compared to food crops. While moderate and mild exposed populaces showed high cancerous risk through contaminated rice compared to drinking water. Biswas et al. (2019) stated that the assimilation of iAs is high through intake of rice in regular diets for the inhabitants living in both the As endemic and non-endemic villages, instead of drinking As-safe water. For all cases, compared to drinking water and rice, vegetables contributed minimum cancerous risk.

Table 31 showed mean HQ (non-cancerous) values, which are considerably high in most of the cases via ingestion of dietary foodstuffs. An unacceptable risk exists when the HQ value is greater than 1 (USEPA, 2005). The differently exposed adults (both males and females) showed HQ value > 1 via drinking water and rice. Non-cancerous risk is in the order of Mathpara > Eithbhata > Madhusudankati > Jamdani. Group of exposed children presented HQ value > 1 through intake of water and rice, exceptionally for mild exposed area. Vegetables contributed minimum HQ value than water and rice; on the other hand, more than 1 for Mathpara, Madhusudankati and Jamdani adults (Table 6). HQ is knowingly lesser for all exposed children via intake of vegetables. On account of consuming As-contaminated water and foodstuffs, HQ value discloses that the studied inhabitants from rural Bengal are susceptible to health hazards.

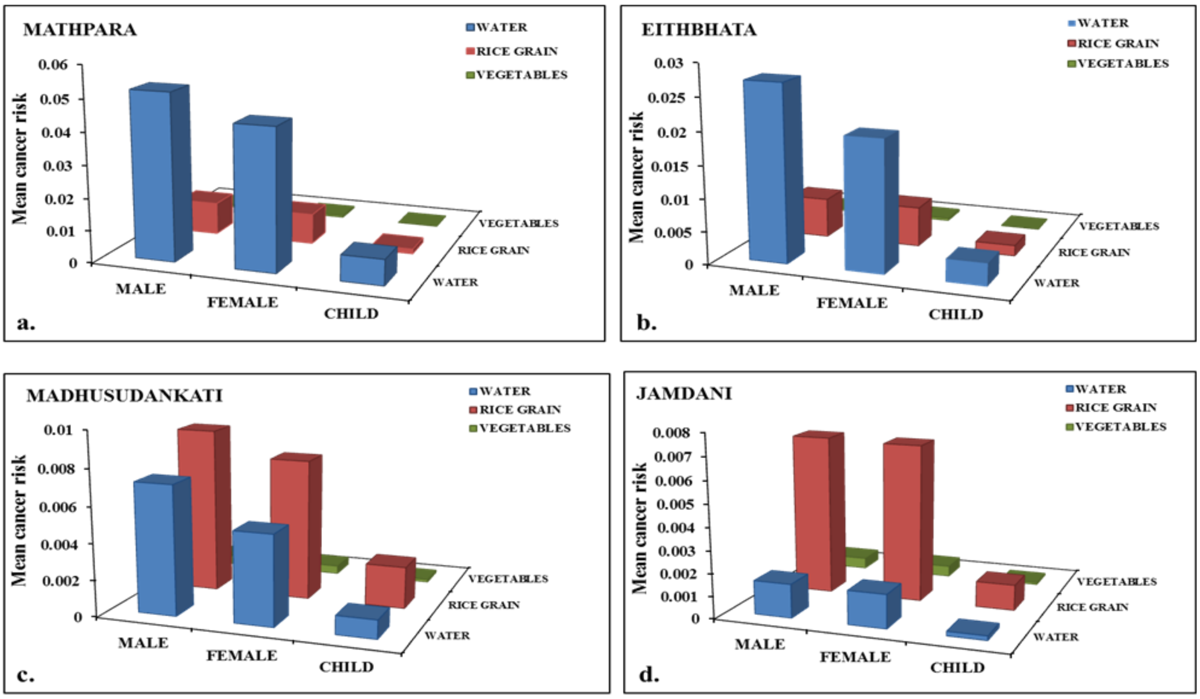


Fig. 41. Distribution of the cancer risk in adult male, adult female and children through ingestion of drinking water, rice grain and vegetables residing in differently exposed areas

Table 31: Cancer and non-cancer risk assessment in adult male, adult female and children through dietary intakes from exposed areas

Exposed area	Groups	Non-cancer risk Mean (Range)			Cancer risk Mean (Range)		
		Drinking water	**Rice grain**	**Vegetables**	**Drinking water**	**Rice grain**	**Vegetables**
Mathpara	**Adult male**	115 (34-204)	22.3 (5.24-84)	1.11 (0.39-2.61)	5.18x10^{-2} (1.5x10^{-2}-9.2x10^{-2})	1.01x10^{-2} (2.4x10^{-3}-3.7x10^{-2})	4.97x10^{-4} (1.8x10^{-4}-1.2x10^{-3})
	Adult female	97.6 (40-179)	20.9 (3.01-56)	1.11 (0.40-2.41)	4.39x10^{-2} (1.8x10^{-2}-8.1x10^{-2})	9.44x10^{-3} (1.4x10^{-3}-2.6x10^{-2})	5.02x10^{-4} (1.8x10^{-4}-1.0x10^{-3})
	Children	17.6 (1.89-53)	3.3 (0.48-12)	0.25 (0.03-0.72)	7.93x10^{-3} (8.5x10^{-4}-2.4x10^{-2})	1.48x10^{-3} (2.0x10^{-4}-5.6x10^{-3})	1.11x10^{-4} (1.4x10^{-5}-3.2x10^{-4})
	Contribution (%)	**82**	**17**	**1**	**83**	**16**	**1**
Eithbhata	**Adult male**	60.3 (3.35-199)	13.5 (3.40-36)	0.66 (0.18-1.23)	2.71x10^{-2} (1.5x10^{-3}-8.9x10^{-2})	6.06x10^{-3} (1.5x10^{-3}-1.6x10^{-2})	2.95x10^{-4} (8.3x10^{-5}-5.5x10^{-4})
	Adult female	44.6 (4.92-150)	13.5 (2.84-34)	0.74 (0.29-1.44)	2.01x10^{-2} (2.2x10^{-3}-6.8x10^{-2})	6.08x10^{-3} (1.3x10^{-3}-1.5x10^{-2})	3.33x10^{-4} (1.3x10^{-4}-6.4x10^{-4})
	Children	7.67 (1.61-18)	3.57 (0.84-8.47)	0.17 (0.08-0.28)	3.44x10^{-3} (7.2x10^{-4}-8.3x10^{-3})	1.61x10^{-3} (3.8x10^{-4}-3.8x10^{-3})	7.58x10^{-5} (3.7x10^{-5}-1.3x10^{-4})

	Contribution (%)	**78**	**21**	**1**	**78**	**21**	**1**
Madhusudankati	**Adult male**	15.8 (0.55-92)	20.2 (2.14-86)	1.09 (0.37-2.60)	7.12x10^{-3} (2.5x10^{-4}-4.2x10^{-2})	9.09x10^{-3} (9.6x10^{-4}-3.9x10^{-2})	4.92x10^{-4} (1.7x10^{-4}-1.2x10^{-3})
	Adult female	11 (0.42-74)	17.2 (1.73-87)	1.0 (0.29-2.36)	4.96x10^{-3} (1.9x10^{-4}-3.3x10^{-2})	7.74x10^{-3} (7.8x10^{-4}-3.9x10^{-2})	4.5x10^{-4} (1.3x10^{-4}-1.1x10^{-4})
	Children	2.26 (0.13-8.3)	5.1 (0.52-21)	0.31 (0.10-0.68)	1.02x10^{-3} (6.0x10^{-5}-3.8x10^{-3})	2.22x10^{-3} (2.3x10^{-4}-9.6x10^{-3})	1.37x10^{-4} (4.5x10^{-5}-3.0x10^{-4})
	Contribution (%)	**39**	**58**	**3**	**39**	**58**	**3**
Jamdani	**Adult male**	3.33 (0.75-11)	15.8 (5.76-30)	1.07 (0.52-2.02)	1.5x10^{-3} (3.4x10^{-4}-5.2x10^{-3})	7.1x10^{-3} (2.6x10^{-3}-1.4x10^{-2})	4.81x10^{-4} (2.3x10^{-4}-9.1x10^{-4})
	Adult female	3.32 (0.69-11)	15.5 (4.89-32)	1.05 (0.50-2.06)	1.49x10^{-3} (3.1x10^{-4}-5.1x10^{-3})	6.99x10^{-3} (2.2x10^{-3}-1.4x10^{-2})	4.76x10^{-4} (2.3x10^{-4}-9.3x10^{-4})
	Children	0.43 (0.26-0.60)	2.51 (1.79-3.24)	0.18 (0.18-0.19)	1.9x10^{-4} (1.2x10^{-4}-2.7x10^{-4})	1.13x10^{-3} (8.1x10^{-4}-1.5x10^{-3})	8.25x10^{-5} (8.1x10^{-5}-8.4x10^{-5}
	Contribution (%)	**17**	**78**	**5**	**17**	**78**	**5**

Overall it can be stated that ingestion of As-contaminated water and foodstuffs is a significant source of exposure pathway for As toxicity among the differently exposed populations. A decreasing trend of As accumulation in biological tissues has been observed in the exposed inhabitants residing in theextremely highly to mild exposed areas. Higher risk of suffering from drinking water and rice grain compared to vegetables in extremely highly and highly exposed populations, whereas, high risk of suffering has been observed from rice grain compared to drinking water and vegetables in moderately and mild exposed populations.

6.7. Health exposure and risk assessment of a sub-population due to arsenic toxicity from an arsenic-prone zone

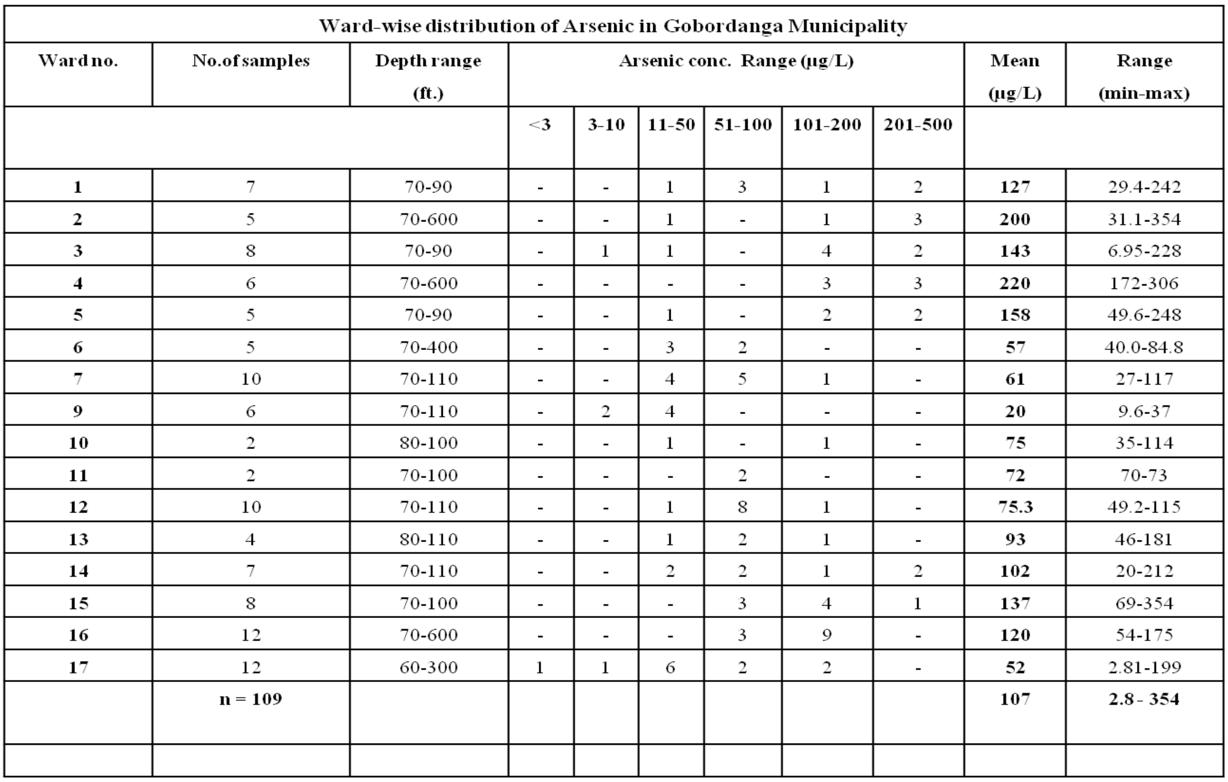
The risk of suffering through natural groundwater As contamination is globally well-known as a crucial water quality problem (Chakraborti et al., 2009). Arsenic in groundwater and rice is the main source of inorganic form, commonly identified as intoxicating carcinogen (IARC, 2012; NRC, 2001). Rice is considered the staple crop which is the main reason for arsenical health problems in major As-endemic areas of the world. Exposure to chronic and acute toxicity due to the As-contaminated water is a notable health threat to human. It has been reported that the As concentration in the body tissues increases with the rate of exposure to As contamination (Roychowdhury, 2010).

The present study aims to survey i) scenario of drinking water and rice grain of the studied populace, ii) health exposure through As contamination, iii) probable risk analysis due to consumption of inorganic As in drinking water and rice grain.

6.7.1. Scenario of drinking water and rice grain of the studied populace

The domestic water samples from the families living in Gobordanga (Gaighata block) showed that the populace usually consumes higher As than the permissible limit. The As concentration in water samples ranged from 20-163 μg/L with a mean value of 70 ± 50 μg/L. Not only contaminated drinking water, the affected populace consumes As through their daily dietary foodstuff which is being cultivated using As-contaminated groundwater. The rice grain samples collected from each family (n=16), showed a considerable amount of As concentration, which is greater compared to the WHO permissible limit in rice i.e. 1000 μg/kg. The rice grain samples showed As with an average concentration of 249 ± 146 μg/kg ranging 70-680 μg/kg.

Table 32: Ward-wise (n=17) As distribution on Gobordanga Municipality



Ward-wise distribution of Arsenic in Gobordanga Municipality										
Ward no.	No.of samples	Depth range (ft.)	Arsenic conc. Range (µg/L)						Mean (µg/L)	Range (min-max)
			<3	3-10	11-50	51-100	101-200	201-500		
1	7	70-90	-	-	1	3	1	2	**127**	29.4-242
2	5	70-600	-	-	1	-	1	3	**200**	31.1-354
3	8	70-90	-	1	1	-	4	2	**143**	6.95-228
4	6	70-600	-	-	-	-	3	3	**220**	172-306
5	5	70-90	-	-	1	-	2	2	**158**	49.6-248
6	5	70-400	-	-	3	2	-	-	**57**	40.0-84.8
7	10	70-110	-	-	4	5	1	-	**61**	27-117
9	6	70-110	-	2	4	-	-	-	**20**	9.6-37
10	2	80-100	-	-	1	-	1	-	**75**	35-114
11	2	70-100	-	-	-	2	-	-	**72**	70-73
12	10	70-110	-	-	1	8	1	-	**75.3**	49.2-115
13	4	80-110	-	-	1	2	1	-	**93**	46-181
14	7	70-110	-	-	2	2	1	2	**102**	20-212
15	8	70-100	-	-	-	3	4	1	**137**	69-354
16	12	70-600	-	-	-	3	9	-	**120**	54-175
17	12	60-300	1	1	6	2	2	-	**52**	2.81-199
	n = 109								**107**	**2.8 - 354**

6.7.2. Health exposure through As contamination

Biomarkers of As (urine, hair, and nail) were analyzed for health exposure study (Fig. 42). Urine and body tissue samples determine the acute and chronic effect of As consumption in the internal body system. Urine samples collected (n=52) showed an average concentration of 5 ± 3 µg/L, whereas, the permissible limit of As concentration in urine is 3-26 µg/L. As a result of high keratin content in the hair and nail tissue, the frequency of As deposition is greater than other parts of the human body. The exposed hair samples (n=55) showed As concentration in the range of 80 to 4060 µg/kg with an average concentration of 1090 ± 1020 µg/kg, where the permissible limit of As in hair is 80-250 µg/kg. Similarly, nail samples (n=55) showed an average As concentration of 2030 ± 1730 µg/kg ranging from 130 to 6720 µg/kg, where the permissible limit of As in nail is 430-1080 µg/kg.

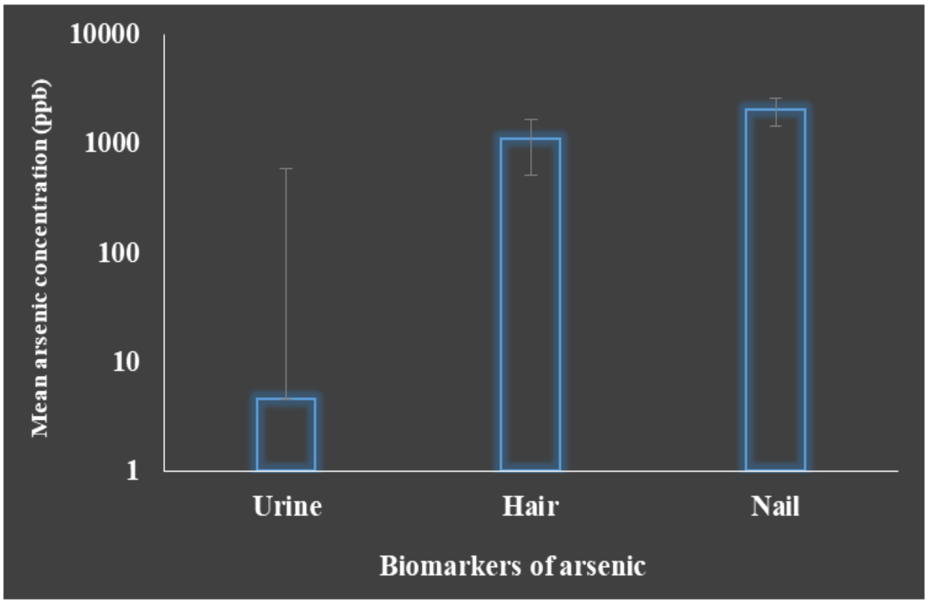


Fig. 42. Mean As concentration in biomarkers of As

6.7.3. Probable risk analysis due to consumption of inorganic As in drinking water and rice grain

Cancer risk through inorganic As (drinking water and rice grain) for male and female has been shown in Fig. 43. Our study revealed that the affected populace the male individuals are prone to higher cancer risk compared to the female individuals. So, the populace are prone to several health hazards not only through contaminated drinking water but also through contaminated foodstuffs found in the affected areas.

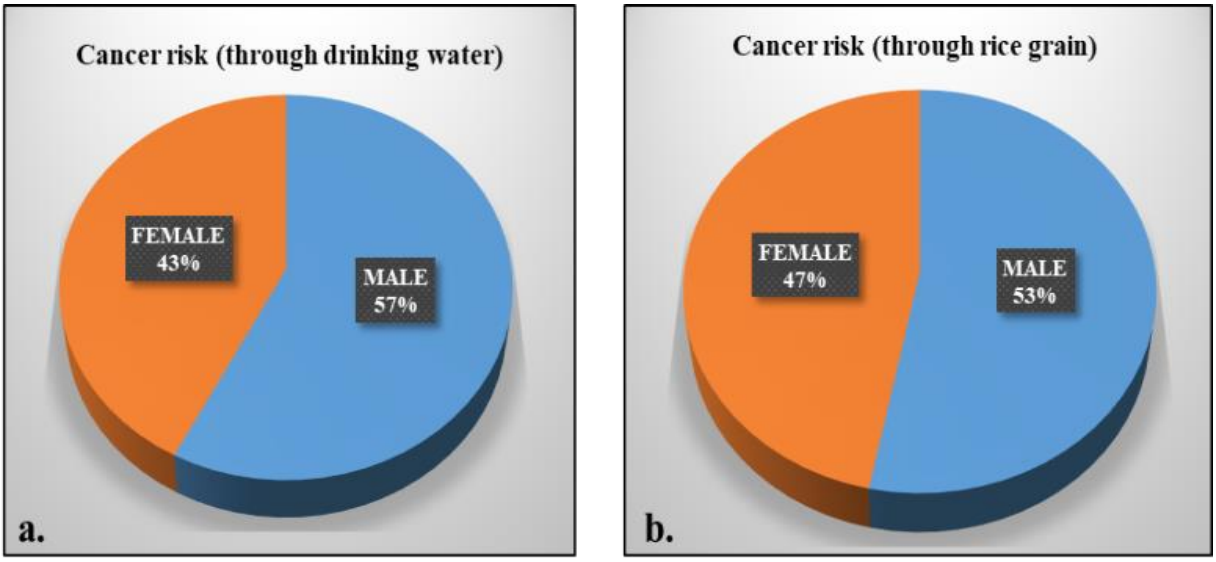


Fig. 43. Cancer risk analysis in male and female individuals

6.8. Evaluating exposure level of arsenic and risk assessment of a mother-infant populace from a severely arsenic prone block, North 24 Parganas, West Bengal

This chapter focuses on a survey performed on an unexposed populace of mothers and infants from a severely As-prone area. This chapter highlights the pre- sent scenario of As exposure of the populace through drinking water, foodstuffs, and baby food products. On a particular note, the level of toxicity has been analyzed through As biomarkers justifying the acute and chronic exposure rate of the mother and infant populace. Statistical interpretation was performed to study the inter- relations between As intakes and excretion of the populace. Furthermore, a health risk evaluation was measured to put forward the carcinogenic and non-carcinogenic risk of the unexposed populace.

6.8.1. Arsenic contamination scenario of the exposed zone

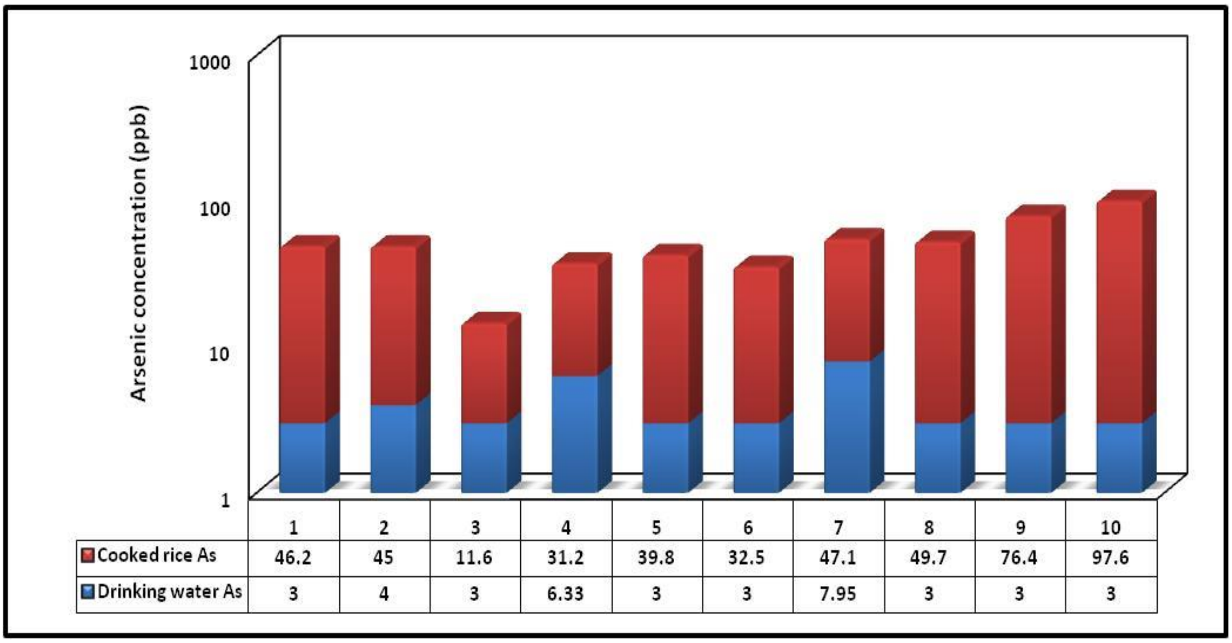
6.8.1.1. Groundwater

In West Bengal, Gaighata is well known as an As-affected block in North 24 Parganas district (Roychowdhury, 2010). Among 13 gram panchayats of Gaighata block, in Sutia gram panchayat a village named Madhusudankati (22º53´53.18” N, 88º46´38.55” E) has been targeted in our study. The distribution of As concentrations in drinking water collected from the unexposed families of the studied area is shown in Figure 6.1. The As concentration in the water (n = 10) collected from the unexposed families which is used for drinking, cooking, and household purposes ranged from 3 to 7.95 µg/L with a mean concentration of 3.92 ± 1.76 µg/l. Water As of the studied populace revealed that they are presently consuming As-safe groundwater.

6.8.1.2. Cooked Rice

Rice grain is well known as the staple food crop which has paved a pathway to human health exposure through its consumption on a daily basis globally (Kumarathilaka et al., 2019) as well as for the rural populace living in Bengal (Chowdhury et al., 2020a). Usage of As-contaminated groundwater at the time of agricultural practices (Chowdhury et al., 2018a) and at the time of the parboiling process to obtain parboiled rice grain (Chowdhury et al., 2018b) leads to food chain contamination. The mean As concentration in the parboiled rice grain collected from the studied (mother and infant) populace was 356 µg/kg (range: 189–628 µg/kg, n = 10). The maximum tolerable level of As for infants is 100 µg/kg in food and for adults is 200 µg/kg in rice-based products (European Commission, 2015). Several reports have highlighted that populaces are exposed to nearly 90% of the total As concentration that accounts for the inorganic form in parboiled rice grain (Biswas et al., 2019; Chowdhury et al., 2020a).

In rural Bengal, parboiled rice grain is consumed in the form of cooked rice as a dietary intake on a daily basis. Locally grown rice grains when consumed in the form of cooked rice pose a health risk to populaces from rural Bengal (Halder et al., 2012, 2014; Chowdhury et al., 2020a). Distribution of As concentrations in cooked rice collected from unexposed families of the studied area has been shown in Fig. 44. At domestic level, the parboiled rice grains were cooked in the ratio of 1:3 (rice to water) using domestic water for both drinking and cooking. The mean As concentration in the cooked rice grain collected from the studied populace (*n* = 10) was 47.7 µg/kg, ranging from 11.6 to 97.6 µg/kg. In rural Bengal, cooking of parboiled rice grain in low As-contaminated water showed adecreasing trend of As accumulation in cooked rice compared to parboiled rice grain (Chowdhury et al., 2020a). As accumulation in cooked rice varies depending on its geographical area, variety, cooking water, and cooking process (Pal et al., 2009; Mondal et al., 2010; Chowdhury et al., 2020a). This work shows that the use of As-safe cooking water during the cooking process results in low accumulation of As in cooked rice. Presently, in our survey the studied populace is exposed to As-safe drinking water, hence the cooked rice grain contributes as a major dietary source of As intake. Earlier studies have reported that As intake through rice grain plays a vital role for the populace exposed to As-safe water (Chatterjee et al., 2010; Biswas et al., 2019).



	1	2	3	4	5	6	7	8	9	10
🟥 Cooked rice As	46.2	45	11.6	31.2	39.8	32.5	47.1	49.7	76.4	97.6
🟦 Drinking water As	3	4	3	6.33	3	3	7.95	3	3	3

Fig. 44. Distribution of As concentrations in drinking water and cooked rice collected from the families of the exposed area

6.8.1.3. Dietary Baby Food Products

In rural Bengal, infants consume breast milk, cow's milk, commercial baby food (Cerelac), and homemade mixture baby food on a daily basis in their diet. As concentrations in the daily diets for the studied populaces are shown in Table 6.1. In this study, the mean As concentration observed in breast milk, cow's milk was6.35 ± 5.06 µg/l, and 17.4 ± 8.59 µg/L respectively. Several reports found that the breast milk contributes least amount of As (Carignan et al., 2015; Rebelo and Caldas, 2016). A rice-based diet among the rural populace is mainly responsible for exposure to As toxicity. In a similar way, commercial baby food (Cerelac) and homemade food mixtures showed an average As concentration of 79.8 ± 16.7 µg/kg, and 207 ± 78.8 µg/kg, respectively. In India, a large populace is dependent on rice and its derivatives through their daily dietary intake (Chowdhury et al., 2018b; Rahman et al., 2008). Several studies have reported that rice byproducts accumulate high concentrations of As compared to rice grain (Sun et al., 2009; Chowdhury et al., 2018b). This study reflects that the As accumulation in rice-based products is high compared to milk products from the studied populace as the rice-based products are made from As-contaminated rice which were locally nurtured in As-exposed areas.

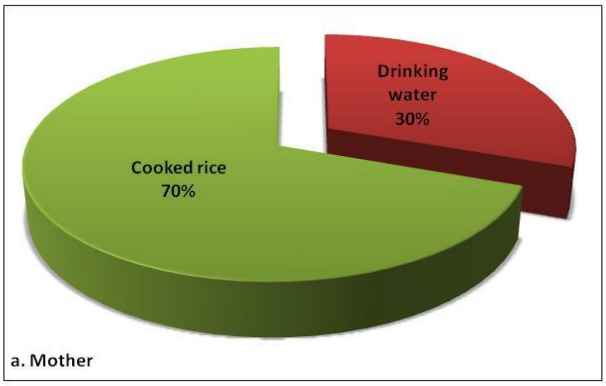
Table 33: Arsenic concentration in the dietary intake samples of the studied populations

Groups	Samples	No. of samples (n)	Mean	SD	Range
Mother	**Drinking water (µg/L)**	10	3.93	1.76	3 - 7.95
	Cooked rice (µg/kg)	10	47.7	24	11.6 - 97.6
Infant	**Drinking water (µg/L)**	11	4.29	2.06	3 - 7.95
	Cooked rice (µg/kg)	11	47.6	22.7	11.6 - 97.6
	Breast milk (µg/L)	2	6.35	5.06	2.76 - 9.93
	Cow milk (µg/L)	3	17.4	8.59	11.3 - 27.2
	Commercial food (Cerelac) (µg/kg)	3	79.8	16.7	60.6 - 90.5
	Homemade food mixture (µg/kg)	3	207	78.8	125 - 282

6.8.2. Observed daily dietary intake rate of As for mother and infant through drinking water and cooked rice

As content (µg) distribution as a percentage in the daily dietary intakes on a daily basis of the studied populace (mother and infant) is shown in Fig. 45. In this survey, the daily dietary intake of As through drinking water and milk was calculated using the respective volume consumed by the infants (aged: 7 months–4 years old) as 0.25–1.5 l and 0.15–0.40 l, respectively with average body weight of 4.5–13 kg (Kazi et al., 2016). The intake of cooked rice, commercial baby food (Cerelac), and homemade food mixture on a daily basis by the infants was calculated considering the respective amount consumed as 20–99 g. Singh and Ghosh (2012) considered intake of cooked rice for children aged between 5 and 10 years as 99–105 g. In a similar way, the daily dietary intake of As through drinking water and cooked rice by the mother was calculated using the daily consumption of 4 l and 750 g, respectively (Roychowdhury, 2010) with an average body weight of 55 kg (Joseph et al., 2015).

The daily dietary intake rates of As for the mothers through drinking water and cooked rice are 0.29 and 0.65 µg/kg bw/day, respectively. Likewise, for the infants the regular dietary ingestion rates through drinking water, cooked rice, breast milk, cow's milk, commercial food (Cerelac), and homemade food mixtures are 0.37, 0.32, 0.14, 0.49, 0.54, and 1.73 µg/kg bw/day, respectively. As a result, the survey specifies that the daily dietary intake rates of the studied mother and infant populace from the exposed area are lower compared to the WHO-recommended value, i.e., 3.0 µg/kg bw/day (WHO, 2011b). Hence, the studied populace is presently not exposed to the toxic effect of As.



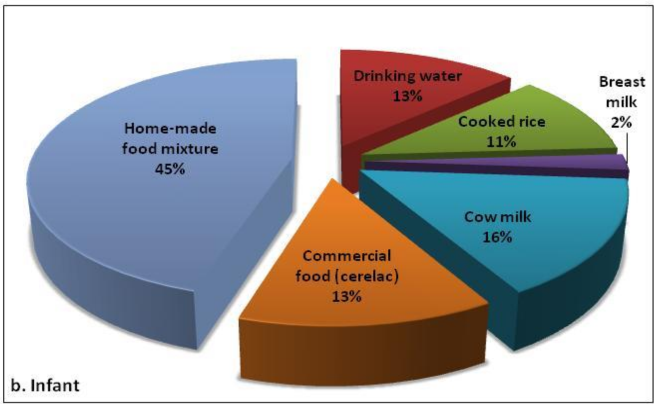


Fig. 45. Arsenic content (µg) distribution in percentage in the daily dietary intakes of the studied a. Mother and b. Infant population

6.8.3. Effect of arsenic toxicity on the unexposed populace

6.8.3.1. Acute Exposure Level

Arsenic exposure through urine is measured as the primary biomarker as it signifies the acute level of toxicity in a human body system (Vahter, 1994; Goswami et al., 2020). The half-time of iAs species is roughly 4 days in a human body as it is not as much of dependent on keratin body tissues (Goswami et al., 2020).

Arsenic concentrations in urine for the studied populace of mother and infant are shown in Table 34. Urine samples from the mothers (n=10) and infants (n =11) showed a mean As concentration of 3.10 and 3 µg/l, respectively. Variations in urine As concentrations of the studied populace (mother and infant) with their respective water As concentrations are shown in Figure 6.3. The urine As concentrations of the studied populaces do not exceed the allowable As value in urine, i.e., 3–26 µg/L (Farmer and Johnson, 1990). Regression analysis between water As and urine As of the studied mothers and infants is shown in Figure 6.4a and 6.4b, respectively. A strong significant correlation has been observed (R^2 = 0.8992 and 0.9084) for the mother and infant populace, respectively, from the studied area. The correlation value signifies the role of consuming As-safe drinking water. As a result, the valuation of urine As reveals that the studied mothers and infants are presently exposed to ingestion of As-safe drinking water

Table 34: Distribution of As concentrations in the biomarkers (urine, hair and nail) of mother and infant from the exposed area

Groups		**Biomarkers of As**		
		Urine (µg/L)	**Hair (µg/kg)**	**Nail (µg/kg)**
Mother	**No. of samples (n)**	10	10	10
	Mean	3.10	3321	5829
	SD	0.26	2509	3184
	Range	3-3.84	1370-8300	2580-12100
Infant	**No. of samples (n)**	11	8	8
	Mean	3	1655	4148
	SD	0	900	2104
	Range	3	80-2910	1810-8160

Normal range of hair As content is 80 - 250 µg/kg, and > 1,000 µg/kg in hair suggests toxic behavior (Arnold et al., 1990**)*

** Normal range of nail As content is 430 - 1,080 µg/kg (**Ioanid et al., 1961**)*

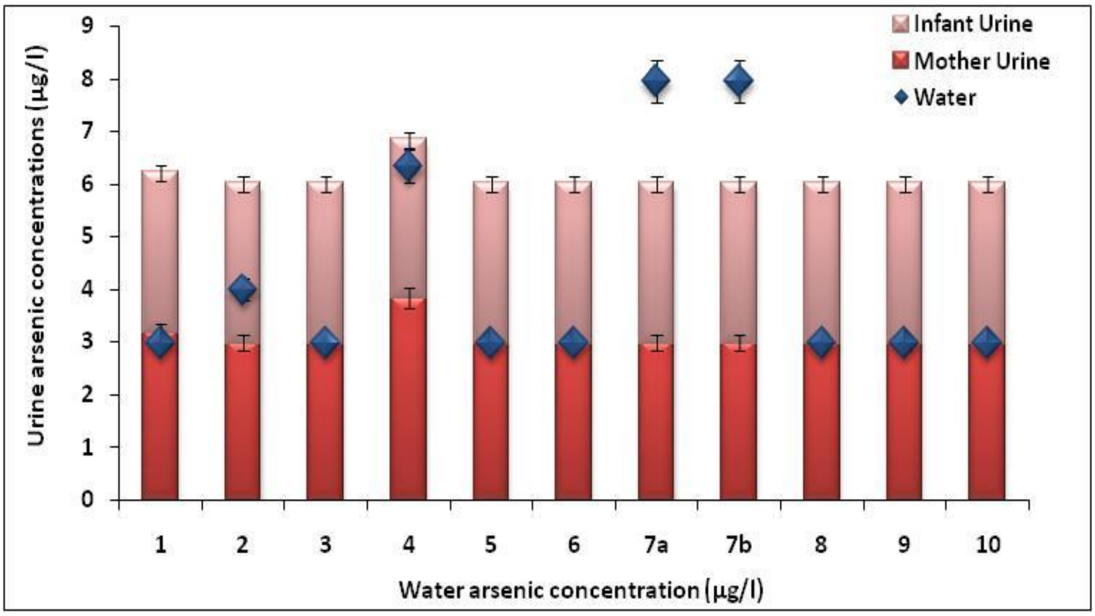
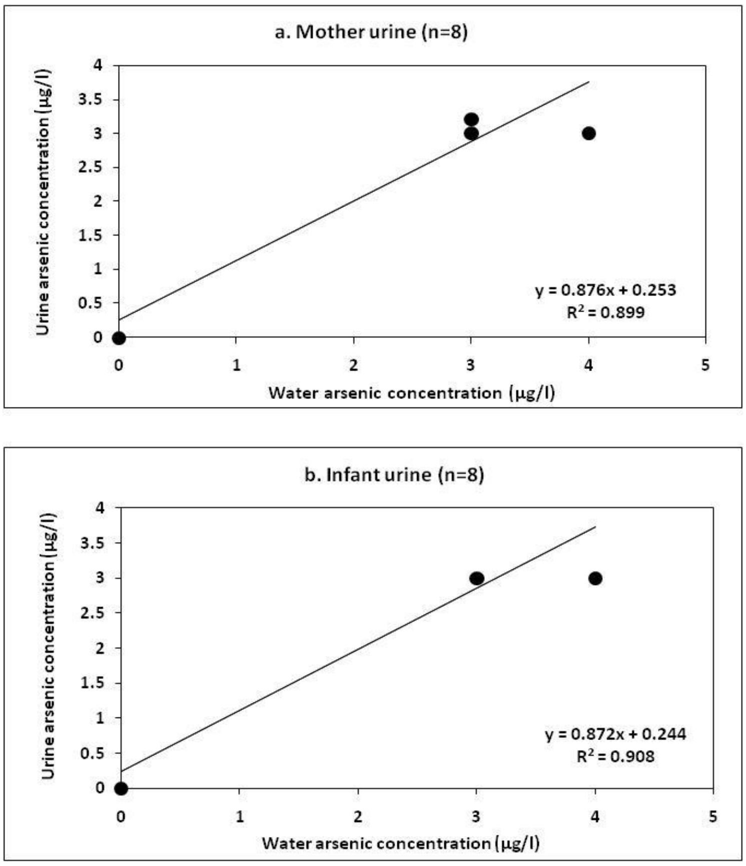


Fig. 46. Variation in urine As concentration of the studied population (mother and infant) with their respective water As concentration



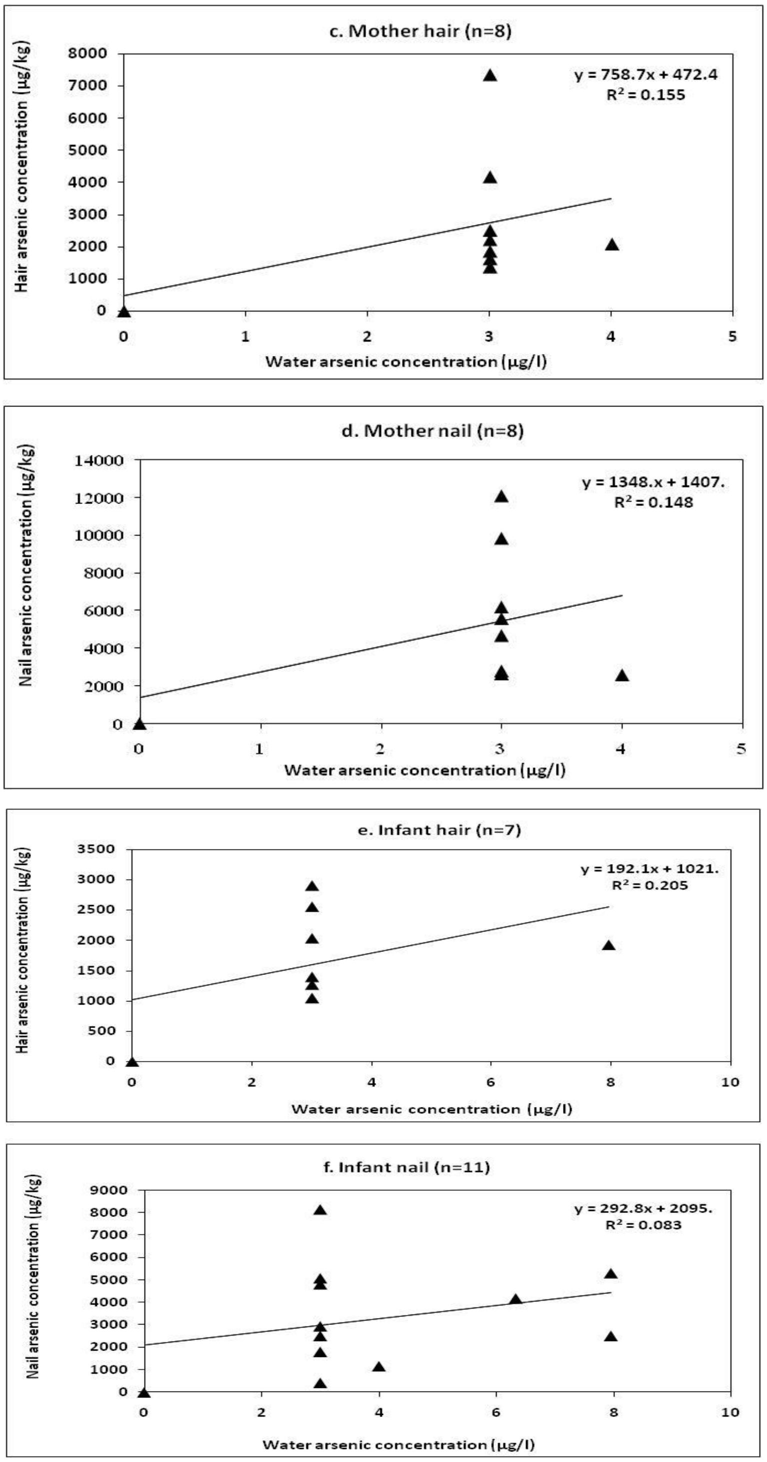


Fig. 47. Regression analysis showing the relation between water As with the biomarkers (urine, hair and nail) of the studied (mother and infant) population

6.8.3.2. Chronic Exposure Level

The chronic level of toxicity in the human body system is determined by monitoring the biomarkers (hair and nail) of As (Povorinskaya and Karpenko, 2009; Goswami et al., 2020). The deposition rate of As is fast as well as high in nails compared to hair (NRC, 1999), because of the keratin protein in the respective body tissues (Shapiro, 1967). In this study, total As in scalp hair and nails of the mother and infant was analyzed to measure the body burden depending on the rate of As exposure.

In this survey, high buildup of As has been found in hair and nail samples collected from the studied populace (mother and infant). In our study, the mother hair samples (n = 10) showed a mean As value of 3321 ± 2509 µg/kg, ranging from 1370 to 8300 µg/kg. Correspondingly, mother nail samples (n = 10) showed a mean As value of 5829 ± 3184 µg/kg, ranging from 2580 to 12100 µg/kg. As well, infants from the studied area indicated a mean As value of 1655 ± 900 µg/kg, ranging from 80 to 2910 µg/kg for hair (n = 11) samples. Similarly, the infants nail (*n* = 11) samples showed a mean As value of 4148 ± 2104 µg/kg, ranging from 1810 to 8160 µg/kg. Arsenic distribution in hair and nail of the mother and infant individuals from the studied area is shown in Fig. 48.

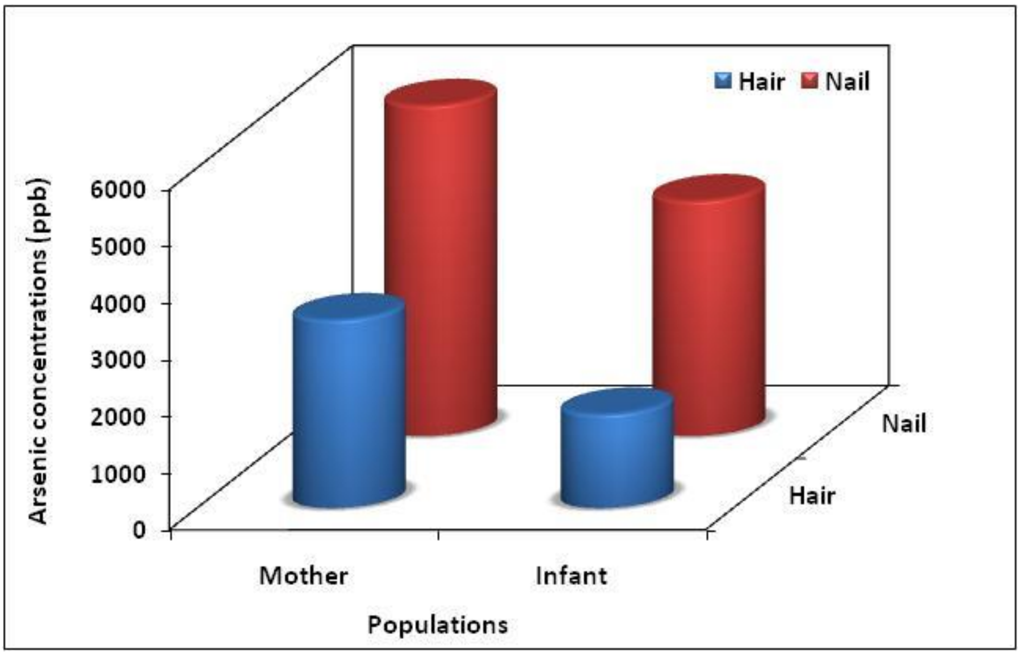


Fig. 48. Arsenic distribution in hair and nail of the mother and infant individuals from the studied area

As the studied populace is presently exposed to As-safe drinking water, it is essential to understand the significant relation among their water and biological markers. No significant association has been detected between water As concentration and hair (R^2 = 0.1557) and nail As concentration (R^2 = 0.1489) for the mothers, respectively (Fig. 47c, d). In the case of infant populaces, no significant association was detected statistically between As concentration in water and that of hair (R^2 = 0.2054) and nail (R^2 = 0.0835), respectively (Fig. 47e, f). Children are more susceptible to adverse health effects caused by toxic elements. Borgono et al. (1977) reported that children aged below and above 6 years demonstrated a substantial quantity of As deposition in hair and nail. The studied populace showed no arsenical skin manifestations in this survey, but still they have a high arsenical body burden in chronic biomarkers (Table 34). As a result, the individuals of the studied area are measured to be sub-clinically affected with As. In rural populaces, malnutrition is held responsible for acute and chronic As toxicity. Good socio-economic position and nutritive balance result in minor arsenical human health risk (Sampson et al., 2008). Existence of vital essential elements, i.e., Zn and Se, in the daily dietary intake shows a dynamic role against the toxic effect of As (Roychowdhury et al., 2002). Roychowdhury (2010) highlighted that the rural Bengal populace survives in conditions of poor nutrition, but as a result they suffer more from As toxicity. In our study, the populaces are suffering from chronic toxicity as they lack proper nutrition in their diet on a daily basis.

6.8.4. Relation between dietary As intake and excretion

A statistical analysis named “two-tailed paired t-test” at 95% confidence level was used to evaluate the inter-relation between As dietary intake and excretion among the studied populace. For the mother populace, the analysis was performed to evaluate the inter-dependence between the intake of As (independent variables) through drinking water and cooked rice and excretion (biomarkers). In a similar way, for the infant populace the inter-relation was evaluated between the dietaryintakes of As (drinking water, cooked rice, breast milk, cow’s milk, commercial baby food (Cerelac) and homemade food mixture) and excretion (dependent variable). Two hypotheses have been assumed for the statistical interpretation: the null hypothesis (H_0) signifies ‘no significant dependence between As intake and excretion’ whereas the alternate hypothesis (H_1) denotes ‘significant dependence between As intake and excretion’. The respective t_{stat} has been evaluated against the $t_{critical}$ along with the ‘degrees of freedom’ (*df*) for the studied populaces (Table 35).

Table 35: “Two-tailed paired t-test” showing the relation between As intakes and excretes among the studied groups

Group	**As Intake**	**As excrete**			**Degrees of freedom (*df*)***	**Remarks**
		Urine	**Hair**	**Nail**		
Mother	**Drinking water**	$t_{stat}(-0.11) < t_{crit}(2.26)$	$t_{stat}(4.18) > t_{crit}(2.26)$	$t_{stat}(5.78) > t_{crit}(2.26)$	9	Null hypothesis: accepted in the case of urine. Alternate hypothesis:
	Cooked rice	$t_{stat}(-5.85) < t_{crit}(2.26)$	$t_{stat}(4.11) > t_{crit}(2.26)$	$t_{stat}(5.73) > t_{crit}(2.26)$	9	

						accepted for hair and nail.
Infant	**Drinking water**	**$t_{stat}(-1.53) < t_{crit}(2.36)$**	**$t_{stat}(6.61) > t_{crit}(2.36)$**	**$t_{stat}(5.57) > t_{crit}(2.36)$**	7	Null hypothesis: accepted in the case of urine. Alternate hypothesis: accepted for hair and nail.
	Cooked rice	**$t_{stat}(-5.01) < t_{crit}(2.36)$**	**$t_{stat}(6.61) > t_{crit}(2.36)$**	**$t_{stat}(5.49) > t_{crit}(2.36)$**	7	
	Breast milk	**$t_{stat}(-0.93) < t_{crit}(12.7)$**	**$t_{stat}(3.6) < t_{crit}(12.7)$**	**$t_{stat}(3.17) < t_{crit}(12.7)$**	1	Null hypothesis: accepted in each case.
	Cow milk	**$t_{stat}(-2.89) < t_{crit}(4.30)$**	**$t_{stat}(2.92) < t_{crit}(4.30)$**	**$t_{stat}(2.06) < t_{crit}(4.30)$**	2	
	Commercial food (Cerelac)	**$t_{stat}(-7.97) < t_{crit}(4.30)$**	**$t_{stat}(3.21) < t_{crit}(4.30)$**	**$t_{stat}(2.24) < t_{crit}(4.30)$**	2	
	Home-made food mixture	**$t_{stat}(-2.55) < t_{crit}(12.7)$**	**$t_{stat}(2.36) < t_{crit}(12.7)$**	**$t_{stat}(8.62) < t_{crit}(12.7)$**	1	

** Significant at $\alpha = 0.05$;*

In view of the mother populace studied, no significant dependence has been observed between As intake and excretion (urine). In contrast, significant dependence was observed in the case of hair and nail (excretion) with As intake as their t_{stat} values are greater than $t_{critical}$ values. Hence, the alternate hypothesis (H_1) is accepted.

Likewise, for the infant populace, no significant dependence has been observed between As intake (drinking water and cooked rice) and excretion (urine). In contrast, in the case of hair and nail (excretion) a significant dependence has been observed with As intake (drinking water and cooked rice). In a similar way, no significant dependence has been observed within the As intake (breast milk, cow's milk, commercial food (cerelac), and homemade food mixture) and excretion (urine, hair, and nail) as their t_{stat}values are lower than $t_{critical}$ values. Hence, the null hypothesis (H_1) is accepted.

As a result, the survey specifies that food chain contamination is majorly respon- sible for exposure to chronic As toxicity. Hence, it can be stated that the proportion of As exposure in humans is solely reliant on the ingestion of As on a regular basis. Therefore, the consumption of As through daily dietary intake paves a way to be exposed to As toxicity.

6.8.5. Health risk assessment analysis on the mother and infant population through consumption of dietary intakes

The potential health risk (carcinogenic and non-carcinogenic) for the studied populace from their respective dietary sources is shown in Table 36. The mean carcinogenic risk from drinking water and cooked rice in the mother populace has been observed as $1.79\text{x}10^{-4}$ and $4.04\text{x}10^{-4}$, respectively. For the infant populace, the mean carcinogenic risk from drinking water, cooked rice, breast milk, cow's milk, commercial food (Cerelac), and homemade food mixture was

2.63×10^{-5}, 2.11×10^{-5}, 2.11×10^{-6}, 2.85×10^{-5}, 1.79×10^{-5}, and 6.15×10^{-5}, respectively. The normal range for lifetime carcinogenic risk is ranging from 10^{-6} to 10^{-4} (USEPA, 2011; Kazi et al., 2016). This study reveals that carcinogenic risk persists for a life- time among the studied (mother and infant) populace through the intake of their respective dietary sources. The potential health risk to infants through consumption of breast milk is lower compared to their other daily dietary intakes. Cancer risk assessment through ingestion of daily dietary intakes of the studied populaces is shown in Fig. 49.

Likewise, for the non-carcinogenic risk (HQ value) the mean value in drinking water and cooked rice observed for the mother populace is 0.39 and 0.89 respectively. Similarly, in infant populaces, the mean HQ values observed are 0.06, 0.05, 0.005, 0.06, 0.04, and 0.14 for drinking water, cooked rice, breast milk, cow's milk, commercial food (Cerelac), and homemade food mixture respectively. The accepted level of non-carcinogenic risk is unity (USEPA, 2005). A study has reported that when HQ values are less than 1, this signifies that the reference dose is greater than DIA and it does not carry a harmful impact for human health (Kazi et al., 2016). In our survey, as the HQ values are less than 1, so the impact of non- carcinogenic risk does not persist among the studied populace. As a result, there is less chance of non-cancerous health hazards among the populaces.

Table 36: Cancer and non-cancer risk among the mother and infant population of the exposed area

Groups	Samples	No. of samples (n)	Non-cancer risk (Range)	Cancer risk (Range)
Mother	**Drinking water**	10	0.27 - 0.77	$1.25\times10^{-4} – 3.47\times10^{-4}$
	Cooked rice	10	0.21 - 1.70	$9.88\times10^{-5} – 7.65\times10^{-4}$
Infant	**Drinking water**	11	0.005 - 0.20	$2.41\times10^{-6} – 9.17\times10^{-5}$
	Cooked rice	11	0.01 - 0.15	$2.56\times10^{-6} – 6.75\times10^{-5}$
	Breast milk	2	0.002 - 0.007	$1.03\times10^{-6} – 3.19\times10^{-6}$
	Cow milk	3	0.01 - 0.09	$4.38\times10^{-6} – 4.34\times10^{-5}$
	Commercial food (Cerelac)	3	0.01 - 0.08	$5.83\times10^{-6} – 3.43\times10^{-5}$
	Homemade food mixture	3	0.06 - 0.24	$2.75\times10^{-5} – 1.09\times10^{-4}$

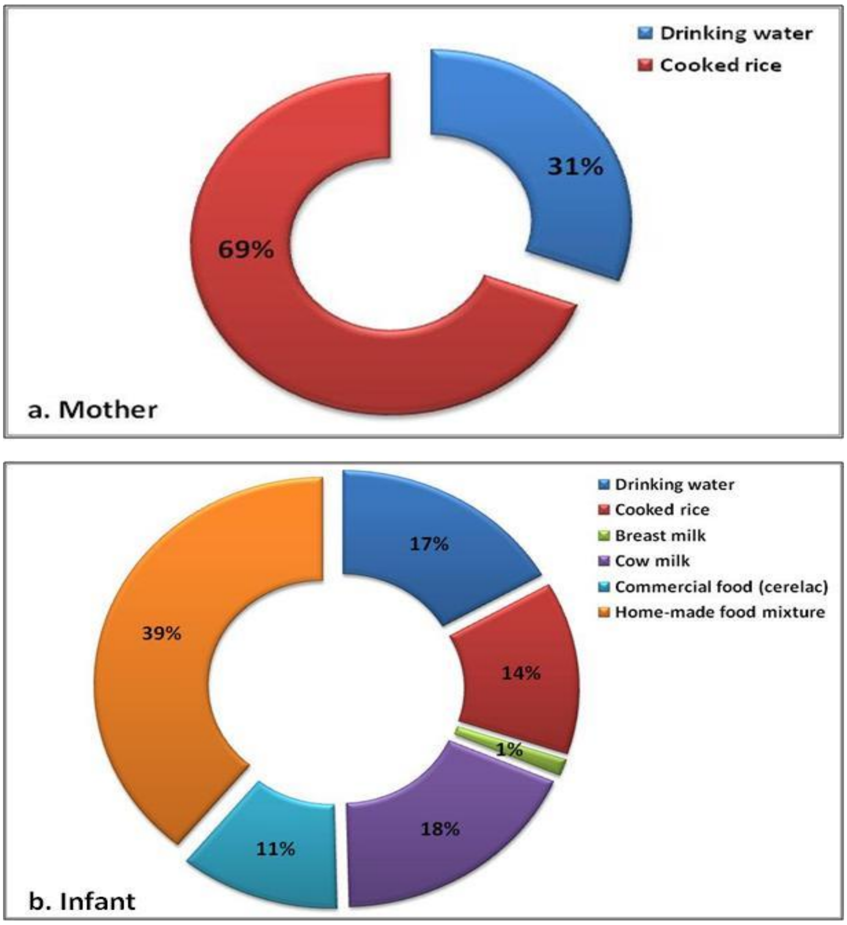


Fig. 49. Cancer risk assessment through ingestion of daily dietary intakes of As for a) Mother and b) Infant population

Overall it can be stated that the studied unexposed (mother and infant) populace is presently exposed to As-safe drinking water. As accumulation in cooked rice is lower than raw rice, as the cooked rice preparation was performed with As-safe drinking water. During statistical interpretation, it was observed that ingestion of As through dietary intakes (drinking water and cooked rice) on a daily basis is a considerable exposure pathway to chronic As toxicity for the studied populace. For the infant populace, the high accumulation of As in the biological tissues (scalp hair and nail) states that they are sub-clinically affected with As. The potential carcinogenic risk persists for a lifetime among the studied (mother and infant) populace through their respective dietary sources. The potential health risk to infants through ingestion of breast milk is least compared to their other daily dietary intakes. Similarly, the non-carcinogenic risk (HQ) showed values less than 1, which signifies that the studied populaces are not prone tosevere non-cancerous health hazards. The studied populaces do not show arsenical skin lesions, as they are sub-clinically affected by As toxicity.

6.9. Exposure and health risk assessment of different aged children due to groundwater arsenic contamination from a severely exposed block, West Bengal, India

The present-day study aims to assess the rate of health exposure and its associated health risk through contaminated drinking water by the different aged children from a severely As endemic area situated in North 24 Parganas of West Bengal. Daily dietary intake rate of As in children has been measured in comparison to the TDI (Tolerable Daily Intake) value. On a subjective note, the acute level of exposure in the children has been examined by analysing the urine (biomarker of As). This study mainly highlights the health status of children exposed attributable to acute As toxicity. Moreover, it aims to focus on the future cancerous and non-cancerous risk among the different aged children instigated as a result of drinking of As contaminated water. To the best of our knowledge, this is possibly a unique health risk assessment study on different aged children from a severely As exposed block of Bengal delta.

A severely As affected area namely Gaighata block, North 24 Parganas district has been targeted as our study area. Differently aged-children i.e. 1-5 years, 6-10 years and 11-15 years have been selected in this study.

Health risk assessment study was made to assess the cancer and non-cancer risks on the different aged-children through consumption of drinking water on a daily basis from the studied area. USEPA (2001) describes the different models to evaluate cancer and non-cancer health risk.

The Average Daily Dose (ADD) of As due to consumption of As-contaminated drinking water is calculated using the above mentioned equation in *section 5.8.8.*

Where, IR = ingestion rate (l/day for drinking water); (1-5 years: 1 l (Rahman et al., 2021)), (6-10 years: 1.5 l (Baig et al., 2016)), (11-15 years: 2.1 l (Hossain et al., 2013));

BW = body weight (kg); (1-5 years: 15.4 kg (Ono et al., 2012)), (6-10 years: 17.5 kg and 11-15 years: 24 kg (Baig et al., 2016));

AT = average life time (365x60 days = 21,900 days) (Chattopadhyay et al., 2020).

6.9.1. Contamination scenario of As

Insufficient access to treated water sources, poverty and lack of awareness among the populace of rural belt of West Bengal, they are prone to As exposure through drinking of As-contaminated groundwater at domestic level. Water samples collected for the health effect study from the domestic tube-well used by different aged children, revealed the respective mean As concentration as 57.7 µg/L (1-5 years, n=16), 58.6 µg/L (6-10 years, n=27), and 57.6 µg/L (11-15 years, n=19) (Table 37). Overall, the average As concentration in drinking water (n=62) is 58.1 µg/L, ranging from 3-169 µg/L. The study revealed that the water As concentrations 5 times were higher than the recommended value set by World Health Organization (WHO) i.e., 10µg/L (WHO, 2011a). As a result, it can be said that presently the different aged children are exposed to As intake through drinking water. Inorganic As mainly arsenite (As III) and arsenate (As V) are found to be the most dominant species which have been testified in the groundwater from the Bengal basin (Tokunaga et al., 2005). The present amount of As in the domestic level tube-wells situated in Gaighata block indicated that the different exposed individuals are quiet on the margin of consuming groundwater which is contaminated with As. Previously, it has been observed that an average As concentration of 70.5 µg/L, ranging from 3-390 µg/L in the water (n=42) samples from residents of the school children of Sutia gram panchayat. Similarly, the study from four different exposed populations of Gaighata block showed mean As concentration of 615, 301, 48 and 20 µg/L from the respective extremely highly, highly, moderately and mild exposed areas.

Table 37: Status of As concentration in the studied tube-wells (domestic purpose)

Groups	Samples (n)	Mean As (µg/L)	SD	Range (µg/L)
1 - 5 years	16	57.7	50.7	3-167
6 - 10 years	27	58.6	50.1	11-162
11 - 15 years	19	57.6	55.7	8.5-169

6.9.2. TDI (Tolerable Dietary Intake) of As through drinking water

Groundwater used for drinking contains inorganic As (iAs) which is around 80% of the overall As content (Roychowdhury, 2008; Signes-Pastor et al., 2008). The observed DDI (daily dietary intake) of As through drinking water for the studied children is placed in Table 38. DDI of As via drinking water by the respective children of 1-5, 6-10 and 11-15 years of age was 3.74, 5.02 and 5.04 µg/kg bw/day. The observed TDI of As for the different aged children are much greater than the acceptable TDI value of iAs, i.e., 3.0 µg/kg bw/day (WHO, 2011b). Hence, the studied children inhabitants are exposed to the noxious effect of As. A aforesaid study report showed that contaminated drinking water consumed through by the children contributed 5.26 µg/kg bw/day of As.

Table 38: Calculated DDI of As for the different age groups of children

Groups	Volume of drinking water consumed / day (litre)	Average body weight (kg)	Observed DDI	Recommended TDI
1 - 5 years	1	15.4	3.74	3.0
6 - 10 years	1.5	17.5	5.02	3.0
11 - 15 years	2.1	24	5.04	3.0

6.9.3. Acute exposure level of As toxicity

Urine As is the primary biomarker which indicates the acute level of As exposure in a human body system (Nermell et al., 2008; Vahter, 1994). The halftime of iAs in human body matters around 4 days, as the aforementioned is not as much of reliant on the keratin cells (Goswami et al., 2020). Arsenic concentrations in urine of the studied children populaces has been shown in Table 39. Differently aged children showed an average urine As concentration of 48.4 µg/l (range: 18-100 µg/l), 72 µg/l (range: 15-212 µg/l), and 66.3 µg/l (range: 3.1-195 µg/l) for 1-5, 6-10 and 11-15 years, respectively. The observed urine As values of the studied inhabitants were much greater than the acceptable limit of As in urine, i.e. 3-26 µg/l (Farmer and Johnson, 1990). Variation in water and urine As of the studied populace has been shown in Fig 50. The prominent urine As level reveals that the different age groups of children are presently exposed to drinking of As-contaminated water. As children do not show dermatological manifestations due to As-toxicity; however, they are sub-clinically affected.

A study report on sub-clinically affected school children (n=43) from Gaighata showed a mean value of 64.6 µg/L As, ranging from 15-212 µg/L in urine. Several researches on children aged between 5-15 years from India, Pakistan, Chile, Bangladesh, China, and Inner Mongolia indicated a high amount of As content in urine than its acceptable range (Baig et al., 2016; Borgoño et al., 1977; Kippler et al., 2016; Mazumder et al., 1998; Watanabe et al., 2007).

Table 39: Urine As concentrations (acute exposure) of the studied children population

Groups	Samples (n)	Mean As (µg/L)	SD	Range (µg/L)
1 - 5 years	16	48.4	23.4	18-100
6 - 10 years	27	72	54.9	15-212
11 - 15 years	19	66.3	63.1	3.1-195

#Standard range of As content in urine (1.5 l) is 5-40 µg/day (**Farmer and Johnson, 1990**)

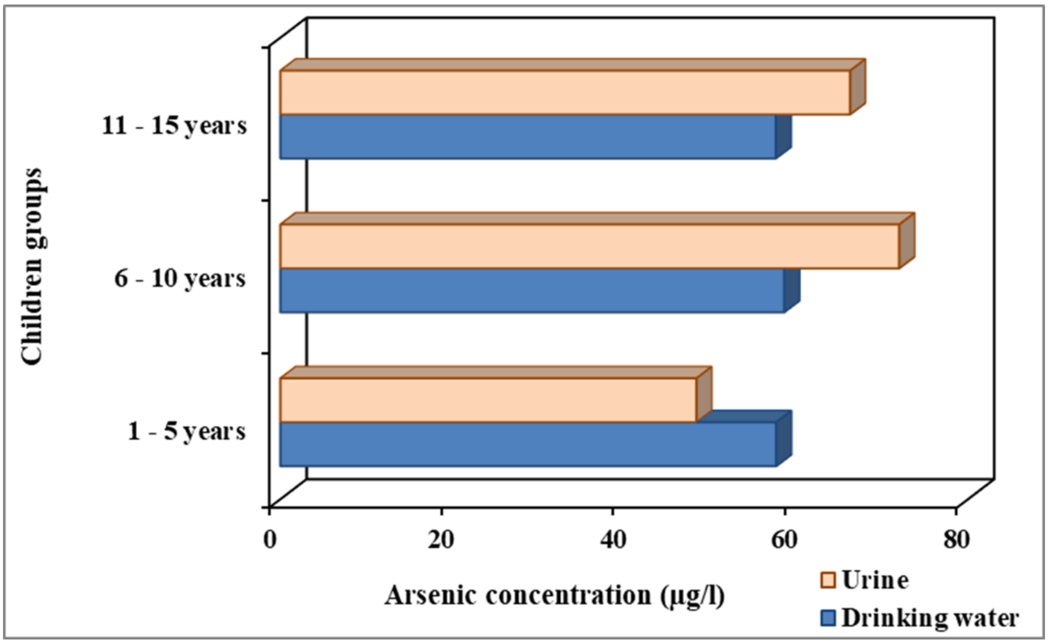


Fig. 50. Distributions of drinking water and urine As concentrations of the different aged children

6.9.4. Chronic exposure level of As toxicity

Deposition rate of As in hair and nail of the considered children populace has been placed in Table 40. The best possible way in determining long-standing As exposure is by measuring the As deposition in hair &nails (Shankar et al., 2014). After a span of time, i.e. 2 to 5 months for hair & 12 to 18 months for nails, the toxic effect of As manifest on human health (Pororinskaya and Karpenko, 2009). Different age groups showed an average hair As of 2188 µg/kg, (n=16; range=1130-5640µg/kg), 2968 µg/kg (n=27; range=790-9230µg/kg), and 3145 µg/kg (n=19; range=2090-4630µg/kg) for the respective 1-5, 6-10 and 11-15 years of children. The observed hair As values of the studied inhabitants were much greater than the acceptable limit of As in hair i.e. 80-250 µg/kg (Arnold et al., 1990). Likewise, different age groups showed an average nail As of 3836 µg/kg, (n=16; range=1780-11300 µg/kg), 4737 µg/kg (n=27; range=1510-13700 µg/kg), and 4981 µg/kg (n=19; range=1240-13800 µg/kg) for the respective 1-5, 6-10 and 11-15 years of children. The observed nail As values of the studied inhabitants were much greater than the acceptable limit of As in nail i.e. is 430 - 1,080 µg/kg (Ioanid et al., 1961). Distributions of As in urine, hair and nail of the different aged children has been shown in Fig 51. From the observations, it can be stated that As accumulation in hair and nail occurs irrespective of the age groups of the children. Among the different age groups nail As appears to be higher compared to hair As by 1.75 (1-5 years), 1.59 (6-10 years) and 1.58 (11-15 years) times, respectively. Our finding i.e. the amount of As deposition is more in nail than hair which corroborates with the report as stated by NRC (1999). This observation highlights that the studied children's age groups are sub-clinically affected as a result of As contamination.

Table 40: Deposition of As in a) Hair & b) Nail (chronic exposure) of the studied children populace

a) Hair As

Groups	Samples (n)	Mean As (µg/kg)	SD	Range (µg/kg)
1 - 5 years	16	2188	1273	1130-5640
6 - 10 years	27	2968	2036	790-9230
11 - 15 years	19	3145	852	2090-4630

#Standard range of As content in hair is 80 - 250 µg/kg (Arnold et al., 1990)

b) Nail As

Groups	Samples (n)	Mean As (µg/kg)	SD	Range (µg/kg)
1 - 5 years	16	3830	2575	1780-11300
6 - 10 years	27	4737	3050	1510-13700
11 - 15 years	19	4981	3886	1240-13800

#Standard range of As content in nail is 430 - 1,080 µg/kg (Ioanid et al., 1961)

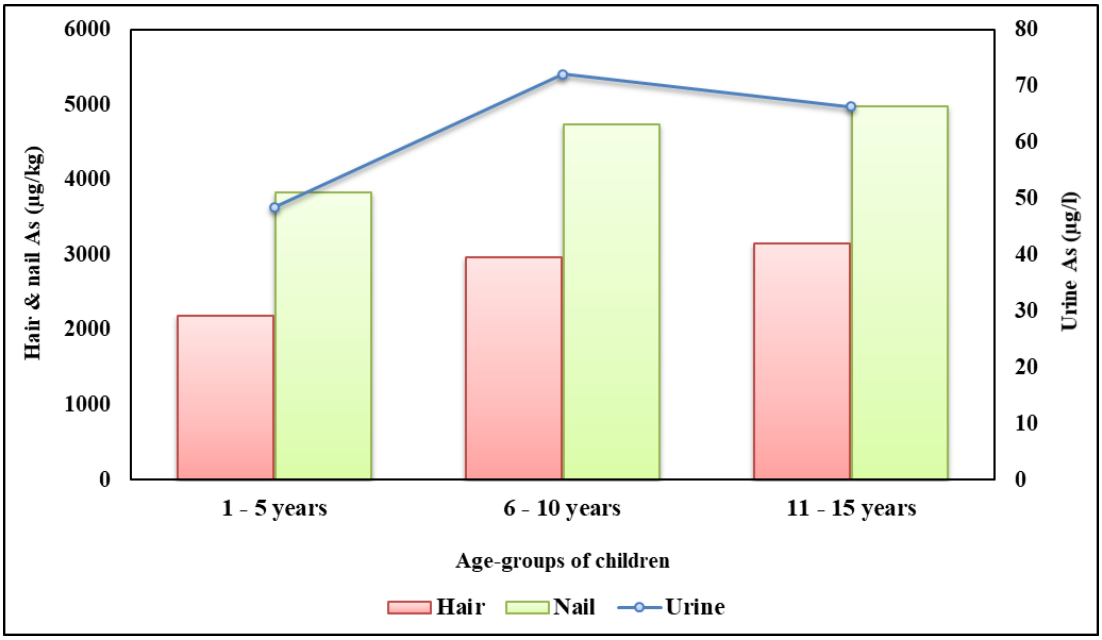


Fig. 51. Distributions of As in urine, hair and nail of the different aged children

6.9.5. Health risk assessment

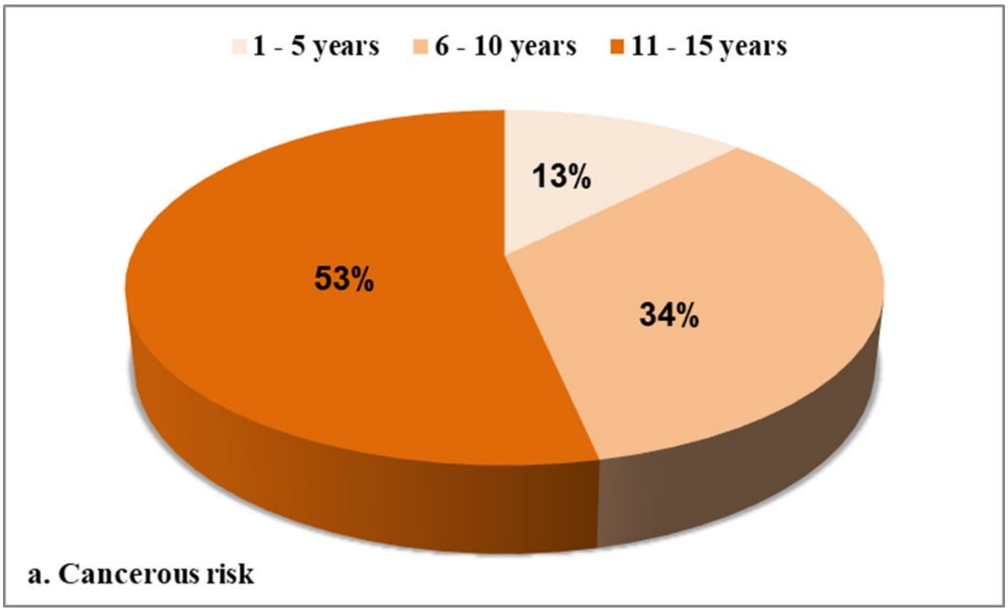
Cancerous and non-cancerous health risk through drinking of As-contaminated water has been shown for the studied children's groups in Table 41. The risk evaluation was organized using the overall approaches taken from USEPA principle (USEPA, 2001). Risk appraisal was executed to calculate the possibility of aged children who are exposed to As via drinking of As-contaminated water. The studied groups of differently aged children are facing substantial future cancerous threat through drinking of As-contaminated water on a daily basis (Fig. 52a). It is well-known that iAs is an intoxicating carcinogen for humans (IARC 2012; NRC, 2001). The observed mean cancerous risk for the (1-5 years) group of children is $3.9 \times 10^{-4}$and (6-10 years) group of children is 1.1×10^{-3} through contaminated drinking water. Similarly, the eldest (11-15 years) group of children showed mean cancerous risk of 1.7×10^{-3}. The greater health (cancerous) risk observed is probably due to the intake rate and duration of As exposure throughout the lifetime of the different aged children. The observed mean cancerous risk values of the studied groups of children are greater compared to 1×10^{-6} (acceptable level of As-induced risk) (Das et al., 2020; USEPA, 2005). As reported, normal range for lifetime cancerous risk is from 10^{-6} to 10^{-4} (Kazi et al., 2016; USEPA, 2011). This study reveals that cancerous health risk persists for lifetime among the studied groups of children inhabitants through drinking of As-contaminated water.

Likewise, HQ (Hazard Quotient) value depicts the non-cancerous risk through drinking of As-contaminated water for the studied age groups of children (Fig. 52b). The mean non-cancerous

(HQ value) risk for 1-5 years' children is 0.88, which is lower than the threshold value (HQ>1) (USEPA, 2005). The observed HQ value for (6-10 years) and (11-15 years) children is 2.43 and 3.85 respectively, are much greater than 1. The accepted level of non- cancerous risk is unity (Das et al., 2020; USEPA, 2005). A study has reported that when HQ values are less than 1, it denotes that the reference dose is greater than daily intake of As, so, it does not carry harmful impact on human health (Kazi et al., 2016). In our study, there is less chance of non-cancerous health hazards for the youngest (1-5 years) group of children as their HQ values are less than 1. Whereas, for 6-10 years and 11-15 years' children non-cancerous health risks persists as the HQ values are much higher than 1. So, it can be concluded that in rural Bengal differently aged children from the studied As-exposed area might be inclined to non-cancerous health threats in future through drinking of contaminated water. This study highlights that the eldest (11-15 years) group of children are more prone to health (cancerous and non-cancerous) risk compared to 6-10 years and 1-5 years' group of children from the studied As-exposed block.

Table 41: Health risk assessment through drinking water for the studied groups of children

Groups	**Average Daily Dose (ADD) (mg/kg bw/day)**		**Cancerous risk**		**Non-cancerous risk**	
	Mean value	**Range**	**Mean value**	**Range**	**Mean value**	**Range**
1-5 years	0.00026	$9.7x10^{-6}$ -0.00079	$3.9x10^{-4}$	$1.46x10^{-5}$ - $1.18x10^{-3}$	0.88	0.032 - 2.63
6-10 years	0.00072	0.00013 - 0.00231	$1.1x10^{-3}$	$1.88x10^{-4}$ - $2.31x10^{-3}$	2.43	0.42 - 7.71
11-15 years	0.00115	0.00018 - 0.00310	$1.7x10^{-3}$	$2.78x10^{-4}$ - $4.65x10^{-3}$	3.85	0.62 - 10.4



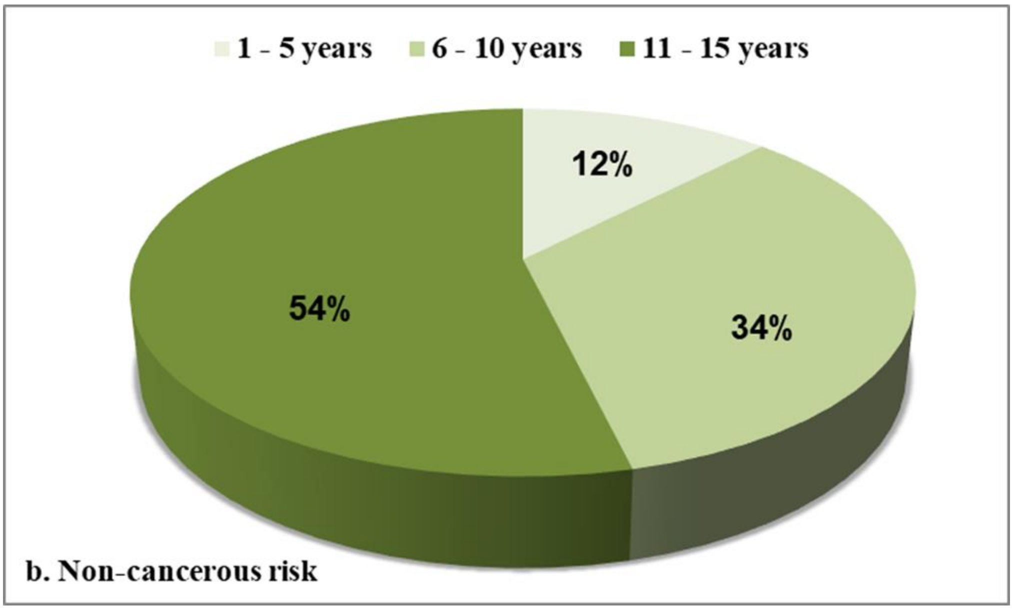


Fig. 52 a. Cancerous risk, b. non-cancerous risk evaluation through drinking of contaminated water for the studied groups of children

Overall, it has been observed that drinking water As concentration from the studied exposed area is 5 times higher than the WHO acceptable limit. The tolerable dietary intake of As by the children through contaminated drinking water is more than the WHO recommended value. Apparently, the elder group of studied children (11-15 years) are at greater risk compared to the (6-10 years) and (1-5 years), because of a longer duration of As exposure. Similarly, the non-cancer risk (HQ value >1) signifies that the studied group of children are prone to several non-cancerous health hazards.

6.10. Appraisal of acute and chronic health exposure due to arsenic toxicity on school children from exposed and apparently control areas of West Bengal, India

A group of school children (age: 5-12 years) has been selected from an As exposed (Gaighata block, North 24 Parganas district) and apparently control (Kolkata) area of West Bengal, India. ‘Madhusudankati Free Primary School’ (22º53´53.82´´N, 88º46´38.33´´E), an exposed school situated in a village named Madhusudankati from Sutia gram panchayat of the block Likewise, apparently control area school named ‘Purba Kalikata Odia High School’ (22º34´53.39´´N, 88º23´36.50´´E) is situated in the northern portion of Kolkata district. Map of the study area has been shown in **Fig. 53.**

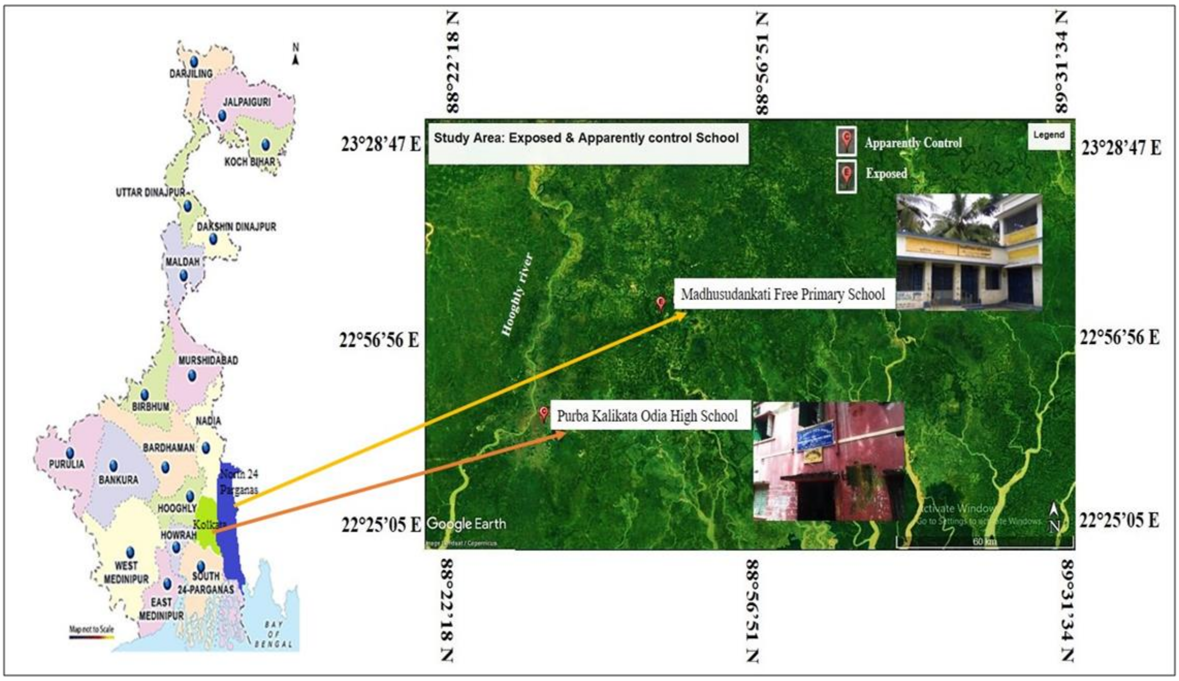


Fig. 53. Map of the study area: Exposed and apparently Control school [Google Earth Pro: 7.3.2.5776]

All age groups have been debilitated by arsenic exposure and its negative effects, and there are few possibilities for mitigation. Therefore, it is imperative to remove As, a potent neurotoxic and carcinogenic agent, as much as probable from food crops and drinking water in order to improve the socioeconomic and physical well-being of future generations. Due to the lack of symptoms, such as skin lesions, identifying As poisoning in children is often difficult. As children experience sub-clinical toxicity, it is more important to evaluate their overall health in order to reduce risk in the future.

Through the consumption of drinking water and rice from As exposed and apparently control areas, the study targets to quantify the cumulative As exposure on school children. To emphasize the impact of both acute and chronic As poisoning on children's (aged between 5 and 12 years) health, quantitative analysis of As deposition in urine and biological tissues was examined. The appraisals of cancerous risk for school-aged individuals from both populaces were assessed. After eight months, health exposure research was carried out to measure the impact of the awareness campaign on As toxicity and the availability of As-safe water among the exposed school children. This is possibly the foremost study on the school children from two differently studied populaces situated in Bengal.

6.10.1. Arsenic contamination scenario

6.10.1.1. Water As

6.10.1.2. Contamination in study area including school tube-wells

Gaighata block is one of the 107 As-impacted blocks recorded in Bengal that is most seriously affected with As (Roychowdhury, 2010). Deep aquifers and ARP’s have been installed to arrange and supply As-safe water. Additionally, local administrations in several endemic areas of West Bengal supplies treated surface water through pipeline. Since, it is difficult to access As-safe water and due to lack of knowledge, As polluted water is frequently used at the time of cooking, drinking, and further household activities, in addition to irrigation, especially during the Boro cultivation (Biswas et al., 2019).

Arsenic accumulation in the domestic tube-wells positioned in Sutia presented that the inhabitants are dependent on the As-contaminated water for drinking. Concentration of As in 83 water samples from Sutia showed a mean value of 49 µg/L, ranging from 3-786 µg/L. Substantial As have been observed in water samples from the surrounding school tube-wells (n=22) situated in Sutia (mean: 23 µg/L, ranging from 3-144 µg/L) (**Fig. 54**). Madhusudankati Free Primary School tube-well water (n=4) showed a mean As value of 98.3 µg/L, ranging from 88-105 µg/L, specifically on which this health exposure study of the school children has been conducted. Likewise, the withdrawn groundwater (apparently control area) from ‘Purba Kalikata Odia High School’ was found to be 3.14 µg/L.

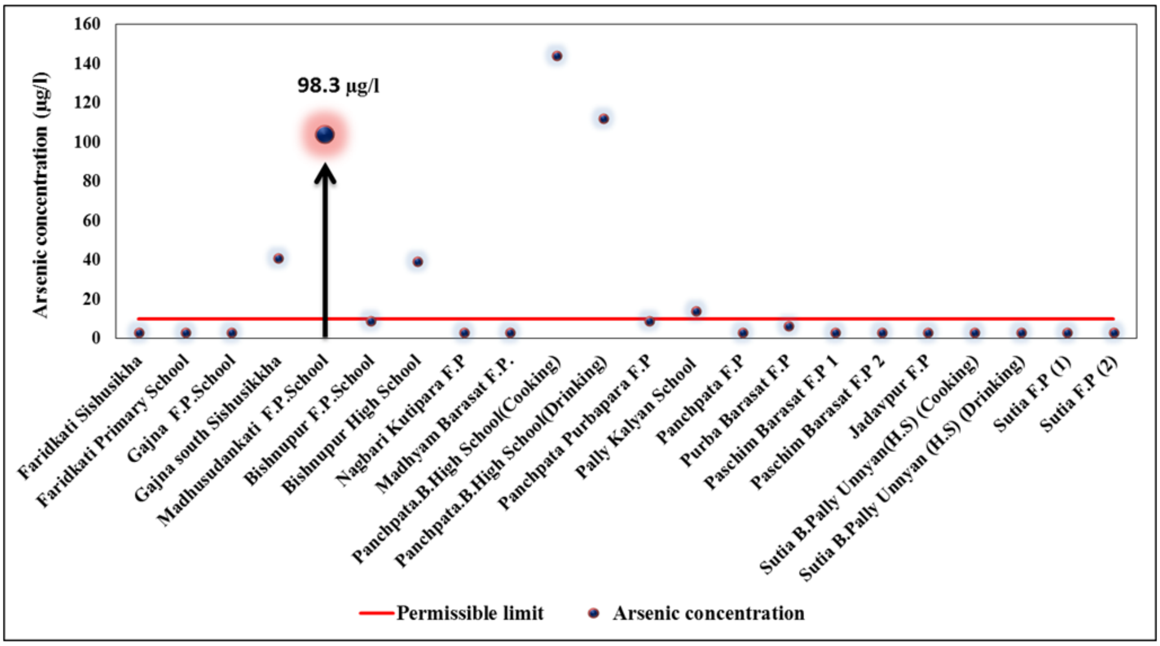


Fig. 54. Status of As concentrations in drinking water collected from school tube-wells located in As exposed area (Sutia gram panchayat, Gaighata block, North 24 Parganas district)

6.10.1.3. Domestic level As contamination in drinking water

In addition, to the concentration of As which is being consumed through water (source: school tube-wells), it is also vital to assess the amount of As contributed via domestic tube-wells. These household tube-wells typically have a depth range of 6.09-24.4 m (20–80 ft). In comparison to the deep aquifer, the prospect of contamination with As is at all times greater than shallow groundwater. According to As concentration in groundwater from the Bengal Delta it initially rises until a depth of about 40 m, then falls as with increasing depth (Roychowdhury et al., 1999). The mean As in water (n=42) samples from the respective exposed school children’s resident was 70.5 µg/L, ranging from 3-390 µg/L. Likewise, water (n=32) samples from the apparently control children’s resident showed a mean As of 3.38 µg/L, which ranged from 3-6.56 µg/L. The situation discloses that the apparently control populace is drinking As-safe water than the exposed populace. Kolkata populace has the way to use safe drinking water attributable to the supply of Ganges water by KMC. As reported earlier, (Biswas et al., 2019) drinking water analyzed from the inhabitants living in Kolkata city were harmless in regard to As (n=30; mean: 3.50 µg/L, ranging from <3-5 µg/L).

6.10.2. Daily dietary intake (DDI) rate of As

In rural Bengal, rice is recognized as a major food crop. The amount of As in rice grain rises when contaminated groundwater is used to irrigate paddy fields (Chowdhury et al., 2018a; Samal et al., 2011). The As load in parboiled rice is more than that of sunned rice when paddy crops are parboiled at domestic scale after harvesting using groundwater contaminated with As (Chowdhury et al.,2018b). In addition to the consumption of As through drinking water, rice also significantly plays a vital role to arsenical health problems in many As prone zones worldwide (Azam et al., 2016). As stated in earlier studies, 2l and 380 g of water and rice has been considered as intake rate in their regular diet by the children of 5-12 years (Brahman et al., 2016; Roychowdhury et al., 2002, 2003). Substantial amount of As concentration has been observed in rice analyzed from the residents of both the studied school children. Rice (n=42) samples from the exposed inhabitants showed a mean As of 414 µg/kg, in the range of 168-1302 µg/kg, which is greater compared to the allowable As value in rice (100 µg/kg) for affected areas (Meharg et al., 2006). Likewise, for the apparently inhabitants, the rice (n=32) showed a mean As of 352 µg/kg, ranging from 234-653 µg/kg, which is within the prescribed As value in rice (1000 µg/kg) for unaffected areas (Bhattacharya et al., 2010).

The populace living in non-endemic areas is greatly threatened by the As-contaminated vegetables and rice mainly cultivated in exposed areas and transported to the unexposed areas (Biswas et al.,2019). Arsenical poses serious health risks to populaces whose staple foods are rice and rice by-products. The DDI of As via ingestion of contaminated water, vegetables and rice for both the studied children has been shown in Table 42.

Table 42: Daily dietary intake of As for both the studied children (a) Exposed area(b) Apparently controlarea

Category	**Source**	**Type**	**Amount consumed per day**	**Consumption of As**			
				(a) Exposed (n=42)		**(b) Apparently Control (n=32)**	
				As concentration (µg/L)	As Total (µg)	As concentration (µg/L)	As Total (µg)
School children	**Drinking water**	**Domestic tube-well**	1.5 l	70.5	106	3.38	5.07
		School tube-well	0.5 l	104	52	3.14	1.57

	Rice	**Domestic**	0.28 kg	414	116	352	99
	Mid-day meal (School)	**Rice**	0.10 kg	244	25	203	20
		Vegetables (cooked)	0.15 kg	446	67	267	40
	Total		-	-	**366**	-	**166**

Overall, for the exposed children the intake of As through water, vegetables and rice in the regular diet is greater than the apparently control children. With respect to As toxicity, our results, highlights that the exposed school children are at a greater risk than the apparently control children. Furthermore, in future, there exists a high prospect that the apparently control children will face health risk because of ingesting iAs via transported vegetable and rice as reported (Biswas et al., 2019).

The DDI of As from water, rice, and cooked rice by the school children are shown in **Table 43.** Overall ingestion of As via foodstuffs by the respective exposed and apparently control area school children were 12.2 and 5.51 µg/kg bw/day. Earlier reports highlighted that DDI of iAs were around 11 and 4.96 µg/kg bw/day considering about 90% of the total iAs in rice and vegetables cultivated in As-contaminated soil (Biswas et al.,2019; Chowdhury et al.,2018a, b). The two studied populaces contributed respective 4.23 and 3.56 µg/kg bw/day of iAs through rice. Drinking water contributed 4.73 µg/kg bw/day of iAs from both the sources (domestic and school tube-well) for the exposed children. In this study, per day intake of iAs from all the regular sources (rice/drinking water) is higher compared to the acceptable value (3 µg/kg bw/day, ranging from 2-7 µg/kg bw/day) (WHO, 2011b), as the preceding PTDI value (2.1 µg/kg bw/day) has been withdrawn (JECFA, 2011; EFSA, 2014). Exposed children are facing risk via As-contaminated water and rice, whereas, contaminated crops lead to an added threat to the apparently control school children, regardless of the drinking As-safe water.

Table 43: Observed dietary intake rate of As for both the studied school children

Category	**Location**	**Source**	**Daily Dietary Intake of As (µg/kg bw/day)**	
			Observed	**Recommended**
School Children	**Exposed**	**Drinking water**	**5.26**	**3.0**
		Rice	**4.7**	
		Vegetables	**2.23**	
	Apparently Control	**Drinking water**	**0.22**	**3.0**
		Rice	**3.96**	
		Vegetables	**1.33**	

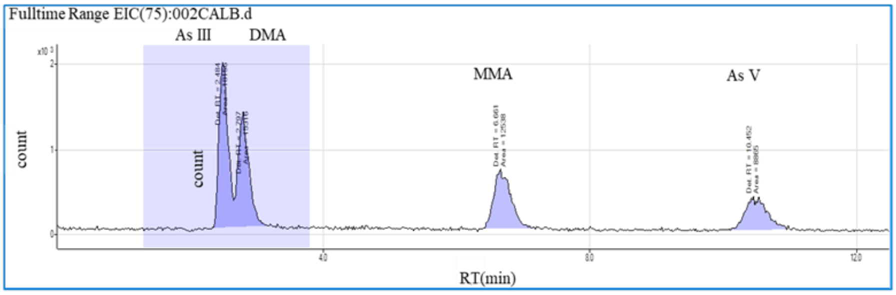
Average weight of school children (aged between 5-12 years) = 30 kg

6.10.3. Intake of inorganic As through consumption of parboiled rice grain

Rice is regarded as one of the important contributors of As in the standard human diet, along with drinking water (Sun et al., 2009). Additionally, the majority of the rice and its byproducts from As-exposed areas are said to contain iAs (Biswas et al., 2019). Compared to soil, the practice of using As-contaminated water at the time of irrigational phase increases the amount of As in grain (Zavala and Duxbury, 2008). The iAs in food, which is a risk to health, accounts for more than 80% of the total As content (Biswas et al., 2019; Signes-Pastor et al., 2008). Yost et al. (2004) reported on evaluating the daily ingestion of iAs in US children shows the highest contribution via rice and its by-products. Rice intake is a primary vital cause of iAs (chronic carcinogen) and Norton et al. (2009) stated that it is vital to decrease the As accumulation in rice (total and iAs), which leads to reduced health threat for humans.

Quantification of As species has been carried out in parboiled rice grain, mainly collected from the exposed children residence. Fig. 55 depicted the chromatogram of 10 µg/L mixed standard solution of As along with parboiled rice. Parboiled rice showed the distributions of respective As species i.e. As (III), DMA and As (V) as 53.4, 16.7 and 88.3 µg/kg. Approximately 89.5% of total As in the rice grain is contributed by iAs. Chowdhury et al. (2018b) reported that in rural Bengal cooked parboiled rice is a regular diet as it is proved to be healthier due to presence of enriched minerals (Doesthale et al., 1979). In near future, continuous eating of parboiled rice might lead to As poisoning along with probable future risk to the children.

a. Standard 10 ppb



b. Parboiled rice grain

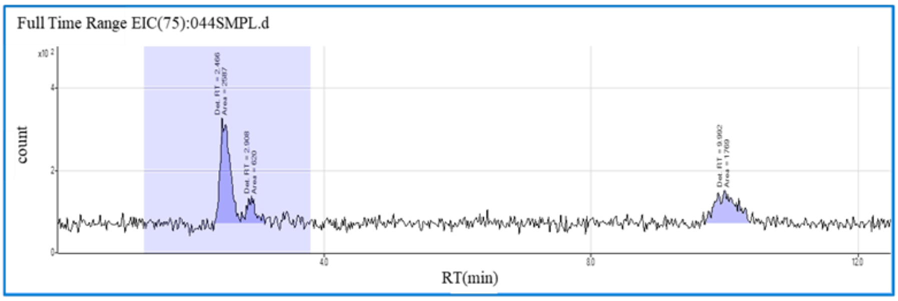


Fig. 55. HPLC chromatograph showing the As species distribution in (a) Standard 10 ppb (b) Parboiled rice graincollected from the domestic level of one of the families from exposed school children

6.10.4. Exposure of As contamination in both exposed and apparently control school children

6.10.4.1. Acute exposure

The total urine As concentration is assessed as a biomarker of recent As exposure, since urine is the foremost means of As species excretion (Buchet et al., 1981; Vahter et al., 1994). In humans, the half-time of iAs excretes within 4 days. As concentrations in the biomarkers of exposed children and apparently control children are shown in Table 44. In West Bengal, higher urine As concentration has been observed from the populace living in exposed areas and consuming high level of As through drinking water (Das et al., 1996). A U.S. populace was chronically exposed to inorganic As through their urine As concentration (Calderon et al., 1999). It is reported that about 83% and 68% of the urine samples collected from the affected populace in Gaighata contained As above 10 and 20 µg/L respectively (Roychowdhury 2010). A research study was conducted on 5-15 years' children from Murshidabad district showed an average As concentration of 74.9 µg/L in urine (Chatterjee et al., 2018). A cohort study was carried out in Bangladesh for analyzing urinary As in the children of 5 and 10 years of age. The average urine

As concentration was found to be 102 and 105 µg/L respectively (Kippler et al., 2016). Urine samples collected from exposed school children of Madhusudankati village (n=43) showed an average As concentration of 64.6 µg/L, ranged from 15-212 µg/L (Table 44). Several research studies on children aged between 5-15 years from Murshidabad and South 24 Parganas districts of West Bengal, India; Bangladesh; Chile; Inner Mongolia, China, and Pakistan showed a high amount of urine As concentration compared to the normal level of As (Table 45). Analyzing the As concentration in urine samples determine the acute effect of As deposition in the internal body system. Our survey showed that the exposed populace is presently not drinking As-safe water, since they have prominent level of As in urine. The urine of Kolkata school children showed an mean As concentration of 4.35 µg/L, ranging from 1.88-6.02 µg/L, n=26 (Table 42). The standard range of As in urine is 3-26 µg/L.

Table 44: Arsenic concentrations in the biomarkers of As in (a) Exposed children (b) Apparently Control children

Statistical Parameters	**(a) Exposed children**			**(b) Apparently Control children**		
	Urine (µg/L)	**Hair (µg/kg)**	**Nail (µg/kg)**	**Urine (µg/L)**	**Hair (µg/kg)**	**Nail (µg/kg)**
No. of Samples (n)	**43**	**43**	**44**	**26**	**24**	**25**
Mean	64.6	2656	4256	4.35	1286	1805
SD	48.6	1933	3053	1.09	1626	1229
Median	48	1960	3505	3.24	570	1310
Range	15-212	170-7940	870-15300	1.88-6.02	70-5960	300-5330

* Normal range of hair As content is 80–250 µg/kg, and > 1,000 µg/kg in hair suggests toxic behavior (Arnold et al. 1990)

* Normal range of nail As content is 430–1,080 µg/kg (Ioanid et al. 1961)

* Normal range of urine As content is 5–40 µg/day (1.5 L) (Farmer and Johnson 1990)

Table 45: Worldwide scenario on the As exposure of the children studied from different countries

Studied area	**Participation of children**		**Observations of Adverse Health Effects**		**References**
	Age	**N**	**Water As**	**As in**	

	(years)			Urine/Hair/Nail	
Antofagasta, Chile	~ 6	411	Range: (600 - 800) µg/L	Nail-As level in mg-% range: (<0.10-7.50); Hair-As level in mg-% range: (<0.10-1.80)	Borgoño et al. 1977
South 24 Parganas, India	<9	21	Range : (<50 - 3400) µg/L	-	Mazumder et al. 1998
Bangladesh	<11	298	37% sample shows >50 µg/L; maximum= 4730 µg/L	90% of children show hair and nail As above the normal level.	Rahman et al. 2001
Inner Mongolia, China	<9	728	79.4% tube-well samples >50 µg/L (n=326); Maximum= 1354 µg/L	-	Guo et al. 2001
Bangladesh	4-15	241	Range: <DL - 535 µg/L (n=241) (*DL = detection limit)	Urine As range: (0-701 µg/L); Median: 110 µg/L	Watanabe et al. 2007
Bangladesh	5-10	1017	(Mean ± SD): 55 ± 100 µg/L (5 years aged children) 60 ± 113 µg/L (10 years aged children)	Urine (Mean ± SD): 102 ± 122 µg/L (5 years aged children) 105 ± 118 µg/L (10 years aged children)	Kippler et al. 2016
Pakistan	6-15	337	Sukkur: 26.0–98.2 µg/l NaushehroFiroze: 18.0–50.6 µg/l Nawab Shah: 52.3–85.2 µg/l Dadu : 63.5–345 µg/l	Hair As range: (0.15-8.90 mg/kg; 6-10 year children) (0.23-10.20 mg/kg; 11-15 year children)	Baig et al. 2016

Murshidabad (Exposed), East Midnapur (Unexposed) India	5–15	68 (exposed) 52 (unexposed)	(Mean ± SD): 50.8 ± 30.8 µg/L (exposed children) 6.2 ± 1.9 (unexposed children)	Urine (Mean ± SD): 74.7 ± 34.9 µg/L (exposed children) 25.4 ± 4.86 µg/L (unexposed children)	Chatterjee et al. 2018
Pakistan	5-10	Non-exposed (145) Low exposed (117) High exposed (116)	Range: Non-exposed (6.51 – 9.98) µg/l Low exposed (26.3 – 44.6) µg/l High exposed area (523 – 2350) µg/l	Total hair As range: Non- exposed (0.16–0.36) µg/g Low exposed (0.36-0.83) µg/g High exposed area (11.5-31.9) µg/g	Brahman et al. 2016
Khairpur, Pakistan	<10	410	ThariMirwah: 28.5 µg/l Gambat: 98.3 µg/l	Scalp hair As: ThariMirwah: (1.25–1.61) µg/g Gambat: (1.73–3.63) µg/g	Kazi et al. 2011
North 24 Parganas(Exposed) Kolkata (Apparently Control) West Bengal, India	5-12	44 (Exposed) 32 (Apparently Control)	Madhusudankati Free Primary School (Exposed)-Range:(3-390) µg/l, n=42 PurbaKalikata Odia High School (Apparently Control)-Range:(3-6.56) µg/l, n=32	Urine: (Exposed) Range:(15-212) µg/l, n=43 (Apparently Control) Range:(1.88-6.02) µg/l, n=26 Hair (Exposed) Range:170-7940 µg/kg, n=43 (Apparently Control) Range:70-5960 µg/kg, n=24	Current Study

				Nail (Exposed) Range:870-15300 µg/kg, n=44 Apparently Control)Range:300-5330 µg/kg, n=25	

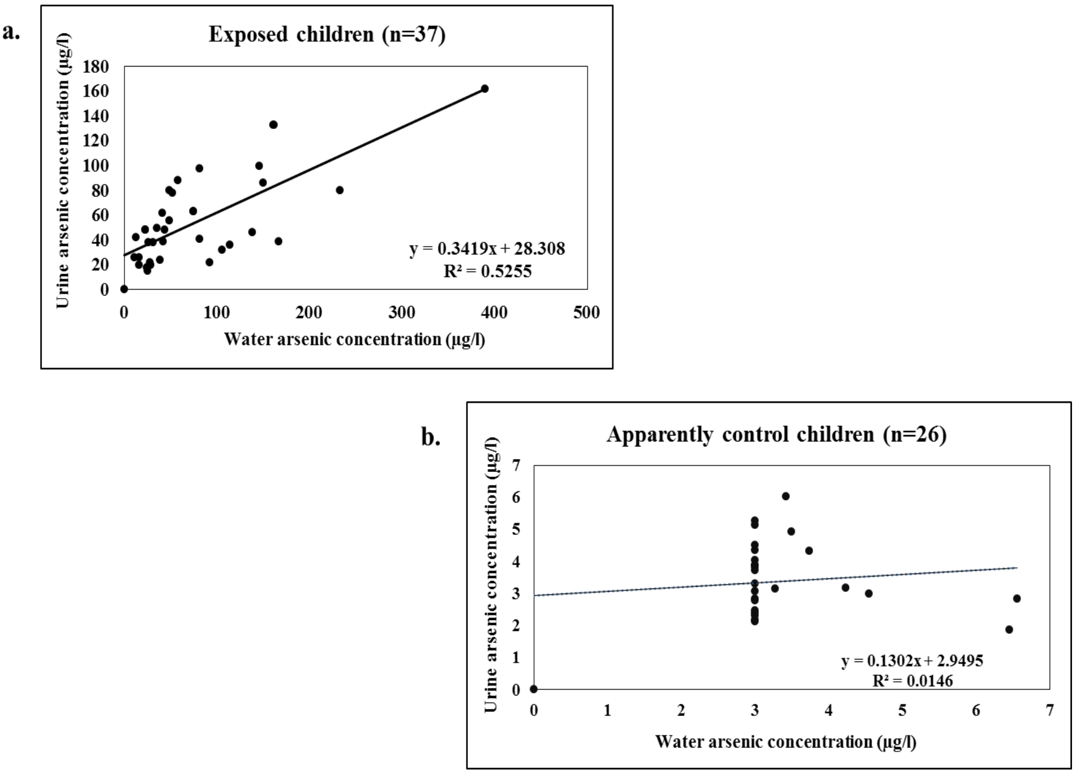


Fig. 56. Regression analysis between As concentration in drinking water and urine of (a) Exposed children (n=37), (b) Apparently control children (n=26)

Between the As content in drinking water and the urine collected from the school children in the exposed area, a moderate significant association (R^2=0.53) has been identified (Fig. 56a). However, there was no clear association (R^2=0.01) in the case of the children from the apparently control area (Fig. 56b). In both instances, the correlation values helped us to better comprehend the significance of drinking tainted water which is being emphasized via their recent urine exposure. In the first situation, the populace is exposed to drinking water that is contaminated with As and is reflected in their urine. Whereas, the control inhabitants showed that they are exposed to As-safe drinking water, as reflected in their urine.

6.10.4.2. Chronic exposure

Samanta et al. (2004) stated that the hair and nail act as the best indicators for long-standing As exposure in humans. It is evidently described in Shapiro (1967) that because of the great amount of keratin in the biological tissues (hair and nail), the rate of deposition is higher. In our study, the hair (n=43) collected from the exposed school children showed a mean As concentration of 2656 µg/kg, ranging from 170-7940 µg/kg. Similarly, the nail (n=44) showed a mean As concentration of 4256 µg/kg, ranging from 870-15300 µg/kg (Table 44). Along with this a histogram plot (Fig. 57) demonstrates the in depth As distribution in hair and nail As for the exposed populace. It is detected that the most of the children contains As ranging from 1000-1999 µg/kg and 1500-4499 µg/kg in their respective hair and nail (Fig. 57a, b). The high concentrations of As in hair and nail samples in our study sharply indicate that the populace is consuming As contaminated drinking water for a long period of time. A cohort study conducted earlier in Chile revealed that children (<6 years) showed As in hair and nail in the range of 710 – 800 µg/kg and 3510 – 4000 µg/kg respectively (Borgono et al., 1977). It has been reported that children (<11 and <10 years) in Bangladesh showed 90% of them had high accumulation of As in hair and nail above the normal level (Rahman et al., 2001; Kazi et al., 2011). Accumulation of As in scalp hair of children aged between 11-15 years is higher compared to younger children between 6-10 years (Baig et al., 2016). Exposure variation due to As accumulation in scalp hair of children has been studied in Brahman et al., 2016. A worldwide table showing similar kinds of observations has been placed in Table 4. Similarly, for the apparently control children hair samples (n=24) showed a mean As concentration of 1286 µg/kg, ranging from 70-5960 µg/kg. In the same way, the nail samples (n=25) showed a mean As concentration of 1805 µg/kg, ranging from 300-5330 µg/kg (Table 44). The histogram plot depicted that a large number of children contains As ranging from 100-399 µg/kg and 300-1299 µg/kg in their respective hair and nail (Fig. 57c, d).

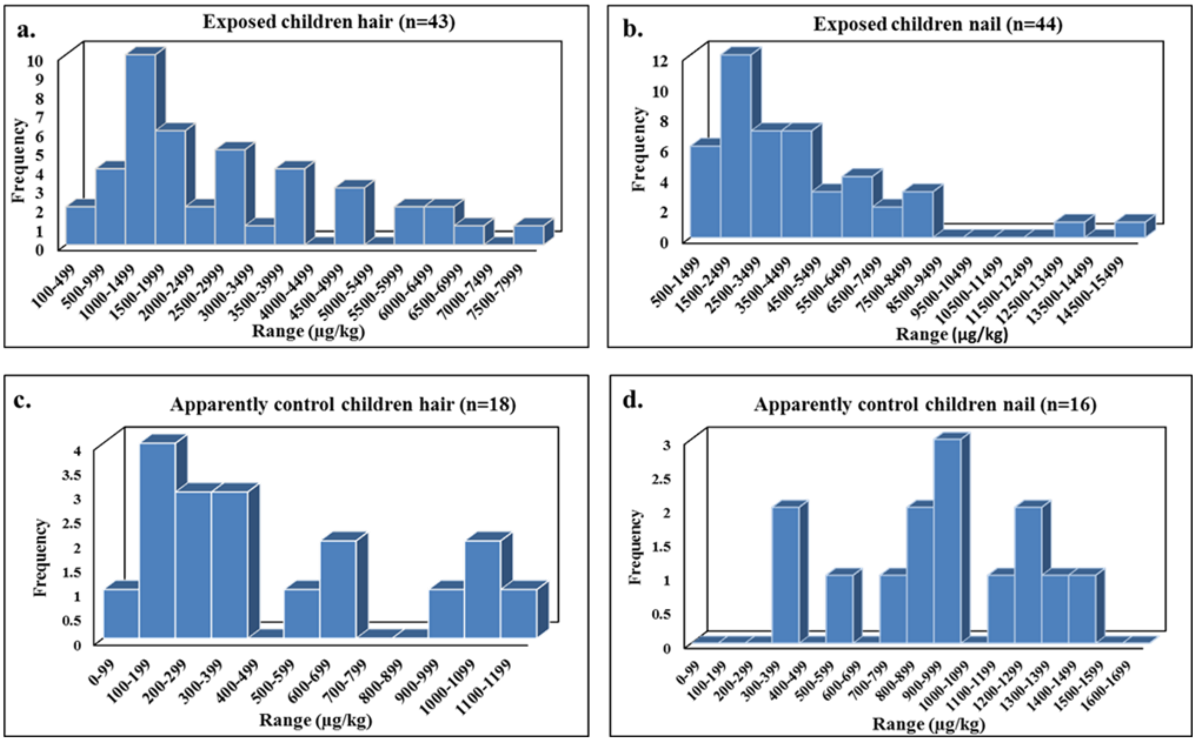


Fig. 57. Histogram showing the distribution of As concentration in a) Exposed children hair (n=43), b) Exposed children nail (n=44), c) Apparently control children hair (n=18) and d) Apparently control children nail (n=16) from the study areas

The regression investigation concerning As concentration in water and that of hair and nail of the respective exposed and apparently control children has been shown in Fig. 58. A significant association has been found in case of the exposed inhabitants between water As and that of respective hair (R^2 = 0.8563) and nail (R^2 = 0.7852) (Fig. 58a, b). Whereas, no significant association has been detected statistically between As in drinking water and that of respective hair (R^2 = 0.1072) and nail (R^2 = 0.1167) (Fig. 58c, d). For the apparently control children, as they are continuously drinking As-safe water, no distinct correlation exists between their water and chronic biological markers.

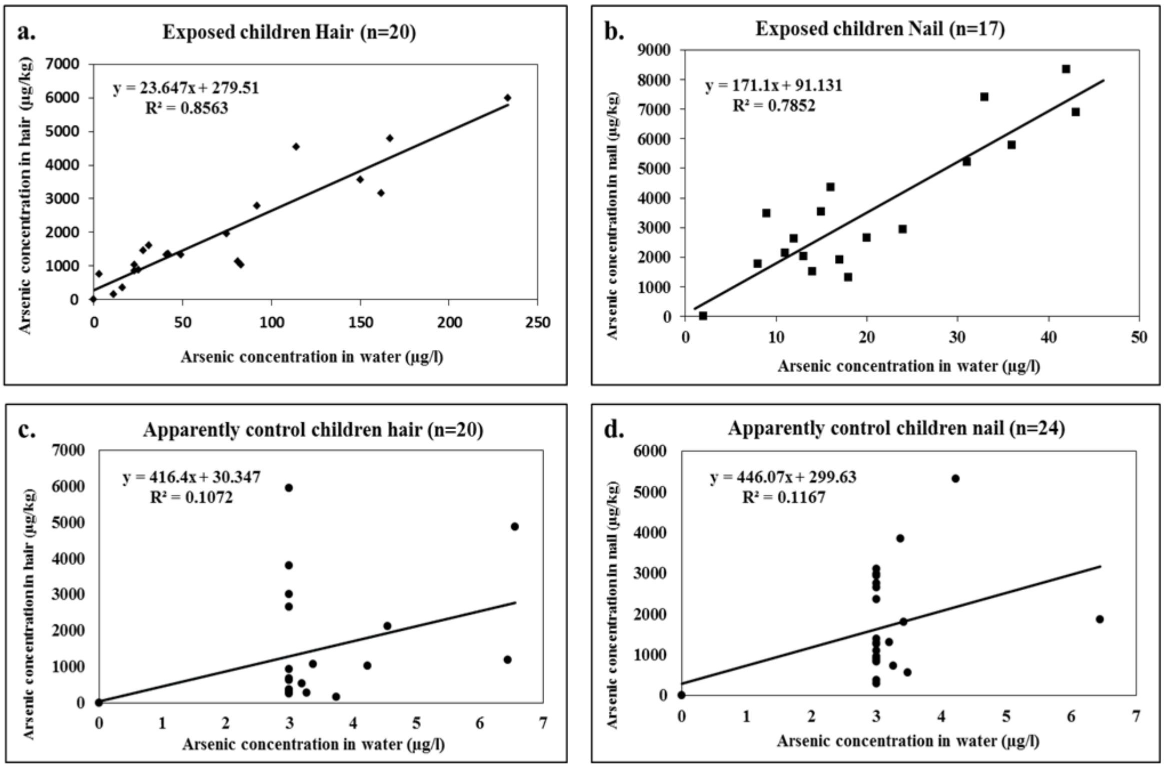


Fig. 58. Regression analysis plot for a) Exposed children hair (n=20), b) Exposed children nail (n=17), c) Apparently control children hair (n=20) and d) Apparently control children nail (n=24) with water As

6.10.5. Comparison study of health effect due to As toxicity between the school children from exposed and apparently control area

Our survey highlights the current status of the school children from both the exposed and apparently control area (Table 44). The urine As exposure discloses that the exposed children were suffering from acute exposure, as they were drinking As-contaminated water than the apparently control children. The school children living in the control area were drinking As-safe water. The long-lasting exposure in the children from both the studied areas has been highlighted via As buildup in the scalp hair and nail. The exposed children were prone to chronic toxicity than the apparently control one. Meanwhile the exposed children were ingesting As from both the contaminated water and rice in their regular diet. Relatively, the control children were drinking As-safe water, as reflected in their urine. The mean As amount accumulation in urine, hair and nail for the exposed children were nearly 14.9, 2.06 and 2.36 times greater than the apparently control children (Table 44).

Children from the exposed area did not show any arsenical symptoms. It has been reported that children below 8-10 years generally do not show arsenical symptoms (Roychowdhury et al., 1997, 2003). Furthermost, high amount of As observed in the hair and nail from the exposed children proves that they were sub-clinically affected because of As toxicity. The rate of As deposition has been commenced in their body, if they continue to drink contaminated water and rice; there is a high probability of risk because of As poisoning. Even, a substantial amount of As has been found in the biological tissues from the apparently control children, this might be attributable to the ingestion of As-contaminated rice for a long period of time.

USEPA 1988 stated the relation of As resistance in the human body with nutrition via regular diet. Relating to diet it is considered to be one of the foremost issues in children (Roychowdhury et al., 2002). Child undernourishment is accountable for As toxicity in the rural populace. Santra et al. (2013) described that residents having healthy nourishment would suffer less from As toxicity than the undernourished residents. The existence of micronutrients (selenium and zinc) in the nourishment plays a vital role to avoid As toxicity (Roychowdhury et al., 2003). Roychowdhury (2010) conveyed that maximum inhabitants from the rural Bengal stay alive depending on poor nourishment due to which they suffer more from As toxicity. In this survey, the nutritious status of the apparently control children is healthier than the exposed. This is the plausible reason that they have a reduced amount of risk because of As toxicity.

6.10.6. Risk assessment on school children from Exposed (Gaighata) and apparently Control (Kolkata) area

Assessments on cancer risk factor were performed on both the exposed and apparently control children (Fig. 59). The evaluation was done using the intake rates of iAs following the formulas amended from USEPA policy (USEPA, 2001).

The health risk calculation was executed to assess the possibility of children being exposed to As via ingestion of contaminated water and rice. Our interpretations indicated that a high cancerous risk might appear in the near future via the continuous ingestion of As-contaminated groundwater for the exposed children. Intake of As-contaminated rice might be a future health risk factor with respect to As for both exposed and apparently control children. Inorganic As is well-known as effective human carcinogen and toxicant (IARC, 2012; NRC, 2001). Inorganic As is contributed predominantly via contaminated groundwater and rice among the inhabitants.

Our study discloses that the exposed children of Gaighata populace are more prone to high cancerous risk through intake of As-contaminated water than the apparently control children, as they consume As-safe water. Cancerous risk for As exposed and apparently control children is 7.78×10^{-3} and0.33×10^{-3}, respectively through drinking of As-contaminated water.

Likewise, rice consumption shows equal distribution of cancerous risk among the As exposed and apparently control school children. It has been detected that the rice (parboiled) contains high quantity of iAs (Fig. 55). Cancerous Risk (CR) for the exposed school children is mainly because of consuming As through rice varied between 3.19x10^{-3} to 24.7x10^{-3}. Likewise, for the apparently control children consuming As through rice varied between 4.45x10^{-3} to 12.4x10^{-3}. In a study, Islam et al. (2019) described that cancerous risk for Bangladeshi inhabitants wide-ranging between 0.57x10^{-3} and 2.88x10^{-3} because of As intake through rice in different sites higher than the threshold value. Both the populaces of our survey are mainly consuming rice, which is being nurtured using As-contaminated irrigational groundwater and soil in As-exposed areas and transported to unexposed areas. Transport of contaminated food crops (rice and vegetables) bears threat to the inhabitants living in the unexposed areas (Biswas et al., 2019). In West Bengal, iAs is high donated via intake of rice and vegetables (Roychowdhury, 2008; Roychowdhury et al., 2003).

For non-cancerous risk (through iAs) for both the studied school children the HQ value is very much greater than 1. It can be determined that both the studied school children are prone to future chronic health threats not only via drinking of contaminated water but also via the contaminated food crops that originate in rural Bengal.

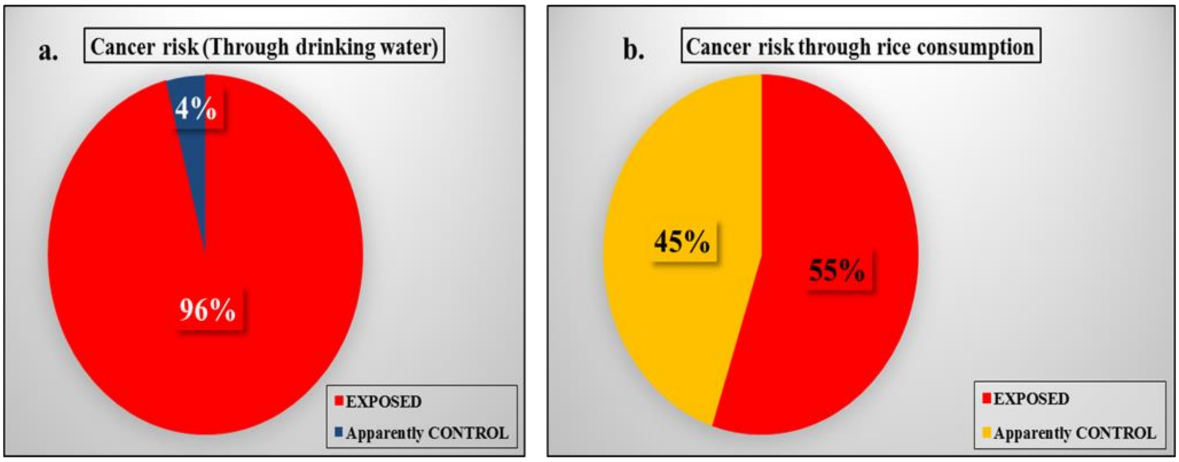


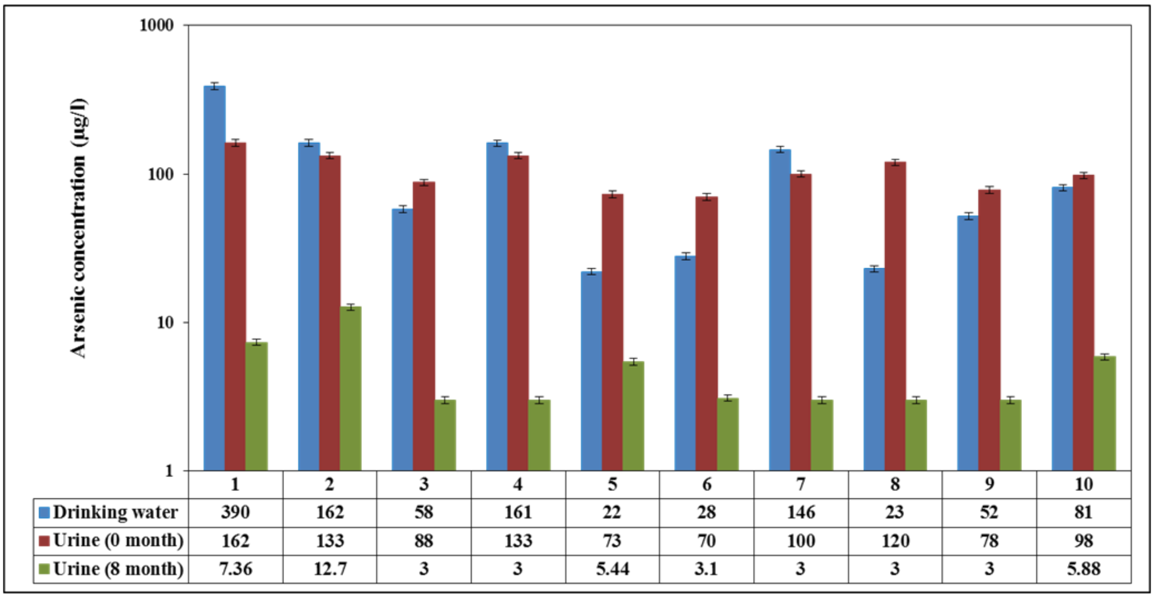
Fig. 59. Cancer risk assessment for the school children from both exposed and apparently control area through(a) drinking water and (b) rice consumption

6.10.7. A follow-up study after eight months, carried on the exposed children after minimization the level of contamination

An awareness campaign was organized for the exposed children in the school campus on the As pollution and directed them to consume As-safe water. The pond (surface water) waschemically treated by slow sand filtration process, monitored by adding disinfectant like bleaching powder and supplied to the inhabitants by a local non-Government organization (Madhusudankati

Krishak Kalyan Samity) linked with 'Sulabh International Social Service Organization' has been used by the school authority and children in domestic scale for drinking and cooking activities (Fig. 60). After 8 months, the biological samples were again collected from children (n=10) exposed to higher As concentration in urine. The mean As concentration in the domestic tube-wells of the studied children was 112 µg/L, ranging from 22-390 µg/L. Pattern of As distributions in water and urine from the exposed children collected during two time-intervals (0 month, 8 months) has been shown in Fig. 61. The mean urine As concentration for the exposed children (n=10) was decreased from 106 µg/L, ranged from 70-162 µg/L at '0' month to 5 µg/L, ranged from 3-12.7 µg/L after 8 months. The picture undoubtedly states that the exposed children has consumed less As-contaminated water for a period of 8 months (Fig. 9).

Fig. 60. Use of treated surface water (chemical treatment) for drinking purpose in Madhusudankati, Gaighata



	1	2	3	4	5	6	7	8	9	10
🟦 Drinking water	390	162	58	161	22	28	146	23	52	81
🟥 Urine (0 month)	162	133	88	133	73	70	100	120	78	98
🟩 Urine (8 month)	7.36	12.7	3	3	5.44	3.1	3	3	3	5.88

Fig. 61. Distribution of As concentrations in drinking water with urine As concentrationscollected from exposed school children during two intervals (0 month, 8 month) with 5% Error

Arsenic distribution in hair and nail from exposed school children during two time-intervals (0 month, 8 month) has been shown in Fig. 62. The mean As deposition in hair from exposed children (n=8) has decreased from 3255 µg/kg, ranged from 790-5780 µg/kg at '0' month to 1775 µg/kg, ranged from 150-4400 µg/kg after 8 months. Correspondingly, the mean As deposition in nail (n=8) has decreased from 5097 µg/kg, ranging from 1320-13300 µg/kg to 2626 µg/kg, ranging from 220-5410 µg/kg after 8 months' time-interval.

Remarkably, hair As for the exposed children (no. 3,7) indicated a respective increasing trend from 790 to 2800 µg/kg and 1340 to 4400 µg/kg after 8 months (Fig. 62a). Likewise, nail As for the exposed children (no. 1,3,7) indicated respective increasing trend from 1320 to 2560 µg/kg, 1840 to 3150 µg/kg and 1320 to 2370 µg/kg (Fig. 62b). This inclination for few children might be because of As intake through regular diet between the period. Presence of heavy metals have been reported in the biological tissues is caused due to their level exposure via water and foodstuffs (Samanta et al., 2004). Though, an overall declining As trend in hair and nail was observed for rest of the exposed children.

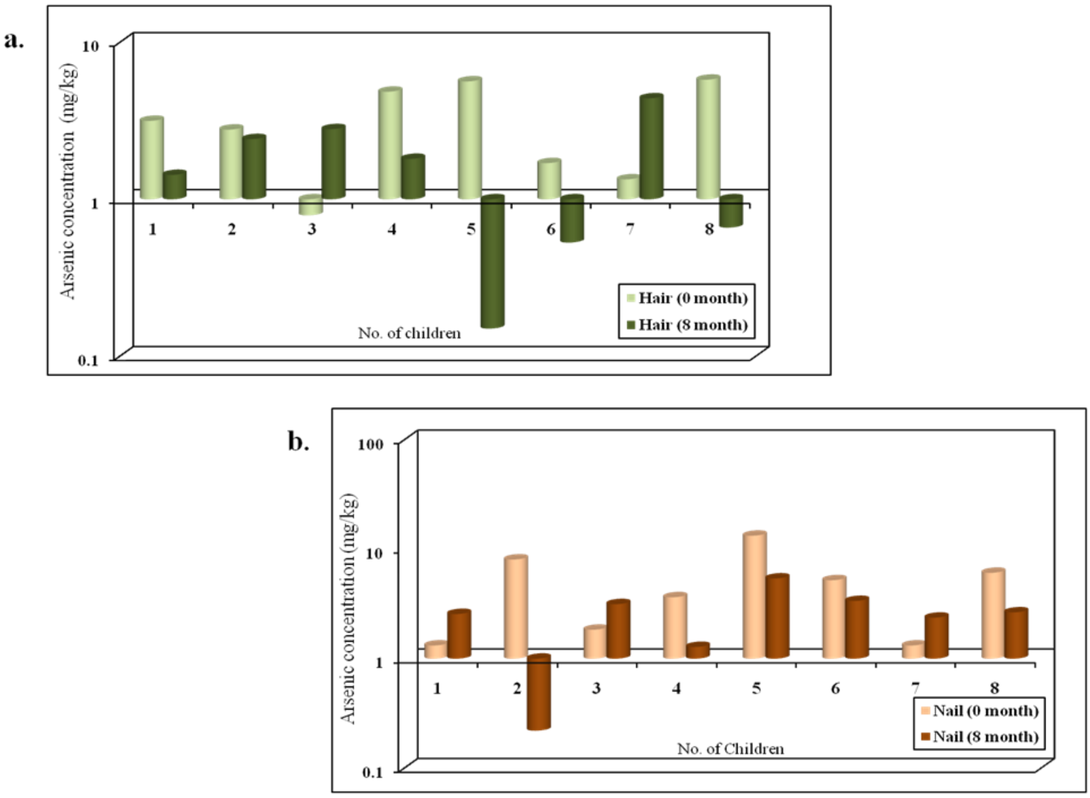


Fig. 62. Distribution of As concentrations (log scale) in a) Hair As and b) Nail As during the two studied intervals (0 month, 8 month) collected from exposed school children

Increased and decreased percentage in As deposition of biomarkers during the two studied time-intervals (0 month, 8 months) has been shown in Fig. 63. A substantial level of decreased As has been detected in most of the children. Summing up, after 8 months a decreasing trend of 95.3%, ranged from 91-98% has been observed in the urine As for children (n=8). Whereas, hair (n=6) and nail (n=5) As showed a decreasing trend of 64.3%, ranged from 13-97% and 62.4%, ranged from 35-97%, respectively (Fig. 63). From our previous reports, a remarkable decreasing As trend has been observed after 8 months from a two years' study in biological samples for 17 populaces from 5 As-affected families after reducing the level of As contamination, Baruipur block, South 24 Parganas district, West Bengal (Mandal et al., 1998). The amount of As decreased in urine, hair and nail has been reported as 81%, 66% and 70%, respectively. Apart from drinking As-safe water, the studied inhabitants during that survey possibly could not prevent consuming As-contaminated foodstuffs (**Mandal et al., 1998**).

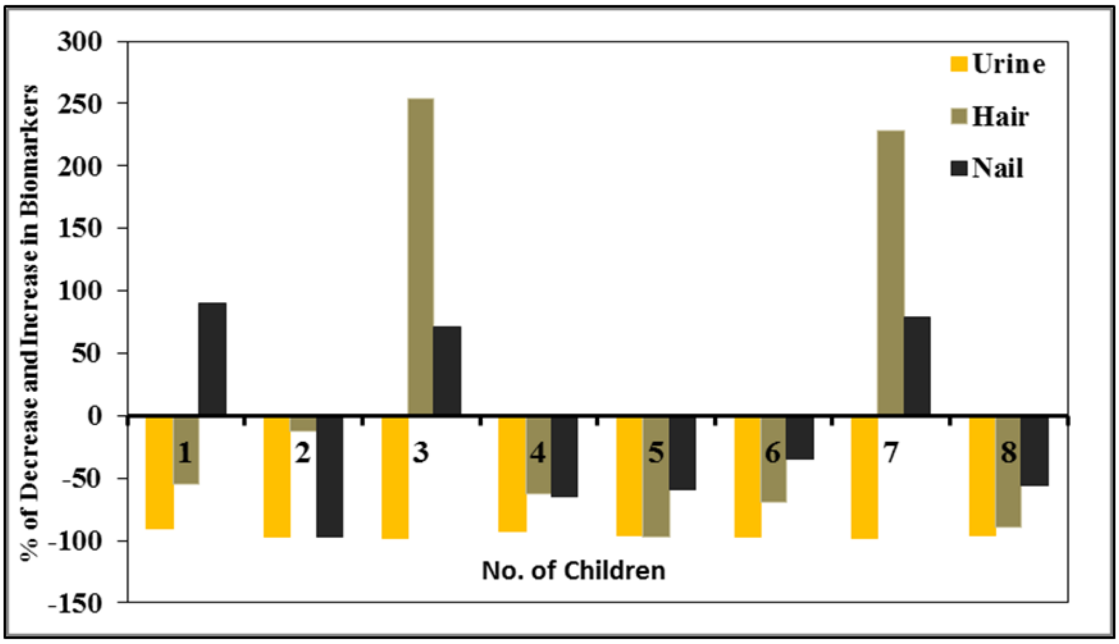


Fig. 63. Percentage of As increase (+) or decrease (-) in As concentrations of biomarkers (Urine, Hair and Nail) during the two studied intervals (0 month, 8 month) collected from exposed school children

Overall, the study highlights that the exposed school children are prone to high danger of As exposure via drinking of contaminated water than apparently control children. Consuming contaminated rice in regular diet of both the studied children is causing probable threat to their health. The high As deposition in the biological tissues of the exposed children states that they are sub-clinically As affected. A follow-up work on the exposed children after a time-period of 8 months put forward the vital impact awareness campaign along with supply of As-safe water amongst the exposed children. Ingestion of As-safe water noticeably supports to reduce the As level in urine and biological tissues.

6.11. A longitudinal health effect study to assess the impact of treated drinking water on chronic arsenic patients along with continuous intake of contaminated dietary foodstuffs from arsenic prone area, West Bengal, India

For one-year (2018-2019), a group of arsenicosis patients (age: 42-75 years including 17 males and 7 females) have been targeted for health exposure study from two severely As exposed villages namely ‘Bishnupur (Mathpara)’, and ‘Teghoria (Eithbhata)’, located in Sutia gram panchayat of the Gaighata block situated within North 24 Parganas, West Bengal.

Growing awareness on the adverse effects of drinking As-contaminated groundwater among the rural inhabitants has led to build up several mitigation strategies such as using deep tube-wells instead of shallow ones, installation of As removal plants (ARP) and surface water treatment plants (SWTP) for accessing As-safe water. However, due to its limited access, the domestic shallow aquifers mostly As contaminated is still used for cooking and sometimes even for drinking, apart from other household purposes like washing, bathing etc. Moreover, using As-contaminated groundwater for irrigation aggravates the problem with its entry in food chain (Chowdhury et al., 2018). So, this work has been planned to analyze the effect of awareness programs on severe As calamity and also to observe the trend of arsenical body burden in arsenicosis patients who are exposed to treated drinking water for the last two years. This present longitudinal health effect study aims to investigate the future risk of selected arsenicosis patients (n=24) from the As-endemic studied areas of West Bengal who are consuming treated drinking water along with continuous intake of contaminated dietary foodstuffs (rice and vegetables) on a daily basis. The trend of arsenical body burden has been measured for a year to analyze the acute and chronic effect of As toxicity through As accumulation in urine and biological tissues (scalp hair and nail) for a period of 6 and 12 months, respectively. To focus on chronic exposure level and elimination rate from human body system, body fluid (sweat) and body hair (hand and leg) As depositions have been analyzed. Statistical interpretation has been performed to correlate among the As intakes and As excretes through deposition in biological tissues as well as dermatological manifestations of the studied group. LMM (linear mixed models) estimated differential temporal trends of As levels through the biomarkers among the studied male and female arsenicosis patients. Severity Adjusted Margin of Exposure (SAMOE) value in ‘risk thermometer’ has been used to classify the risk and its respective concern level associated with the consumption of domestic tube-well water (previously consumed), treated surface drinking water and As-contaminated foodstuffs. Assessing future risk of the arsenicosis patients was executed to highlight the cancerous and non-cancerous risk through the consumption of safe drinking water and As-contaminated foodstuffs. This study has a great significance in providing a clear image on health effect of arsenicosis patients exposed to treated drinking water for last two years and potential future health risk through consumption of As-contaminated foodstuffs, mainly locally grown rice and vegetables.

6.11.1. Groundwater As-contamination scenario

As-contamination scenario in different available water sources from the studied areas has been shown in Table 46. Mean As concentration of 328±245 µg/L, ranging from 28-887 µg/L has been found in domestic shallow tube-well water (n=24) samples which are higher than the recommended value provided by WHO (10 µg/L). Boring of deep tube-wells by local government through gram-panchayat (cluster of villages) level and ICDS (Integrated Child Development Services) to supply treated drinking water were found with the mean As concentration of 4.5 µg/L (n=9, ranging from 3-11.4 µg/L) and 7.47 µg/L (n=3, ranging from 3-16.2 µg/L), respectively. Water samples (n=24) from the SWTP mainly used for drinking by the studied populaces was safe with respect to the concentration of As (< 3 µg/L) in drinking water. Presence of higher concentration of As in water from the domestic tube-wells was reported earlier from the two studied villages of Gaighata block, namely Mathpara (615 µg/L) and Eithbhata (301 µg/L), respectively. Consuming water from domestic shallow tube-wells (depth range: 7.87-26m) for drinking purpose is a common practice for the rural populace in West Bengal.

Table 46: Arsenic contamination scenario in available water sources from the studied area

		Arsenic concentrations		
Sources	**Samples (n)**	**Mean (µg/L)**	**SD**	**Range (µg/L)**
Domestic shallow tube-well*	24	328	245	28-887
Treated surface water**	24	<3	0	-
Shallow tube-well (surrounding)***	15	21.5	43.9	3-144
Deep tube-well, installed by local government***	9	4.5	3.08	3-11.4

Deep tube-well, installed by ICDS (Integrated Child Development Services) ***	3	7.47	7.56	3-16.2

*****_Previously used domestic shallow tube-well for drinking, cooking and other household purposes by the arsenicosis patients_

**Presently source of water mainly used for drinking purposes by the arsenicosis patients

***Other available sources of water from the studied area

6.11.2. Contribution of As through drinking water and foodstuffs to the daily dietary intakes

Different dietary foodstuffs for the studied populace include rice and vegetables (Table 47). The mean As concentration contributed by the raw rice and raw vegetables is 528 ± 236µg/kg, ranging from 172-1057 µg/kg and 214 ± 92 µg/kg, ranging from 91.1-469 µg/kg, respectively. In a similar way, the cooked rice and vegetables, which are consumed on a daily basis by the populace contribute mean As concentration of 440±263 µg/kg (range: 119-1054 µg/kg) and 54.5±63.9 µg/kg (range: 5.61-257 µg/kg), respectively. Among all food crops, As uptake in rice is substantially high because of the toxic As (arsenite) species, under paddy-soil conditions (Hussain et al., 2021). Arsenic accumulation in cooked rice mainly depend on the concentration of As in cooking water, apart from rice As concentration, rice variety and also that on the upper-bound cooking water As value on which its percolation mainly depends (Chowdhury et al., 2020). Movement of As from cooking water to rice occurs while preparing it with increased As value in cooking water and also using low to moderate As-contaminated cooking water leads to lower contribution of the toxic element in its cooked form (Raab et al., 2009).

Dietary consumption rate of drinking water, raw rice grain, cooked rice, raw vegetables and cooked vegetables on daily basis by individual patients (n=24) along with their body weights have been shown in Table 48. A pie-chart has been shown to observe the actual contributions of cooked meal (rice and vegetables) and treated drinking water (As-safe) to regular dietary intake rates of As (µg/kg bw/day) for the studied populace, evaluated following the equations mentioned earlier (Fig. 64). Treated drinking water, cooked rice, and cooked vegetables (curry of mixed raw vegetables) contributed 0.18, 4.91 (range: 1.29-12.5), and 0.52 (range: 0.03-2.50) µg/kg bw/dayof As, respectively. As comparing with the recommended Provisional Tolerable Dietary Intake (PTDI) As value i.e. 3.0 µg/kg bw/day, cooked rice itself contributed considerably higher value (WHO, 2011b).Water from domestic tube-well consumed by the same studied populace (n=24) for a prolonged period contributed much higher value of daily dietary intake (mean: 19.4 µg/kg bw/day; range: 1.32-56.2 µg/kg bw/day; n=24) andplayed a major role behind the chronic As exposure of the patients.In rural Bengal, intake of As-contaminated dietary components leads to an additional entry of Asposingfuture risk to the populace,considering consumption of As-safe drinking water for time being (Halder et al., 2013).

Table 47: Status of As accumulation (μg/kg) in raw and cooked rice and vegetables from the studied areas

Dietary sources		**No. of samples (n)**	**Mean (μg/kg)**	**Range (μg/kg)**
Raw rice grain		**24**	**528 ± 236**	**172-1057**
Cooked rice		**24**	**440 ± 263**	**119-1054**
Raw vegetables	Potato (outer skin)	24	199 ± 90.9	88.6-364
	Potato (inner flesh)	24	50.7 ± 34.4	28.4-140
	Carrot	6	115 ± 123	14.9-352
	Radish	19	231 ± 122	61-554
	Brinjal	12	171 ± 79.9	56-322
	Turnip	5	106 ± 55.4	55.8-190
	Cauliflower	22	72.3 ± 51.6	9.99-213
	Arum	19	143 ± 106	15-403
	Lablab beans	19	127 ± 52.6	26-210
	Red spinach leaf	23	480 ± 448	12-1807
	Red spinach stem	23	427 ± 279	23-949
	Arum leaf	20	202 ± 119	51.3-503
	Puin leaf	9	149 ± 145	58-518
	Coriander leaf	7	386 ± 130	168-613
		232	**214 ± 92**	**91.1-469**
Cooked vegetable (curry of mixed raw vegetables)		**24**	**54.5 ± 63.9**	**5.61-257**

Table 48: Daily dietary consumption rate of drinking water, raw rice grain, raw vegetables, cooked rice and cooked vegetables by individual patients (n=24) along with their body weights

Patient	**Consumption rate**					**Previous body weight (kg)**	**Present body weight (kg)**
	Water (L)	**Raw rice (kg)**	**Cooked rice (kg)**	**Raw vegetables (kg)**	**Cooked vegetables (kg)**		
P1	4.5	0.4	0.8	0.5	0.6	55	63
P2	3	0.25	0.5	0.5	0.6	47	48
P3	3	0.3	0.6	0.4	0.48	55	*Died**
P4	4.5	0.35	0.7	0.4	0.48	60	62
P5	2.5	0.25	0.5	0.3	0.36	44	42
P6	2.5	0.25	0.5	0.6	0.72	57	60
P7	3.5	0.35	0.7	0.6	0.72	52	51
P8	3	0.5	1	0.5	0.6	55	58
P9	4	0.4	0.8	0.4	0.48	55	53
P10	4	0.5	1	0.7	0.84	61	65
P11	4	0.35	0.7	0.5	0.6	59	61
P12	3.5	0.3	0.6	0.2	0.24	57	57
P13	2	0.2	0.4	0.2	0.24	48	51
P14	3	0.35	0.7	0.5	0.6	58	57
P15	4	0.4	0.8	0.5	0.6	72	75
P16	3	0.25	0.5	0.5	0.6	47	48
P17	5	0.4	0.8	0.6	0.72	62	61
P18	4	0.3	0.6	0.3	0.36	61	63
P19	2.5	0.2	0.4	0.4	0.48	55	56
P20	3	0.25	0.5	0.4	0.48	54	55
P21	3	0.3	0.6	0.4	0.48	70	71
P22	3.5	0.35	0.7	0.6	0.72	74	76
P23	4	0.4	0.8	0.5	0.6	71	*Died**
P24	3	0.4	0.8	0.6	0.72	59	63

**Patient died in 2020 due to severe As toxicity*

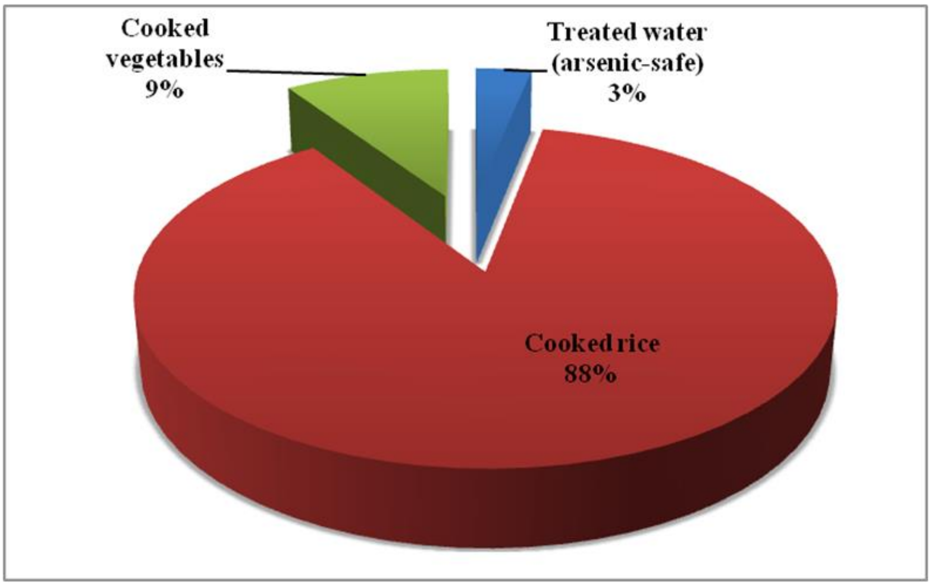


Fig. 64. Contributions of daily dietary intake rates of As (µg/kg bw/day) through treated drinking water and cooked foodstuffs

6.11.3. Factors dependable for health risk analysis of the patients

6.11.3.1. Rate of acute exposure from the body

Urinary As is considered to be the primary biomarker to measure the rate of acute As toxicity (Watanabe et al., 2001). Table 49 showed the urinary As concentration of the 24 arsenicosispatients monitored for a period of 6 months. A notable decrease in urinary As concentration has been observed from the 1st month (mean:8.06±4.71 µg/L; range: 3-22.9µg/L) to 6th month (mean: 4.60± 2.42 µg/L; range: 3-13.6µg/L). The mean decrease percentage observed in urinary As concentration for 24 patients after a period of 6 months is 42.9% (Table 3). A distribution pattern of urinary As concentration of the patients (n=24) for each month (for a period of 6 months) has been plotted in Fig. 65a. The medianurinaryAs concentration showed a lower value in the 6th month (3.44) compared to the 1stmonth (7.19). A decreasing trend of 52.2% in the median value of urinaryAs concentration has been observed after a period of 6 months of this study. This observationjustifies that the studied arsenicosis patients had been consuming treated drinking water for past two years, which contains As within the recommended value. A two-year study report on impact of safe drinking water on arsenicosis patients (n=8) showed a decreasing trend 84.6% (75.3-90.2%) in urinary As concentration (Mandal et al., 1998). Lower level of As in urine samples has been observed among the inhabitants consuming As-safe drinking water inGaighatablock.A mean decreasing trend of 39.2% (range: 0.75-83.1%; n=21) of urinary As concentration has been observed after a period of 6 months in this study; whereas, three arsenicosispatientsshowed an increased percentage of urinary As concentration (mean:43.1%, range: 26.1-59.8%). The consumption of As through dietary foodstuffs, especially rice grain (the staple crop) might be responsible behind the increased amount of urinary As concentration (Meharg et al.,2014; Wei et al., 2014).

Table 49: Statistical interpretation of As concentrations in urine and biological tissues (hair and nail) of 24 patients for a period of 12 months

Month	**Urine arsenic(μg/L)**				**Hair arsenic(μg/kg)**				**Nail arsenic(μg/kg)**			
	N	**Mean ± SD**	**Range**	**(%) I/D***	**N**	**Mean ± SD**	**Range**	**(%) I/D***	**N**	**Mean ± SD**	**Range**	**(%) I/D***
1	24	8.06 ± 4.71	3 - 22.9	-	24	3848± 3882	430-12800	-	24	3278± 2863	550-9140	-
2	24	4.06 ±2.38	3 - 11.4	49.6 D	18	1862 ± 1028	280- 3270	51.6 D	18	5188 ± 3648	500-12200	58.3 I
3	24	5.26 ± 3.25	3 - 14.9	29.5 I	19	1828 ± 1556	160-6860	1.82 D	24	4485 ± 4023	410-15900	13.6 D
4	24	3.95 ± 1.65	3 - 8.70	24.9 D	24	6937 ± 4967	740-17700	279 I	23	4636 ± 2774	1220-10700	3.36 I
5	24	5.15 ± 3.91	3 - 19.2	30.3 I	18	3799 ± 3080	200-10500	45.2 D	18	4800 ± 3106	140-11900	3.53 I
6	24	4.60 ± 2.42	3 - 13.6	10.7 D	20	3062± 1902	420-6760	19.4 D	20	3388 ± 2282	820-7520	29.4 D
7	-	-	-		17	3965 ± 2963	740-9380	29.5 I	16	2904 ± 2521	220-9760	14.2 D
8	-	-	-		24	2788 ± 1776	380-7710	29.6 D	24	2208 ± 1319	460-5480	23.9 D
9	-	-	-		15	2586 ± 2255	420-6750	7.24 D	15	2230 ± 1956	60-5660	0.99 I
10	-	-	-		17	2702 ± 1967	290-6870	4.48 I	14	2800 ± 2069	530-7530	25.5 I
11	-	-	-		17	2367 ± 1912	50-6020	12.4 D	17	2652 ± 2135	620-7060	5.28 D
12	-	-	-		24	2242 ± 1878	150-6740	5.28 D	24	1940 ± 1496	140-7050	26.8 D
Total (%) I/D**				42.9 D				41.7 D				40.8 D

*Normal range of hair As content is 80–250 μg/kg, and > 1,000 μg/kg in hair suggests toxic behavior (**Arnold et al., 1990**); Normal range of nail As content is 430–1,080 μg/kg (**Ioanid et al., 1961**); Normal range of urine As content is 5–40 μg/day (1.5 L) (**Farmer and Johnson, 1990**);*

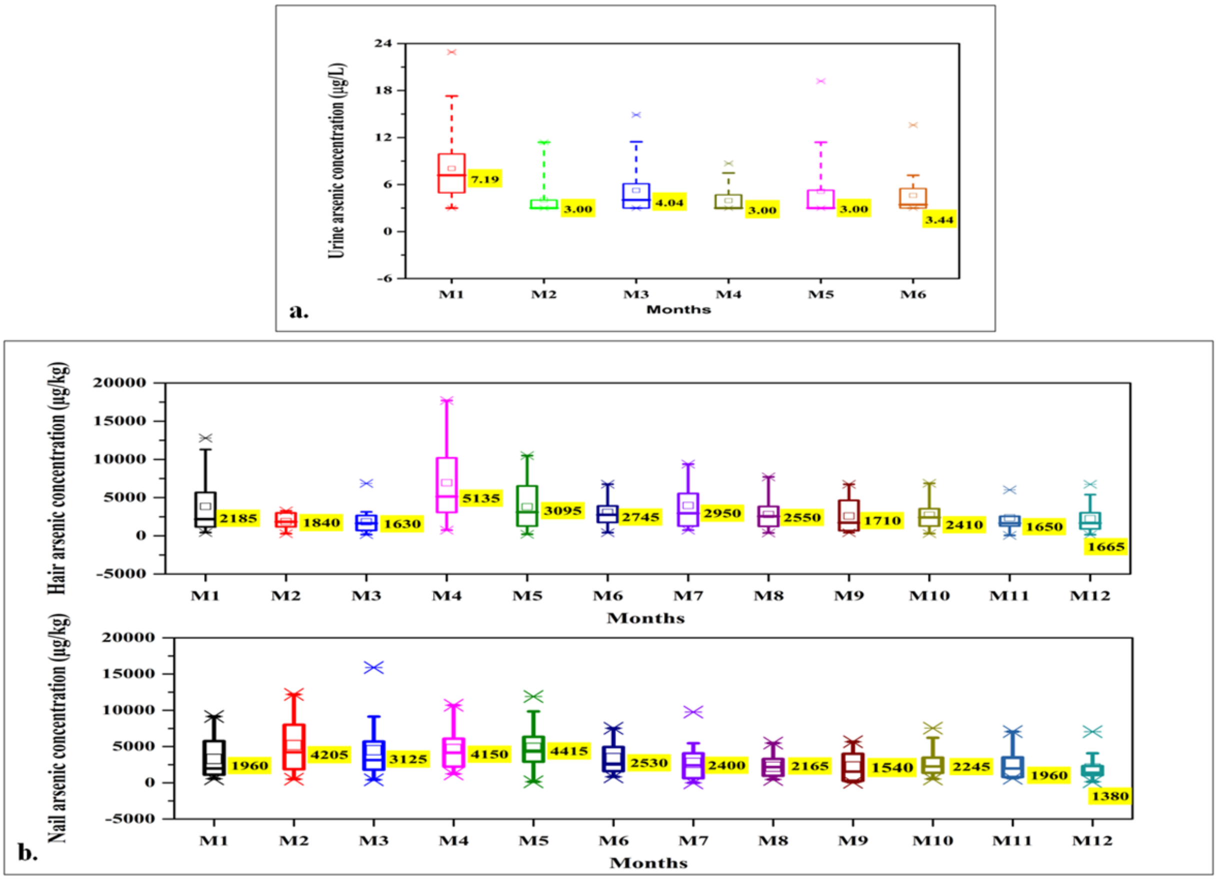
** Percentage (%) of increase (I) or decrease (D) on mean As concentration between each month-interval*

***Total Percentage (%) of increase (I) or decrease (D) on mean As concentration between first and twelfth month*

6.11.3.2. Chronic exposure through biological tissues (scalp hair, and nail)

Evaluation of hair and nail As is the paramount approach to determine the chronic As exposure rate (Brima et al., 2006, Samanta et al., 2004). Hair and nail tissues accumulate significantly high amount of As due to the presence of keratin proteins (Gault et al., 2008). During this one-year study, the mean As content in the patients' hair samples (n=24) dropped from 3848 g/kg (range: 430-12800 g/kg) in the "1st" month to 2242 g/kg (range: 150-6740 g/kg) after 12 months (Table 49). In the same way, the mean As content in nail samples decreased from 3278 g/kg (550-9140 g/kg) during the "1st " month to 1940 g/kg (140-7050 g/kg) after 12 months.

This decreasing trend in accumulation of As clearly describes that the exposed populace consumed treated water (As-safe) for past few years. The maximum hair As concentration observed among the group decreased by 41.7% while that of nail decreased by 40.8% at the end of 12 months (Table 3).A distribution pattern of hair and nail As concentrations of the patients (n=14-24) for each month(total period of 12 months) has been plotted (Fig. 65b). It has been clearly observed that the median As concentration for both hair and nail of the 12th month was lower than that of the 1st month. This observable fact can be attributed to drinking of treated water for a period of past few years, containing As within the permissible limit. A decrease trend of 24%and 30% median hair and nail As concentrations have been observed, respectively after 12 months of study.



a. The median value of urinary As distribution is signified by the yellow boxes of the box-plot. The box-plot represents 25 and 75 percentiles for the lower end and upper end, respectively. The cross marks in the plot indicates 99 (upper) and 1 (lower) percentiles. The 95th and 5th values are identified by the upper and lower end of the whiskers, respectively. **b.** The lower and higher end of the boxes represents 25 and 75 percentiles, respectively. The yellow boxes signify the median values of the respective hair and nail As distribution box-plot. The cross marks indicate 99 and 1 percentiles. The upper and lower ends of the whiskers indicate the 95th and 5th values, respectively.

Fig. 65. Box-whisker plot of As concentrations in **a.** urine for 6 months and **b.** biological tissues (hair and nail) for a period of 12 months

Distribution of hair and nail As concentrations in all samples during these two intervals (1st and 12th month) has been shown in Fig. 66 a, b, respectively. Exceptionally, the hair As concentration for the patient number 1, 3, 14, 15 and 23 showed an opposite respective trend of increase from 1100 to 1130 µg/kg, 2570 to 6330 µg/kg, 1150 to 1200 µg/kg, 440 to 840 µg/kg, and 1960 to 2130 µg/kg after a period of 12 months (Fig. 2a). Similarly, after 12 month's interval, the As concentration in nail for the patient number 8,14,17,18, 22, and 23) revealed an increasing respective trend from 3050 to 3220 µg/kg, 2150 to 2270 µg/kg, 960 to 1480 µg/kg, 3060 to 3880 µg/kg, 580 to 770 µg/kg and 1110 to 1390 µg/kg (Fig. 2b). This exceptional inclination of increasing As accumulation in few of the individuals might be due to the As contaminated foodstuffs consumption within the study period. Samanta et al. (2004) reported that the existence of elevated levels of toxic elements like As, Pb, Mn, and Ni in the biological tissues such as hair and nail was caused by individual exposure through foodstuffs and drinking water. The maximum number of individuals with arsenicosis, however, showed a general decreasing tendency in the amount of As in their biological tissues.

The percentage of As concentrations in biomarkers (hair, nails) that increased (+) or decreased (-) during the first and twelfth months of the study period has been shown in Fig. 66c. A substantialdecreasing trend inhair and nail As concentrations has been observed inmajority cases. A decreasing trend of 39.3% (range: 1.34-86.2%) of As was observed in hair of the patients (n=19) after 12 months. In a similar way, the nail As showed a decreasing trend of 36.9% (range: 0.88-85%, n=18).A two-year study report on the inhabitants (n=17; aged <70 years)from five As-affected families in As prone area of West Bengal, India highlighted a substantial decreasing trend of As accumulation in hair (65.5%, range: -2.12-96.3%) and nail (69.6%, range: 13.5-87.1%), respectively(Mandal et al., 1998). From the group, arsenicosis patients (n=8) showed severe arsenical skin manifestations and also a noteworthy declining trend in hair (59.5%, range: -2.12-81.7%) and nail (75.7%, range: 46.3-87.1%) As concentration (Mandal et al., 1998). Remarkably, for few arsenicosis patients, the hair and nail As concentrations showed an increasing trend of As. In particular, hair (n=5) and nail (n=6) of the patients showed an increased As concentration of 24.4% (range: 2.65-59.4%) and 18.6% (range: 5.27-35.1%), respectively (Mandal et al., 1998). Aside from drinking treated (As-safe) water, it can be said that the populace presently could not prevent As consumption through contaminated foodstuffs (rice, vegetables), and occasionally through contaminated water used for drinking and cooking. Several studies reported that inorganic As is considered as predominating species present in rice (Halder et al., 2014) contributed consistently to As biomarkers among individuals not exposed to contaminated water (Davis et al., 2017; Meharg et al., 2014).

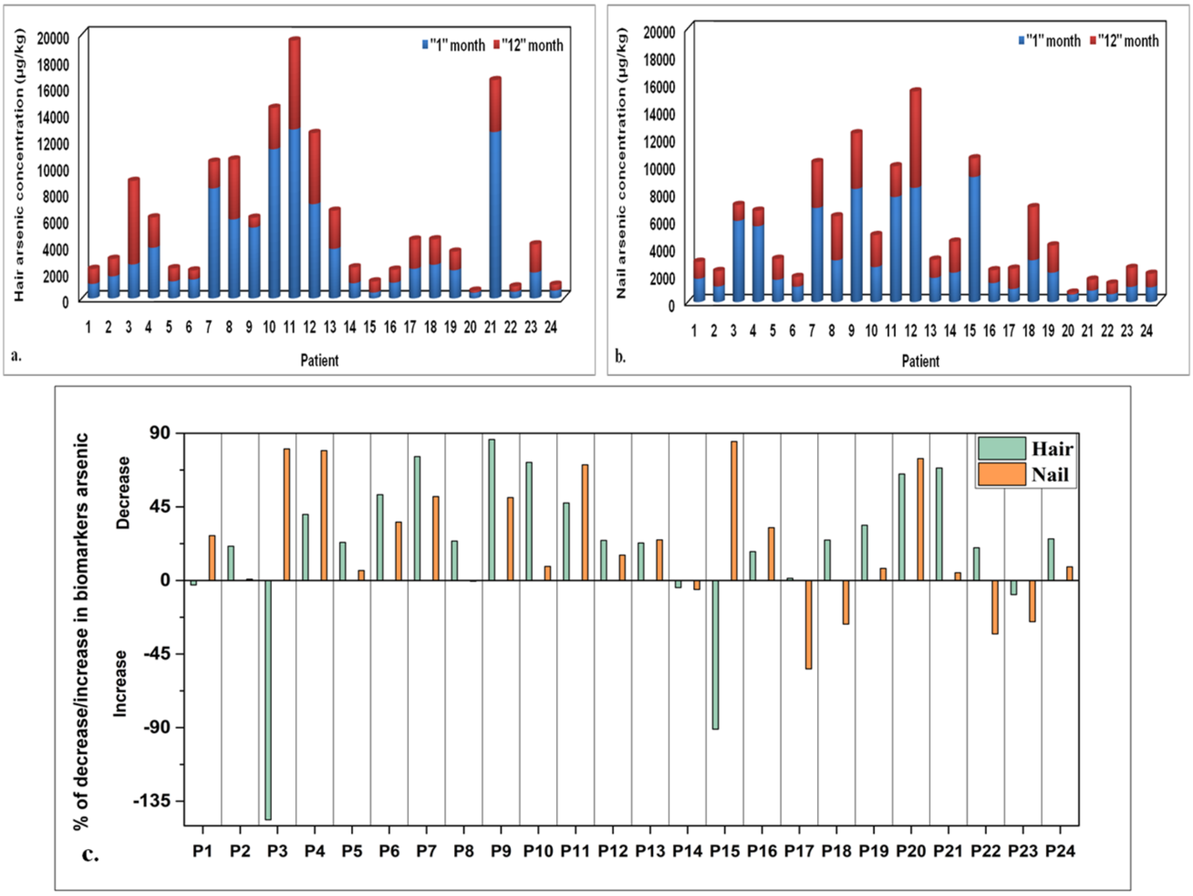


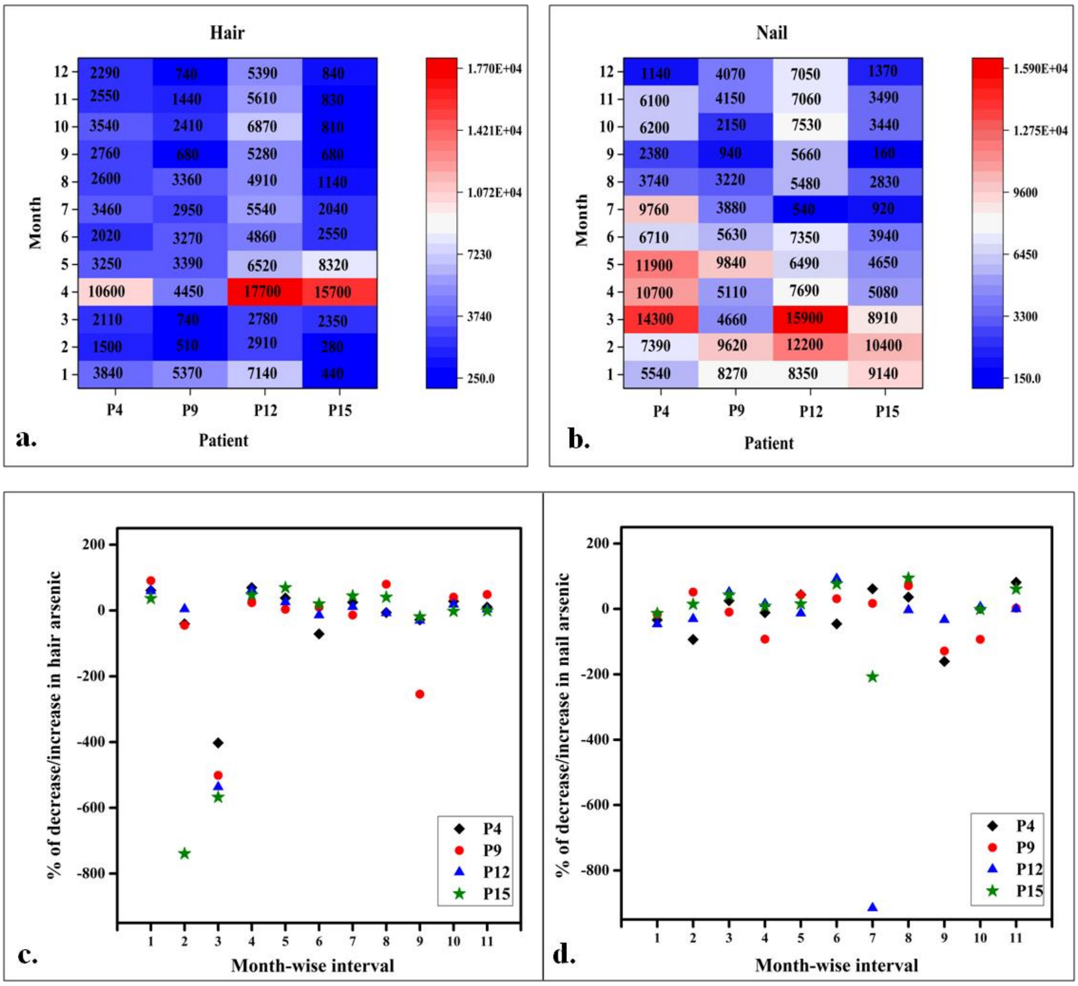
Fig. 66. Stacked bar-diagram showing **a.** hair and **b.** nail As accumulation in the 1st and 12th month of 24 arsenicosis patients,**c.**Percentage of As increase (+) or decrease (-) in As concentrations of biomarkers (hair and nail) between 1st and 12th month of 24 patients

Fig. 67a represented a heat-map to show the As distribution pattern between intervals (1 month – 12 months) for 4 patients, selected from the studied group. The colour bars in the heat map indicated the progressive change in As concentrations of hair and nailforthe patients (n=4) being monitored for a period of 12 months. The dark blue colourindicates low concentration while dark red signifies high concentration of As accumulation in hair and nail samples of the patients. In the case of hair samples, an initial decrease in Asconcentrationshas been observed after drinking treated waterfor a certain period of time. However, in the fourth month a drastic increase in hair As concentration was observed for all the four patients. This contribution of As might be due to occasionally intake of contaminated drinking water from domestic tube-well and consumption of contaminated foodstuffs for a quite longer period. After the first fourth months, the hair As concentration showed a varyingtrendwhich is evident from the heat map. However, in the final (12th) month, the hair As concentration showed lower accumulation than the initial hair As of

1st month for3 patients. Exceptionally, patient number 15 showed a drastic increase in As concentration of the final (840 µg/kg) month from its initial (440 µg/kg) stage. However, comparing with the final concentrations of the other patients, patient 15 showed its final (12th month) hair concentration in lower range, so it is indicated in blue colour.

The scenario of As concentrations in the nail samples is shownin a different heat map (Fig. 67b), with exceptional observation for patient 4. Patient 4 showed a drastic increase in nail As concentration in the 3rd month and it remained quite high for the next four months, although a decrease was observed in the 6th, 8th, 9th and 12th month, respectively. The nail As concentration showed a varying trend for the initial months; however, finally it showed lowerAsdeposition in the 12th month.The other three patients (number 9, 12 and 15) showed very high nail As concentrations for the first three months; however, eventually the concentration decreased to a value less than the initial (1st month) concentration. However, in case of patient number 12, the percentage decrease in nail As concentration from the 1st to 12th month was very low compared to rest of the patients (n=3).

The percentage increase (+) or decrease (-) in hair and nail As concentration of 4 patients for month-wise interval has been plotted between each consecutive month (11 month-wise intervals) (Fig. 67c, d). Negative percentage decrease value indicates an increase in As concentration of hair and nail samples. In this study, among 4 patients, three of them (patient number 4,9, and 12) showed the respective decreasing trend of hair As concentration from 3840 to 2290 µg/kg, 5370 to 740 µg/kg, and 7140 to 5390 µg/kg after 12 months. Whereas, patient number 15 showed an increased As concentration from 440 to 840 µg/kg after a period of 12 months. Similarly, nail As concentration showed a significant drop/trend of decrease from 5540 to 1140 µg/kg, 8270 to 4070 µg/kg, 8350to 7050 µg/kg, and 9140 to 1370 µg/kg, respectively for all the studied four patients after 12 months. Overall, a decreasing percentage in hair and nail As has been observed after 12 months for patient number 4, 9, and12 as 40.6 and 79.4%, 86.2 and 50.7%, 24.5 and 15.6%, respectively. Exceptionally, patient number 15 showed increased percentage in hair (90.9%) and decreased percentage in nail (85%) As concentrations after 12 months. This variation of hair and nail As accumulation in samples for all the four patients is not only due to drinking of treated water but also attributed to As exposure through contaminated foodstuffs (i.e. rice and vegetables) on a daily basis for rural populace. For the severely As-exposed populace, drinking As-safe water might be responsible for observing a monotonous decreasing trend in hair and nail As concentrations.



Hair

Month	P4	P9	P12	P15
12	2290	740	5390	840
11	2550	1440	5610	830
10	3540	2410	6870	810
9	2760	680	5280	680
8	2600	3360	4910	1140
7	3460	2950	5540	2040
6	2020	3270	4860	2550
5	3250	3390	6520	8320
4	10600	4450	17700	15700
3	2110	740	2780	2350
2	1500	510	2910	280
1	3840	5370	7140	440

Nail

Month	P4	P9	P12	P15
12	1140	4070	7050	1370
11	6100	4150	7060	3490
10	6200	2150	7530	3440
9	2380	940	5660	160
8	3740	3220	5480	2830
7	9760	3880	540	920
6	6710	5630	7350	3940
5	11900	9840	6490	4650
4	10700	5110	7690	5080
3	14300	4660	15900	8910
2	7390	9620	12200	10400
1	5540	8270	8350	9140

Fig. 67. Heat-map showing the As distribution pattern between the intervals (1st and 12th month) for 4 As patients **a.** hair and **b.** nail; Scatter-plot showing percentage increase (+) or decrease (-) in **c.** hair and **d.** nail As of four patients

6.11.4. Arsenic deposition in different kinds of body hair (scalp, hand, and leg) of arsenicosis patients

Among the studied populace, a limited number of patients (number 2, 3, 9, 15, 21 and 22) were examined to estimate the As accumulation in different kinds of body hair (scalp, hand and leg) (Table 50). The mean As concentration in the body hair showed a variation in distribution pattern. In the case of patient number 2, 3, 9, and 15, the maximum As deposition has been observed in the leg hair (mean: 6710 µg/kg; range: 3268-11578 µg/kg) compared to the hair on scalp (mean: 3133 µg/kg ranging from 1057-7123 µg/kg and hand hair (mean: 4297 µg/kg ranging from 2140-8208 µg/kg. Whereas, patient number 21 and 22 showed lower deposition in leg hair (mean: 1389 µg/kg; range: 500-2278 µg/kg) compared to scalp hair (mean: 1868 µg/kg; range: 708-3028 µg/kg).That means, a substantial amount of As is excreted through different kinds of body hair (hand and leg) other than its deposition in scalp hair and all these values are much higher than the normal As level in hair i.e. 80-250 µg/kg (Arnold et al., 1990).It has been reported earlier that continuous deposition of As occurs in hair present in different parts all over the body (Althausen and Gunther, 1929).

6.11.5. Arsenic release through skin scale and body fluid (sweat)of arsenicosis patients

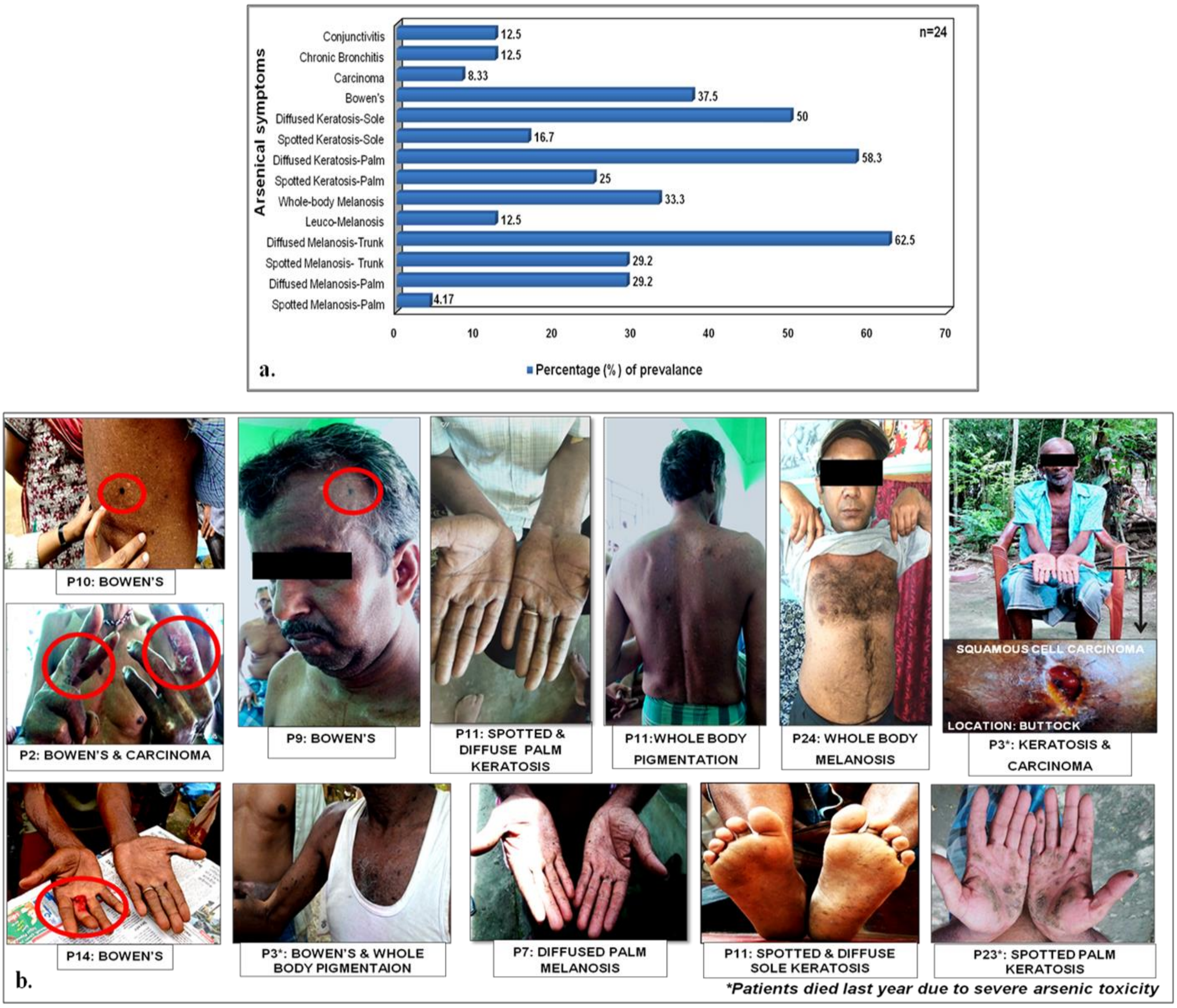
This study has been performed to evaluate the concentration of toxic element preferentially excreted through skin scale and body fluid (sweat) (Table 50). The skin scales collected from the limited number of patients (number 3, 6, 12, 21 and 22) in two intervals showed high As accumulation (mean: 1188 µg/kg; range: 136-2730 µg/kg). Roychowdhury (2010) reported that the mean As concentration in skin scales of few arsenicosis patients (n=6) from Bishnupur and Teghoria of Gaighata block was 4176 µg/kg (range: 1410-9650 µg/kg). A similar study from Bangladesh showed As in skin scale ranging from 280-23500 µg/kg (Karim, 2000) Sweating can be referred as a probable mode for elimination of the toxic element from the human body (Genuis et al., 2011; Sheng et al., 2016). Sweat analysis for As elimination from the body is measured as an added way for monitoring the bioaccumulation of poisonous element in human body (Sears et al., 2012). Sweat excreted from the human body can be categorized under external biological samples for As estimation. Arsenic excretion through sweat samples of patient (number 9, 15, 21, and 22) showed a mean value of 37.7, 54.3, 37.7, and 9.13 µg/L, respectively, collected in two intervals. The excretion of As through sweat is higher than urine for the studied individuals. The lower level of urinary As might be due to the As-safe drinking water consumption by the studied populace. Urinary As is proved to be a good biomarker of recent As exposure level (Li et al., 2011) and within a few days, 60–75% of ingested As is eliminated through the urine (Vahter, 1994). Whereas, sweating deserves high consideration for toxic element detoxification, as rural people regularly undergo exercise due to their occupational activities. Sheng et al. (2016) reported that exercising habit in everyday life helps in sweating and in that way removes toxic elements. Few reports have examined the levels of toxic elements in body fluids like sweat from the As-exposed populaces, thus enabling to study the efficiency of toxic element elimination through sweat (Genuis et al., 2011; Hoshi et al., 2001). Moreover, external contamination take place due to use of As-contaminated water for different human activities might contribute an increased level of As in sweat samples.

Table 50: Accumulation of As in body hair (scalp, hand and leg) and other biological samples (skin scales and sweat) of chronic patients

Patient No.	Arsenic in body hair (µg/kg)									Arsenic in other biological samples			
	Scalp			Hand			Leg			Skin scales		Sweat (µg/L)	
	n	Mean	Range	N	Mean	Range	n	Mean	Range	Interval 1	Interval 2	Interval 1	Interval 2
P2	2	2185	2130-2240	2	2140	2100-2180	2	6375	5340-7410	-	-	-	-
P3	4	7123	6020-8280	4	8208	6510-11800	4	11578	7410-15500	2010	-	-	-
P6	-	-	-	-	-	-	-	-	-	1120	-	-	-
P9	5	2168	680-3360	5	3286	1140-5030	5	5620	2180-7510	-	-	42	33.4
P12	-	-	-	-	-	-	-	-	-	2730	-	-	-
P15	6	1057	680-2040	6	3555	610-5730	6	3268	300-4880	-	-	65	43.6
P21	4	3028	800-5470	4	1420	410-2860	4	2278	370-4280	1120	968	43.7	31.7
P22	6	708	380-1530	6	477	410-640	6	500	270-700	230	136	13.5	4.76

6.11.6. Dermatological manifestations of the arsenicosis patients

Severe arsenical skin manifestations like keratosis (spotted and diffuse), melanosis (spotted and diffuses), whole body melanosis, Bowen's, carcinoma, and conjunctivitis have been observed in the studied patients. Field visit programs were conducted for 3 days with medical team assistants along with a dermatologist for the dermatological study (detecting patients with severe dermatological manifestations). Prevalence of dermatological manifestations and arsenical skin lesions of few of the patients have been shown in Fig. 68a, b. Distribution of different kinds of arsenical features including the severity level of As exposure has been noticed among the studied patients (Table 51). Approximately, 62.5, 58.3, 50, and 33.3% of the studied populace (n=24) have been suffering from Diffuse Melanosis on the Trunk, Diffuse Keratosis on the Palm, Diffuse Keratosis on the Sole, and Whole Body Melanosis, respectively. Presence of Bowen's (37.5%) and Carcinoma (8.33%) indicated the severity of As exposure among the studied populace. Two of the arsenicosis patients, namely P2 and P23suffering from severe As toxicity died in 2020 (Fig. 68b and Table 51). Roychowdhury (2010) reported the existence of arsenical patients (n=104) suffering from severe dermatological symptoms in Gaighata block. The exposure rate of As particularly depends on its duration and typically, long-term chronic exposure cause cancer (Vazquez et al., 2016). The severe health hazards specifically depend on the As methylation which is initiated by amount, method and form of As and particularly low nutritious status of the populace residing in As-exposed areas (Goswami et al., 2020). Long-lasting As exposure shows distinctive pattern of dermatological symptoms in humans, which increases with the whole body rain-drop pigmentation to keratosis and hyperkeratosis (either diffuse or spotted) (NRC, 2001). The individuals from extremely high (Mathpara) and high (Eithbhata) As contaminated areas of Gaighata block were observed with maximum body burden in terms of chronic As poisoning.



Patients died last year due to severe arsenic toxicity

Fig. 68. a. Distribution of dermatological manifestations in arsenicosis patients from studied area; **b.** Arsenical skin manifestations of selected patients

Table 51: Description of arsenicosis patients with sex and age along with distribution of different kinds of arsenical features in the study area

Patient	Sex/Age	Melanosis						Keratosis				Skin cancer		Chronic Bronchitis / Conjunctivitis
		Palm		Trunk		Leuco	Whole body	Palm		Sole		Bowen's	Squamous cell carcinoma	
		Spotted	Diffused	Spotted	Diffused			Spotted	Diffused	Spotted	Diffused			
P1	F/44	-	-	+	++	-	-	-	-	-	-	-	-	-
P2	M/65	-	+	+	+	-	+	-	-	-	-	++	+	-
P3*	M/70	-	+	-	+	-	+	-	+	-	+	++	+	+
P4	F/65	-	-	-	+	-	-	++	-	-	-	-	-	-
P5	F/42	-	++	-	-	-	-	-	++	-	-	-	-	-
P6	F/37	-	-	-	-	-	-	-	-	-	-	-	-	-
P7	M/57	-	++	-	+	-	+	-	++	-	++	-	-	-
P8	M/55	-	-	-	+	+	-	+	+	+	+	+	-	-
P9	M/52	-	-	-	++	-	++	-	+	-	+	+	-	-
P10	M/44	-	-	+	++	-	-	-	+	-	+	+	-	-
P11	M/51	-	-	-	-	-	++	++	++	++	++	+	-	-
P12	F/48	-	-	-	++	-	-	-	-	-	-	-	-	-
P13	F/72	-	+	-	-	-	-	-	+	-	-	-	-	-
P14	M/43	-	-	++	-	-	-	-	+	+	+	++	-	-
P15	M/57	-	-	+	+	-	-	-	-	+	+	-	-	-
P16	M/56	-	-	-	-	-	-	-	-	-	-	+	+	-
P17	M/70	-	+	-	+	-	+	-	-	-	+	-	-	-
P18	M/67	-	+	-	-	-	-	-	+	-	+	-	-	-
P19	M/75	-	-	-	+	-	-	-	+	-	-	-	-	-
P20	F/47	-	-	+	+	-	-	-	-	-	-	-	-	-
P21	M/68	-	-	-	-	-	-	+	+	-	-	+	-	-
P22	M/61	-	-	+	+	+	+	-	+	-	+	-	-	-
P23*	M/46	-	-	-	++	-	-	++	-	-	-	-	-	+
P24	M/43	+	-	-	-	++	+	+	++	-	++	++	-	+

'+' = moderate dermatological features

'++' = severe dermatological features

**Patients died in 2020 due to severe arsenic toxicity*

6.11.7. Relation between As intakes, biological tissues and dermatological manifestations

One-way ANOVA (Tukey-test) has been performed at 95% confidence level to assess the relationship among As intakes (domestic tube-well water, cooked rice and cooked vegetables), As excretes through biological tissues and dermatological manifestations (DM) of the patients. The As concentration in dietary intakes is considered as the dependent variable whereas biological tissues (scalp hair and nail) and dermatological manifestations (DM) are taken as independent variable, respectively. Alternate (H_1) hypothesis denotes 'the means of dependent and independent variables are different' whereas, null(H_0) hypothesis denotes for 'the means of all the variables are equal'. The respective values of F_{cal} against the $F_{critical}$ and the p value have been shown in Table 52.

Alternate (H_1) hypothesis is accepted in all the studied groups, as their $F_{cal\ values}$ are higher than the $F_{critical}$ values. The difference of the means for the studied groups is significant at the 0.05 level, which denotes significant relationship within the As intakes, biological tissues and dermatological manifestations (DM), respectively. As a result, it can be said that apart from ingestion of higher level of As through domestic tube-well water for prolonged period, consumption of As-contaminated dietary foodstuffs on a daily basis contribute significantly to the health exposure. Exposure to As toxicity through dietary foodstuffs leads to chronic and severe health hazards (Martinez et al., 2011; Melkonian et al., 2013).

Table 52: One-way ANOVA (Tukey-test) evaluating relation between As intakes, biological tissues and dermatological manifestations (DM) of patients from the studied area

Category	**Groups**	F_{cal}	***p* value**[#]	$F_{critical}$	**Remarks**
Arsenic intakes - Biological tissues	Domestic shallow water - Scalp Hair	53.9	2.75×10^{-9}	4.1	Significant
	Cooked rice - Scalp Hair	49.7	7.63×10^{-9}		Significant
	Cooked vegetable*- Scalp Hair	65.8	2.02×10^{-10}		Significant
	Domestic shallow water - Nail	49.7	7.68×10^{-9}	4.1	Significant
	Cooked rice – Nail	45.8	2.02×10^{-8}		Significant
	Cooked vegetable* - Nail	60.4	6.42×10^{-10}		Significant
Arsenic intakes - Dermatological manifestations (DM)	Domestic shallow water – DM	41.2	6.65×10^{-8}	4.1	Significant
	Cooked rice – DM	65.2	2.3×10^{-10}		Significant
	Cooked vegetable*- DM	13.5	0.0006		Significant
Biological tissues - Dermatological manifestations (DM)	Scalp Hair – DM	67.9	1.31×10^{-10}	4.1	Significant
	Nail – DM	62.3	4.23×10^{-10}		Significant

*#Significant at α=0.05; *Curry of mixed raw vegetables*

6.11.8. Differential temporal trends of As levels through biomarkers for the studied male and female patients

LMM (linear mixed models) has been used to estimate the temporal trend of As levels in different biomarkersconsidering each patient as a random variable to account for the variability which is a distinctive constant for every individual. There was no sex specific difference in As content in urine across the 6 months. However, the temporal trend shows significant difference between each month ($p<0.05$) (Fig. 69a). These findings corroborate with several reports on study groups using safe drinking water, which showed decrease in urine As metabolites within a short time period (Buchet et al., 1981; Mandal et al., 1998; Tam et al., 1979).

Hair and nail As levels indicate that the populace are having higher body burden. In case of biological tissues (hair and nail), differential temporal trend of As accumulation was observed across all the time-points (12 months). The temporal pattern across all time-points for both male and female have been shown for hair and nail As concentrations in Fig. 69b and Fig. 69c, respectively. A significant declining trend in hair As concentration has been observed during the 2nd (p= 0.0001), and 3rd (p=0.0003) month, respectively (Fig. 5b). However, a sudden burst in hair As abundance was observed in the 4th month ($p=2.34x10^{-6}$), followed by a significant decline throughout the 6th (p=0.0419), 8th (p=0.0160), 9th (p=0.0114), 10th (p=0.0204), 11th (p=0.0023) and 12th (p=0.0012) months. In hair, slightly higher variability has been observed than nail, which might be because of As adherence to hair at the time of bathing with As-tainted water and overall absorbed removal of As from the external surface of hair before analysis could not be accomplished (Mandal et al., 1998). Whereas, the temporal trend across 12 time-points for nail As concentration showed a significant increase in the 2nd (p=0.0103), 3rd (p=0.0276) and 4th (p=0.0105) month, respectively, following an overall declining trend from 5th month onwards (Fig. 5c). The overall trend indicates that As concentrations in different tissues significantly decreases with a period of time. These outcomes further stated that underneath controlled environment, As is usually eliminated through physiological processes from the body system (Mandal et al., 1998).

A significant ($p=1.78x10^{-9}$) increase in present body weight (estimated mean weight gain of 1.1 kg) was observed for both male (mean=53.3 kg; n=15) and female (mean=55.7 kg; n=7) arsenicosis patients from the studied populace, when compared to their respective previous body weights (male: mean=52.2 kg; n=15 and female: mean=53.5 kg; n=7) (Fig. 69d). This observation focuses that the studied male and female patients are presently aware of the severe arsenical body burden and undergoing a proper maintained nutritional diet (mainly As-treated drinking water) on a daily basis.

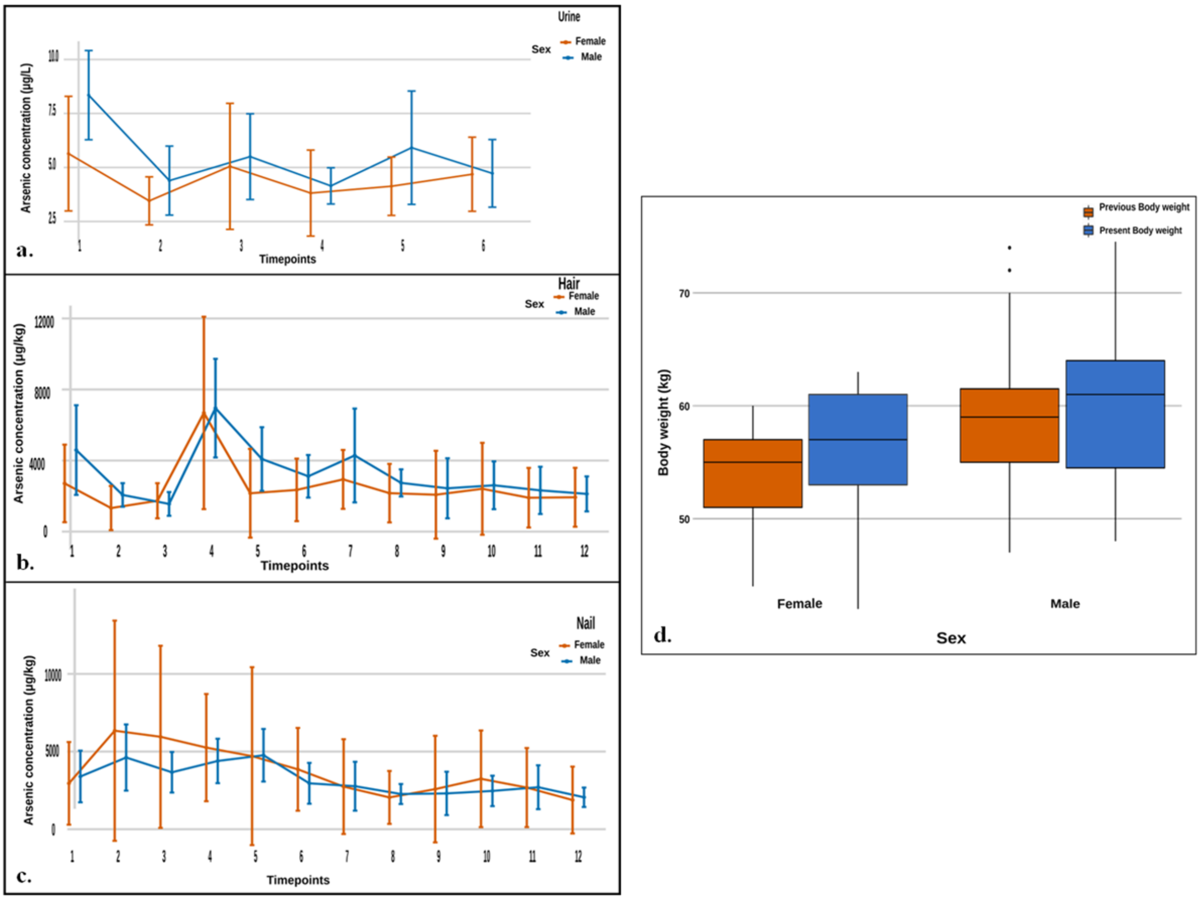


Fig. 69. Linear mixed modeling using biomarkers for both male and female arsenicosis patients **a.** Urine: 6 months(time-points); **b.** Hair: 12 months(time-points); **c.** Nail: 12 months (time-points). The circular dots showed the mean As concentrations of the respective biomarkers, the length of the bars are confidence interval for each measure; **d.** Comparative study based on the body weight (kg) of the studied population

6.11.9. Distribution of risk class through regular dietary intakes

Risk class thermometer categorizes the concern level among the populace visible through the intake of daily stuffs. The risk class (SAMOE) and their relative degree of concern associated with consuming As-contaminated water, treated drinking water, and food (both raw and cooked rice and vegetables), as determined by the risk thermometer (Sand et al., 2015a), are displayed in Table 53. Fig. 70 are presents the risk of all the dietary intakes in comparison to reference thermometer with SAMOE, risk class and concern level values. The treated drinking water showed concern level with low to moderate risk class 3, whereas for As-contaminated water, the risk class was 5 (high). In the case of cooked dietary intakes, the risk thermometer showed the high concern level (class 5) for rice and low to moderate risk of suffering (class 3) for vegetables. Hence, the future risk of suffering from As toxicity still perseveres for the exposed patients through consumption of contaminated rice compared to vegetables and treated drinking water.

6.11.10. Future risk for the patients through consumption of different dietary intakes

Assessment of cancerous and non-cancerous health risk has been performed to evaluate the risk in the patients through dietary intakes (Table 53). The evaluation showed the probability of future cancer risk factors of the patients due to the exposure of As through the consumption of safe drinking water and contaminated dietary foodstuffs. The domestic shallow water (As-contaminated) which was previously consumed for a long period of time showed highest cancer ($2.7x10^{-2}$) and non-cancer (60.6) risk among the patients and these values are much higher compared to the treated water ($2x10^{-4}$, 0.54), respectively which is presently used for drinking. Arsenic toxicity has a threshold level of $1x10^{-6}$ for both cancer and non-cancer risk (acceptable range for lifetime cancer risk: 10^{-6} to 10^{-4}) and HQ value becomes >1, respectively (USEPA, 2005). The cooked rice contributed high cancer ($6.8x10^{-3}$) and non-cancer risk (15.1) compared to the cooked vegetables ($7x10^{-4}$, 1.54), respectively. Moreover, compared to treated drinking water and vegetables, consumption of cooked rice poses a greater health risk. An unacceptable non-carcinogenic risk exists for the studied patients through dietary intakes, as HQ value is greater than 1 in all cases, other than treated drinking water. The observed HQ value reveals that the patients are prone to numerous future health risks caused due the intake of rice contaminated with As. Overall, the order of cancerous and non-cancerous risk through the daily dietary intakes is as cooked rice>cooked vegetables>treated drinking water. As toxicity among the studied patients is responsible for the future risk and it might due to the consumption of As through dietary foodstuffs (rice and vegetables). The cancerous and non-cancerous risk for all the individuals through consumption of treated drinking water and cooked foodstuffs like rice and vegetables crosses the respective threshold level of arsenic in each case (Fig. 70). Higher cancerous and non-cancerous risk have been reported among the inhabitants from As exposed areas of West Bengal, India and Bangladesh through the ingestion of rice and other dietary foodstuffs (Islam et al., 2017).

Overall, it has been observed that in rural Bengal, proper supply of treated water among the arsenicosis patients is providing better understanding to overcome this severe As crisis. Subsequently, intake of As-contaminated dietary foodstuffs on a daily basis poses potential future health risk. Statistical modelling assessed differential temporal trends of As levels through the biomarkers (urine, hair and nail) for both the male and female individuals.

Table 53: ‘Cancer and non-cancer risk assessment’ and ‘Risk thermometer’ based on the As exposure level through dietary intakes of the studied patients

Sources		Domestic shallow water (As-contaminated)	Treated water (As-safe)	Raw rice grain	Raw vegetables	Cooked rice	Cooked vegetable (curry of mixed raw vegetables)
Health risk assessment							
ADD(mg/kg bw/day)	Mean	0.0182	0.0002	0.003	0.0015	0.004	0.0004
	Range	0.013 - 0.0477	0.00008 - 0.0003	0.001 - 0.005	0.0002 - 0.0038	0.001 - 0.011	0.00004 - 0.0025
Cancer risk (CR)	Mean	$2.7*10^{-2}$	$2*10^{-4}$	$4.1*10^{-3}$	$2.3*10^{-3}$	$6.8*10^{-3}$	$7*10^{-4}$
	Range	$2*10^{-3}$–$7.1*10^{-2}$	$1*10^{-4}$ - $4*10^{-4}$	$1.5*10^{-3}$ – $7.9*10^{-3}$	$3.8*10^{-4}$ – $5.7*10^{-3}$	$1.5*10^{-3}$ - $1.6*10^{-2}$	$7*10^{-5}$ - $4*10^{-3}$
Non-cancer risk (HQ)	Mean	60.6	0.54	8.98	5.13	15.1	1.54
	Range	4.48-159	0.27 - 0.94	3.43–17.7	0.85–12.8	3.38– 35.4	0.15–8.47
Risk thermometer							
Dietary intake of arsenic (µg/kg bw/day)		19.4	0.18	2.94	1.69	4.91	0.52
SAMOE		0.003	0.17	0.011	0.02	0.008	0.16
Risk class		Class 5	Class 3	Class 5	Class 4	Class 5	Class 3
Concern level		High	Low-moderate	High	Moderate-high	High	Low-moderate

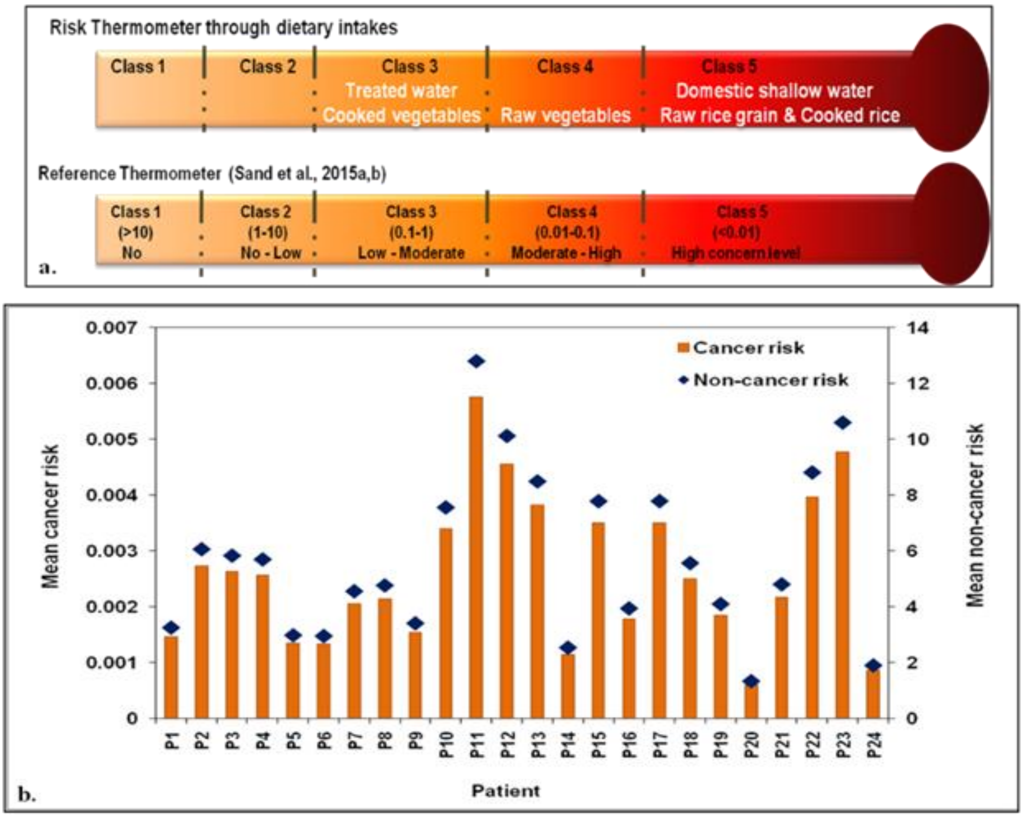


Fig. 70. a. Riskthermometer through dietary intakes; **b.** Cancer and non-cancer risk assessment


RISK
MITIGATION

6.12.1. Introduction

Arsenic being a fatal carcinogenic heavy metal, its contamination in groundwater and the adverse health effects in South-East Asian countries, especially West Bengal and Bangladesh came to limelight for the whole world throughout the last 20 years (Chakraborti et al., 2009). Arsenic generally enters the human body through drinking of contaminated groundwater, which is a major threat for the population, but when the same tainted groundwater is used for cultivation purposes the problem amplifies and leads to As bioaccumulation and toxicity in human body (Ruíz-Huerta et al., 2017). Accumulation of a high amount of As is constantly creating food insecurity within the food chain itself which in turn possess severe health hazards to the human population (Dey et al., 2014). In these South-East Asian countries, especially in India (Lower-Gangetic plain), As contaminated groundwater is used extensively for cultivation of paddy grains, typically during the pre-monsoonal season. Being the staple food crop, rice grains provide>70% of the total daily caloric intake for the population of the Bengal delta, which if grown on As contaminated soils may potentially increase As exposure to the exposed population (Pal et al., 2009). Thus, for South-East Asia, the As contaminated rice is regarded as a well-recognized disaster.

Rice (*Oryza sativa* L.), being one of the most vital staple foods for almost 50% of the world's population, is potentially responsible to create massive As exposure to the human population by its consumption, which is a global health issue nowadays. In rural parts of South-east Asia, especially in Bengal basin, rice is usually cooked with As contaminated groundwater including the precooking procedures i.e., washing, soaking etc., and consumption of this As enriched rice causes a significant health exposure in humans (Mridha et al., 2022). Few available reports show increasing As concentration after using contaminated water for cooking. (Sengupta et al., 2006). Arsenic toxicity in the human body through consumption of staple food rice is a global health concern. As the staple food for most of the Asian countries and with its potential ability in As bio-accumulation, rice consumption becomes a leading pathway for As exposure to the human population. Rice being the foremost sources of As in the exposed areas of West Bengal acts as an indirect exposure pathway to the groups exposed to ‘low or no’ As through drinking water (Biswas, 2019). Excessive amount of As can be accumulated by rice grains from water-logged soils, which acts as a serious threat to human health. Soaking is a popular pre-cooking process for preparing rice products, has important effects on As concentrations and it’s flow through the grain. Few previous studies revealed that soaking could remove As effectively from some varieties of rice grains with regulated conditions (Zhang et al., 2020b).

It has been well established for at least 4 decades that, water tainted with As is a foremost human health hazard through drinking water, cooking, irrigational, other domestic uses etc. Rice is said to be consumed by half of the population globally as a staple food and taking into account the higher accumulation possibility of As in raw rice grain it supplies significant amount of As to the human body and related health hazards arise by consumption of cooked rice. Several factors like As concentration in uncooked rice, water and various cooking methods used by the population, types of rice etc., might affect As accumulation in cooked rice. With increasing water As concentration, the metal can move from water to rice grain, which shows a noteworthy As increase in cooked rice while cooked with contaminated water. On the other hand, when cooked with low-As containing water, according to the As speciation study similar reduction percentage of AsIII, AsV and total As in wet cooked rice has been established, thus, amount of cooking water As may positively have few vital part in cooked rice As accumulation (Chowdhury et al., 2020; Halder et al., 2014).

Reports have showed that, total concentrations of As constantly found to be much higher in parboiled rice rather than in sunned grains. As The sunned rice is obtained completely by routine de-husking, whereas boiled rice can be derived after boiling fresh paddy grain before removing the husk mechanically, so this can be related with the use of As polluted water in making boiled rice by parboiling the wet paddy grains. Paddy plants contaminated with As can contribute a high amount of As in rice after cooking, specifically when cooked with high As water. Studies on cooking method including water volume with washing step and rice types (e.g., atab and boiled) showed that, a decrease of total As in raw boiled rice when cooked by the traditional method, but an increase of the same when cooked by the intermediate or contemporary methods, respectively. It has been proved that concentration of As in cooked rice, is notably reliant on cooking method and types of rice varieties (Signes et al., 2008). To reduce As content of cooked rice, using large amount of uncontaminated water for washing purpose proved to be useful. A significant amount of total As reduction in cooked rice was studied, with the discarded gruel holding most of the removed As from the rice when cooked in a ratio of 1:6(rice: water). It has been reported that high water rice ratio of 6:1 showed the maximum outcome for reducing amount of As rice after cooking process. Exhaustive rinse washing, soaking may cut down the As concentration additionally when linked with large water- rice ratio (Raab et al., 2009). Immediate identification of these exposure routes through diet, specifically by staple foods like rice is essential for the selection of appropriate remediation approaches (Mondal et al., 2010).

Consumption of contaminated foodstuffs like rice grains cooked with As contaminated water through the daily diet is a detrimental threat to good health for populations located in As exposed areas. Arsenic induced skin disorders have been reported amongst the exposed populations from different areas due to ingesting higher level of As through dietary intakes. Ingesting As contaminated rice by human is triggering severe health risks and posing a serious threat worldwide. Along with As bioaccumulation in rice grains, studies showed that, sulphate treatment and cooking could reduce the cancerous and non-cancerous hazard for the population from As accumulation in parboiled rice grains in comparison to sunned rice grains. Recommendation on sulphate application in soil to obtain comparatively safe rice grains followed by cooking with As safe water needs to be maintained to prevent any chance of health hazards in high As exposed areas (Mridha et al., 2022).

Research has been performed to see the variations in toxic metal concentration by cooking as well as by methods used prior to cooking of different types of rice grains, which in turn helps to evaluate the effects of various washing and cooking process (Rinsing and Kateh) and soaking in different time interval like 1 hour, 5-hour, 12-hour etc., which could help to remove toxic elements. According to the study it has been said that each cooking procedure could remove toxic metals from the rice grains considerably.

It has been established that, the ideal settings for rice preparation to minimize toxic metals like As, involves washing, soaking 1 hour, after that cooking with method of rinsing. Though, in case of some rice grains, non-carcinogenic risk value is associated in a high level and the carcinogenic risk remained unsolved even after cooking (Sharafi et al., 2019a). In another consecutive study, the effect of washing, soaking time interval, and cooking procedures of rice including cooking in excess water and conventional cooking method for As removal were estimated. The rinsed cooking method disclosed higher efficiency for removal of toxic metals. Moreover, by increasing soaking time of rice from 1 to 12 hour, the elimination of harmful elements was enhanced to a significant amount for As and other metals. Though the reduction of non-carcinogenic risk by As toxicity was regarded as acceptable level after all pre-cooking and cooking processes, but, these reductions did not lower the cancerous health risk to an tolerable limit due to the elevated primary Arsenic concentration of raw rice. Regarding the particular study area, it was suggested in that report, to prepare rice by rinse method, after washing and soaking to 5 h for maximum reduction of As and other studied heavy metals (Sharafi et al., 2019b).

The outcome of daily As intake by rice-cooking water and cooking experiments of rice in the laboratory scale study with changing cooking water As concentration established distinct linear correlation amongst the cooking water As and the change in As concentration of rice after cooking. Potential causes that could influence amount of As in rice after cooking are mainly raw rice As content and in water used for cooking, changes in water As concentration of rice both before and after the cooking procedure, finally the variation of rice types, specifically, between parboiled and non-parboiled rice. Therefore, controlling and as well as decreasing As concentration in cooking water is the utmost important point to focus on after obtaining As safe water for drinking purpose (Ohno et al., 2009). A study based on Spain and Ecuador assessed the effect of rinsing and boiling of different types of rice (e.g., polished and brown) on total As content with its inorganic and organic forms. Established report said that the treatment consists of three consecutive sets of rinsing, thereafter, boiling using excess water which resulted in a substantial decrease of the total As content compared with raw rice, the different treatments significantly reduced the most toxic forms of As content from the final product as well. Their health hazards estimation during a lifetime indicated that methods used before rinsing itself could lower the risk by 50%, and when combined with draining extra water, it could lower the risk by 83%; that is why study suggested that last-mentioned method as the most preferable for cooking rice (Atiaga et al., 2020).

Investigation on the overall impact of rice cooking methods on harmful effects linked with As species revealed, washing, soaking and boiling the rice grains mainly for white rice varieties, processing with surplus amount of water has high efficiency for a significant amount of inorganic As removal. More reduction of toxic effect of this heavy metal As the population can be achieved by selecting the suitable approach of cooking i.e., pre-washing the grains and removal of gruel leads to mainly inorganic As removal in a assuring amount (Jitaru et al., 2016).Gray et al., (2016) reported a lowering tendency of inorganic As accumulation in rice at the time of cooking As affected rice grains with gradually increasing the volume of deionised water with a rice-water ratio of 1:2,1:6 and 1:10. Using low amount of cooking water was not useful to remove As though; while water volume increases it reduces up to 45% of inorganic As in the final cooked rice. A review by Rokonuzzaman, et al., (2022) evaluated health hazard of human caused after consumption of As polluted rice, also different cultivation techniques to reduce As accumulation in rice. It has been reported that, altering water management regimes can potentially reduce grain As accumulation. Incorporation of bio char in the rice fields can also reduce As through immobilization, physical adsorption etc. Like many before this study also concluded that, irrigation source and As content of raw rice is directly responsible for the cooked rice As content. Raw rice As concentration is not the only determinant of total dietary exposure though, little knowledge is available on the remaining cooked rice As content after following the traditional methods practiced by the residents of As epidemic areas for cooking rice. A variety of experimental methods have been used to estimate cancer risks associated with As-bearing rice consumption. According to some reports using both As contaminated rice and water for cooking rice, could increases As concentration in cooked rice, not the raw rice As concentration alone, but also the rice grain, cooking water As concentration and different cooking methods impact As retaining in rice even after cooking process. As compared to cooked rice gruel of both parboiled and non-parboiled rice comprised high As implies that removal of the gruel water reduces As concentration in cooked rice. For the preparation of any rice dishes, it has been suggested several times to use plentiful amount of water, which must be drained once the cooking procedure has done. It can be said that it is safer to make rice with surplus water quantity to decrease the concentration of As in rice after cooking for population of As epidemic areas but the discarded gruel must be discarded and also it should not be fed to the domestic livestock (Rahman et al., 2006; Mihucz et al., 2007).

The main issues for extremely As contaminated cooked rice in high As exposed areas are: cultivation of rice with As-contaminated soils, usage of As-contaminated cooking water and also contaminated raw rice which contributes inorganic As to cooked rice in an excessive amount. It was investigated why cooked rice contains high levels of inorganic As, and the possibility of reducing inorganic As levels after harvesting and cooking, especially in As-endemic areas. Successive rinsing of raw rice using extra water for cooking decreases As in cooked rice. Methods of Post-harvesting and variations in different rice cooking approaches could reduce As content in cooked rice to a larger range. Additionally, solutions to decrease in As contamination of the staple rice crop involves continuous development of education regarding old-style cooking procedures using safe water; suitable approaches to increase the use of surface, rainwater irrigation to save water; using rice varieties which requires low quantity of water to prepare; and finally, modification of a targeted rice genotype that would be able in bio-accumulation of As in no or low quantity (Kumarathilaka et al., 2019; Pal et al., 2009).

As speciation and total As were performed on rice that had been cooked in a variety of ways.

Polished, wholegrain, as well as parboiled rice, were investigated. The effect of rinse washing, low volume, and high-volume cooking with rice-water ratio of 1:2.5 and 1:6 respectively, as well as process of steaming, were also has been studied (Basu et al., 2017). Steaming process reduced both tAs and iAs content in rice, but not similarly in all examined rice types. Cooking with low water have not showed removal of As. High water quantity cooking showed effective removal of both tAs and iAs for long basmati rice grain than raw rice. To decrease iAs content in cooked rice, use of huge water for rinsing and cooking has been proved to be effective (Naito et al., 2015).

In a study by Carey et al. (2017), rice was cooked in a continual stream of percolating water with low and no As content. The advantage lies not only in bringing the grain to higher volumes of water, but also in removing the amount of leached out As from the grain into the cooking water. Both approaches proved highly effective in cooked rice As removal. Whereas, during coffee percolation process, the effectiveness of As removal was 49% for both polished and whole grain samples. This study highlights the probable applications, optimization of percolating cooking water for further As removal. Mihucz et al. (2005) studied the process of As elimination from cooked rice by washing and cooking the raw rice with water. Enzymatic hydrolysis and sonication in the study showed that As (III) possibly will be eliminated in utmost quantity by the process of washing and cooking, whereas, As(V) remained in the cooked rice.

Raab et al. (2009) showed that cooked rice preparation with huge water to rice ratio decreases the As concentration in cooked rice. The study highlighted the outcome of rinse washing method, low volume ratio of rice to water 1:2.5 and high-volume ratio 1:6 of cooking and also steaming. Rinse washing has been proved useful in eliminating circa. Findings of this study showed that rice types, different processes are the valuable factors in removing As content from the rice grain. Compared to low volume water cooking, high water to rice ratio cooking efficiently eliminated 35% of tAs and 45% of iAs in cooked rice. Reducing As content in cooked rice, precisely the iAs content, rinse washing, cooking in high volume of water proved to be more effective. In Japan, Naito et al. (2015) highlighted the effects of different processes like rice polishing, storing, and cooking, on total As concentration and As species distributions in rice grain. Due to polishing, the total and iAs levels in white rice (n=3) were reduced by 51–70% than brown rice. Washing of white rice with deionised water followed by cooking reduced As levels by 71-83% than raw rice.

The key research gaps regarding As removal from cooked rice needs to be properly addressed and mitigation of As accumulation in soils and higher As concentration in irrigational water is the need of the hour to limit the As build-up in rice and other food stuffs. Importance should be given not only to mitigate As from drinking water but also to develop ideal rice pre-cooking and cooking practices which in turn will reduce As concentrations in the final cooked rice. The present study aims to perform three different experimental set-ups to remove As in cooked rice by the most convenient pre-cooking methodologies, i.e., effect of soaking of rice with different time intervals, co-precipitation, using natural sources as adsorbents. The purpose of this study is to reveal the comparative role of pre-cooking procedures and methods of rice cooking leading to As exposure in humans using different water: rice ratios, i.e., 3:1 and 6:1.

6.12.2. Materials and Methods

6.12.2.1. Study area

‘BORO’ raw rice has been collected from rural Bengal i.e., Gaighata and Deganga block, North 24 Parganas district for cooked rice preparation. The samples were collected from domestic-level (farmer’s residence), which are mainly cultivated in local agricultural land using As-contaminated irrigational water. Different rice cultivars like Maharaaj, Minikit, and Satabdi Minikit of parboiled raw rice grains has been collected for both lab-based and field-based study. Blocks named Gaighata and Deganga have been previously described as severely contaminated As-exposed zones of West Bengal (Chowdhury et al., 2018a; Pal et al., 2009).

6.12.2.2. Sample collection and preparation

Raw rice (parboiled), cooked rice of different ratio, cooking water and its gruel/total discarded water were collected from the field-based study. The additional starch water left during cooked rice preparation is known as ‘gruel’/ ‘stewed rice water’/total discarded water, which is mainly discarded by tilting the pot (Kumarathilaka et al., 2019; Mandal et al., 2019). Zip-lock packets have been used to collect the raw rice samples, whereas sterile polyethylene containers have been used for the liquid or semi-liquid samples. Samples of groundwater mainly used as cooking water has been stored in sterile polyethylene containers with 0.1% (v/v) concentrated nitric acid used as preservative and stored at 4°C until As analysis (Chowdhury et al., 2018a, b). Raw rice has been taken directly for acid-digestion. 0Approximately 0.2 g (dry weight) and 0.4 g (wet weight) of individual rice samples were taken in Teflon vessels adding nitric acid (concentrated, 69%) and 30% v/v of hydrogen peroxide maintaining a ratio of 2:1. The respective Teflon was placed in bombs for 6 h in a hot air oven at 120°C. Afterwards, the samples were evaporated for 1 h on a hot-plate at 90°C. The evaporated solutions were utilized to the appropriate volume of 5–10 ml of double distilled water, which was later filtered using a suction filter of 0.45 μm millipore paper. Subsequent to filtration the solutions filtered were directly used for As estimation (Chowdhury et al., 2018a, b; Roychowdhury, 2010). 2ml of total discarded water (TDW) or gruel has been directly used for acid-digestion and the rest solution were divided into two fractions:

supernatant and residue by centrifugation at 1500 rpm for 10 min. The supernatant was analysed after filtration using Whatman 42 to remove the colloidal particles. The residue has been dried using a hot air oven for 24–48 h at 50 °C till the constant dry weight was achieved.

Fig. 71a. Different rice cultivars collected from farmers from As-exposed areas

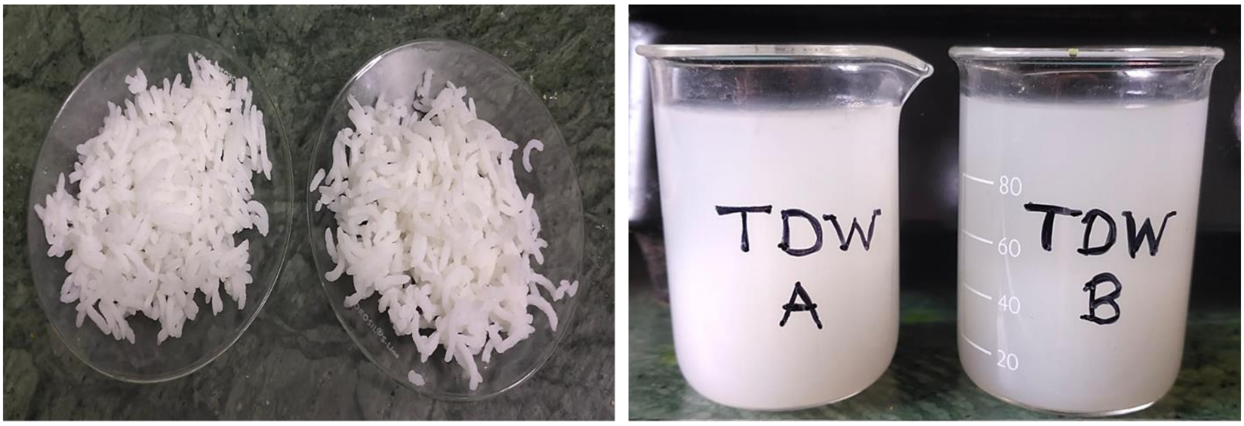
6.12.2.3. Preparation of cooked rice

Preparing rice using high volume of water and draining the excess water or gruel after cooking is a common practice all over the rural India. The mentioned method has several advantages and some disadvantages as well (Roychowdhury et al., 2003; Roychowdhury, 2008a). keeping this method of cooking in mind, raw and parboiled rice of all cultivars were cooked maintaining the rice-water ratio of 1:3 both in the field/ household level similarly in laboratory level.

As-safe water (As: <3 μg/L) was used to carry out this study in a laboratory scale with varieties of parboiled rice grains for cooked rice preparation. Raw grains were weighed using individual glass beakers, then they have undergone washing with tap water (As <3 μg/L) with rice-water ratio of 1:2 for three continuous cycles, after that, variation in soaking time with tap water for 15 minutes, 30 minutes, 1h, 1.5h maintaining the 1:2 ratios before cooking. Potential amount of As can be lost from raw rice mainly during washing and soaking procedure. The soaked rice was directly used for cooking at different rice to water ratios 1:2, 1:3, 1:4, 1:5 and 1:6. A part of wet cooked rice were directly processed for acid-digestion. A graphical flow chart has been prepared to illustrate the rice cooking procedure. From field study (domestic level), the parboiled raw rice and different fractions of cooked rice has been collected, maintaining the same protocol during cooking. Halder (2013) has described the effects of traditional methods of rice cooking carried out in rural Bengal. In the current research report, an endeavour has been considered to develop a balanced practice that should be maintained to reduce the toxic effect and recommend the rural populace to develop best suitable agricultural systems.

6.12.2.4. Chemicals and reagents

Analytical grade reagents, chemicals and double distilled water have been used during all the analytical, chemical, and experimental processes. Nitric acid and hydrogen peroxide from Merck were used for acid-digestion. Two routine blank samples have been prepared following the same protocol as digested samples.



a. Cooked rice

b. Total discarded water

Fig. 71b. Different fractions obtained after cooking a. Cooked rice and b. Total discarded water

6.12.2.5. Analysis

6.12.2.5.1. Total As

Atomic Absorption Spectrophotometer of model named Varian AA140 from USA attached with Vapor Generation Accessory of model named VGA-77 from Malaysia (5.1 software version) was used for analyzing tAs by HG-AAS method (Das et al., 2021a, b).

6.12.2.5.2. Extraction and instrumentation for As speciation

Arsenic species extraction has been performed using a mixture of 1% nitric acid in a ratio of 1:1(v/v). The detail systematic procedure for extracting As species i.e. inorganic As, MMA and DMA has been defined in Signes-Pastor et al. (2016). High Performance Liquid Chromatography attached with Inductively Coupled Plasma-Mass Spectrometry ICP-MS was employed for analyzing As speciation in rice (Islam et al., 2017b).

6.12.2.6. Statistical analysis

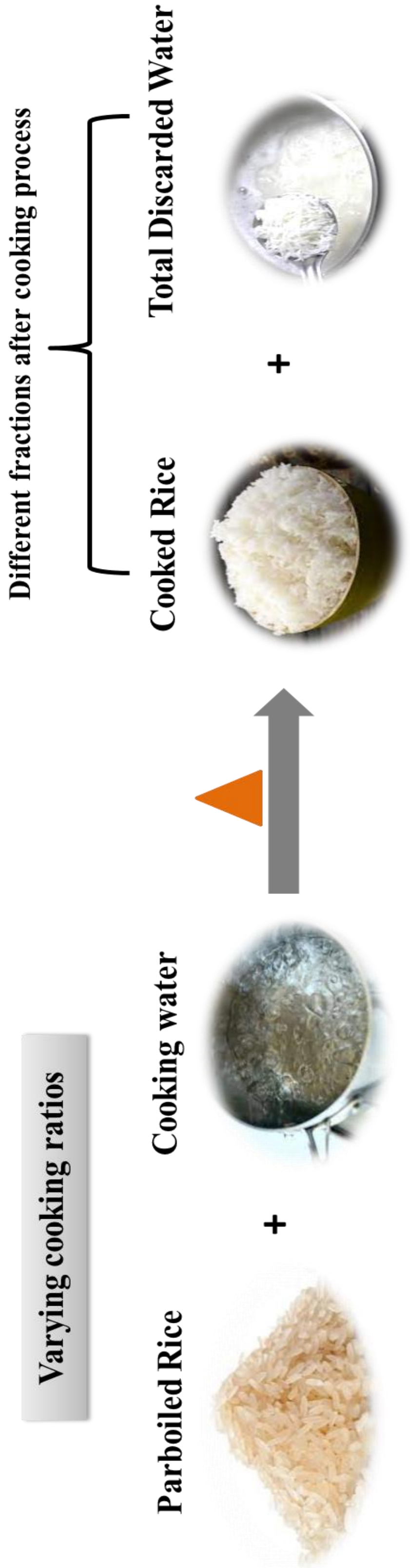
Statistical interpretations and presentations have been performed using Microsoft Office Professional Plus 2016.

6.12.2.7. Quality control and quality assurance

Hot-plate digestion procedure has been applied to digest 30% of the solid samples for maintaining quality control and quality assurance (Chowdhury et al., 2018a). As ‘Standard Reference Material (SRM)’, Rice flour 1568a (NIST, Gaithersburg, MD, USA) has been used. Subsequent analysis of As after Teflon Bomb digestion showed 94% recovery compared to the certified value (0.29 µg/g), on the other hand, 82% recovery percentage has been showed by the hot plate digestion. Analysing duplicates and calculating recovery of spiked digested samples were also used to assess quality control in this study.

6.12.3. Results and Discussion

Remediate accumulation of arsenic in cooked rice using different methodologies



Objective I: Field-based remediating As in cooked rice using cooking water through co-precipitation process

Objective II: Remediating As in cooked rice using different soaking time variation

Objective III: An attempt taken to resist arsenic from rice grain using citrate and tartrate solution at the time of soaking by photo-catalysis method followed by cooking with As-safe water.

6.12.3.1. Objective I: Field-based remediating arsenic in cooked rice using cooking water through co-precipitation process

The main objective of this study was to use the As-concentrated cooking water after different co-precipitation time intervals, to evaluate the reduction percentage of As from rice grain at field level.

Five different rice concentrations of Minikit variety from Madhusudankati village of Gaighata block, North 24 Parganas has been used during this experiment. Among the two types of rice grain i.e. sunned and parboiled rice, mainly parboiled rice is commonly used for cooking purposes for both rural and urban populaces of Bengal. Minikit variety of parboiled rice is most commonly used among the populaces of Bengal. The five different concentrated Minikit rice cultivar has been cooked in a ratio of 1:3 and 1:6 (domestic scale) at for time intervals. The targeted cooking time intervals are as follows: 0-h, 6-h, 12-h and 24-h. In Bengal, mainly 1:3 cooking ratio is preferred during cooked rice preparation, so 1:3 ratio along with 1:6 has been selected for this study. As several researches has showed that maximum reduction percentage has been observed at 1:6 cooking ratio compared to 1:3 (Raab et al., 2009).

Co-precipitation procedure in presence of ferric chloride is considered as an effective and cost-effective method for As removal from water (Meng et al., 2001). Several studies have reported that reduction of As concentration in the water sample occurs as a result of co-precipitation process (Meng et al., 2001; Otter et al., 2017). The co-precipitation method of As on iron hydroxides is an operative method for removal of As from water (Cheng et al., 2004). So, this technique has been applied in this experimental study, to evaluate the reduction of As in cooking water followed by using the reduce As cooking water at domestic scale ratio for cooked rice preparation in field level.

Four different time variation i.e. 0-h, 6-h, 12-h and 24-h has been targeted for co-precipitation process. The raw cooking water (As-contaminated) sample has been collected directly from the source (tube-well) and kept for cooking purpose following the above-mentioned time intervals.

In this study, the observed mean As of uncooked rice (Minikit) is 220 ± 80 µg/kg, ranging from 89-319 µg/kg. Likewise, initially, at 0-h the raw cooking water As concentration was 71.3 µg/L, followed by 60.1 µg/L (6-h), 55.4 µg/L (12-h) and 33.5 µg/L (24-h). Around 53% As reduction has been observed in cooking water after 24-h in our findings (Fig. 72).

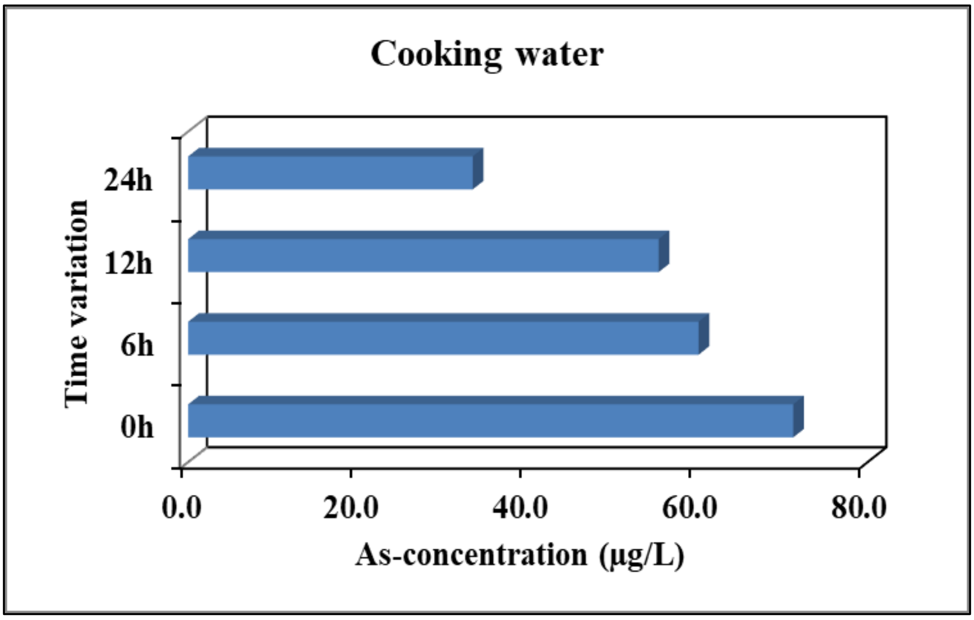


Fig. 72. Distribution of As concentrations in cooking water through co-precipitation process

Maintaining domestic scale cooking ratio of 1:3, the mean As concentration in cooked rice for respective 0-h, 6-h, 12-h and 24-h has been found to be 201 ± 67 µg/kg, ranging from 96-279 µg/kg; 170 ± 47 µg/kg, ranging from 92-216 µg/kg; 161 ± 57.3 µg/kg, ranging from 80.5-222 µg/kg and 111 ± 42.2 µg/kg, ranging from 49.9-157 µg/kg. Similarly, in case of increased cooking ratio i.e. 1:6, the mean As concentration in cooked rice for respective time-intervals that is 0-h, 6-h, 12-h and 24-h has been observed as 170 ± 76 µg/kg, ranging from 74-286 µg/kg; 156 ± 64 µg/kg, ranging from 60-221 µg/kg; 120 ± 56.5 µg/kg, ranging from 49.2-181 µg/kg and 91 ± 37.4 µg/kg, ranging from 32.5-129 µg/kg.

The mean reduction percentage (%) has been observed for 1:3 and 1:6 cooking ratios, respectively in Fig. 73. For all cases, 1:6 cooking ratio showed higher reduction percentage compared to 1:3 cooking ratio. It has been observed that the reduction percentage increases in an order of 0-h< 6-h<12-h<24-h for both the ratios used for cooking at domestic scale. The highest reduction percentage (%) has been observed in the case of 24-h which is as follows for 1:3 (48.6%) and 1:6 (59.1%) cooking ratio, respectively.

Table 54: Arsenic concentrations in cooked rice along with reduction percentage during different cookig ratios

		Cooking ratios			
		0-h			
	UCR As (µg/kg)	**1:3 WCR As (µg/kg)**	**1:6 WCR As (µg/kg)**	**Reduction (%) 1:3**	**Reduction (%) 1:6**
Mean	220	201	170	5.7	22.1
SD	88	67	76	10.6	12.2
min	89	96	74	-8.2	10.3
max	319	279	286	14	36.6
		6-h			
Mean	220	170	156	17.8	28.4
SD	88	47	64	15.7	15.6
min	89	92	60	-3.95	3.19
max	319	216	221	32.3	46
		12-h			
Mean	220	161	120	24.6	46.1
SD	88	57.3	56.5	10.1	7.8
min	89	80.5	49.2	9.1	35.3
max	319	222	181	34.0	54.9
		24-h			
Mean	220	111	91	48.7	59.1
SD	88	42.2	37.4	4.1	2.7
min	89	49.9	32.5	43.7	55.7
max	319	157	129	53	63.3

Table 55: Mean reduction perentages of different cooking ratios (1:3 and 1:6)

	Mean reduction (%)	
	Cooking ratio (1:3)	**Cooking ratio (1:6)**
0-h	5.71	22.1
6-h	17.8	28.4
12-h	24.6	46.1
24-h	48.6	59.1

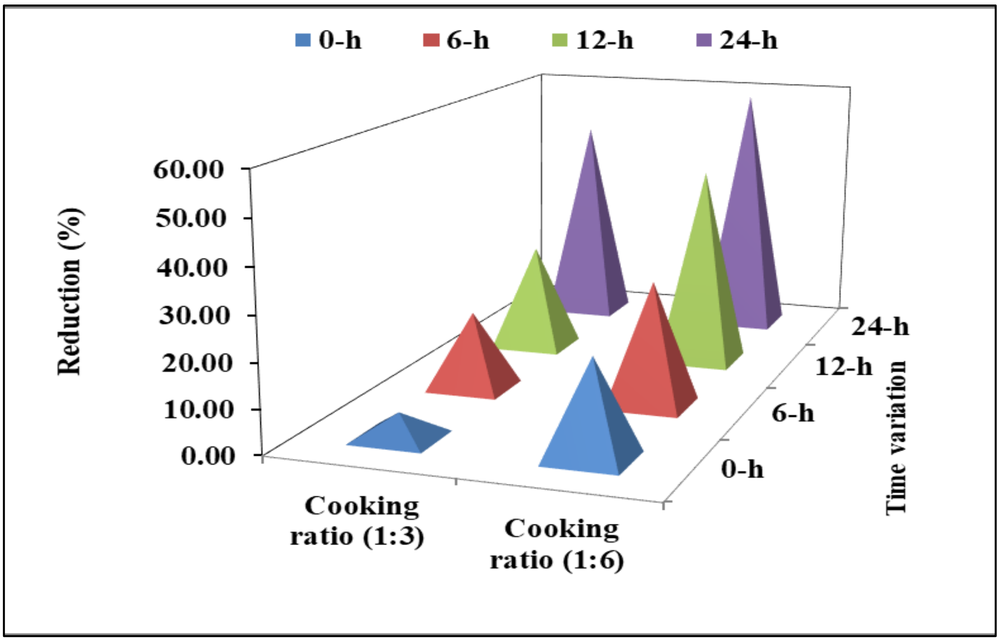
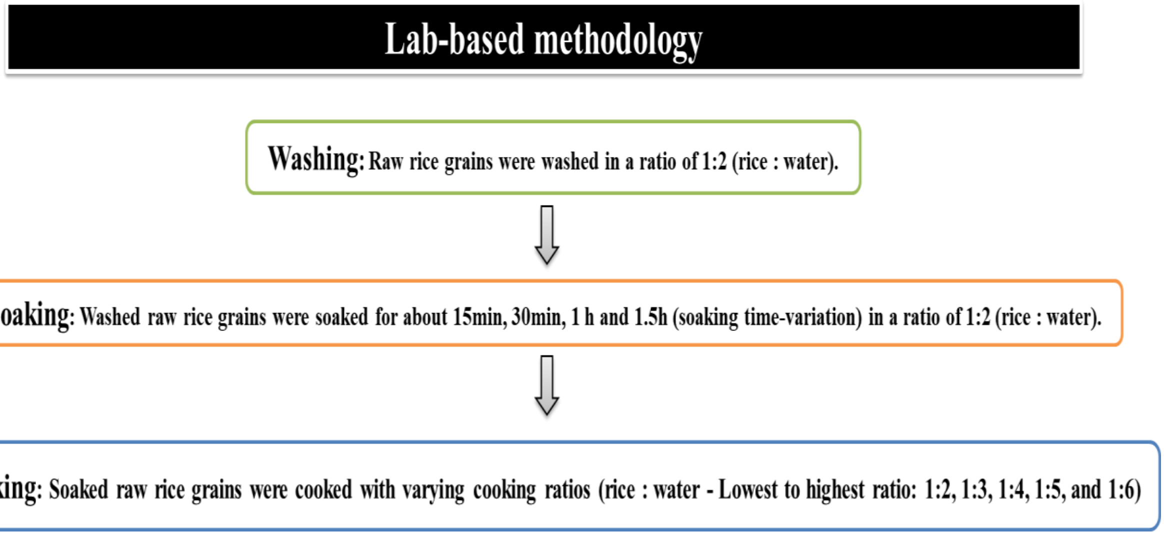


Fig. 73. Bar-daigram showing the reduction percentage of As at four different time-intervals

Overall, the maximum reduction has been observed at 24-h of the As-contaminated cooking water after co-precipitation process. Using of the 24-h cooking water for cooked rice preparation it has been observed that maximum As is reduced during both the respective cooking ratios i.e. 1:3 and 1:6. The study has been mainly performed to recommend the rural Bengal populace living in the severely As-exposed area that if the inhabitants are not having huge access to As-safe cooking water, then at least they should use the As-contaminated water only after co-precipitation of As for cooking purpose.

6.12.3.2. Objective II: Remediating As in cooked rice using different soaking time-variation: Lab-based study using As-safe water

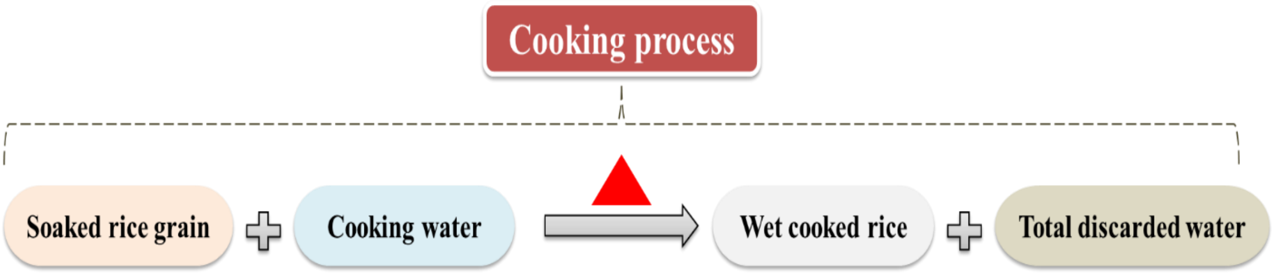
The main objective of this study was to use different As-contaminated rice grains (uncooked) for cooked rice preparation (1:3 and 1:6 cooking ratio) using As-safe cooking water with varying soaking time intervals, to evaluate the reduction percentage of As from rice grain.



Washing: Raw rice grains were washed in a ratio of 1:2 (rice : water).

Soaking: Washed raw rice grains were soaked for about 15min, 30min, 1 h and 1.5h (soaking time-variation) in a ratio of 1:2 (rice : water).

Cooking: Soaked raw rice grains were cooked with varying cooking ratios (rice : water - Lowest to highest ratio: 1:2, 1:3, 1:4, 1:5, and 1:6)



Rice contain iAs, which is surface-bound and soluble (Lombi et al., 2019; Menon et al., 2021), hence pre-cooking techniques including washing, soaking as well as cooking procedures may be able to minimize iAs levels. Despite the fact that there have been several studies on this subject, only few have used iAs data. Another study indicated that washing rice in cold water reduced the amount of iAs in white rice by 10% to 40%. (Atiaga et al., 2020; Naito et al., 2015; Raab et al., 2009). Studies carried out by Mandal et al. (2019) and Sharafi et al. (2019) have showed that washing for about 5 times results in a 5% reduction in total As (tAs, which is the sum of iAs and oAs).

Zhang et al. (2020b) evaluated the effects of soaking with varied rice to water ratios (1:2 to 1:5), temperatures of 30 to 70°C, along with soaking time-interval of 2 to 48 h for two rice varieties, which reported that temperatures of 60-70°C resulted in reducing 40% of tAs. In India, numerous research examined the consequences of cooking rice in surplus water (Sengupta et al., 2006). Correspondingly, another study by Gray et al. (2015) has also stated that rice when cooked with surplus cooking water results in reducing iAs by 40% (white rice) and 50% (brown rice), respectively. In this experimental study, Minikit rice cultivar has been selected of four different concentrations from farmers of Madhusudankati village, Gaighata block. Minikit variety of parboiled rice is most commonly used among the populaces of Bengal. The four different Minikit rice cultivars showed As accumulation of 127 µg/kg, 91.8 µg/kg, 310 µg/kg and 241 µg/kg, respectively. Four different soaking time intervals such as 15 min, 30 min, 1-h, and 1.5-h has been selected for remediating As from uncooked rice (raw parboiled rice) during cooking process in a ratio of 1:3 and 1:6 (rice: water ratio), respectively.

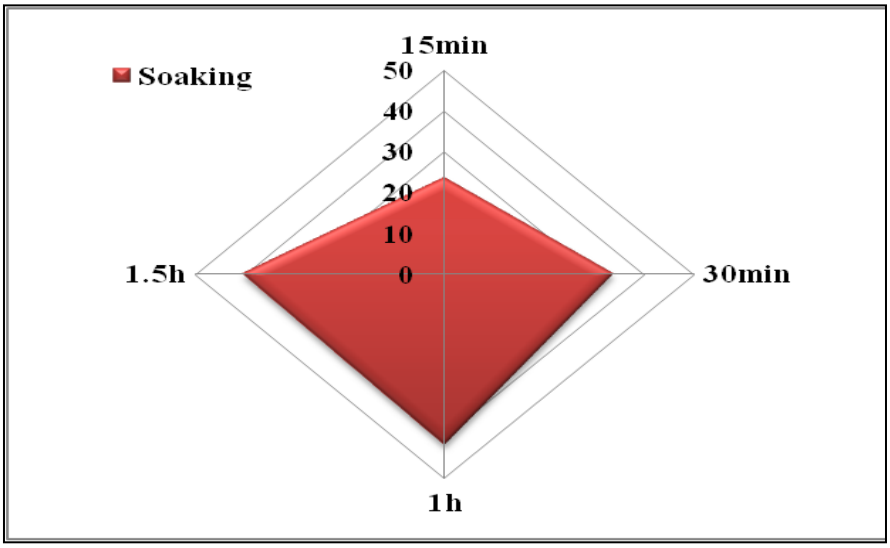


Fig. 74. Distribution of soaking time-intervals

Table 56: Arsenic concentrtaions during different soaking time variation

			Arsenic concentration (µg/kg)			
	Time variation	**Cooking ratio**	**UCR**	**WRG**	**SRG**	**WCR**
A.	**15min**	**1:3**	127	83.1	98.8	34.4
		1:6	127	83.1	98.8	28.02
	30min	**1:3**	127	83.1	81.3	36
		1:6	127	83.1	81.3	29.1
	1-h	**1:3**	127	83.1	73.9	30.4
		1:6	127	83.1	73.9	23.8
	1.5-h	**1:3**	127	83.1	75	30.9
		1:6	127	83.1	75	23
B.	**15min**	**1:3**	91.85	86.5	73.4	26.5
		1:6	91.85	86.5	73.4	24.3
	30min	**1:3**	91.85	86.5	71	28.1
		1:6	91.85	86.5	71	22
	1-h	**1:3**	91.85	86.5	63.8	27.9
		1:6	91.85	86.5	63.8	32.1
	1.5-h	**1:3**	91.85	86.5	73.3	25.1
		1:6	91.85	86.5	73.3	33.9
C.	**15min**	**1:3**	310	253	216	128
		1:6	310	253	216	111
	30min	**1:3**	310	253	189	109
		1:6	310	253	189	91
	1-h	**1:3**	310	253	162	97.1
		1:6	310	253	162	80.4
	1.5-h	**1:3**	310	253	157	89
		1:6	310	253	157	79
D.	**15min**	**1:3**	241	201	189	119
		1:6	241	201	189	101
	30min	**1:3**	241	201	151	106
		1:6	241	201	151	96.7
	1-h	**1:3**	241	201	126	83.4
		1:6	241	201	126	77.6
	1.5-h	**1:3**	241	201	119	81.1
		1:6	241	201	119	79.3

Among the four different soaking time interval maximum reduction has been found as 41.9% and 40.3% for 1-h, 1.5-h, respectively. Soaking time plays a major role in reducing As from uncooked rice.

It has been observed that 1:6 cooking ratio showed higher reduction percentage compared to 1:3 cooking ratio. The reduction percentage (%) for cooking ratio 1:3 for different soaking time interval is in an order of 1.5-h (71.6%) > 1-h (69.9%) > 30 min (65.4%) > 15 min (63.3%). Likewise, for cooking ratio of 1:6 the reduction percentage is in the order of 1.5-h (71.6%) > 1-h (71.7%) > 30 min (70.9%) > 15 min (68.4%).

Table 57: Reduction percentages in different fractions of cooking of the uncooked rice at four soaking time-variation

		Reduction (%)			
		UCR to WRG	**UCR to SRG**	**UCR to 1:3 WCR**	**UCR to 1:6 WCR**
UCR 1 (127 µg/kg)	**15min**	34.5	22.2	72.9	77.9
	30min	34.5	35.9	71.6	77.1
	1-h	34.5	41.8	76.1	81.2
	1.5-h	34.5	40.9	75.6	81.8
UCR 2 (91.8 µg/kg)	**15min**	5.82	20.1	71.1	73.5
	30min	5.82	22.7	69.4	76
	1-h	5.82	30.5	69.6	65.1
	1.5-h	5.82	20.2	72.7	63.1
UCR 3 (310 µg/kg)	**15min**	18.4	30.3	58.7	64.1
	30min	18.4	39	64.8	70.6
	1-h	18.4	47.7	68.6	74.1
	1.5-h	18.4	49.4	71.2	74.5
UCR 4 (241 µg/kg)	**15min**	16.6	21.6	50.6	58.1
	30min	16.6	37.3	56	59.9
	1-h	16.6	47.7	65.3	66.3
	1.5-h	16.6	50.6	67.2	67.1

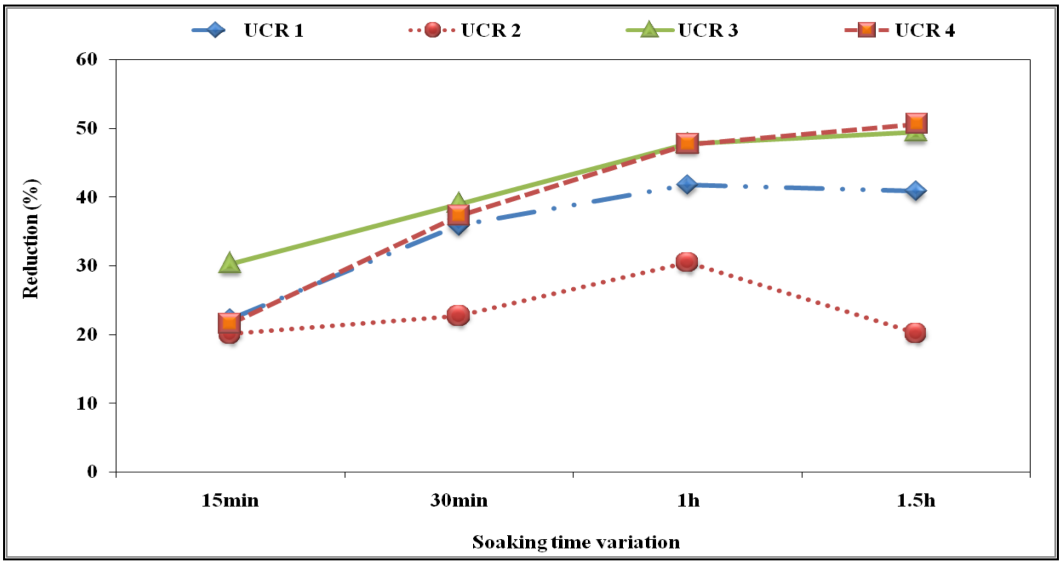


Fig. 75. Line daigram showing reduction percentages of the uncooked rice during different soaking time-intervals

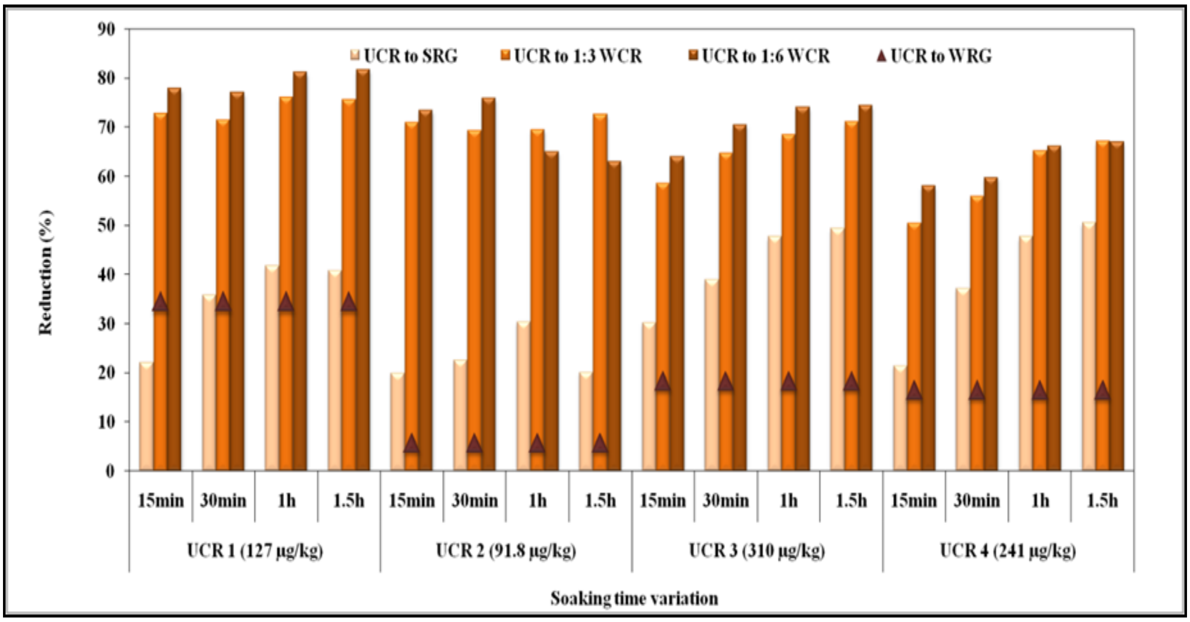


Fig. 76. Comparison of the reduction of As in different cooking fractions for four soaking time variation

Overall, the study states that using different soaking time interval (domestic level usage) – 15min, 30 min, 1h, and 1.5 h, it has been observed that 1h, 1.5h soaking of rice grain in As-safe water reduces nearly 40% of As. Mean reduction percentage while using As-safe water for 1:3 and 1:6 cooking ratio varies from 60-70%.

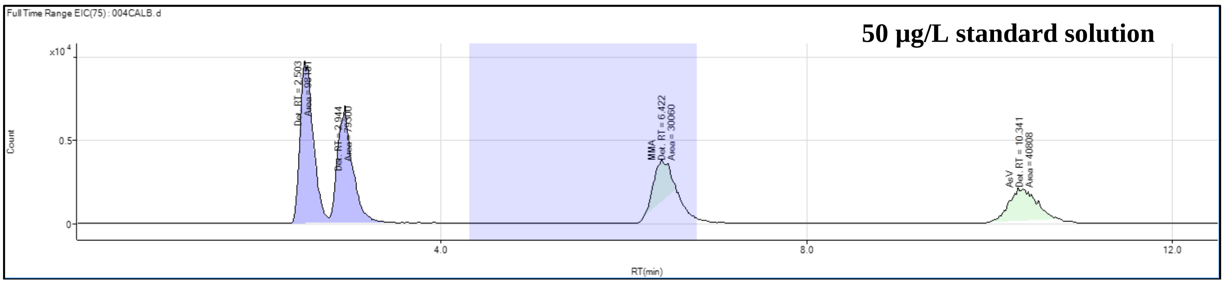
6.12.3.2.1. Distribution of As species

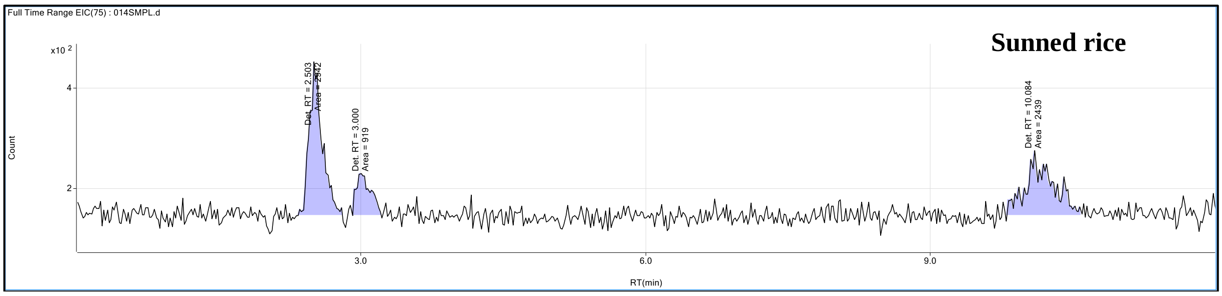
A speciation study has been performed on parboiled rice mainly originating from sunned rice followed by cooking in a ratio of 1:3 and 1:6 respectively using As-safe water. Sunned and parboiled rice grain (Satabdi minikit variety) collected from a farmer residing in Madhusudankati village of Gaighata field. The farmer has collected the parboiled rice grain from sunned rice grain by the process of post-harvesting (domestic-level). In this study, it has been detected that the parboiled rice accumulates higher As than sunned rice, which is in good agreement with the findings of Chowdhury et al., 2018b. This is due to the use of As-contaminated water at the time of post-harvesting. The sunned rice grain showed As III species dominating over As V species. Whereas, parboiled rice and its respective cooked rice showed As V species dominates over As III species. Interestingly, the As V species dominates over As III species in cooked rice when cooked in varying ratios. The total As concentrations of sunned rice, parboiled rice, 1:3 cooked rice, and 1:6 cooked rice are 121, 191, 153 and 135 µg/kg respectively. The total As accumulation in cooked rice reduces with increased ratio of cooking. The flow of As during cooking process follows the order as parboiled rice > 1:3 cooked rice >1:6 cooked rice. This corroborates with the findings of Chowdhury et al., 2020a. MMA is neither present in uncooked rice nor in cooked rice, as it is obvious that iAs generally dominates rice As in presence of a smaller amount of DMA (Halder et al., 2014). The percentage (%) distribution of iAs in sunned rice, parboiled rice, 1:3 cooked rice, and 1:6 cooked rice is observed as 85.5, 87.5, 89.1, and 86.2%, respectively. This corroborates with the main findings of Chowdhury et al., 2020a. Several research reports have highlighted that iAs species in rice grain is both toxic and carcinogenic, as it contributes nearly 80-85% of total As content (Halder et al., 2013, 2014; Meharg et al., 2009; Signes-Pastor et al., 2008).

Table 58: Distribution of As species in rice from field level and cooked at lab-scale with As-safe water

Sno.	Sample	As III	DMA	MMA	As V	Total As	% of inorganic As (As III + As V)
1	Sunned rice	60.8	17.4	0	42.7	121	85.5
2	Parboiled rice	63.2	23.9	0	104	191	87.5
3	1:3 cooked rice	24.5	16.7	0	112	153	89.1
4	1:6 cooked rice	0	18.6	0	116	135	86.2

 # Sample collected from exposed area - Gaighata, Satabdi Minikit variety.





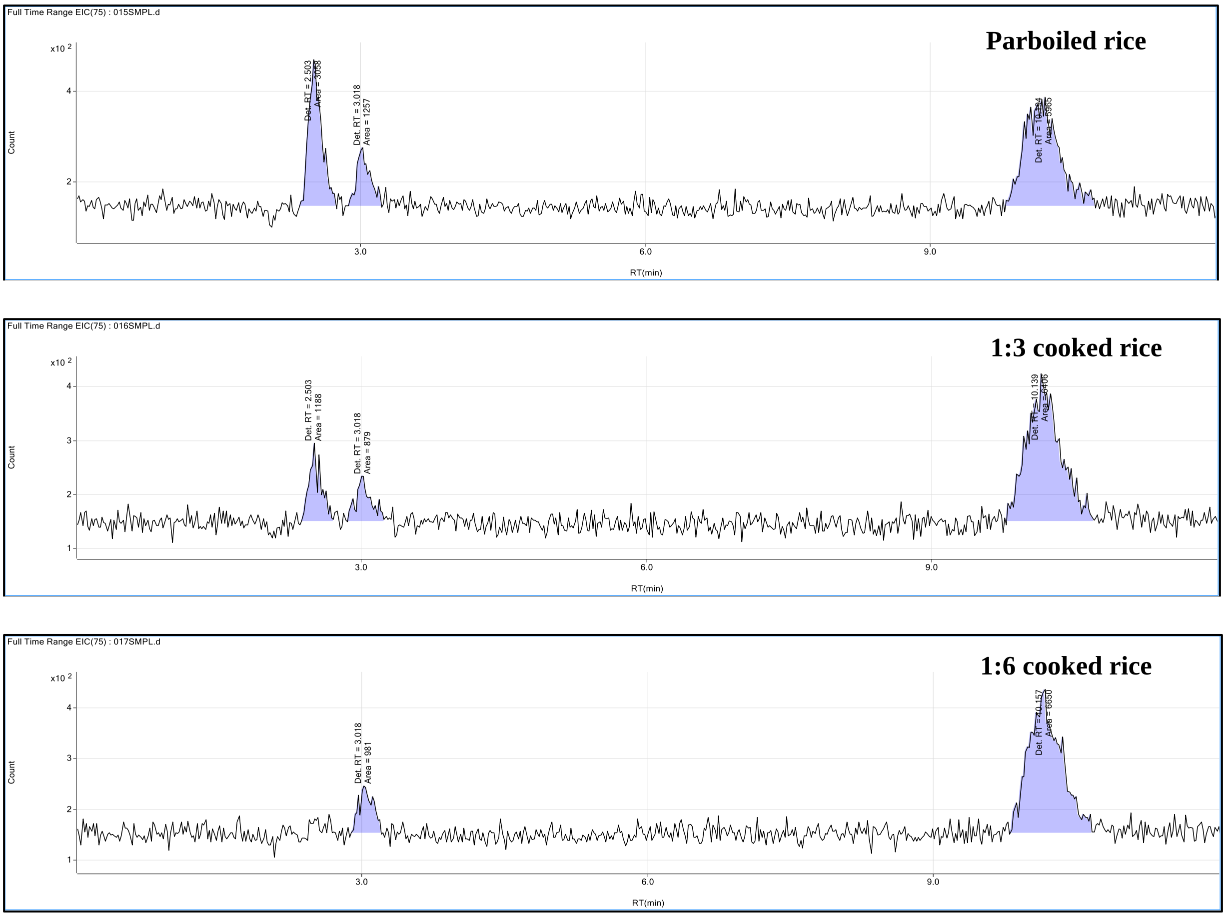


Fig. 77. HPLC chromatograph showing the As species distribution in Standard 50 µg/L and sunned rice, parboiled rice and its respective 1:3 and 1:6 cooked rice

6.12.3.3. Objective III: Lab-based remediation of As in cooked rice using citrate and tartrate solution during soaking time by photo-catalysis method: A comparative study

Behrouzi et al. (2018) has stated rice as a hugely consumed diet worldwide. Numerous techniques are existing for removing As from contaminated groundwater (Mukherjee et al., 2007). Solar oxidation and removal of As is considered as a low cost-effective method for removing As from contaminated water (Majumder et al., 2013). An approach has been carried out using natural citric acid sources removing As from drinking water at household level (Majumder et al., 2013). The methodology involves oxidation of As which is inhibited by the presence of lime (Hug et al., 2001). In a research study, lime has been reported as one of the essential promoter of removing As using photo-catalysis methodology (Majumder et al., 2013).
Recent researches highlighted remediating As from contaminated drinking water using non-toxic natural citrate sources (Majumder et al., 2013; Razafsha et al., 2016). A research study on simultaneous steps of soaking followed by cooking resulted in reducing percentage of trace elements using different chelating agents (Karimi and Goli, 2021). Using potassium tartrate and citrate as chelating agents, about 92 to 98% of the trace element (lead and cadmium) has been reduced from the rice grain (Karimi and Goli, 2021). A methodical study has been performed using sour lemon peel as it is cost-effective and easily available for removing heavy metals from rice as a bio-sorbent (Razafsha et al., 2016). In the above-mentioned study, it has been observed that significantly higher amount of heavy metal content can be removed nearly 67-90% from rice which has been previously washed followed by soaked for an hour. A recent study has highlighted that iAs content in rice can be removed using food-safe chemical before cooking procedure (Pogoson et al., 2021). In the aforesaid study it has been identified that food-safe citric acid (chelator) can effectively help in reducing As content through pre-soaking process.

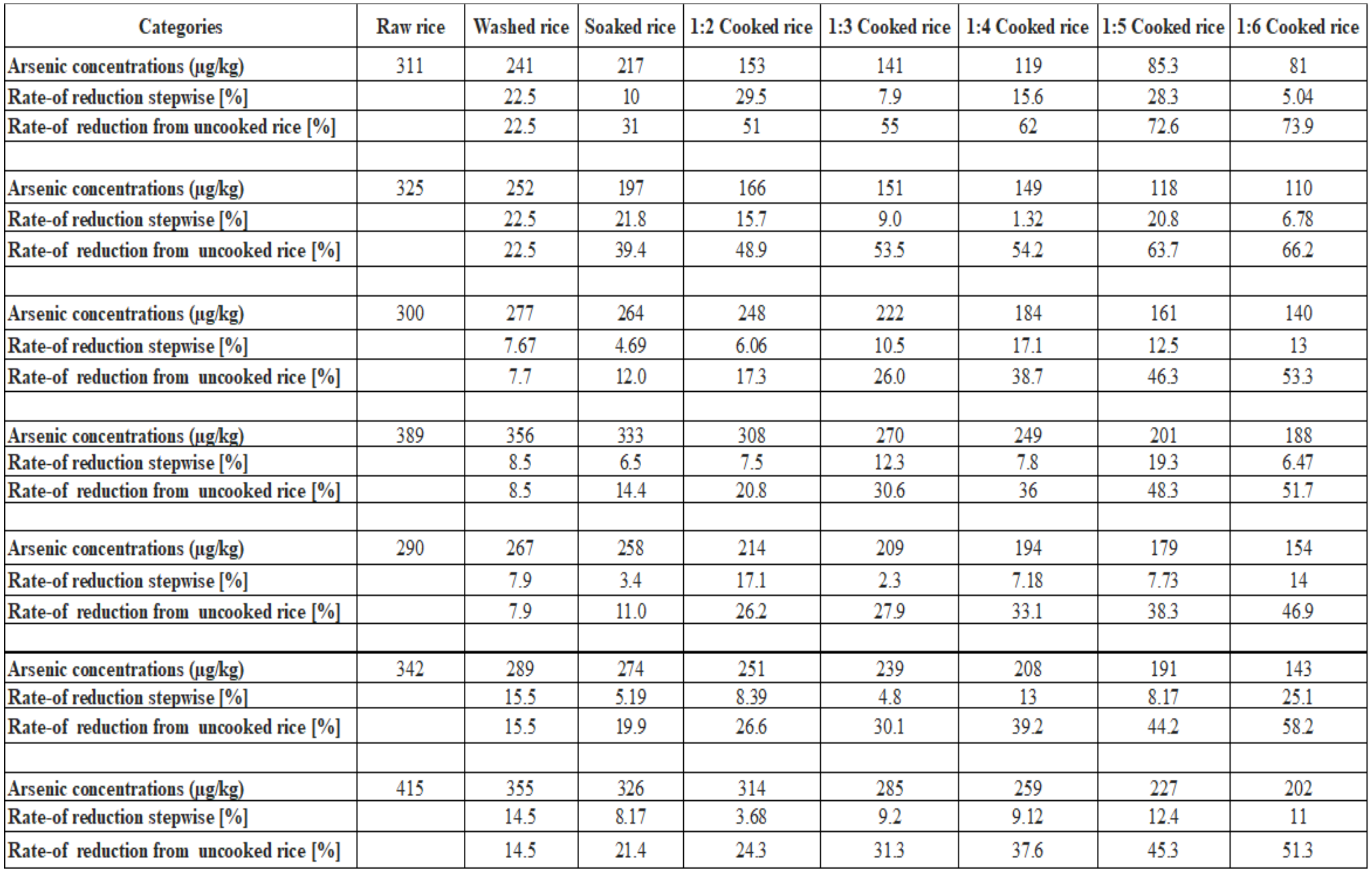
Three experimental set-ups have been carried out to remediate As from rice grain (uncooked) following three steps: washing, soaking and cooking ratio. The foremost aim of this study is evaluating the reduction percentage of As from uncooked rice during soaking step using natural sources of citric acid and tartaric acid i.e. citrus (lemon/lime) and tartrate. These chelating agents or bio-sorbents has been selected for this study as they are cost-effective and easily available in rural Bengal.

The three set-ups which have been used at the time of soaking are as follows:
Set-up A: As safe-water
Set-up B: Citrate solution

Set-up C: Tartrate solution

All the three set-ups after their respective treatments have been cooked in different ratios (1:2, 1:3, 1:4, 1:5 and 1:6) using As-safe water.

Table 59: Soaking with As-safe water and step-wise rate of As reduction from raw rice with As-safe cooking water using different cooking ratios



Categories	Raw rice	Washed rice	Soaked rice	1:2 Cooked rice	1:3 Cooked rice	1:4 Cooked rice	1:5 Cooked rice	1:6 Cooked rice
Arsenic concentrations (µg/kg)	311	241	217	153	141	119	85.3	81
Rate-of reduction stepwise [%]		22.5	10	29.5	7.9	15.6	28.3	5.04
Rate-of reduction from uncooked rice [%]		22.5	31	51	55	62	72.6	73.9
Arsenic concentrations (µg/kg)	325	252	197	166	151	149	118	110
Rate-of reduction stepwise [%]		22.5	21.8	15.7	9.0	1.32	20.8	6.78
Rate-of reduction from uncooked rice [%]		22.5	39.4	48.9	53.5	54.2	63.7	66.2
Arsenic concentrations (µg/kg)	300	277	264	248	222	184	161	140
Rate-of reduction stepwise [%]		7.67	4.69	6.06	10.5	17.1	12.5	13
Rate-of reduction from uncooked rice [%]		7.7	12.0	17.3	26.0	38.7	46.3	53.3
Arsenic concentrations (µg/kg)	389	356	333	308	270	249	201	188
Rate-of reduction stepwise [%]		8.5	6.5	7.5	12.3	7.8	19.3	6.47
Rate-of reduction from uncooked rice [%]		8.5	14.4	20.8	30.6	36	48.3	51.7
Arsenic concentrations (µg/kg)	290	267	258	214	209	194	179	154
Rate-of reduction stepwise [%]		7.9	3.4	17.1	2.3	7.18	7.73	14
Rate-of reduction from uncooked rice [%]		7.9	11.0	26.2	27.9	33.1	38.3	46.9
Arsenic concentrations (µg/kg)	342	289	274	251	239	208	191	143
Rate-of reduction stepwise [%]		15.5	5.19	8.39	4.8	13	8.17	25.1
Rate-of reduction from uncooked rice [%]		15.5	19.9	26.6	30.1	39.2	44.2	58.2
Arsenic concentrations (µg/kg)	415	355	326	314	285	259	227	202
Rate-of reduction stepwise [%]		14.5	8.17	3.68	9.2	9.12	12.4	11
Rate-of reduction from uncooked rice [%]		14.5	21.4	24.3	31.3	37.6	45.3	51.3

Table 60: Step-wise rate of As reduction from raw rice using different cooking ratios with As-safe water of a Minikit rice cultivar

Stages	**Raw rice**	**Washed rice**	**Soaked rice**	**1:2 Cooked rice**	**1:3 Cooked rice**	**1:4 Cooked rice**	**1:5 Cooked rice**	**1:6 Cooked rice**
Arsenic concentration (µg/kg)	311	241	217	153	141	119	85.3	81
Rate-of reduction stepwise (%)		22.5	10	29.5	7.9	15.6	28.3	5.04
Rate-of reduction from raw rice (%)		22.5	31	51	55	62	72.6	73.9

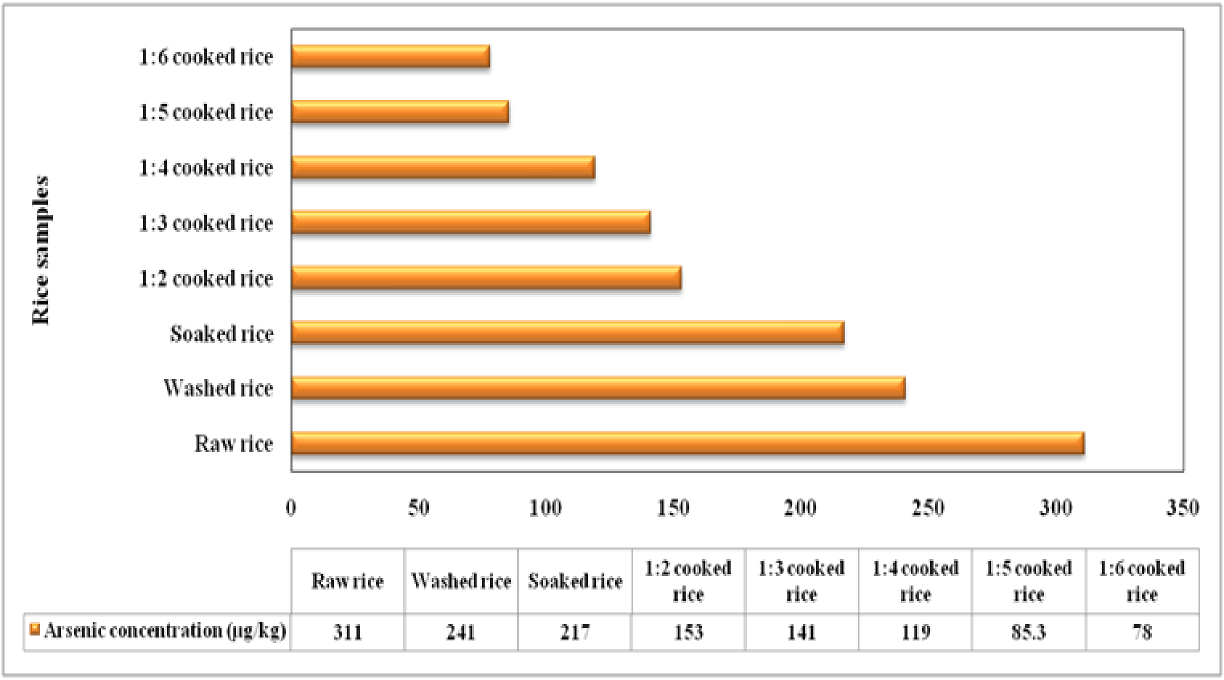


Fig. 78. Rate of As reduction from raw rice using As-safe water in varying cooking ratios of a Minikit rice cultivar

Raw rice As (µg/kg) = 311 ppb

Total reduction from raw rice to soaked rice = 31%

Reduction from soaked rice to lowest ratio of 1:2 cooked rice = 29.5%

Reduction from soaked rice to highest ratio of 1:6 cooked rice = 62.6 %

Reduction from raw rice to lowest ratio of 1:2 cooked rice = 50.8%

Reduction from raw rice to highest ratio of 1:6 cooked rice = 73.9%

Mass - balance study of a Minikit rice cultivar

Initial As concentration of raw rice grain = 311 µg/kg

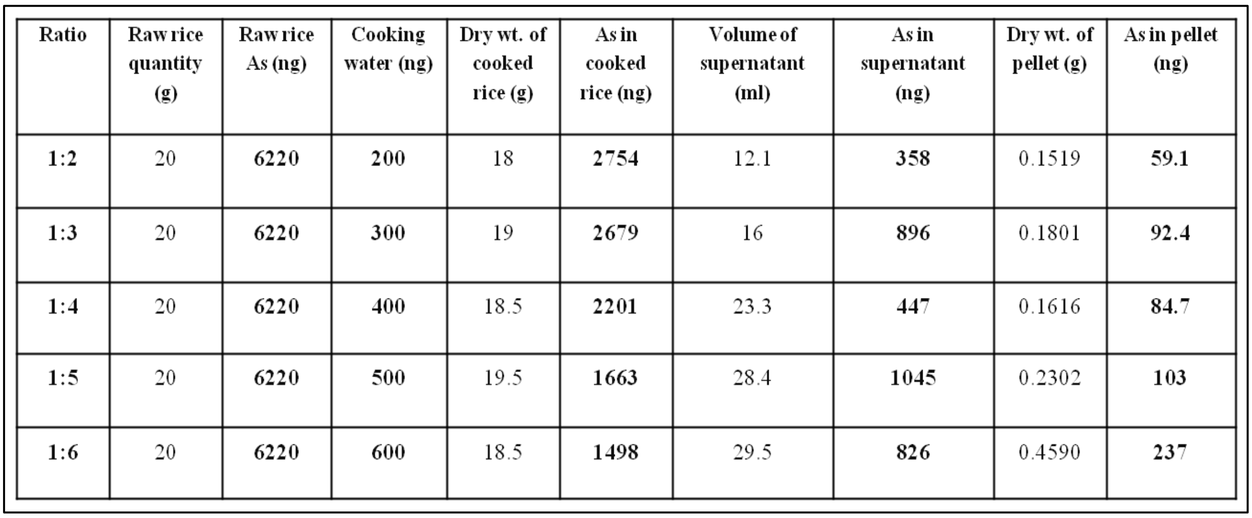
So, considering 1 g of raw rice contains 311 ng of As concentration.

Therefore, 20 g contains 6220 ng raw rice As concentration.

Considering 1ml of water contains 5 ng of As concentration.

Therefore, 40 ml contains 200 ng of As concentration.

Table 61: Representing the data evaluated from mass-balance study of a Minikit rice cultivar



Ratio	Raw rice quantity (g)	Raw rice As (ng)	Cooking water (ng)	Dry wt. of cooked rice (g)	As in cooked rice (ng)	Volume of supernatant (ml)	As in supernatant (ng)	Dry wt. of pellet (g)	As in pellet (ng)
1:2	20	**6220**	**200**	18	**2754**	12.1	**358**	0.1519	**59.1**
1:3	20	**6220**	**300**	19	**2679**	16	**896**	0.1801	**92.4**
1:4	20	**6220**	**400**	18.5	**2201**	23.3	**447**	0.1616	**84.7**
1:5	20	**6220**	**500**	19.5	**1663**	28.4	**1045**	0.2302	**103**
1:6	20	**6220**	**600**	18.5	**1498**	29.5	**826**	0.4590	**237**

Minikit parboiled rice variety has been used in this study collected from farmers of Deganga block, North 24 Parganas district. Among the two types of rice grain i.e. sunned and parboiled rice, mainly parboiled rice is commonly used for cooking purposes for both rural and urban populaces of Bengal. So, Minikit variety of parboiled rice has been targeted for this experimental study.

Respective tartrate and citrate solution was prepared using tartrate and citrate in a ratio of 1:10 (i.e. 1g of tartrate or 1ml of citrate solution in 10 ml of As-safe water). It is preferred to use the dilution of 1:10 of citrate or tartrate solution as it does not affect the taste of the cooked rice, while using domestic scale cooking ratio of 1:3 and 1:6, respectively. In this study, 1-h soaking contact time has been maintained for all the three experimental set-ups.

Table 62: Soaking with citrate solution and step-wise rate of As reduction from raw rice with As-safe cooking water using different cooking ratios

Categories	Raw rice	Washed rice	Soaked rice	1:2 Cooked rice	1:3 Cooked rice	1:4 Cooked rice	1:5 Cooked rice	1:6 Cooked rice
Arsenic concentrations (µg/kg)	311	244	215	205	168	172	179	223
Rate-of reduction stepwise [%]		21.5	11.9	4.7	18.0	-2.4	-4.1	-24.6
Rate-of reduction from uncooked rice [%]		21.5	30.9	34.1	46.0	44.7	42.4	28.3
Arsenic concentrations (µg/kg)	325	210	192	148	125	156	157	192
Rate-of reduction stepwise [%]		35.4	8.6	22.9	15.5	-24.8	-0.64	-22.3
Rate-of reduction from uncooked rice [%]		35.4	40.9	54.5	61.5	52.0	51.7	40.9
Arsenic concentrations (µg/kg)	300	183	171	128	119	127	128	157
Rate-of reduction stepwise [%]		39	6.56	25.1	7.03	-6.72	-0.79	-22.7
Rate-of reduction from uncooked rice [%]		39	43	57.3	60.3	57.7	57.3	47.7
Arsenic concentrations (µg/kg)	389	304	283	239	228	255	261	290
Rate-of reduction stepwise [%]		21.9	6.91	15.5	4.6	-11.8	-2.35	-11.1
Rate-of reduction from uncooked rice [%]		21.9	27.2	38.6	41.4	34.4	32.9	25.4
Arsenic concentrations (µg/kg)	290	198	177	163	151	157	173	194
Rate-of reduction stepwise [%]		31.7	10.6	7.91	7.36	-3.97	-10.2	-12.1
Rate-of reduction from uncooked rice [%]		31.7	39	43.8	47.9	45.9	40.3	33.1
Arsenic concentrations (µg/kg)	342	258	213	180	159	179	184	188
Rate-of reduction stepwise [%]		24.6	17.4	15.5	11.7	-12.6	-2.8	-2.2
Rate-of reduction from uncooked rice [%]		24.6	37.7	47.4	53.5	47.7	46.2	45
Arsenic concentrations (µg/kg)	415	340	287	264	248	263	276	291
Rate-of reduction stepwise [%]		18.1	15.6	8.01	6.06	-6.05	-4.94	-5.43
Rate-of reduction from uncooked rice [%]		18.1	30.8	36.4	40.2	36.6	33.5	29.9

Table 63: Soaking with tartrate solution and step-wise rate of As reduction from raw rice with As-safe cooking water using different cooking ratios

Categories	Raw rice	Washed rice	Soaked rice	1:2 Cooked rice	1:3 Cooked rice	1:4 Cooked rice	1:5 Cooked rice	1:6 Cooked rice
Arsenic concentrations (µg/kg)	311	291	269	131	123	127	138	158
Rate-of reduction stepwise [%]		6.4	7.6	51.3	6.11	-3.25	-8.66	-14.5
Rate-of reduction from uncooked rice [%]		6.4	13.5	57.9	60.5	59.2	55.6	49.2
Arsenic concentrations (µg/kg)	325	319	315	158	113	132	170	232
Rate-of reduction stepwise [%]		1.8	1.3	49.8	28.5	-16.8	-28.8	-36.5
Rate-of reduction from uncooked rice [%]		1.8	3.1	51.4	65.2	59.4	47.7	28.6
Arsenic concentrations (µg/kg)	300	272	252	216	169	171	178	179
Rate-of reduction stepwise [%]		9.3	7.4	14.3	21.8	-1.18	-4.09	-0.56
Rate-of reduction from uncooked rice [%]		9.3	16	28	43.7	43.0	40.7	40.3
Arsenic concentrations (µg/kg)	389	381	375	267	252	251	263	291
Rate-of reduction stepwise [%]		2.1	1.6	28.8	5.62	0.40	-4.78	-10.6
Rate-of reduction from uncooked rice [%]		2.1	3.6	31.4	35.2	35.5	32.4	25.2
Arsenic concentrations (µg/kg)	290	260	221	155	142	161	174	197
Rate-of reduction stepwise [%]		10.3	15.0	29.9	8.39	-13.4	-8.07	-13.2
Rate-of reduction from uncooked rice [%]		10.3	23.8	46.6	51	44.5	40	32.1
Arsenic concentrations (µg/kg)	342	309	253	190	181	189	215	248
Rate-of reduction stepwise [%]		9.6	18.1	24.9	4.74	-4.42	-13.8	-15.3
Rate-of reduction from uncooked rice [%]		9.6	26.0	44.4	47.1	44.7	37.1	27.5
Arsenic concentrations (µg/kg)	415	374	339	278	263	272	283	301
Rate-of reduction stepwise [%]		9.9	9.4	18	5.40	-3.42	-4.04	-6.36
Rate-of reduction from uncooked rice [%]		9.9	18.3	33	36.6	34.5	31.8	27.5

The mean As concentration of uncooked rice is 339 ± 46.8 µg/kg, ranging from 290 - 415 µg/kg. The observed mean As concentrations for the respective washed and soaked rice are 291 ± 46.7 µg/kg and 267 ± 50.6 µg/kg (using As-safe water), 248 ± 57.5 µg/kg and 219 ± 47.5 µg/kg (using citrate solution), and 315 ± 47.1 µg/kg and 289 ± 55.2 µg/kg (using tartrate solution). The reducing trend of As increases gradually with the cooking ratio from 1:2 to 1:6 while using As-safe water throughout the process. Likewise, use of citrate or tartrate solution during washing and soaking time reduces more As during cooking in ratio of 1:2 and 1:3 compared to 1:4, 1:5, 1:6 respectively. The reduction percentage increases initially but gradually decreases with increased cooking ratio.

Using As-safe water, in set-up A it has been observed that 1:6 cooking ratio showed a mean of 57.3% As reduction in cooked rice compared to 1:3 cooking ratio, which showed 36.3%.

In set-up B, using citrate solution (soaking time: 1-h) it resulted in reducing As around 50.1% at 1:3 cooking ratio compared to 1:6 cooking ratio (35.8%). Similarly, using tartrate solution (soaking time: 1-h) it showed 48.5% As reduction during 1:3 cooking ratio compared to 1:6 cooking ratio (32.9%). As a result, overall the reduction percentage in respective safe-water showed 1:6 > 1:3, citrate Solution 1:3 > 1:6, and tartrate Solution 1:3 > 1:6.

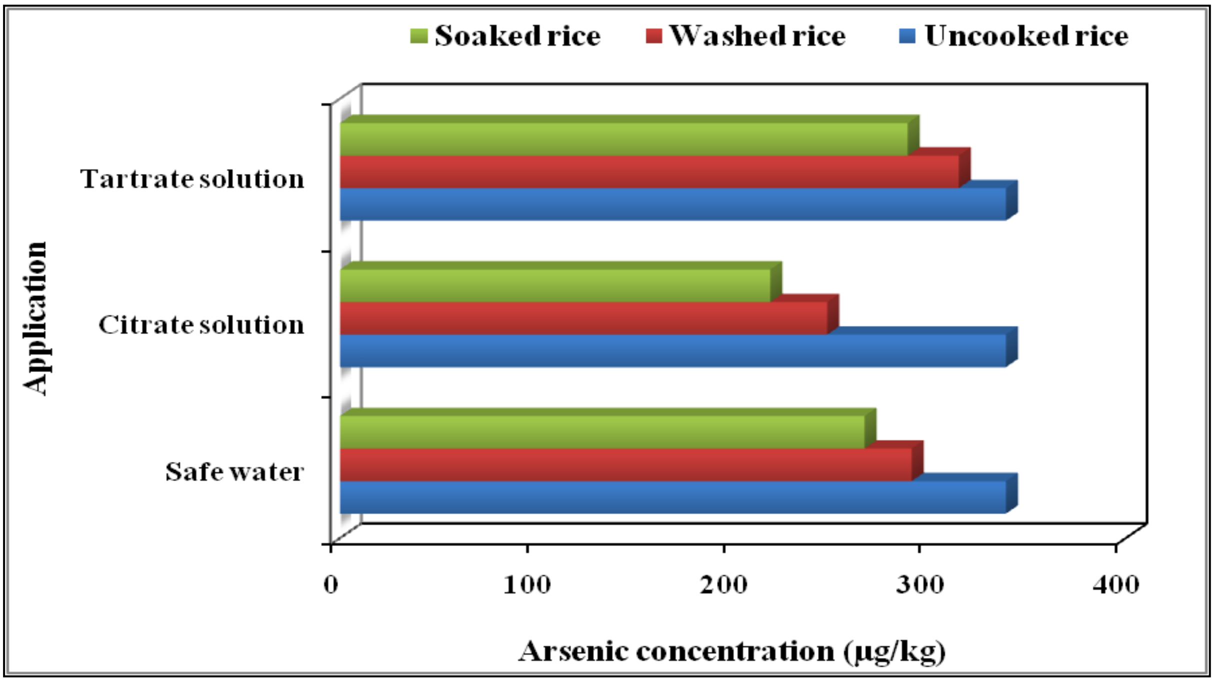


Fig. 79. Mean As concentrtaions in uncooked, washed and soaked rice

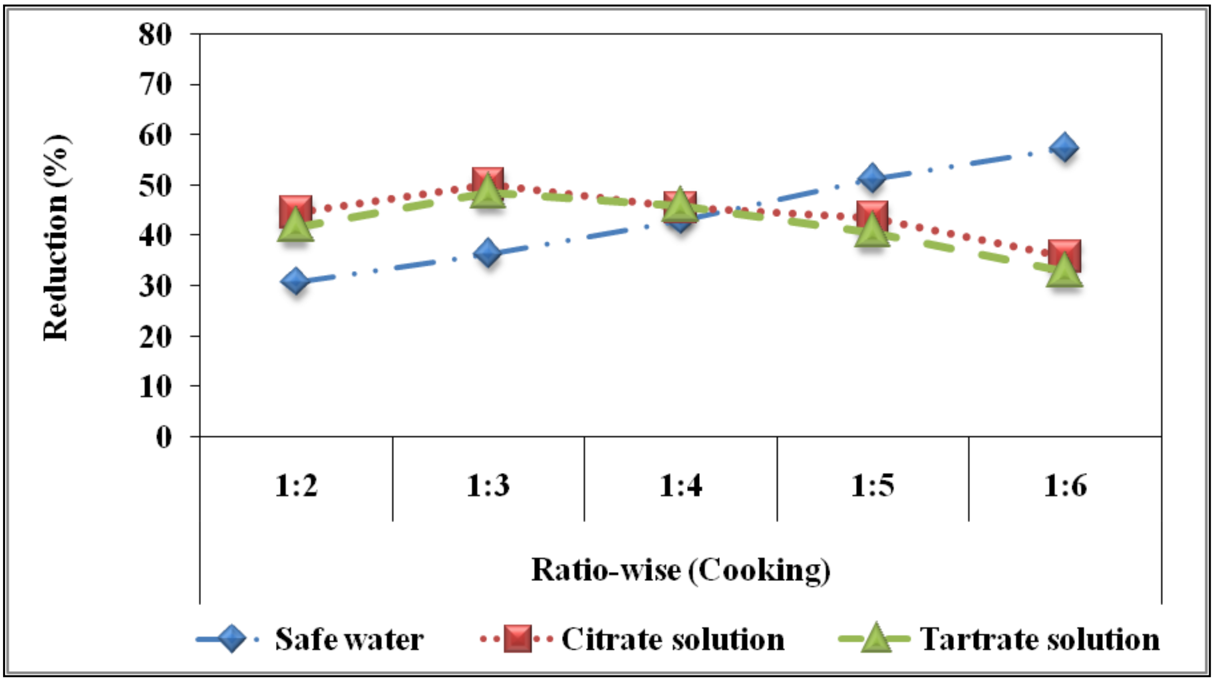


Fig. 80. Line diagram showing reduction using three experimental set-ups for varying cooking ratios

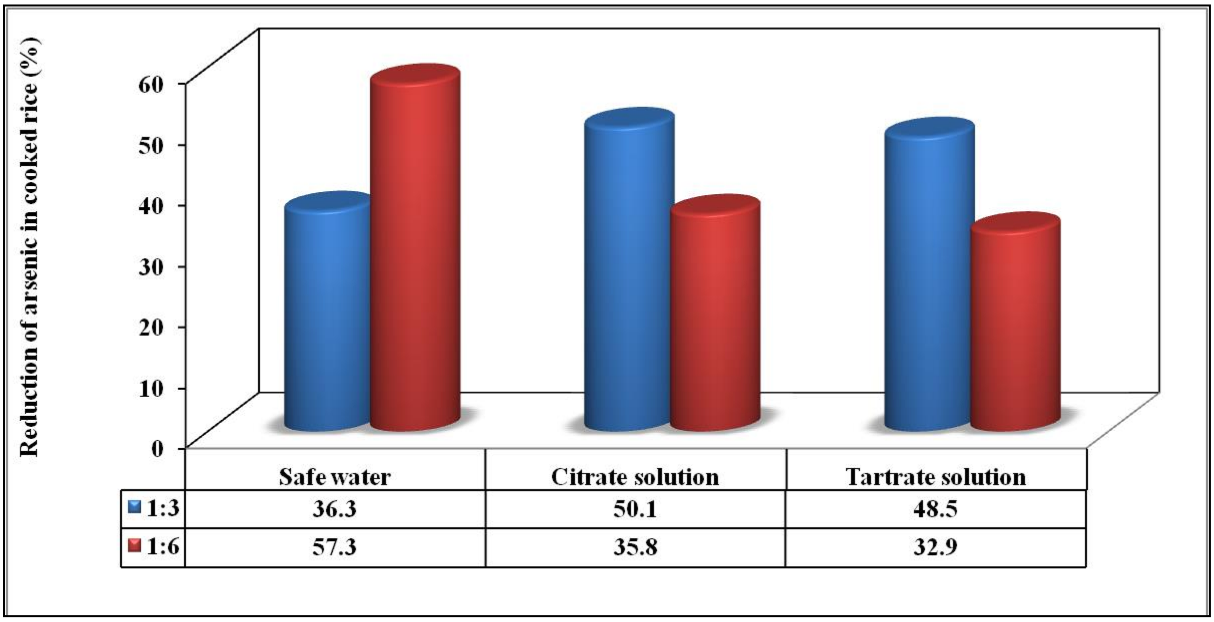


Fig. 81. Bar-daigram showing the mean As reduction percentages from three different experimental set-ups

Whereas, availability of sufficient As-safe water in As-exposed area is questionable; so, after soaking in respective citrate and tartrate solution, 1:3 ratio cooking resulted in reduction of 50% As in cooked rice. As, Bengal populace maintains or prefers the ratio 1:3 for cooking purpose, So, they can soak the rice grain for about 1h in citrate and tartrate solution as pre-treatment before cooking process.

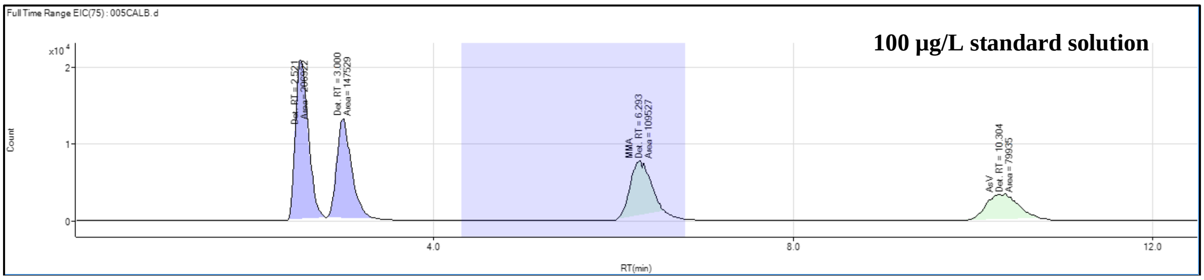
6.12.3.3.1. Distribution of As species

Parboiled rice grain (Minikit variety) collected from a farmer residing in a village of As-exposed field. This rice grain has been used for cooked rice preparation using As-safe cooking water in varying ratios (1:2, 1:3, 1:4, 1:5, and 1:6) following three steps: washing, soaking and cooking. The total As concentrations of raw rice, washed rice, soaked rice 1:2 cooked rice, 1:3 cooked rice, 1:4 cooked rice, 1:5 cooked rice and 1:6 cooked rice are 286, 268, 224, 174, 132, 124, 112 and 98.2 µg/kg respectively. The total As accumulation in cooked rice reduces with increasing ratio of cooking. In our study, it has been observed that the flow of As during cooking process follows the order as raw rice > washed rice > soaked rice > 1:2 cooked rice > 1:3 cooked rice > 1:4 cooked rice >1:5 cooked rice >1:6 cooked rice. Interestingly, the As V species dominates over As III species in cooked rice cooked in varying ratios. Presence of MMA is negligible in raw as well as cooked form of rice grain, as it is obvious that iAs mainly dominates rice As in presence of a smaller amount amount of DMA (Halder et al., 2014). Overall, the percentage (%) distribution of iAs in raw rice, washed rice, soaked rice, 1:2 cooked rice, 1:3 cooked rice, 1:4 cooked rice, 1:5 cooked rice and 1:6 cooked rice is observed as 100, 96.2, 94.3, 95.4, 94.2, 92.2, 90, and 92.3%, respectively. A study by Raab et al. (2009) showed that cooking rice in a high water to rice ratio decreases the cooked rice As. Our results corroborate with the main findings of Chowdhury et al., (2020a). Several researches has showed that the iAs species of rice grain is toxic and carcinogenic, it contributes nearly 80% of total As content (Halder et al., 2013, 2014; Meharg et al., 2009; Signes-Pastor et al., 2008).

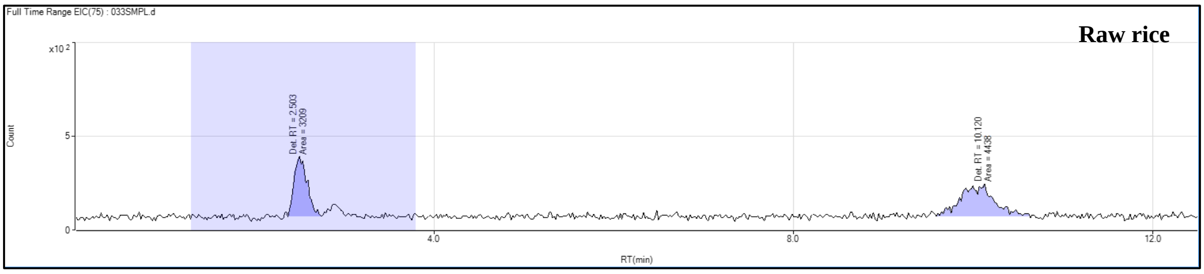
Table 64: Arsenic species distribution in raw rice and its cooked rice while cooking with As-safe water in different cooking ratios

	Observed values of As species (ppb)					
Sample name	**As III**	**DMA**	**MMA**	**As V**	**Total As**	**% of Inorganic As (As III + As V)**
Raw rice[a]	65.9	0	0	220	286	100
Washed rice	51.5	10.3	0	206	268	96.2
Soaked rice	49.6	12.9	0	162	225	94.3
1:2 cooked rice	47.2	7.98	0	119	174	95.4
1:3 cooked rice	40.3	7.53	0	83.9	132	94.2
1:4 cooked rice	37.2	9.7	0	77.5	124	92.2
1:5 cooked rice	30.7	11.2	0	70.4	112	90
1:6 cooked rice	21.5	7.55	0	69.1	98.2	92.3

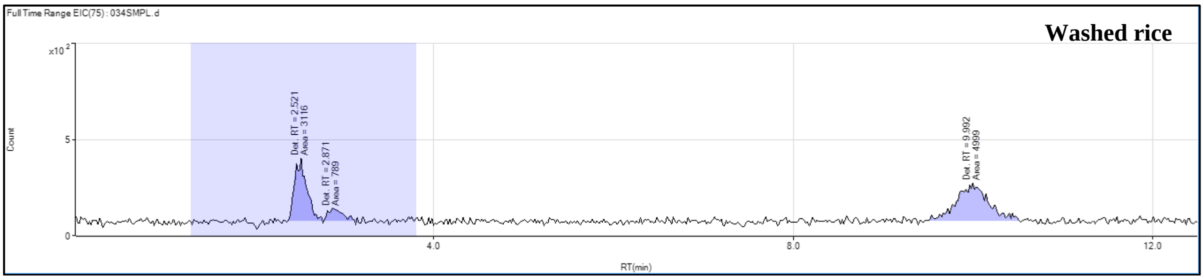
[a] Parboiled rice grain (Minikit variety) from Deganga farmer (domestic scale)



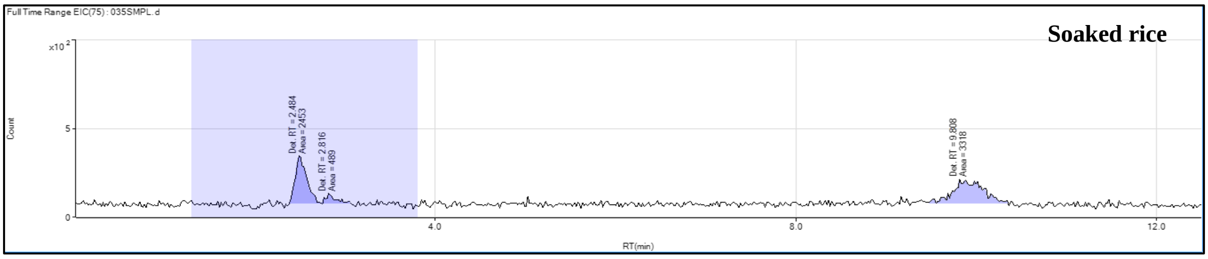
Full Time Range EIC(75) : 005CALB.d
100 µg/L standard solution
x10 4
2
1
0
Count
Det. RT = 2.521
Det. RT = 3.000
Area = 147529
MMA
Det. RT = 6.293
Area = 109527
AsV
Det. RT = 10.304
Area = 79935
4.0
8.0
12.0
RT(min)



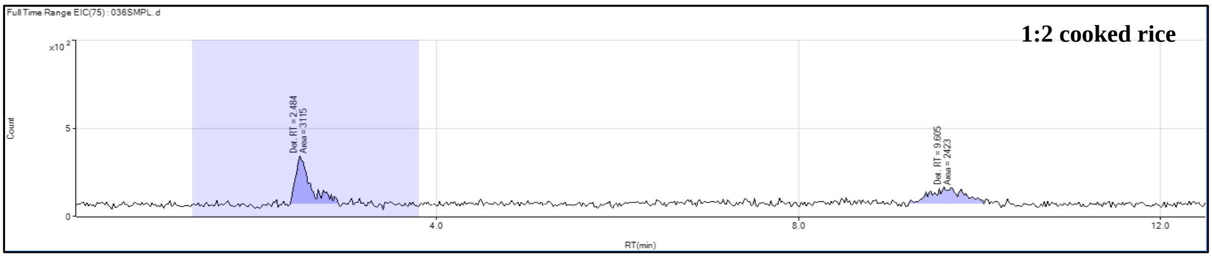
Full Time Range EIC(75) : 033SMPL.d
Raw rice
x10 2
5
0
Count
Det. RT = 2.503
Area = 3209
Det. RT = 10.120
Area = 4438
4.0
8.0
12.0
RT(min)



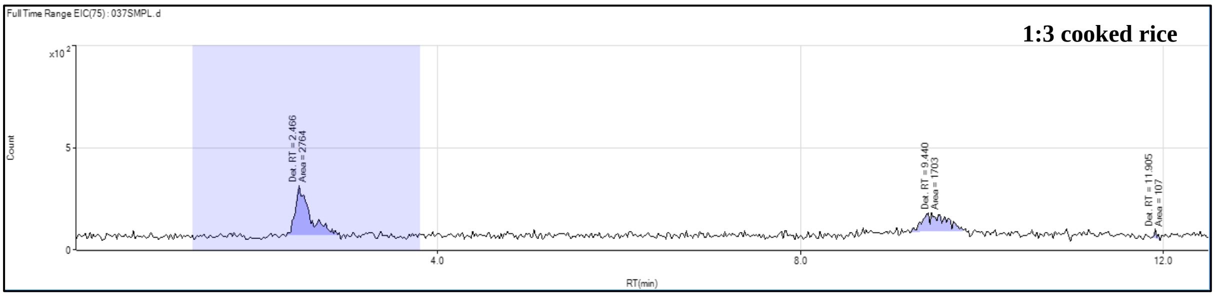
Full Time Range EIC(75) : 034SMPL.d
Washed rice
x10 2
5
0
Count
Det. RT = 2.521
Area = 3116
Det. RT = 2.871
Area = 789
Det. RT = 9.992
Area = 4999
4.0
8.0
12.0
RT(min)



Full Time Range EIC(75) : 035SMPL.d
Soaked rice
x10 2
5
0
Count
Det. RT = 2.484
Area = 2453
Det. RT = 2.816
Area = 489
Det. RT = 9.808
Area = 3318
4.0
8.0
12.0
RT(min)



Full Time Range EIC(75) : 036SMPL.d
1:2 cooked rice
x10 2
5
0
Count
Det. RT = 2.484
Area = 3115
Det. RT = 9.605
Area = 2423
4.0
8.0
12.0
RT(min)



Full Time Range EIC(75) : 037SMPL.d
1:3 cooked rice
x10 2
5
0
Count
Det. RT = 2.466
Area = 2764
Det. RT = 9.440
Area = 1703
Det. RT = 11.905
Area = 107
4.0
8.0
12.0
RT(min)

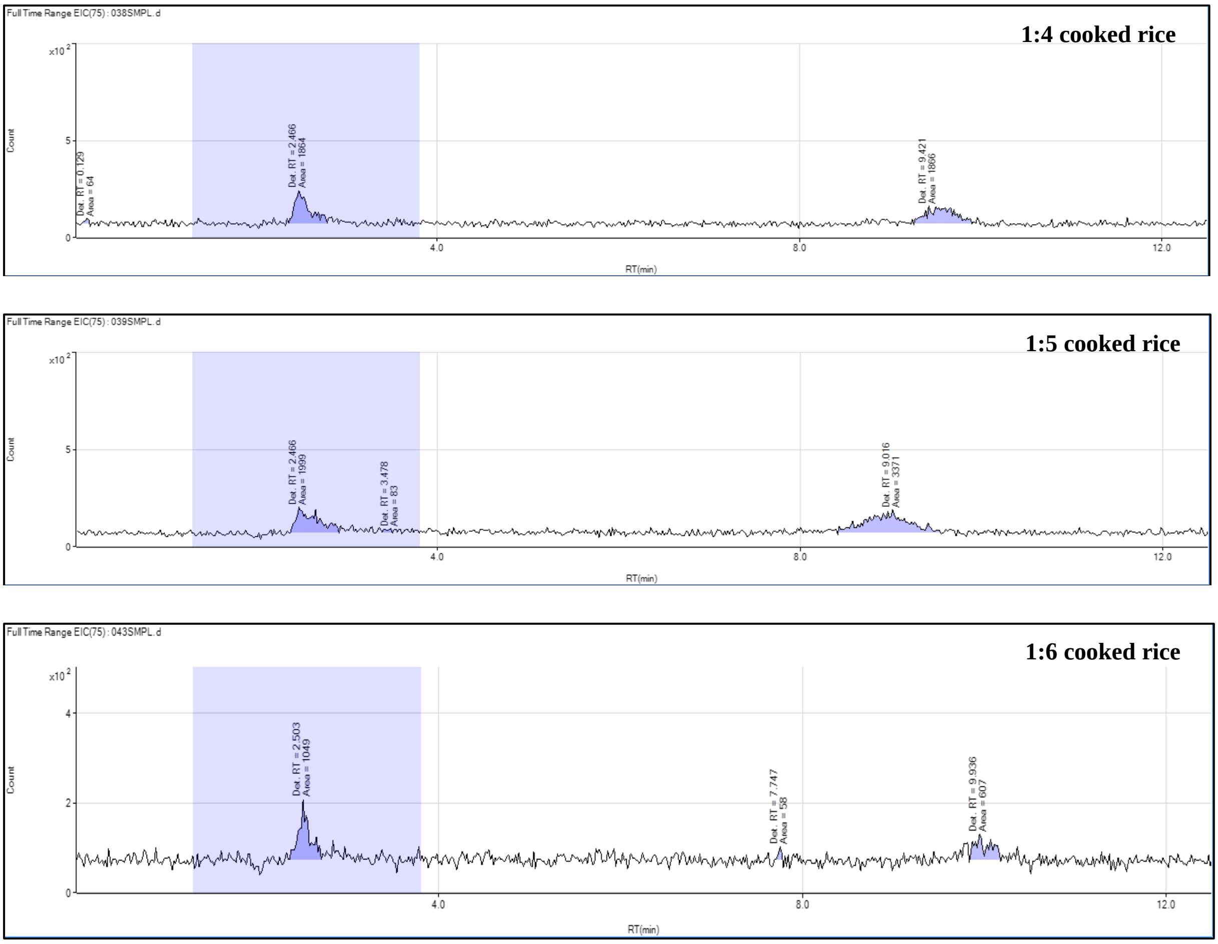


Fig. 82. HPLC chromatograph showing the As species distribution in Standard 100 µg/L and raw rice and its cooked rice while cooking with As-safe water in different cooking ratios

Chapter Seven

CONCLUSION

Consumption of groundwater for drinking purpose in As-prone areas is of great concern. Overall groundwater quality of the domestic shallow and deep tube-wells from two As-affected blocks through evaluation of different physico-chemical parameters has been categorized as alkaline and hard in nature. About 78.5 and 70% of the deep tube-well groundwater samples from Gaighata and Deganga block, respectively, have been identified with As concentration less than 10 µg/L. The groundwater quality indexing showed that 36% and 25% of deep tube-well water samples are characterized under 'good water quality', recommended for drinking purpose in the respective Gaighata and Deganga block. The domestic shallow tube-well water quality indexing clearly indicates that the water is 'unsuitable for drinking' from both the studied blocks. As a result, the groundwater from deep aquifer is comparatively safer with respect to shallow aquifer for drinking, cooking and other household purposes; however, continuous monitoring of water quality is required. The potential carcinogenic and non-carcinogenic risk due to severe As exposure through drinking water is high from domestic shallow tube-well compared to deep tube-well among the studied blocks. Comparatively, blocks named Swarupnagar and Gaighata showed quantitative evaluation of ecological risk has been categorized under very high-risk class considering all the gram panchayats. Health risk persists among the populations from all the gram panchayats of the two studied blocks through consumption of deep tube-well water, as the cancer risk values are higher than the recommended value i.e. $1x10^{-6}$. Likewise, probability of non-cancerous diseases exists among the populace of the two studied blocks, where the HQ value > 1. Exceptionally, populations residing in Sutia gram panchayat from Gaighata block and Balti gram panchayat from Swarupnagar block show no probability of non-cancerous risk. Overall, it can be said that inhabitants residing in Gaighata block are more prone to severe health risk compared to Swarupnagar block.

Rice is the staple food crop of Bengal delta, which is mainly locally cultivated in As-contaminated agricultural soil and groundwater. Cultivation of staple crops like paddy on As contaminated agricultural fields is one of the major routes for human dietary exposure. Translocation of As (iAs form) in paddy plant occurs in a sequence of root to rice grain for both the seasons. Root accumulated highest As compared to others parts of the paddy plant. Overall, the percentage distribution of iAs in different parts of the pre-monsoonal paddy is observed as 94.4, 95.8, 95.3, 82, and 99.8% in rice grain, rice husk, leaf, stem, and root, respectively. Whereas, 89, 915, 87.6, 97.4, and 99.5% of iAs distribution has been in post-monsoonal rice grain, rice husk, leaf, stem, and root, respectively. The total rice grain As concentrations from pre-monsoon and post-monsoon season cultivated in the As exposed fields are 135 and 112 µg/kg. Our findings clearly showed that risk through post-monsoonal rice cultivars is lower compared to pre-monsoonal rice cultivars. Moreover, the health risks through unpolished rice are higher compared to the polished rice cultivars.

Consumption of rice is mainly considered a major source of As exposure to human health. Cooking practices at a domestic scale (1:3 ratio) with As-safe water reduce high As accumulation in cooked rice compared to uncooked rice, irrespective of their geographical area. The MoE values which are less than 1 symbolize that there exists a margin of exposure due to the toxic contaminant for all the age groups of the differently studied populations. The study also highlights the presence of a considerable amount of iAs in uncooked rice and its respective cooked rice from all the studied areas. The SAMOE value categorized cooked rice under risk class 4 for exposed (rural) and risk class 3 for apparently control and control populations. Considering the probabilistic risk (uncertainty) analysis, the LCR and HQ through cooked rice follow the order as adult male > adult female > children for all the studied populations. Overall, this study stated that the three differently studied populations are at a high health risk through consumption of cooked rice for adults compared to children mainly depend on the IR and C factors. The plausible explanation for the greater risk to the control population is due to the high IR of cooked rice on a daily basis, which has been supported through sensitivity analysis. The study also highlighted that despite decreased As levels in cooked rice, the health risk of As exposure to both rural and urban populations from cooked rice consumption remains substantial. Consumption of lower amount of Se through cooked rice showed that the exposed population had less protective nature against As-toxicity compared to control and apparently control population. Benefit-risk assessment also supported the fact that Se-rich values in cooked rice are effective in avoiding the toxic effect and potential health risk. As a result, attempts should be undertaken to decrease As accumulation in uncooked rice, through the implementation of cultivation practices during the post-monsoonal season and improvement of post-harvesting practices. So, to avoid the As-induced health risks, a very important proposal is to reduce the ingestion rate of cooked rice for control populace. Otherwise, irrespective of the geographical area, the prevalence of health risk through rice As poisoning would be exacerbated in near future.

Adverse human health exposure and perception of risk assessment through consumption of the toxic element (As) present in drinking water, rice, seasonal vegetables from different populations has been assessed. Apart from consumption of As-contaminated water, intake of contaminated foodstuffs in the daily diet for all the differently exposed populations poses a potential threat to human health. A decreasing trend of As accumulation in biological tissues has been observed in the exposed inhabitants residing in the extremely highly to mild exposed areas. Ingestion of As-contaminated water and foodstuffs is a significant source of exposure pathway for As toxicity among the differently exposed populations. Arsenical skin manifestations have been identified among the exposed populations from extremely highly and highly exposed areas due to consumption of much higher level of As through dietary intakes. The accumulation of high concentration of As in the biological tissues of the children from the differently exposed populations indicates that they are sub-clinically affected due to As toxicity. The SAMOE value in ‘risk thermometer’ supports the higher risk of suffering from drinking water and rice grain (both belong to class 5) compared to vegetables (class 4) in extremely highly and highly exposed populations. High risk of suffering has been observed from rice grain (class 5) compared to drinking water and vegetables (both belong to class 4) in moderately and mild exposed populations. The ILCR is high for the adult male, adult female and children from the differently exposed areas through consumption of daily dietary intakes. The lifetime cancer risk is proportionally distributed among the studied populations with the exposure levels through ingestion of As-contaminated drinking water and is highest through consumption of rice grain in moderately and mild exposed populations compared to drinking water. Vegetables contribute least cancer risk to all the exposed populations. Likewise, the non-carcinogenic risk level for the exposed populations reveals the fact that the exposed individuals from rural Bengal are prone to several health risks in their future due to the ingestion of As through dietary intakes. Our study revealed that the affected male population is prone to higher cancer risk compared to the female population. An unexposed (mother and infant) population from an As-exposed area are presently exposed to As-safe drinking water. Urine As concentration reflected that the studied population is exposed to a lower level of acute toxicity. The rate of As accumulation in scalp hair and nail signified the level of chronic exposure among the studied populations. The high As deposition in biological tissues (scalp hair and nail) reveals that the studied mother population had been exposed to As toxicity for a long period of time. During statistical interpretation, it was observed that ingestion of As through dietary intakes (drinking water and cooked rice) on a daily basis is a consider- able exposure pathway to chronic As toxicity for the studied population. For the infant population, the high accumulation of As in the biological tissues (scalp hair and nail) indicates that they are sub-clinically affected by As toxicity. The potential carcinogenic risk persists for a lifetime among the studied (mother and infant) population through their respective dietary sources. The potential health risk to infants through ingestion of breast milk is least compared to their other daily dietary intakes. Similarly, the non-carcinogenic risk (HQ) showed values less than 1, which signifies that the studied populations are not prone to severe non-cancerous health hazards. The studied populations do not show arsenical skin lesions, as they are sub-clinically affected by As toxicity. Considering, school children of the exposed area who are at a high risk of As exposure through the consumption of contaminated drinking water compared to apparently control area children. The As concentration in the drinking water from the exposed area is 7 times higher than the WHO permissible limit. Intake of contaminated rice grain in the daily diet for both the studied populations poses a potential threat to children's health. Exposure to acute As toxicity through drinking water was confirmed by the analysis of urine samples of school children from the exposed area. The As concentration in drinking water was found significantly correlated with urine, hair, and nail of the exposed school children compared to the control children. The high concentration of As in the biological tissues of the exposed school children proves that they are sub-clinically affected due to As toxicity. Our study also revealed that future cancer risk is high through the consumption of contaminated drinking water for the exposed children compared to the apparently control children. Similarly, the rate of future cancer risk is equally distributed for both the exposed and apparently control children through the ingestion of contaminated rice grains, which contains a high amount of inorganic As. In the same way, for the non-cancer risk assessment (through inorganic As) of the children, the HQ value is very much higher than 1. So, the children from the exposed population will be prone to severe health hazards in their near future not only through the ingestion of contaminated drinking water but also through the consumption of contaminated foodstuffs (i.e. rice grain). At present, the exposed children (aged between 5-12 years) did not show any arsenical skin manifestation, but with a span of time, if they pursue to consume contaminated drinking water and rice grain for a longer time, they would be suffered to related arsenical health hazards, as As is well-known for its slow poisoning characteristics. A follow-up study on the exposed children (n=10) after 8 months reveals the importance of awareness program and supply of As-safe water among the exposed population. Intake of As-safe water substantially helps to decrease the level of As in urine and other biological tissues. Consumption of contaminated drinking water on a daily basis poses a probable threat to different aged children's health. Drinking water As concentration from the studied exposed area is 5 times higher than the WHO acceptable limit. The tolerable dietary intake of As by the children through contaminated drinking water is more than the WHO recommended value. Exposure to acute As toxicity through drinking water was established by the urine As of studied groups of children from the exposed area. Urine As concentrations revealed the fact that the studied children are presently consuming As-contaminated drinking water. This work revealed that future health risk is considerably high through the ingestion of As-contaminated drinking water. Apparently, the elder group of studied children (11-15 years) are at greater risk compared to the (6-10 years) and (1-5 years), because of a longer duration of As exposure. Similarly, the non-cancer risk (HQ value >1) signifies that the studied group of children are prone to several non-cancerous health hazards. Presently, the studied exposed groups of children didn't show any dermatological manifestations, however, with a long period of time and with continuous consumption of contaminated water for drinking, there might be a chance to develop severe health hazards due to the slow poisoning characteristics of As. In rural Bengal, proper supply of treated water among the arsenicosis patients is providing better understanding to overcome this severe As crisis. The background As concentration of domestic shallow groundwater and dermatological skin manifestations clearly distinguished that the studied patients have been exposed to severe As toxicity for a long period of time. Consumption of As-contaminated dietary foodstuffs on a daily basis poses potential future health risk. The studied population is presently consuming treated (As-safe) drinking water, which is being reflected through their urinary As concentrations. A decreasing trend of As accumulation in biological tissues (hair and nail) has been observed for the arsenicosis patients in one-year health exposure study. Statistical modeling estimated differential temporal trends of As levels through different biomarkers (urine, hair and nail) for both the male and female individuals. The risk thermometer categorized higher future risk through rice (cooked) compared to vegetables (cooked) and treated water for studied exposed population. The carcinogenic and non-carcinogenic risk of As is high through consumption of cooked rice and vegetables compared to treated drinking water.

As a mitigation strategy, firstly, field-based remediating As in cooked rice using cooking water through co-precipitation process is recommended. Maximum As-reduction has been observed at 1:3 and 1:6 ratios during cooking with contaminated water after keeping it for 24 h. Secondly, soaking time of 1 h with As-safe water shows highest As reduction in soaked rice. Reduction of As in cooked rice is dependent on several factors such as rice cultivars, cooking water and soaking time. An attempt taken to resist As from rice grain during cooking process using chelating agents like citrate and tartrate solution during soaking time by photo-catalysis method. Soaking with 3 different process such as As-safe water, citrate solution and tartrate solution showed reduction percentage is higher with As-safe water during cooking ratio 1:6 compared to 1:3. As huge availability of As-safe water is of serious concern in As-prone areas, so used of citrate and tartrate solution (1:10) at the time of soaking followed by cooking with As-safe water reduces As maintaining the domestic scale cooking ratio of 1:3.

Overall, it is suggested to take attempts should be undertaken to decrease As accumulation in rice grain by implementation of cultivation practices during the post-monsoonal season and improvement of post-harvesting practices. It can be concluded that production of As-safe water through a proper watershed management using rainwater harvesting and treated surface water is required for irrigational purposes to restrict its entry in food chain system. Supply of As-safe drinking water and healthy nutritional food is highly recommended for the endangered population to fight against the devastating As calamity.

Chapter Eight

8.1. Groundwater, as an intermediate solution

Due to quality and quantity limitations, groundwater cannot be a reliable supply of drinking water in the KMC. Depending on its quality and accessibility, it may serve as an interim solution prior to the implementation of a full-fledged surface water network. Each ward's groundwater activity mapping has to be made. Prior to the installation and use of bore wells, it is important to monitor changes in the groundwater's piezometric level. Through the use of GIS, all of the bore wells must be located, and ongoing monitoring of all these sources must be carried out throughout. The construction of new tube-wells in the As-contaminated wards should no longer be permitted.

8.2. Recycling the existing surface water source

The existing surface water availability for the KMC from the Hoogly River (98000 MLD) is much more than the present fresh water requirement, which is 1320 MLD (ADB, 2012; Maiti, 2012). Renovating the surface water delivery infrastructure should thus be prioritized in order to make this sector technologically and financially sustainable. Installing household meters is necessary, and developing flow and pressure monitoring systems at the consumer level is strongly advised. If at all feasible, the water tax should be implemented with exemptions for people who are considered to be in poverty (Mitra, 2008). Advanced technology needs to be implemented for the production and supply of treated water.

8.3. Harvesting the rainwater

In the KMC area, the average annual rainfall is 1821 mm and the net rainwater available annually is 247 Mm^3. Considering the hydro geological condition in the KMC area and to collect this huge rainfall, rooftop water harvesting should be strictly implemented in the area. Though West Bengal government has done rooftop rain- water harvesting a mandatory for a building larger than 60,000 sq. ft. or more than 100 flats, nothing significant has been achieved in this respect.

8.4. Surface water treatment plant

A local non-Government organization (Madhusudankati Krishak Kalyan Samity) collaborating with ‘Sulabh International Social Service Organization’ located in Madhusudankati village, Gaighata block, north 24 Parganas district, West Bengal, India.

Objective:

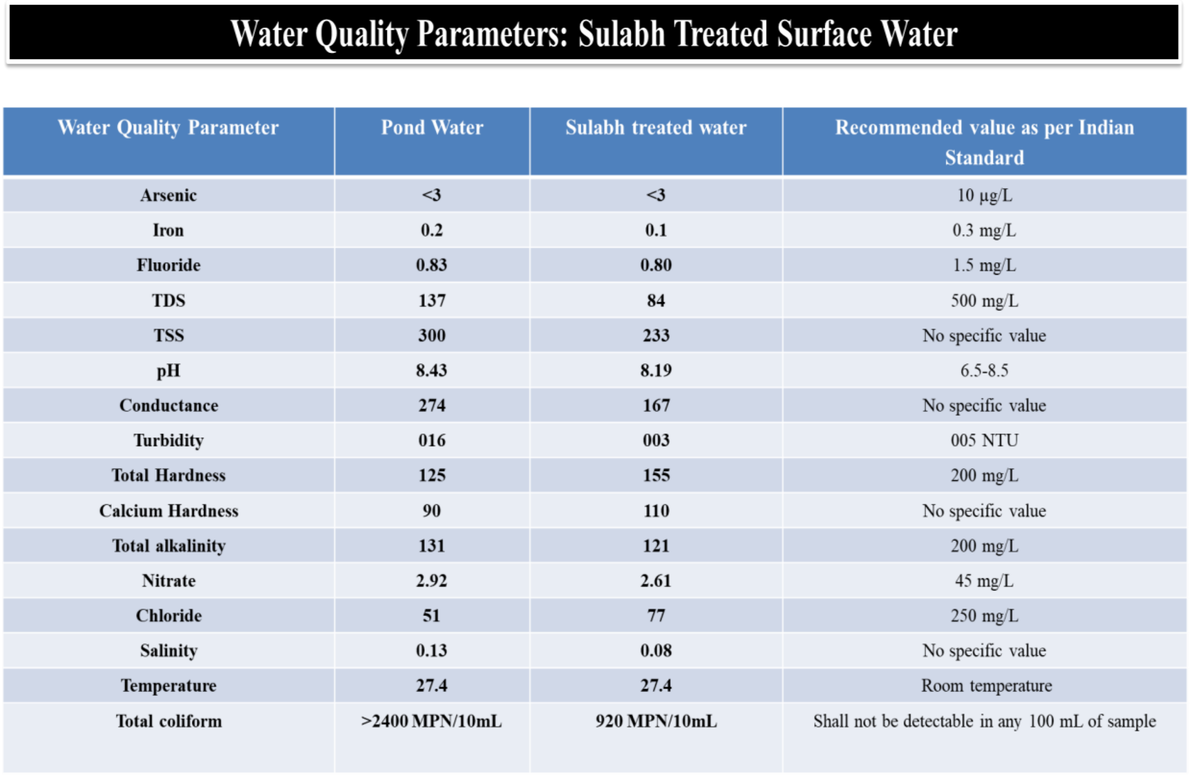
To provide affordable safe drinking water to the rural community.

Strategies:

1. Cost effective treatment of water from surface water sources (pond, river, lakes etc.)
2. Training and capacity building of the local workers.
3. Creation of local management, infrastructure for operation.

Implementations:

1. Selection of site and obtaining of land.
2. Sensitization and awareness generation.
3. Water quality analysis.
4. Design of treatment process.
5. Construction and operation.
6. Safe water distribution among the community.



Water Quality Parameters: Sulabh Treated Surface Water

Water Quality Parameter	Pond Water	Sulabh treated water	Recommended value as per Indian Standard
Arsenic	<3	<3	10 µg/L
Iron	0.2	0.1	0.3 mg/L
Fluoride	0.83	0.80	1.5 mg/L
TDS	137	84	500 mg/L
TSS	300	233	No specific value
pH	8.43	8.19	6.5-8.5
Conductance	274	167	No specific value
Turbidity	016	003	005 NTU
Total Hardness	125	155	200 mg/L
Calcium Hardness	90	110	No specific value
Total alkalinity	131	121	200 mg/L
Nitrate	2.92	2.61	45 mg/L
Chloride	51	77	250 mg/L
Salinity	0.13	0.08	No specific value
Temperature	27.4	27.4	Room temperature
Total coliform	>2400 MPN/10mL	920 MPN/10mL	Shall not be detectable in any 100 mL of sample

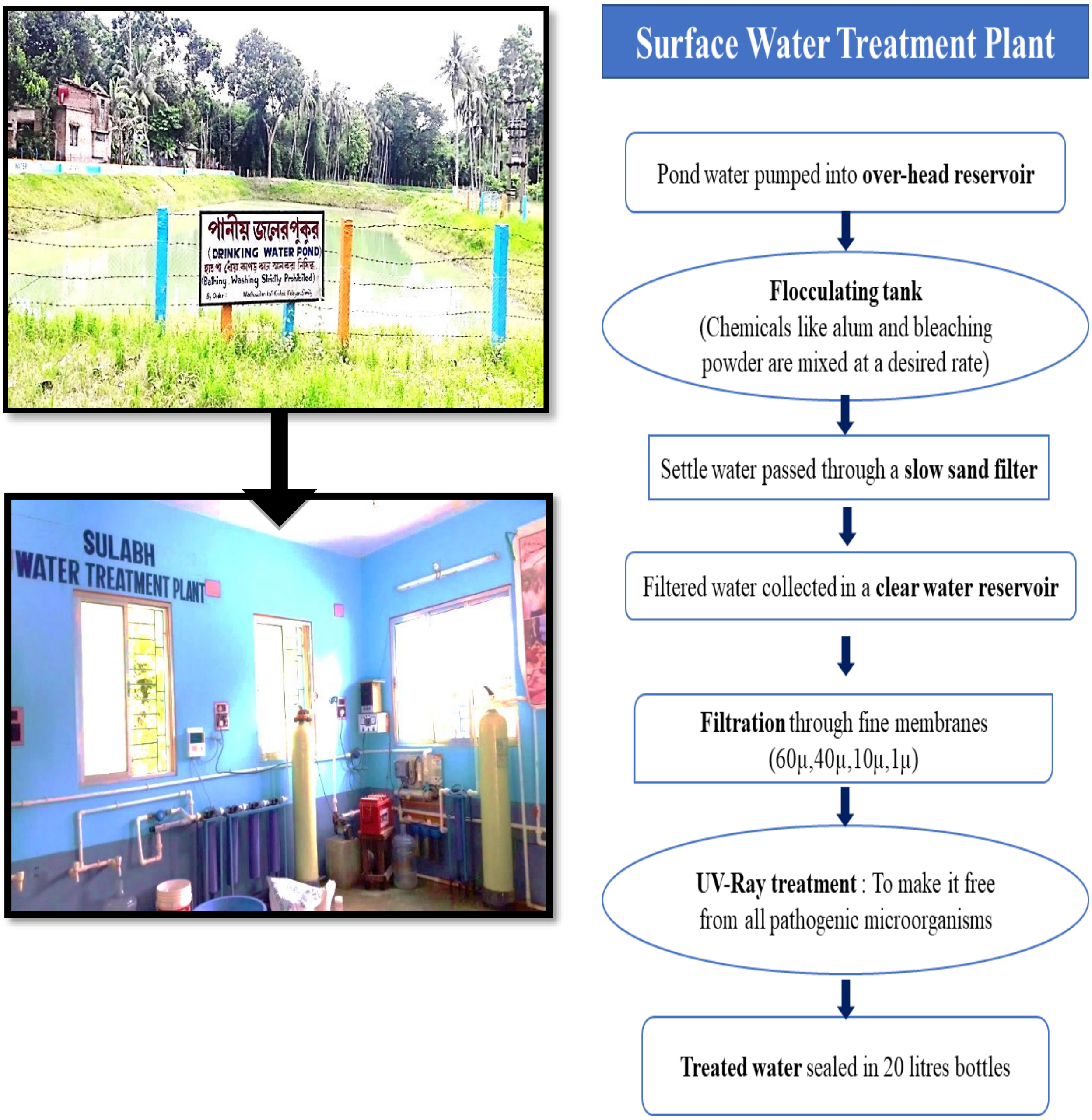
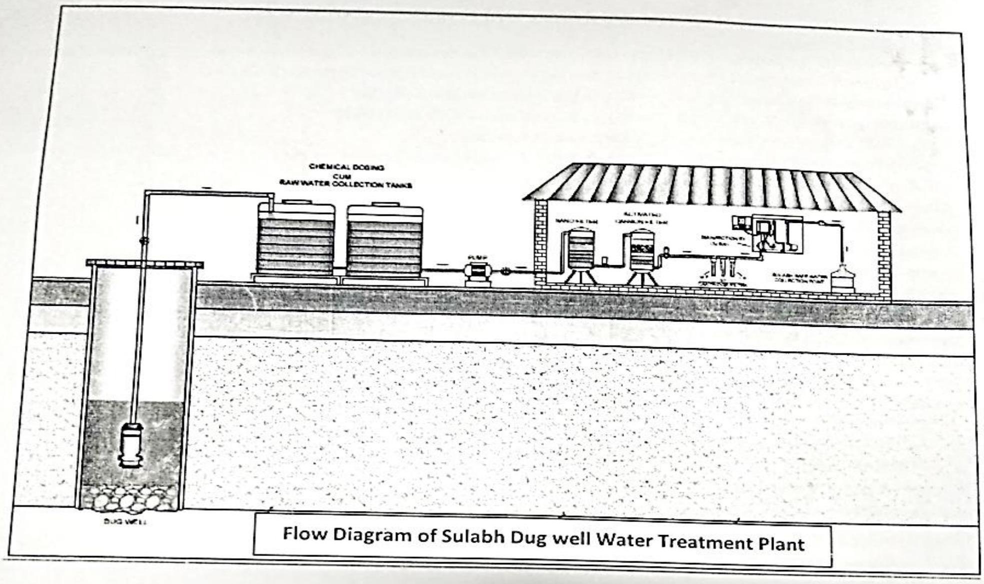
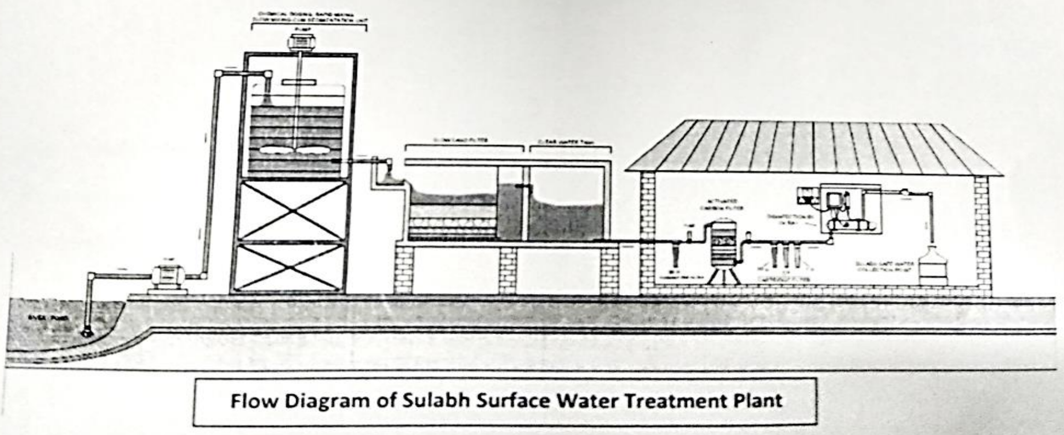


Fig. 83. Flow chart of Sulabh Surface Water Treatment process (Madhusudankati village, Gaighata)



Flow Diagram of Sulabh Dug well Water Treatment Plant



Flow Diagram of Sulabh Surface Water Treatment Plant

Fig. 84. Flow diagram of Sulabh Surface Water Treatment Plant (Madhusudankati village, Gaighata)

Chapter Nine

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FUTURE SCOPE

1. Detailed study on As speciation in daily dietary foodstuffs along with human biological samples (urine, hair and nail) is essential to provide deeper insight of health toxicity and future health risk assessment.

2. Water quality evaluation of agricultural shallow water from As-exposed and control areas of West Bengal to improve the cultivation practices of food crops like paddy, wheat, vegetables etc.

3. Comparative assessment of the alternative paddy cultivation practices in As-exposed and control areas for remediating accumulation of As in paddy, cereals and vegetables.

4. Adverse human health effect and perception of risk assessment through consumption of toxic elements along with As in rice grain, various seasonal vegetables and cereal crops needs further investigation from As-exposed, apparently control, control populations of West Bengal, India.

RESEARCH IN LABORATORY (PHOTOGRAPHS)


UV-Spectrophotometer


Conductivity meter


ISE-Fluoride


Vortex


Weighing balance


Centrifuge


Weighing balance


pH meter

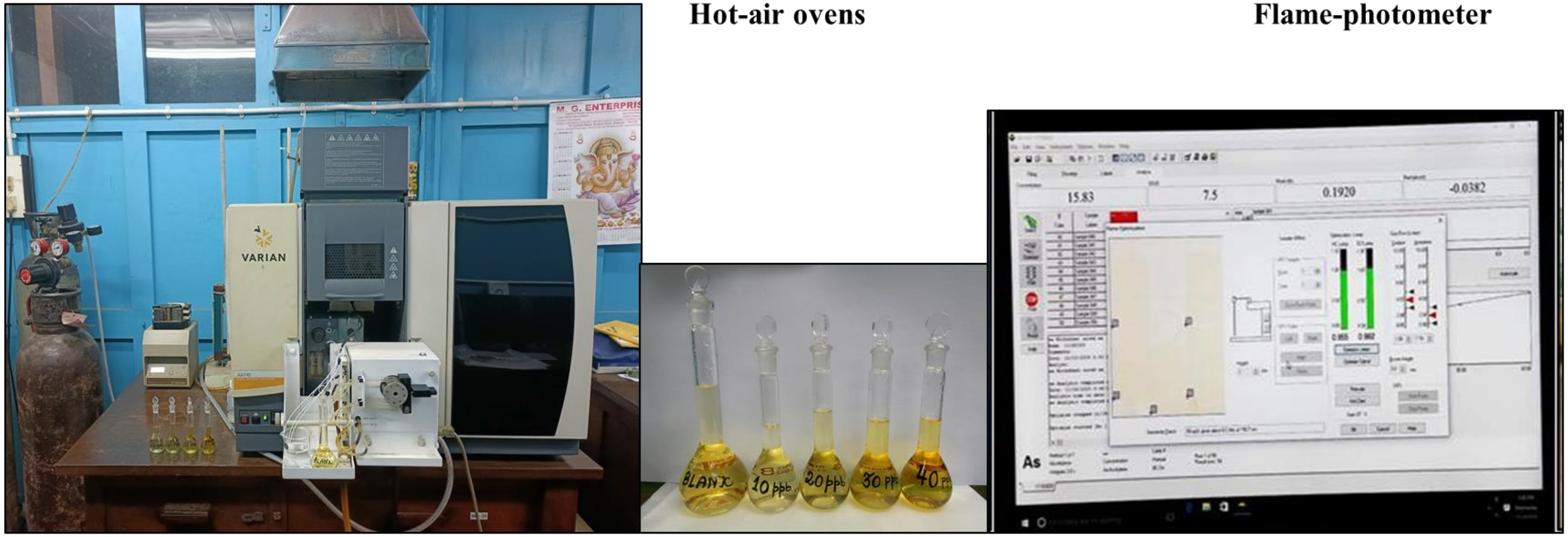

Magnetic stirrer


ISE-Nitrate

Hot-Plate for acid-digestion

Hot-air ovens

Flame-photometer



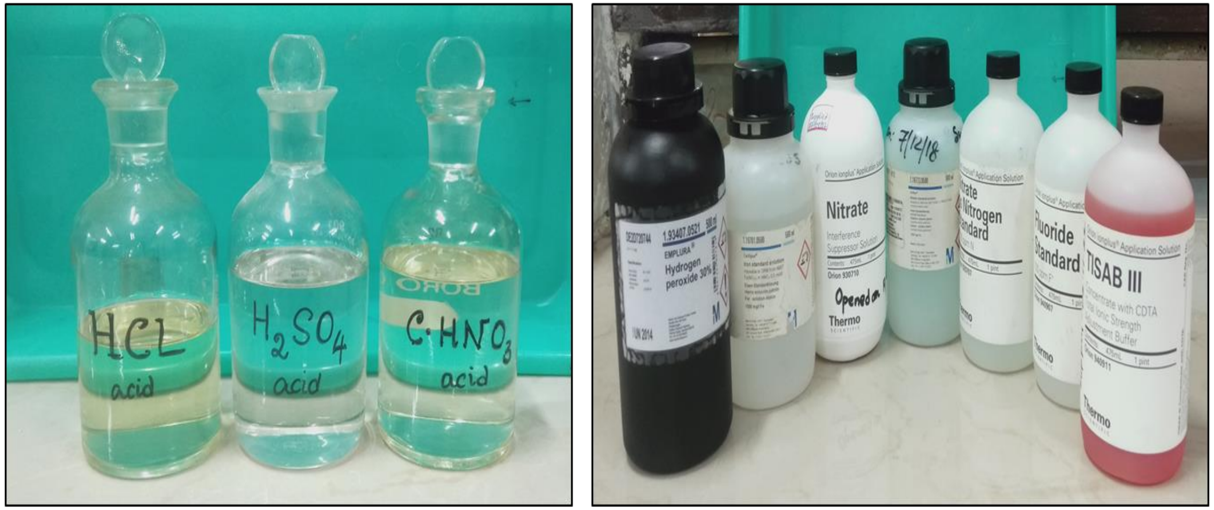
Atomic Absorption Spectrophotometry for Arsenic estimation

Turbidity meter

Desiccator-SRM

GPS

Filtration Unit



Chemicals & Reagents

Centrifuging samples

RESEARCH IN FIELD (PHOTOGRAPHS)


ପୂର୍ବ କଳିକତା ଓଡ଼ିଆ ହାଇସ୍କୁଲ
PURBA KALIKATA ODIA HIGH SCHOOL
ESTD. - 1979
(Co-Educational)
Recognised & Aided by Govt. of West Bengal
C.I.T. PARK, SCHEME VI-M, KANKURGACHHI, KOLKATA - 700 054
বিদ্যালয় নং-৫৩
ওয়ার্ড নং-৩১
বোরো-৩
পৌরনিগম প্রাথমিক বিদ্যালয়
সি.আই.টি. পার্ক-স্কীম ৬এম.
কলকাতা -৫৪


MEDIA
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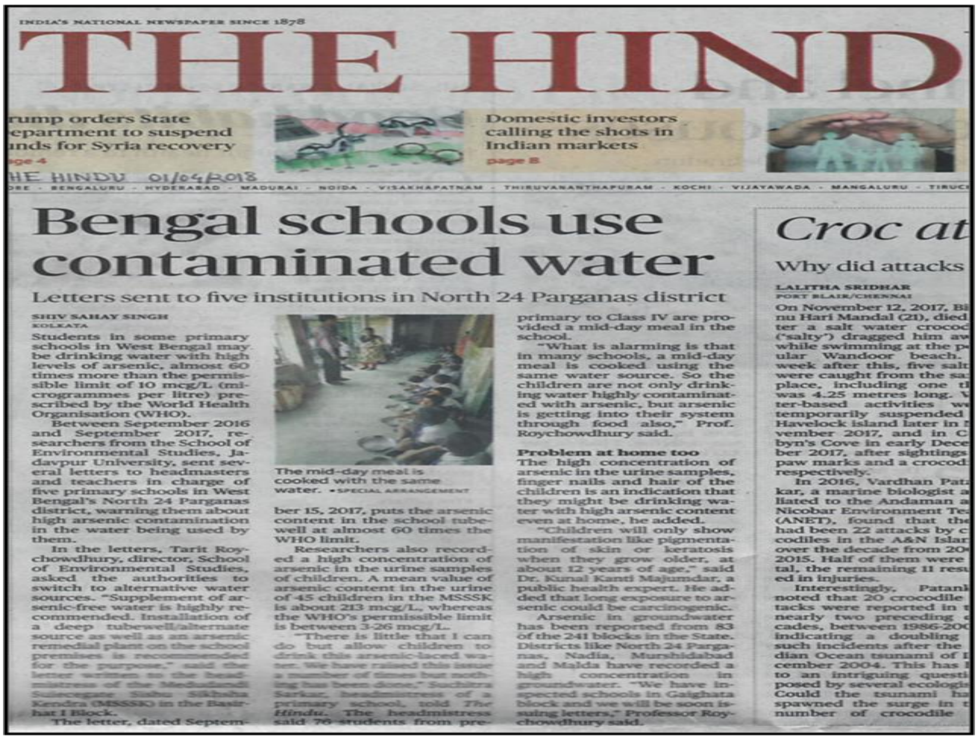
THE HINDU

1st April, 2018



INDIA'S NATIONAL NEWSPAPER SINCE 1878

THE HIND

rump orders State
epartment to suspend
unds for Syria recovery
age 4

Domestic investors
calling the shots in
Indian markets
page 8

HE HINDU 01/04/2018

ORE · BENGALURU · HYDERABAD · MADURAI · NOIDA · VISAKHAPATNAM · THIRUVANANTHAPURAM · KOCHI · VIJAYAWADA · MANGALURU · TIRUC

Bengal schools use contaminated water

Letters sent to five institutions in North 24 Parganas district

SHIV SAHAY SINGH
KOLKATA

Students in some primary schools in West Bengal may be drinking water with high levels of arsenic, almost 60 times more than the permissible limit of 10 mcg/L (micrograms per litre) prescribed by the World Health Organisation (WHO).

Between September 2016 and September 2017, researchers from the School of Environmental Studies, Jadavpur University, sent several letters to headmasters and teachers in charge of five primary schools in West Bengal's North 24 Parganas district, warning them about high arsenic contamination in the water being used by them.

In the letters, Tarit Roychowdhury, director, School of Environmental Studies, asked the authorities to switch to alternative water sources. "Supplement of arsenic-free water is highly recommended. Installation of a deep tubewell/alternate source as well as an arsenic remedial plant on the school premises is recommended for the purpose," said the letter written to the headmistress of the Medhabandi Sukongapara Sishu Sikksha Kendra (MSSSK) in the Basirhat I Block.

The letter, dated September 15, 2017, puts the arsenic content in the school tubewell at almost 60 times the WHO limit.

The mid-day meal is cooked with the same water. • SPECIAL ARRANGEMENT

Researchers also recorded a high concentration of arsenic in the urine samples of children. A mean value of arsenic content in the urine of 45 children in the MSSSK is about 213 mcg/L, whereas the WHO's permissible limit is between 3-26 mcg/L.

"There is little that I can do but allow children to drink this arsenic-laced water. We have raised this issue a number of times but nothing has been done," Suchitra Sarkar, headmistress of a primary school, told *The Hindu*. The headmistress said 76 students from pre-primary to Class IV are provided a mid-day meal in the school.

"What is alarming is that in many schools, a mid-day meal is cooked using the same water source. So the children are not only drinking water highly contaminated with arsenic, but arsenic is getting into their system through food also," Prof. Roychowdhury said.

Problem at home too

The high concentration of arsenic in the urine samples, finger nails and hair of the children is an indication that they might be drinking water with high arsenic content even at home, he added.

"Children will only show manifestation like pigmentation of skin or keratosis when they grow older, at about 12 years of age," said Dr. Kunal Kanti Majumdar, a public health expert. He added that long exposure to arsenic could be carcinogenic.

Arsenic in groundwater has been reported from 83 of the 241 blocks in the State. Districts like North 24 Parganas, Nadia, Murshidabad and Malda have recorded a high concentration in groundwater. "We have inspected schools in Gaighata block and we will be soon issuing letters," Professor Roychowdhury said.

Croc at

Why did attacks

LALITHA SRIDHAR
PORT BLAIR/CHENNAI

On November 12, 2017, Bi
nu Hari Mandal (21), died
ter a salt water crocod
("salty") dragged him aw
while swimming at the p
ular Wandoor beach.
week after this, five salt
were caught from the sa
place, including one t
was 4.25 metres long. V
ter-based activities w
temporarily suspended
Havelock island later in
vember 2017, and in C
byn's Cove in early Dece
ber 2017, after sightings
paw marks and a crocod
respectively.
In 2016, Vardhan Pata
kar, a marine biologist a
liated to the Andaman a
Nicobar Environment Te
(ANET), found that the
had been 22 attacks by c
codiles in the A&N Islan
over the decade from 20
2015. Half of them were
tal, the remaining 11 resu
ed in injuries.
Interestingly, Patank
noted that 20 crocodile
tacks were reported in t
nearly two preceding
cades, between 1986-200
indicating a doubling
such incidents after the
dian Ocean tsunami of
cember 2004. This has
to an intriguing questi
posed by several ecologis
Could the tsunami ha
spawned the surge in t
number of crocodile

THE HINDU

19th May, 2018

Death by slow poisoning

An estimated 10 million people in nine districts of West Bengal drink arsenic-laden groundwater. **Priyanka Pulla** finds that despite alarms having been sounded over decades, the State government has moved at a glacial pace to tackle the crisis, while people struggle to cope with the symptoms

“Current Science Reports”
25.06.2022

Current Science Reports

Trees to Clean Jodhpur Air
Which are the best?

Jodhpur is the most polluted city in Rajasthan. Located in the Thar desert region, the city gets scant rainfall. So particulates with heavy metals hang in the air.

Trees can absorb particulate matter from the air. But which tree is most efficient for adsorbing atmospheric particulate matter in Jodhpur? Gyan Singh Shekhawat and Lovely Mahawar from the Jai Narain Vyas University, Jodhpur collaborated with researchers in Poland to find out.

They selected the leaves of 10 common trees, shrubs and climbers in Jodhpur. To collect particulate matter from the leaf surfaces, they washed the leaves with distilled water. And, to collect particulate matter trapped in the wax layer on the leaves, they washed the leaves with chloroform.

By passing these solutions through pre-weighted mesh sieves, they could calculate the weight of particles adsorbed on the leaf surfaces and trapped in the wax.

The team found that peepal, *Ficus religiosa*, is the most efficient phytoremediator of particulate matter. The Assyrian plum tree and giloy came next.

To check for the adsorption of heavy metals by the leaves, the researchers digested the dried and ground leaves with nitric acid and analysed heavy metals in the leaf extracts. The peepal tree was found to be the highest adsorber of heavy metals.

The accumulation of atmospheric particulate matter causes oxidative stress in plants. To manage the oxidative stress, antioxidant enzymes should increase in plants. The researchers checked by measuring the amount of heme oxygenase in the 10 plant species.

'There is a strong correlation between the particulate matter adsorbed and the amount of heme oxygenase enzyme,' says G. S. Shekhawat.

This research has now identified the best trees for planting along the edges of the Thar Desert. Horticulturists must include these efficient phyto cleaners when planning plantation schemes for cities.

DOI: 10.1007/s11356-022-20769-y

Arsenicosis in West Bengal
Despite treated water?

Chronic exposure to arsenic-contaminated drinking water affects many in nine districts of West Bengal. The region now has quite a few arsenic removal plants. And people there have been mostly consuming arsenic-free drinking water for at least the past two years. Even after prolonged awareness and safe drinking water programmes, why does chronic arsenicosis continue to plague the region?

Researchers from the Jadavpur University, Kolkata collaborated with the National Institute of Biomedical Genomics, Kalyani and the KPC Medical College and Hospital, Jadavpur to look into the matter.

From the severely arsenic-affected Mathpara and Eithbhata villages in the North Parnagas district, they selected seventeen males and seven females aged between 42 and 75. These chronic arsenicosis patients showed severe arsenic skin lesions due to prolonged exposure to arsenic. For one year, the team collected the daily dietary intakes from individual arsenicosis patients.

Urinary arsenic, the primary biomarker for acute toxicity, showed an overall 43% decrease in arsenic levels over six months.

To evaluate the body burden of arsenic toxicity, the team collected samples of scalp hair and nails every month for one year. In one year, arsenic accumulation decreased overall by about 41% in scalp hair and nails. A few people, however, showed increased arsenic in biological tissues. This could be due to consuming arsenic-contaminated water and food, say the researchers.

They collected samples of drinking water and raw and cooked rice as well as raw and cooked vegetables. Arsenic in domestic shallow tube well water was up to 88 times the prescribed limits! Raw and cooked foods contained high levels of arsenic. Cooked rice alone contributed 4.91 microgram of arsenic per kilogram of body weight, higher than the daily tolerable dietary intake limit of 3.0 microgram per kilogram of body weight.

People in the region consume safe, treated water. But they use arsenic-contaminated groundwater for irrigating crops and for cooking.

'The main dietary foodstuffs, rice and vegetables, are cultivated by irrigating with arsenic-contaminated groundwater,' says Tarit Roychowdhury, Jadavpur University, Kolkata.

Rice irrigated with arsenic-contaminated shallow tube-well water posed the maximum risk.

To reduce the incidence of arsenicosis in severely affected districts, it is not enough to supply treated water for drinking and cooking. Irrigation with uncontaminated water and shifting to cultivating crops that do not accumulate arsenic also need to be considered, say the researchers.

DOI: 10.1016/j.gsd.2022.100786

RNA Spray Silences Genes
Protects potatoes from late blight

Image: I. Šáček, via Wikimedia Commons

Late blight disease, caused by the oomycete, *Phytophthora infestans*, causes darker spots on leaves and stems where water or dew collects. The oomycete, or water mould, diminishes potato yield by 15%. The pathogen is not easily controlled by chemical fungicides because it evolves rapidly and develops resistance against the fungicides. Attempts to develop potato cultivars that are resistant to the water mould have also been in vain.

So S. Sundaresha and team from the Central Potato Research Institute, Shimla recently came up with a technique to control the pathogen: silencing five genes involved in the pathogenesis.

এই সময়
সংবাদপত্র
30.03.2017

সচেতনতার অভাবেই ছড়াচ্ছে আর্সেনিক বিষ, দাবি গবেষণায়

দেবাশিস দাস

গ্রামে আর্সেনিক মুক্ত পানীয় জল সরবরাহের ব্যবস্থা হয়েছে বেশ কয়েক বছর হল। সেই নমুনা পরীক্ষায় উত্তীর্ণ হয়েছে সরকারের তৈরি আর্সেনিক মুক্ত প্রকল্পের জল। তবু গ্রামবাসীদের শরীরে আর্সেনিকের উপস্থিতি প্রবল। যাদবপুর বিশ্ববিদ্যালয়ের স্কুল অব এনভায়রনমেন্টাল স্টাডিজের সদ্য হওয়া সমীক্ষায় এই উদ্বেগজনক চিত্র উঠে এসেছে। এর কারণও অনুসন্ধান করেছেন ওই সমীক্ষকেরা। যা থেকে স্পষ্ট হয়েছে এক উদ্বেগজনক তথ্যও। শুধু আর্সেনিকমুক্ত জল প্রকল্প বসিয়ে এই ক্ষতিকর উপাদানের হাত থেকে এলাকাবাসীকে মুক্ত রাখা সম্ভব হচ্ছে না। কারণ তাঁরা এর পরেও আর্সেনিকযুক্ত জল খাচ্ছেন। তাই প্রয়োজন আর্সেনিক নিয়ে উপযুক্ত সচেতনতাও।

সমীক্ষকেরা দেখেছেন, আর্সেনিক মুক্ত জলের প্রকল্প চালু হলেও গ্রামবাসীরা অভ্যাসবশত হাতকলের জল পান করছেন। যাতে এই ক্ষতিকর রাসায়নিক ক্ষতিকারক মাত্রায় রয়েছে। প্রকল্প চালুর মুখে গ্রামবাসীদের বলা হয়েছিল স্নান, শৌচকর্ম, জামা-কাপড় কাচা এবং গৃহস্থালির অন্যান্য কাজে হাতকলের জল আগের মতোই ব্যবহার করা যাবে। কিন্তু পানীয় জল হিসেবে ব্যবহার করতে হবে শুধু মাত্র সরকারি প্রকল্পের জল। কিন্তু যথাযথ প্রচারের অভাবে সেই পরামর্শ ভুলে গিয়েছেন গ্রামবাসীরা। ফলে বাড়িতে বা আশপাশে থাকা হাতকলের জলও পান করছেন তাঁরা। তাই আর্সেনিক মুক্ত পানীয় জলের প্রকল্প চালু হলেও আর্সেনিক মুক্তি ঘটছে না গ্রামবাসীদের। যদিও, চালু হয়ে যাওয়া একাধিক সরকারি আর্সেনিক প্রকল্পের জলে প্রথমে আর্সেনিক বিহীন জল মিললেও পরে সেখান থেকে পাওয়া জলেও অনেক ক্ষেত্রেই আর্সেনিক মেলায়, সমস্যা বাড়ছে।

> আর্সেনিক কবলিত এলাকায় ভূগর্ভস্থ জলের ব্যবহারের বিকল্প ব্যবস্থা না করা গেলে এই সমস্যা থেকে মুক্তি পাওয়া কঠিন
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> অশোক দাস।
> আর্সেনিক প্রতিরোধ কমিটির কর্তা

কী ভাবে বিপত্তি জানা গেল?

স্কুল অব এনভায়রনমেন্টাল স্টাডিজের অধিকর্তা অধ্যাপক তড়িৎ রায়চৌধুরী বলেন, 'দেগঙ্গা ও বসিরহাটের দু'টি গ্রামের একশো জন মানুষের উপরে আমরা সমীক্ষা চালিয়েছি। দেখা গিয়েছে তাঁদের প্রস্রাবের নমুনায় ক্ষতিকর মাত্রায় আর্সেনিক রয়েছে। আর্সেনিক মুক্ত জল না খেলে এমনটি হওয়ার কথা না।' প্রস্রাবে ক্ষতিকর মাত্রায় আর্সেনিক পাওয়ার কারণ অনুসন্ধান করতে গিয়ে সমীক্ষকেরা জানতে পারেন, গ্রামবাসীরা স্নান, শৌচকর্ম, জামা-কাপড় কাচা এবং গৃহস্থালির অন্যান্য কাজের পাশাপাশি সেই জল পান করছেন। যার জেরে বাড়ছে বিপদ।

স্কুল অব এনভায়রনমেন্টাল স্টাডিজেরই গবেষক মীনাক্ষী রায়চৌধুরী জানান, গ্রামের লোকেদের প্রস্রাবের নমুনায় অধিকাংশ ক্ষেত্রেই স্বাভাবিকের চেয়ে অনেক বেশি মাত্রায় আর্সেনিকের উপস্থিতি রয়েছে। তাঁর দাবি, প্রস্রাবের ক্ষেত্রে স্বাভাবিকভাবে প্রতি লিটারে যা থাকার কথা, তার বদলে গড়ে প্রতি লিটারে অনেক বেশি আর্সেনিক মিলেছে। যা এক জন মানুষের শরীরের পক্ষে খুবই বিপজ্জনক বলে তিনি দাবি করেন। তাঁর বক্তব্য 'ভালো আর মন্দ নিয়ে সচেতনতা গড়ে না ওঠায় গ্রামবাসীরা এই আর্সেনিক মিশ্রিত জল পান করতে বাধ্য হচ্ছেন।' সমীক্ষকরা অভিযোগ করেন, গ্রামবাসীরা প্রথমে তাঁদের কাছে তথ্য গোপনের চেষ্টা করেন। এরপরে প্রমাণ দিলে, তাঁরা স্বীকার করতে বাধ্য হন বাড়িতে থাকা হাতকলের জলকে পানীয় হিসেবে ব্যবহার করার কথা।

আর্সেনিক প্রতিরোধ কমিটির কর্তা অশোক দাস বলেন, 'শুধু সচেতনতা না, আর্সেনিক কবলিত এলাকায় ভূগর্ভস্থ জলের ব্যবহারের বিকল্প ব্যবস্থা না করা গেলে এই সমস্যার হাত থেকে মুক্তি পাওয়া কঠিন।' দেগঙ্গার বিডিও মনোজ কুমার বৈশ্য বলেন, 'এই সব কারণের জন্যই এখানে আর্সেনিক মুক্ত পানীয় জলের নিখুঁত ব্যবস্থা গ্রাম পঞ্চায়েতের মাধ্যমে পরিচালনা করার সিদ্ধান্ত নেওয়া হয়েছে। খুব শীঘ্রই তা কার্যকর হবে।'

এই সময়
সংবাদপত্র
24.07.2018

তৃষ্ণা মেটানোয় ভরসা সমবায়ের 'সুলভ জল'

কোথাকার জল নিরাপদ? জানেন না কেউ। উত্তর খুঁজছেন সকলে। গাইঘাটা চত্বরে এমন জলপানের খোঁজখবর করল এই সময়। আজ শেষ পর্ব

জলের আর্সেনিক থেকে এলাকার অনেকে ক্যান্সারেও আক্রান্ত হচ্ছেন। ভরসা এই সমবায় — শুভ্রদীপ রায়

কৌশিক সরকার ■ গাইঘাটা

বৃষ্টির জল ধরা হচ্ছে পুকুরে। প্রক্রিয়াকরণের পরে সে জল পান করছে ৫০০ পরিবার। আর্সেনিক কবলিত গাইঘাটায় যেখানে আর্সেনিক-মুক্ত বিশুদ্ধ পানীয় জল সরবরাহ করতে নাজেহাল সরকার, সেখানে মধুসূদনকাটি সমবায় কৃষি উন্নয়ন সমিতির উদ্যোগে গড়ে তোলা এই মডেলই এখন ভরসা জোগাচ্ছে। দুই ২৪ পরগনা এবং মেদিনীপুরেও এখন গড়ে উঠেছে কৃষকদের সমবায় পরিচালিত এমন কেন্দ্র।

স্থানীয় মানুষ চেনেন 'সুলভ জল' হিসেবে। সুটিয়া গ্রাম পঞ্চায়েতের মধুসূদনকাটি, বিষ্ণুপুর, ফরিদকাটি, তেখরিয়া, গাজনা ছাড়াও ইছাপুর ২ গ্রাম পঞ্চায়েতের শিমুলপুর, আনন্দপাড়া, বেরগুম গ্রাম পঞ্চায়েতের মল্লিকপুর মৌজায় এখন যাচ্ছে সেই জল। এমনকি পার্শ্ববর্তী গোবরডাঙা পুর এলাকাতেও বেশ কয়েকটি পরিবার এখন নির্ভরশীল এই জলের উপরে।

সকাল থেকে এখন দম ফেলার ফুরসত মেলে না পীযূষ সরকার, স্বপন মণ্ডল, পিন্টু মণ্ডল, বাপ্পা সরকার, প্রদীপ পালদের। ব্যস্ততা চলে বিকেল পর্যন্ত। সকাল থেকে আগের দিনের ব্যবহৃত জারগুলি তিন দফায় ধোয়া, জারে জল ভরে বাড়ি বাড়ি পৌঁছনোর ব্যবস্থা, প্রকল্প থেকে রোজ যাঁরা নিজেরাই জল নিয়ে যান, তাঁদের জল দেওয়া— সব দায়িত্ব এই পাঁচ জনের উপরে। সে পর্ব মেটার পরে পরের দিন যে জল সরবরাহ করা হবে, তা শোধনের ব্যবস্থা করে শেষ হয় তাঁদের দৈনন্দিন কাজ।

গাইঘাটায় আর্সেনিকের সমস্যায় জেরবার মানুষ যখন বিকল্প জলের সন্ধান করছিলেন, তখন হাতেকলমে সে কাজই করে দেখিয়েছে মধুসূদনকাটি সমবায় কৃষি উন্নয়ন সমিতি। সংস্থার কর্মী স্বপন মণ্ডল জানান, নিজেরা নিয়ে গেলে কুড়ি লিটারের জারের দাম পড়ে ১২ টাকা। আর বাড়ি পৌঁছে দিলে সুটিয়া অঞ্চলের জন্য জার পিছু বাড়তি ২ টাকা এবং গোবরডাঙা এলাকায় ৪ টাকা গুণতে হয় ক্রেতাদের। আর্সনিকের প্রকোপের কারণে যেখানে এই ব্লকে গভীর নলকূপগুলিও বন্ধ করে দিতে বাধ্য হচ্ছে সরকার, সেখানে কৃষকদের এই সমবায় এলাকায় জল সরবরাহের যে উদ্যোগ নিয়েছে, তা যথেষ্ট উৎসাহব্যাঞ্জক বলেই মনে করেন সুটিয়া গ্রাম পঞ্চায়েতের উপ প্রধান মিহির বিশ্বাস।

সমবায়ের সদস্য প্রায় ১,৮০০। তার প্রায় ১,৪০০ জনই কৃষক। কৃষকদের সমবায়ের গড়ে তোলা এই প্রকল্পটি থেকে ওই গ্রাম পঞ্চায়েতের আর্সেনিক আক্রান্ত পরিবারগুলিতে নিখরচায় জল সরবরাহ করা হচ্ছে। সমবায়টির বর্তমান চেয়ারম্যান কালীপদ সরকার জানান, সুটিয়া গ্রাম পঞ্চায়েতের মধুসূদনকাটি এবং বিষ্ণুপুর প্রাথমিক বিদ্যালয়, গোবরডাঙা পুরসভার বাদেখাঁটুরা, খাঁটুরা প্রাথমিক বিদ্যালয় ছাড়াও মধুসূদনকাটি এবং বিষ্ণুপুর অঙ্গনওয়াড়ি কেন্দ্রেও এখান থেকে বিনামূল্যে জল সরবরাহ করা হয়। তিনি জানান, ১৮ বছর ধরে প্রথমে ভূগর্ভস্থ জল, পরে ভূপৃষ্ঠের জল ব্যবহার করে বিশুদ্ধ পানীয় জল সরবরাহের এই উদ্যোগ নেওয়া হয়েছিল তাঁদের সমবায়ের তরফে। বছর তিনেক আগে সুলভ ইন্টারন্যাশনালের কারিগরি এবং আর্থিক সহায়তায় এই প্রকল্পটিকে আরও বিস্তৃত এবং আধুনিক করা হয়েছে।

রাজ্যের জনস্বাস্থ্য কারিগরি দপ্তর অনুমোদিত বনগাঁর চাঁপাবেড়িয়া, বারাসতের পরীক্ষাগার ছাড়াও অল ইন্ডিয়া ইনস্টিটিউট অফ হাইজিন অ্যান্ড পাবলিক হেলথ, যাদবপুর বিশ্ববিদ্যালয়ের স্কুল অফ এনভায়রনমেন্টাল স্টাডিজের তরফেও তাদের জলের মান পরীক্ষা করে শংসাপত্র দেওয়া হয়েছে। সমবায় সূত্রে জানা গিয়েছে, নির্দিষ্ট সময়ের ব্যবধানেই জল পরীক্ষা করানো হয়। সমবায়ের নিজস্ব এবং তাদের অধীনে থাকা দু'টি পুকুরের সংগৃহীত জলই কেবলমাত্র ব্যবহার করা হচ্ছে। কারণ, অন্যান্য খেতে রাসায়নিক, কীটনাশকের ব্যবহারে সেগুলি জলে রয়ে যাবার আশঙ্কা থাকে। খেতের সেই জলই বৃষ্টিতে ধুয়ে পুকুরে মেশে। যাদবপুরের স্কুল অফ এনভায়রনমেন্টাল স্টাডিজের অধিকর্তা অধ্যাপক তড়িৎ রায়চৌধুরী বলেন, 'ভূপৃষ্ঠের এবং বৃষ্টির জল সংরক্ষণ করে যেভাবে জল শোধন করা হচ্ছে, ভবিষ্যতে আর্সেনিক মোকাবিলায় এই ধরনের উদ্যোগই নেওয়া প্রয়োজন।'

রাজ্যের সমবায় দপ্তরও মনে করছে, সরকারি উদ্যোগের পাশাপাশি কৃষকদের সমবায়গুলি রাজ্যের অন্যত্র এমন উদ্যোগ নিলে আর্সেনিক মোকাবিলায় তা কার্যকরী পদক্ষেপ হতে পারে। বাস্তবেও কৃষকদের সমবায় পরিচালিত এই মডেলটিই অনুসরণ করা হচ্ছে উত্তর ২৪ পরগনার হিঙ্গলগঞ্জ ছাড়া মেদিনীপুর এবং দক্ষিণ ২৪ পরগনাতেও। ওই তিনটিও পরিচালনা করছে স্থানীয় প্রাথমিক কৃষি সমবায় সমিতি (প্যাকস)।


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PUBLICATIONS

&


SEMINARS AND CONFERENCES

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Oral presentations

- Presented a paper on "Arsenic Toxicity: Health exposure and perception of risk assessment on a populace from an exposed area in West Bengal, India" at the **4th International Conference on Advances in Civil and Ecological Engineering Research (ACEER 2022), 4th – 7th July, 2022.**
- Presented a paper on "Health exposure and risk assessment of a sub-population due to arsenic toxicity from an arsenic-prone zone in West Bengal, India" in the **8th International Congress and Exhibition on Arsenic in the Environment, Bridging Science to Practice for Sustainable Development (As2021), organized digitally at the Wageningen University and Research, Wageningen, The Netherlands from 7-9 June, 2021.**
- Presented a paper on "Arsenic exposure and health risk assessment of the school children from exposed and apparently control areas of West Bengal, India and possible mitigation strategies" in the **International Interdisciplinary Conference on "COVID 19: Challenges and Impact on Health, Environment, Livelihood and Education" organized by the Scientific and Environmental Research Institute, Kolkata, held on 28th – 30th May, 2021.**
- Presented a technical paper on "Evaluation of acute and chronic exposure on school children from arsenic-exposed and apparently control populations of West Bengal, India and its remedial strategies" in the **Web-based Exposition on Engineering and Technology Research at Jadavpur University, WEBINAR-FET-JU R&D Expo**

2021, organized by R&D Committee, TEQIP-III, Jadavpur University during February 26-27, 2021.

- Presented a paper titled “Effect on acute & chronic arsenic toxicity through drinking water and rice grain with special reference to adverse health effects from arsenic affected areas in West Bengal, India, at **UEM GREEN 19 (1stInternational Conference on Energy Management for Green Environment), 25th -27th September, 2019**.
- Presented a paper on “Groundwater arsenic contamination problem in Ganga-Megna-Brahmaputra (GMB) plain: its health effects, socio-economic implications & mitigations strategies”, organized **by Department of Economics, Vijaygarh Jyotish Ray College, on in collaboration with School of Environmental studies, Jadavpur University, 25th March, 2019.**
- Presented a paper on “Naturally produced low-cost antiseptic healing solution” at one-day seminar on “**Emerging Trends in Environmental Science and Technology”, March 17, 2017, School of Environmental Studies, Jadavpur University.**
- Presented a paper “Additional danger of arsenic through dietary intake pathways from arsenic-affected areas of West Bengal” in **1st Areaal Science & Technology congress, 2016, Presidency Division, West Bengal, 13th & 14th November, 2016 organized by Department of Science and Technology, Government of West Bengal.**

Seminars and Conference proceedings

- Attained seminar on “Clean & Sustainable Industrial & Urban Environment” organized by **Millennium Institute of Energy & Environment Management, on February 20, 2016 at CSIR-CGCRI, Kolkata.**

- Attained UGC-sponsored National Seminar Environmental Awareness: Demand of the Day, September 9th & 10th, 2016 organized by **Environmental Development Committee The Bhawanipur Education Society College, Kolkata, In collaboration with Department of Environmental Science, University of Calcutta, Kolkata.**

- Attained Faculty of Engineering and Technology, Jadavpur University TEQIP-II Sponsored One Day National Workshop on **—Revisiting Intellectual Property Rights in the Context of Recent Developments in Science & Technology, 20th October, 2016.**

- Attained South Asian Areaal Workshop on Agricultural Waste Management Practice to

Policy, **29th April, 2017, Kolkata** organized by **South Asian Forum for Environment SAFE, under Asia Pacific Network, Global Change Research.**

- Attained "Groundwater arsenic contamination with special reference to food chain in West Bengal, India: Magnitude, Health effects and Remedial Strategies" Nilanjana Roy Chowdhury, **Madhurima Joardar,** Antara Das, Shrestha Swain, Anuja Joseph, Sourav Maity, Debapriya Sinha, DuhitaKar, Rishika Chakraborti, Tarit Roychowdhury at '**Brain Storming Session' on "Water Resources of Eastren (West Bengal, Bihar & Jharkhand) and North-Eastern States of India", 8th and 9th June, 2018 at CSIR-CGCRI, Kolkata, organized by Centre for Groundwater Sources.**
- Attained National Conclave on Water Resources Management, jointly organized by Academy of Water Technology and Environ Management & Corporate Monitoring association with **CSIR-Central Glass & Ceramic Research Institute, Kolkata, 17th &18th January, 2019.**
- Attended "One–Day State Level Webinar On Ecosystem Restoration Towards Sustainable Society" organized by **Acharya Brojendra Nath Seal College, Cooch Behar, West Bengal, India on 5th June, 2021.**
- "Groundwater arsenic contamination with special reference to food chain in West Bengal, India: Impact, Measurement and Remediation Strategies" **Madhurima Joardar**, Nilanjana Roy Chowdhury, Shrestha Swain**,** Antara Das, Anuja Joseph, Debopriya Sinha, Sourav Maity, Tarit Roychowdhury at **national seminar on Environmental Challenges: Monitoring, Assessment and Remediation organized by Department of Zoology, Patna University, Patna (Bihar), 2018.**
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