Journal of Agroforestry and Environment

Volume 18, Issue 1, 2025

Journal DOI: https://doi.org/10.55706/jae
Journal homepage: www.jagroforenviron.com

Health Risk Assessment by Determining Heavy Metals (As and Fe) in Tube Wells Water of Tangail Municipality, Bangladesh

Jinat Mahjabin Sweety, Rezuana Afrin* and Mausumi Rehnuma

Department of Environmental Science and Resource Management, Mawlana Bhashani Science and Technology University, Tangail-1902, Bangladesh.

*Correspondence: afrin.mbstu038@gmail.com; Phone: +8801913641108

Received: 11/01/2025

Accepted: 20/03/2025

Available online: 24/03/2025

Abstract: Tangail Municipality is a rapidly urbanizing area in Bangladesh that faces challenges in maintaining safe drinking water due to natural and anthropogenic contamination. The presence of heavy metals, particularly arsenic (As) and iron (Fe), in groundwater poses potential health risks to residents. The study was conducted to assess the water quality of tube wells water of Tangail Municipality in February 2023. A total of 18 water samples from 6 wards were collected from Tangail Municipality. The concentrations of pH, Electrical Conductivity (EC), Arsenic (As), and Iron (Fe) ranged from 6.32±0.01 to 7.48±0.01; 185±1 $\mu S/cm^{-1}$ to 1305±1 $\mu S/cm^{-1}$; 0.0021 to 0.0068 mg/l and 0.658 to 2.194 mg/l, respectively. The study found that the water samples' pH, EC, and As values were suitable for drinking, domestic activities, irrigation, farming, and other purposes according to Environmental Conservation Rules (ECR) and World Health Organization (WHO) guidelines. However, all the Iron values of water samples exceeded the standard value of WHO and ECR. The Target Hazard Quotient of Arsenic in all water samples was less than 1. Nevertheless, the Target Hazard Quotient values of Iron in each sample exceeded the limiting value except for sample 17. The highest Target Hazard Quotient value of Fe is found at 9.37 in sample 15 at Ward 5. The reasons for Fe prevalence might be natural, i.e., weathering and erosion of bedrock, ore deposits, or anthropogenic, such as excessive groundwater use. The highest Carcinogenic Risk of Arsenic was found to be 0.001119 in sample 12 at Ward 4, and the lowest value was 0.000018 in sample 17 at Ward 6. The findings underscore the urgent need for regular monitoring and alternative water sources to ensure safe drinking water in Tangail Municipality.

Keywords: Arsenic; Iron; Water Quality; Target Hazard Quotient; Carcinogenic Risk.

INTRODUCTION

Water is an invaluable natural resource in the world and survival without water is impossible (Chakrabarty and Sarma, 2011). There are mainly two sources of water those are ground water and surface water. Among the water sources, groundwater is the most decentralized and reliable for millions of families in rural and urban areas (Kundu *et al*., 2018). Hand pump tube wells are a key technology for collecting groundwater, and over 90% of households in Bangladesh rely on tube wells for drinking, cooking, washing, and other daily needs (Luby *et al*., 2008). However, water is getting polluted with organic and inorganic matter (Rezania *et al*., 2015). Water is contaminated in two ways: natural and anthropogenic. Generally, groundwater is clean and fancy to be pure, but it has never been found in its original state. Inorganic contaminants that originate from geological strata through which water flows lead to pollution and affect the physico-chemical quality of water (Sultana *et al*., 2013). Clean and wholesome water is the fundamental right of human beings. Unsafe and impure water threatens human health (Ahmmed and Kibria, 2019). Approximately 80% of diseases and more than one-third of deaths in developing countries result from consuming contaminated water (WHO, 2002). Tangail is one of the prominent districts in Bangladesh in terms of historical, cultural, and educational aspects. The urban dwellers of Tangail

Municipality prefer and rely on groundwater through tube wells for drinking purposes. A bulk portion of society does not know whether they take safe drinking water or not. They may ignorantly use unsafe tube well water, which may cause serious health issues. Information about groundwater quality is insufficient. Knowing the status of groundwater quality is a matter of great concern. Assessing health risks associated with the contamination of tube well water by arsenic and heavy metals has become a primary concern for environmental scientists (Ravenscroft *et al.*, 2009; Alkarkhi *et al.*, 2008). The high concentrations of heavy metals may cause toxicity. The adverse effects of these metals include symptoms like stomach pain, headaches, mood swings, fluctuations in blood pressure, kidney disease, nerve damage, skeletal disorders, cancer, and cognitive impairments (Khan *et al.*, 2013). In this context, the study aimed to assess the concentrations of heavy metals (As and Fe) in tube well water. The main objectives of this study were (i) To assess pH, Electrical Conductivity (EC), Arsenic (As), and Iron (Fe) concentrations of Tube wells water of Tangail Municipality and (ii) To assess Health Risk Quotient and Carcinogenic Risk of As and Fe.

MATERIALS AND METHODS

Study Area

The study was conducted in Tangail Municipality, located in Tangail District. It has a population of about 128785. There are a total of 18 wards in Tangail Municipality. The study was conducted on six wards of this municipality, namely Biswas Betka, Akur Takur Para, Pardighulia, Kandapara, Tangail, and Santosh. To analyze the data, the ward numbers were rearranged as Biswas Betka –Ward 1; Akur Takur Para- Ward 2; Pardighulia- Ward 3; Kandapara- Ward 4; Tangail- Ward 5; Santosh- Ward 6 128785. There are a total of 18 wards in Tangail Municipality. The study was conducted on six wards of this municipality, namely Biswas Betka, Akur Takur Para, Pardighulia, Kandapara, Tangail, and Santosh. To analyze the data, the ward numbers were rearranged as Biswas Betka – Ward 1; Akur Takur Para- Ward 2; Pardighulia- Ward 3; Kandapara- Ward 4; Tangail- Ward 5; Santosh- Ward 6.

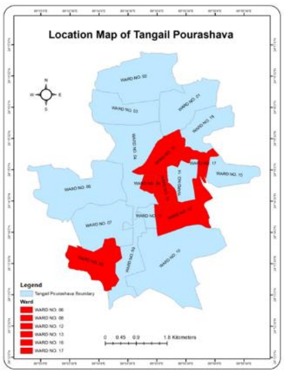

Figure 1. Map of the study area of Tangail Municipality, Tangail

Sample Collection

In February 2023, three water samples from each tube well were collected for heavy metal analysis from six selected wards of Tangail Municipality. The Water samples were collected from average shallow to medium depth (30-60 feet) tube wells. Three different points from each ward were selected for random sampling. Plastic bottles, each with a volume of 250 mL and labeled with ward and sample numbers, were used for collection. Before collecting water samples, the bottles were cleaned with distilled water and dried. Important information such as the depth and age of the tube well, the daily water intake rate, and the average age of the people were written down in the book. After sampling, the bottles were securely screwed and transported to the laboratory, covered with black plastic bags to prevent sunlight exposure. The samples were delivered to the lab on the same day, frozen at 4°C to prevent further contamination until analysis.

Sample Analyses

The water quality parameters such as pH and EC were determined by the digital pH meter (Model: pH HI98107, HANNA meter) and EC meter (Model: HI98304, HANNA meter), respectively. For heavy metal concentrations (As and Fe) analyses, a 100 ml water sample was taken in a beaker by using a pipette. Next, 4-5 mL of concentrated HNO_3 was added to the sample, and the beaker was placed on a hot plate for digestion. Once digestion was complete, the sample was transferred to a 100 mL volumetric flask and diluted with distilled water up to the calibration mark. It was then filtered using Whatman Qualitative 1 filter paper and stored in a container. This procedure was repeated for each water sample (APHA, 1998). Heavy metal concentrations (As and Fe) analyses were determined by Flame-AAS (Flame-Atomic Absorption Spectrophotometer); Model: GTA 120-AA240Z with PSD120 autosampler, Varian, Australia at Asia Arsenic Network Environmental Laboratory in Jashore.

Calculation

Health Risk Assessment of Arsenic and Iron

Two parameters assess health risk:

(I) Target Hazard Quotient and

(II) Carcinogenic Risk Assessment

(I) Target Hazard Quotient (HQ)

The Target Hazard Quotient is calculated as:

$$\mathbf{HQ = ADD / RfD_o} \quad \mathbf{(1)}$$

Where,

ADD = the average daily intake dose (mg/l/day).

RfD_o = the reference oral dose (mg/kg/d).

DOI: https://doi.org/10.55706/jae1802

The Average Daily Dose (ADD) is calculated using the following formula:

ADD= {(Cwater *IRwater)*EF*ED}/ (AT*BW) (1.1)

Where,

Cwater is the arsenic concentration in water (mg/L)
IRwater is the water ingestion rate (L/day)
EF is the exposure frequency (days/year)
ED is the exposure duration (years)
AT is the average age time (days)
BW is the body weight (kg).

The water ingestion rate (IR) was 2–3 liters (an average of 2.5 L) of water per day. Exposure frequency (EF) was 365 days/year. Exposure duration (ED) varied from 8 to 20 years. Average age time (AT) was counted for only the adults. Body weight (BW) was measured by weighing each individual using a body weight scale.

RfDo Value

A reference dose (RfDo) is an estimated daily exposure level for the human population, including vulnerable subgroups, that is unlikely to cause significant harmful effects over a lifetime.
The reference dose (RfDo) for arsenic is 0.0003 mg/l/day, and for iron, it is 0.007 mg/l/day.
(Source: USEPA IIRIS, 2011)

If the calculated Hazard Quotient (HQ) is less than 1, (HQ < 1,) no adverse health effects are expected from exposure. However, if the HQ is greater than 1, (HQ < 1) adverse health effects may be possible (Source: USEPA, 1998).

(II) Carcinogenic Risk (R) Assessment

The target carcinogenic risk associated with chemical intake was determined using the equation provided in the USEPA Region III Risk-Based Concentration Table (USEPA, 2000). The carcinogenic risk factor (R) represents the probability of developing cancer due to chemical exposure and is calculated using the following formula:

R= 1 − exp [(SF *ADD)] **(2)**

Where,
SF is the oral slope factor.
ADD is the average daily intake dose (mg/L/day).

Oral Slope Factor (SF)

The oral slope factor measures the incremental lifetime risk of cancer caused by chemical intake. It represents the upper-bound estimate of the dose-response curve.

The oral slope factor (SF) for Arsenic is 1.5 mg/l/day, and the oral slope factor for Iron is 0.

Statistical analysis

The data were statistically analyzed using SPSS 20.0 (SPSS, USA), while other calculations were carried out using Microsoft Excel 2013.

RESULTS AND DISCUSSION

pH

The pH value indicates the acidic or alkaline nature and the concentration of hydrogen ions in water (Miah *et al.*, 2015). The pH value range of 7 to 14 is alkaline, 0 to 7 is acidic, and 7 is neutral (Dohare *et al.*, 2014). According to WHO (2006) and ECR (1997), the standard pH range for tube well water in Bangladesh, suitable for drinking and other purposes, is 6.5–8.5 (Bhowmick and Biswas, 2016).

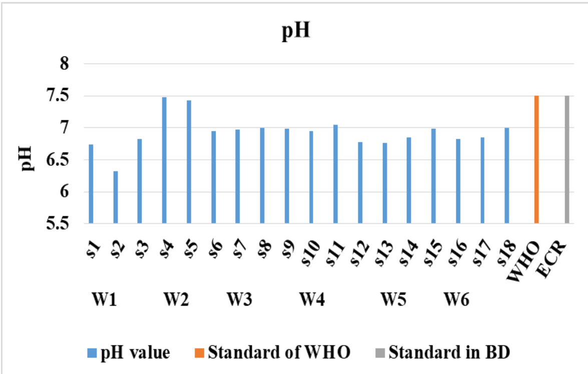

Figure 2. Average values of pH in different tube wells.

The values of pH ranged from 6.32±0.01 to 7.48 ±0.01. The highest pH value was found at 7.48±0.01 in Akur Takur Para (S4) W2, and the lowest was found at 6.32±0.01 in Biswas Betka (S2) W1. All sample values were found in the permissible range according to WHO (2006) and ECR (1997).

Electrical Conductivity (EC)

Electrical conductivity (EC) truly measures the ionic method of a solution that permits it to transmit current. Consistent with WHO (2006) and ECR (1997), the commonplace electrical conduction value of tube well water for drinking and other purposes ranges between 500-1000 µS/cm (Bhowmick and Biswas, 2016).

DOI: https://doi.org/10.55706/jae1802

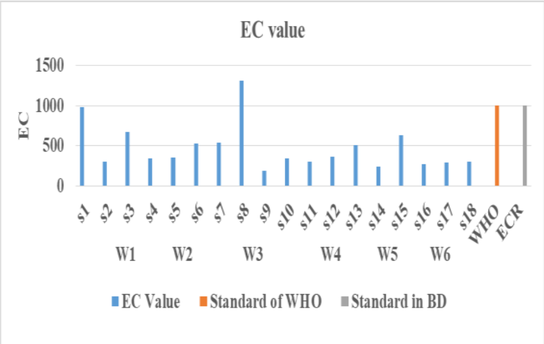

Figure 3. Average values of EC in different tube wells.

The EC values ranged from 185±1 to 1305±1µS/cm. The highest value was found at 1305±1µS/cm in Pardighulia (S8) W3, and the lowest value was also found at 185±1µS/cm in Pardighulia (S9) W3. The study found considerable variation in EC values. All sample values were found in the permissible range according to WHO (2006) and ECR (1997) except S8, and this water sample is not suitable for consumption.

Arsenic

Arsenic is a naturally occurring chemical element widely distributed in the Earth's crust. Arsenic has an atomic number of 33 and an atomic mass of 74.92. In its inorganic form, arsenic is highly toxic. The greatest public health risk arises from contaminated water used for drinking, food preparation, and irrigation of food crops (WHO, 2022). The standard arsenic (As) value recommended by WHO is 0.01 mg/L, while in Bangladesh, the permissible value is 0.05 mg/L (Shaibur *et al.*, 2012).

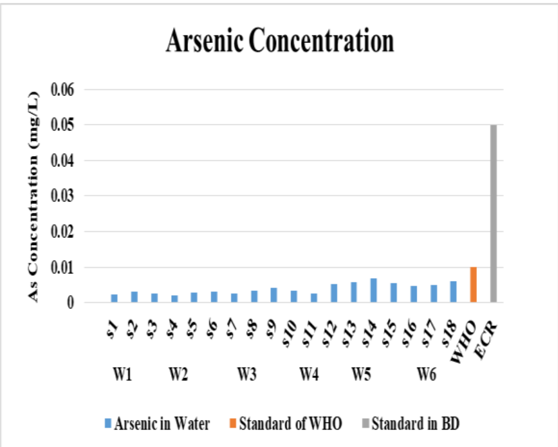

Figure 4. Average values of As in different tube wells.

The arsenic values ranged from 0.0021 to 0.0068 mg/L. The highest value was found at 0.0068 mg/L in Tangail (S14) Ward 5, and the lowest value was found at 0.0021 mg/L in Akur Takur Para (S4) Ward 2. According to WHO (2006) and ECR (1997), all the samples were considered suitable for drinking and other purposes.

Iron

Iron (Fe) is the second most abundant metal in the Earth's crust, making up approximately 5%. Its atomic mass is 55.85. Iron is most commonly found in nature through its oxides (Elinder *et al.*, 1986). In various regions of Bangladesh, groundwater withdrawal is leading to significant iron contamination in groundwater, particularly during the dry season (Ahmed *et al.*, 2000). The standard iron (Fe) concentration recommended by WHO is 0.30 mg/L, in Bangladesh, the permissible range is 0.3 to 1.0 mg/L (Shaibur *et al.*, 2012).

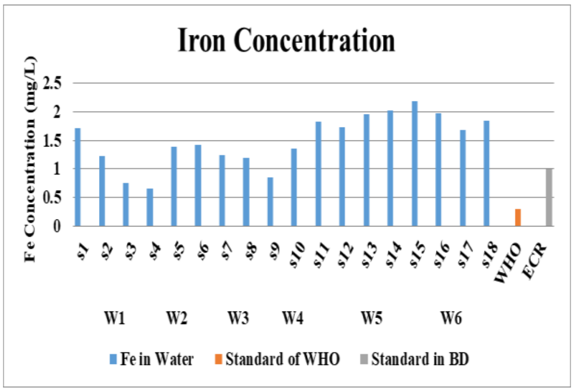

Figure 5. Average values of Fe in different Tube wells.

The iron values ranged from 0.658 to 2.194 mg/L. The highest value was found at 2.194 mg/L in Tangail (S15) Ward 5, and the lowest was at 0.658 mg/L in Akur Takur Para (S4) Ward 2. All of the samples exceeded the WHO standard value. Most of the samples exceeded the BD standard value, both the lower and upper limits. Samples 3, 4, and 9 from wards 1, 2, and 4 exceeded the lower limit of the BD standard.

A high concentration of iron in drinking water can create an unpleasant metallic taste. While iron is essential for human nutrition, elevated levels in drinking water may lead to chronic anemia and fatigue (Søgaard *et al.*, 2017). High levels of iron in the body can damage the liver, bones, bone marrow, thyroid, heart, and other glands and organs (WRC, 2020).

DOI: https://doi.org/10.55706/jae1802

Table 3. Average Daily Intake Dose (ADD) of Arsenic and Iron Found in Different Water Samples.

Serial No.	Sample	ADD Value (mg/L)	
		Arsenic	Iron
01	Sample 1	0.0000431	0.0306
02	Sample 2	0.000114	0.0439
03	Sample3	0.000258	0.00716
04	Sample 4	0.00005	0.0157
05	Sample 5	0.000051	0.0248
06	Sample 6	0.0000718	0.034
07	Sample 7	0.0000484	0.0222
08	Sample 8	0.0000628	0.0215
09	Sample 9	0.000103	0.020
10	Sample10	0.0000416	0.0161
11	Sample 11	0.0000622	0.043
12	Sample12	0.0000746	0.0248
13	Sample 13	0.000150	0.0514
14	Sample 14	0.0000569	0.0170
15	Sample 15	0.000164	0.0656
16	Sample 16	0.0000402	0.0165
17	Sample 17	0.0000122	0.00403
18	Sample 18	0.000111	0.0332

Table 4. Hazard Quotient (HQ) of Arsenic and Iron of tube well water samples for adults.

Serial No.	Sample No.	HQ Value	
		Arsenic	Iron
01	Sample 1	0.143	4.4
02	Sample 2	0.38	6.27
03	Sample 3	0.86	1.023
04	Sample 4	0.166	2.24

DOI: https://doi.org/10.55706/jae1802

05	Sample 5	0.17	3.54
06	Sample 6	0.239	4.85
07	Sample 7	0.161	3.17
08	Sample 8	0.209	3.07
09	Sample 9	0.343	2.86
10	Sample 10	0.139	2.3
11	Sample 11	0.207	6.14
12	Sample 12	0.248	3.54
13	Sample 13	0.5	7.34
14	Sample 14	0.18	2.43
15	Sample 15	0.55	9.37
16	Sample 16	0.134	2.35
17	Sample 17	0.040	0.575
18	Sample 18	0.37	4.74

The Hazard Quotient values were calculated using ADD values, as presented in Table 3. The methodology for estimating the Hazard Quotient was applied following the guidelines provided by the U.S. Environmental Protection Agency (USEPA) Region III's risk-based concentration table.

The Target Hazard Quotient values of Arsenic in all samples were less than 1 and ranged between 0.17 (sample 5) to 0.343 (sample 9). Based on these findings, the residents are not at risk of chronic arsenic toxicity, as indicated by HQ values being less than 1.

However, each sample's Target Hazard Quotient values of Iron exceeded the limiting value except for sample 17 from ward 6 (0.575), which is less than 1. The highest HQ value is 9.37 in sample 15 at ward 5.

Table 5. Carcinogenic Risk (R) Assessment of Arsenic.

Serial No.	Sample No.	R
01	Sample 1	0.000064
02	Sample 2	0.000171
03	Sample 3	0.000387
04	Sample 4	0.000075
05	Sample 5	0.000076
06	Sample 6	0.000107
07	Sample 7	0.000073
08	Sample 8	0.000094
09	Sample 9	0.000154
10	Sample 10	0.000062
11	Sample 11	0.000093
12	Sample 12	0.001119
13	Sample 13	0.000225

DOI: https://doi.org/10.55706/jae1802

14	Sample 14	0.000085
15	Sample 15	0.000246
16	Sample 16	0.000060
17	Sample 17	0.000018
18	Sample 18	0.000166

The carcinogenic risk factor represents the probability of developing cancer due to chemical exposure. According to the USEPA, the carcinogenic risk from oral exposure (drinking water) to arsenic is 5×10^{-5} per µg/L or 0.00005 mg/L.

The highest carcinogenic risk value was found at 0.00119 mg/L in sample 12 of Ward 4, and the lowest at 0.000018 mg/L in sample 17 of Ward 6. Most of the samples exceeded the carcinogenic risk value except sample 17. The findings of this study suggest that consuming tube-well water in the studied areas may pose a cancer risk to individuals who drink it over prolonged periods.

CONCLUSION

Based on the study, the pH, EC, and Arsenic values were within permissible limits set by WHO and Bangladesh (ECR) standards. However, most Iron values were higher than the WHO and ECR standards. The higher concentration of Iron in tube well water causes a metallic taste water with a foul odor. The Target Hazard Quotient values of Iron in each sample exceeded the limiting value except for sample 17. The higher concentrations of iron found in the studied area may harm the residents who consume the tube-well water. Regularly monitoring tube well water quality is essential to ensure safe drinking water. People need to be aware of their drinking water quality and consider seeking alternative sources of clean drinking water. For example, rainwater can be harvested, and surface water can be purified to reduce excessive pressure on groundwater. Increasing awareness about water purification for drinking purposes and primary treatment like boiling water and filtering is necessary. Urban areas must have a proper drainage system, waste should be managed appropriately, and leachate discharge should be prohibited.

The results of this study may help make the users aware of the present status of tube well water quality, which may protect public health and concern the inhabitants to ensure safe and sound water for drinking and other purposes.

Acknowledgment

The authors gratefully acknowledge the Department of Environmental Science and Resource Management at Mawlana Bhashani Science and Technology University and the Asia Arsenic Network Environmental Laboratory, Jashore, for their invaluable support in providing equipment and laboratory facilities essential to this research.

Conflict of Interest

The authors declare no conflicts of interest.

REFERENCES

Ahmed, M.J., Ahsan, A., Haque, M.R., Siraj, S., Bhuiyan, M.H.R., Bhattacharjee, S.C. and Islam S. 2010. Physicochemical assessment of surface and groundwater quality of the greater Chittagong region of Bangladesh. *Pakistan Journal of Analytical & Environmental Chemistry*, *11*(2), p.11.

Ahmmed, B. and Kibria, K.Q. 2019. Suitability of Tube-Wells Water for Drinking at Lalpur Upazila in Natore District, Rajshahi, Bangladesh. *International Journal of Scientific and Research Publications*, *9*.

Alkarkhi, A. F. M., Ahmad, A., Ismail, N. and Mat Easa, A. 2008. Multivariate analysis of heavy metals concentrations in river estuary. *Environmental Monitoring and Assessment*.

APHA (American Public Health Association), 1998. “Standard methods for the examination of water and wastewater”.19th edition. American Public Health Association, Washington DC, USA.

Bhowmick, A.C. and Biswas, F.B. 2016. Assessment of Drinking Water Quality in MBSTU Campus.

Chakrabarty, S. and Sarma, H.P. 2011. Heavy Metal Contamination of Drinking Water in Kamrup District, Assam, India. *Environ Monit Assess*, 179, pp. 479–486. https://doi.org/10.1007/s10661-010-1750-7

Datta, T., Islam, M.S., Tusher, T.R., Rehnuma, M., and Kabir, M.H. 2017. Quality Assessment of Water in Different Sources at Tangail Municipality of Bangladesh. *Bangladesh J. Environ. Sci.*, 32, pp. 15-22.

Dohare, D., Deshpande, S. and Kotiya, A., 2014. Analysis of Ground Water Quality Parameters: A Review 3, 6.

ECR (Environment Conservation Rules) 1997. Ministry of Environment and Forest, Government of the People's Republic of Bangladesh.

EQS (Environmental Quality Standard) 1997. Bangladesh Gazette, registered nr. DA-I Ministry of Environment, Government of the People’s Republic of Bangladesh.

Elinder, C.G., 1986. “Handbook on the technology of metals.” *Amsterdam, Elsevier*, 2, pp. 276-297.

Khan, K., Lu, Y., Khan, H., Ishtiaq, M., Khan, S., Waqas, M., Wei, L., and Wang, T. 2013. Heavy metals in agricultural soils and crops and their health risks in Swat

District, northern Pakistan. *Food and Chemical Toxicology*.

Kundu, A., Datta, D.K., Tonu, N.T. and Haque, M.R. 2018. Evaluating the Quality of Ground Water for Drinking Purpose in Jhenaidah Municipal Area. *International Journal of Innovative Research in Science, Engineering and Technology*, *7*(10), pp.10527-10536.

Luby, S.P., Gupta, S.K., Sheikh, M.A., Johnston, R.B., Ram, P.K. and Islam, M.S. 2008. Tube well water quality and predictors of contamination in three flood-prone areas in Bangladesh. *Journal of applied microbiology*, *105*(4), pp.1002-1008.

Memon, M., Soomro, M.S., Akhtar, M.S. and Memon, K.S. 2011. Drinking water quality assessment in Southern Sindh (Pakistan). *Environmental monitoring and assessment*, *177*(1), pp.39-50.

Miah, M.Y., Robel, F.N., Bhowmik, S., Bhattacharjee, S., Paul, S.C., Hossain, M.J. and Hossain, M.Z., 2015. Assessment of the Coastal Area Water Quality in Noakhali, Bangladesh. 6, 9.

Ravenscroft, P., Brammer, H., and Richards, K., 2009. *Arsenic pollution: A global synthesis*.

Rezania, S., Ponraj, M., Talaiekhozani, A., Mohamad, S.E., Din, M.F.M., Taib, S.M., Sabbagh, F. and Sairan, F.M. 2015. Perspectives of phytoremediation using water hyacinth for removal of heavy metals, organic and inorganic pollutants in wastewater. *Journal of environmental management*, *163*, pp.125-133.

Sultana, M., Saifullah, A.S.M., Latif, M.B., Mamun, S.A. and Sultana, D.S., 2013. Drinking water quality at academic institutions of Tangail municipality. *Journal of Environmental Science and Natural Resources*, *6*(1), pp.247-252.

Shaibur M.R., Anzum H.M.N., Rana M.S., and Khan M.A.S., 2012. Assessment of supplied water quality at Jessore Municipality (Pourashava), Bangladesh. *Bangladesh Journal of Environmental Research*, 10, pp. 69-87.

Shaibur, M. R. 2019. Distribution of Arsenic and Heavy Metals and Correlation among them in Groundwater of South Fukra, Kashiani, Gopalganj. *Bangladesh. Journal of Environmental and Biological Research*, 1 (1), pp. 84-105.

Søgaard, K.L., Ellervik, C., Svensson J. and Thorsen, S.U. 2017. The role of iron in type 1 diabetes etiology: A systematic review of new evidence on a longstanding mystery. *The Review of Diabetic Studies*, 14, pp. 269-278.

Uddin, M.N., Rahaman, M.M. and Mondal, M.S. 2013. Assessment of Ground Water Quality at Mawlana Bhashani Science and Technology University Campus, Tangail, Bangladesh. *Journal of Environmental Science and Natural Resources*, *6*(2), pp.177 180.

USEPA, 1998. Integrated risk information system: arsenic, inorganic CASRN. 7440-38-2.

USEPA, 2000. Risk-based Concentration Table US Environmental Protection Agency Washington, DC/Philadelphia, PA.

USEPA IIRIS, 2011. United States, Environmental Protection Agency, Integrated Risk Information System.

WHO (World Health Organization), 2002. Managing Water in the Home: Accelerated Health Gains from Improved Water Sources. Geneva, pp. 3-7. DC/Philadelphia, PA.

WHO (World Health Organization), 2006. Guidelines for drinking water quality. 3rd ed., vol.1, Geneva, Switzerland.

WHO (World Health Organization), 2022. Guidelines for drinking water quality, 5th ed., vol.3, Geneva, Switzerland.

WRC (Water Research Commission), 2020. Annual Final Report.

DOI: https://doi.org/10.55706/jae1802