

Monitoring of Trace Elements in Groundwater of Municipal Area at Kushtia and Jhenaidah District of Bangladesh

ABSTRACT

Groundwater samples from the municipal residential areas of the Pearatola, Kushtia (23.897975° N and 89.123735° E) and the DPHE, Jhenaidah (23.544454° N and 89.164694° E) districts were analyzed for trace elements determination of Iron (Fe), Manganese (Mn), Lead (Pb), Cadmium (Cd) and Zinc (Zn) evaluating the health effect of these trace elements is the prime object of this investigation. Fe, Mn, Pb, Cd and Zn in groundwater were determined by atomic absorption spectroscopy (AAS) on direct flame methods. The examined concentrations of Fe, Mn, Pb, Cd and Zn are respectively 0.740 mg/L, 0.370 mg/L, 0.040 mg/L, 0.0040 mg/L and 0.0570 mg/L (ppm) which were present in the groundwater sample of Kushtia. The absolute concentrations of Fe, Mn, Pb, Cd and Zn are respectively 0.490 mg/L, 0.220 mg/L, 0.030 mg/L, 0.0030 mg/L and 0.0310 mg/L (ppm) which were present in the groundwater sample of Jhenaidah. Fe contamination of examined areas samples in 0.740 ppm and 0.490 ppm of cases exceeded the WHO criteria and 0.30 ppm exceeded BD standards which is a very scary risk factor for human health. The investigated data should be useful and helpful for general public awareness intake of groundwater.

Keywords: AAS, Groundwater, Health effect, Kushtia and Jhenaidah, Trace element.

1.0 Introduction

Many countries use groundwater as the prime source of drinkable water which also serves the purpose of agriculture and industry [1-2]. Groundwater is extensively used and becoming more important due to cases including climate change, global warming, the rise in ambient temperature and evaporation, dramatic population growth and excessive utilization of fresh water in agricultural and industrial activities [3-4]. Groundwater is presently essential to both social and economic development. All over the world, about 2.50 billion people depend on groundwater for drinking purposes [5]. Organic or inorganic contaminants have recently polluted water reservoirs by pollution, soil leaching, population growth and increased anthropogenic sources activity [6]. Among all contaminants, Arsenic is one of the most significant pollutants all over the world which affects approximately 70.0 million people [7]. Some water-borne diseases like cholera, diarrhoea, dysentery, hepatitis A, etc. are spreading out by unclean and contaminated water. It was studied that globally every year 8,42,000 people die from diarrhoea [8,56,57,58]. Also, water scarcity has been a significant issue in recent days due to global warming which is created due to variations in rainfall and irregularity of rainfall [9]. Within 2025, 1.8 billion people will be under the scarcity of drinking water [10]. Bangladesh is a densely populated and agriculture-based country that extracts groundwater of nearly 32.0 km³ (cubic kilometers) every year from this 90.0 % is used for irrigation and the remaining is used for domestic and industrial purposes. This quantity is about 4.0 % of the world's total groundwater withdrawals [11]. In Bangladesh, 11.0 million tube wells are used for the extraction of groundwater and about 98.0 % population uses it as drinking water [12-14]. Several variables have an effect on water quality and quantity in Bangladesh whether directly or indirectly [12]. The contamination of groundwater by arsenic (As) and different trace elements in Bangladesh

creates health issues [17]. “Groundwater is a high threat of Arsenic (As), Lead (Pb), cadmium (Cd), iron (Fe), manganese (Mn) and zinc (Zn) contamination that is very high in our nation. As a result, 35.0 to 77.0 million people were exposed to trace elements in the first decades of this millennium” [15]. Water-borne diseases are caused by water, sanitation and hygiene-related problems for that reason about 8.50 % of deaths in Bangladesh [16]. Twenty million humans consume groundwater with arsenic that is above the national acceptable limit [18] which was studied in 61.0 districts in Bangladesh. Apart from arsenic, other common metals such as Lead (Pb), cadmium (Cd), iron (Fe), manganese (Mn) and zinc (Zn) are responsible for significant contamination of groundwater in Bangladesh [19]. Not only metal, bacteria and pesticides were also responsible for groundwater contamination [20-21]. The standard criteria of groundwater are presented in Table 1. Table 1, shows that the lead (Pb) concentration of BD standard is 0.10 ppm, likely cadmium (Cd) is 0.01 ppm, iron (Fe) 0.30 ppm, manganese (Mn) is 0.10 ppm and zinc (Zn) is 5.0 ppm around the permissible intake limit. On the other hand, the WHO prescribed limits for lead (Pb) concentration are 0.010 ppm, cadmium (Cd) is 0.0030 ppm, iron (Fe) 0.30 ppm, manganese (Mn) is 0.10 ppm and zinc (Zn) is 3.0 ppm.

Table 1. Drinking water quality parameters prescribed by the US EPA [23], WHO [22, 25] and Bangladesh guidelines (BD)[24].

Constituent	US EPA	WHO Guideline	BD Guideline
Arsenic (mg/L)	0.05	0.01	0.05
Iron (mg/L)	0.30	0.30	0.30
Sodium (mg/L)	--	200.0	--
Calcium (mg/L)	--	--	75.0 (200.0)
Copper (mg/L)	1.30	1.0-2.0	1.50
Manganese (mg/L)	0.05	0.1-0.5	0.1 (0.50)
Zinc (mg/L)	5.00	3.00	5.0 (15.0)
Aluminum (mg/L)	0.05-0.20	0.20	0.10 (0.20)

Lead (mg/L)	0.015	0.01	0.10
Chromium (mg/L)	0.10	0.05	0.05
Cadmium (mg/L)	0.005	0.003	0.01
Barium (mg/L)	2.00	0.70	1.00
Antimony (mg/L)	0.006	0.005	--
Molybdenum (mg/L)	--	0.07	--
Nickel (mg/L)	0.10	0.02	--
Selenium (mg/L)	0.050	0.01	--
Silver (mg/L)	0.10	--	--
pH	6.50-8.50	6.50 - 8.50	6.50 -8.50
Sulphate (mg/L)	250.0	--	100.0
Fluoride (mg/L)	4.00	--	1.00
Chloride (mg/L)	250.0	250.0	200.0 (600.0)
Bromide (mg/L)	--	--	--
Nitrate (mg/L)	10.0	--	10.0
Nitrite (mg/L)	1.00	--	--
Phosphate (mg/L)	--	--	6.0
Total Dissolved Solid (TDS)	500.0	1000.0	500.0 (1000.0)

From analysis, Fe, Mn, Pb, Cd and Zn contamination of examined samples, Fe in 0.740 ppm exceeded the WHO criteria and BD standard of 0.30 ppm [22, 24]. From this study, we have identified the quantitative analysis and monitoring of trace amounts of groundwater in the Kushtia and Jhenaidah municipal regions as the prime focus of the study.

2. Materials and Methods

2.1. Study Location

The study areas are in different districts such as Kushtia and Jhenaidah municipal. In this present investigation, a total of two tube-well water samples were collected from the Pearatola residential area of Kushtia whose central absolute location is 23.897975° N and 89.123735°E and the other one is the DPHE residential area of Jhenaidah municipal which central location is 23.544454°N and 89.164694°E in Fig. 1.

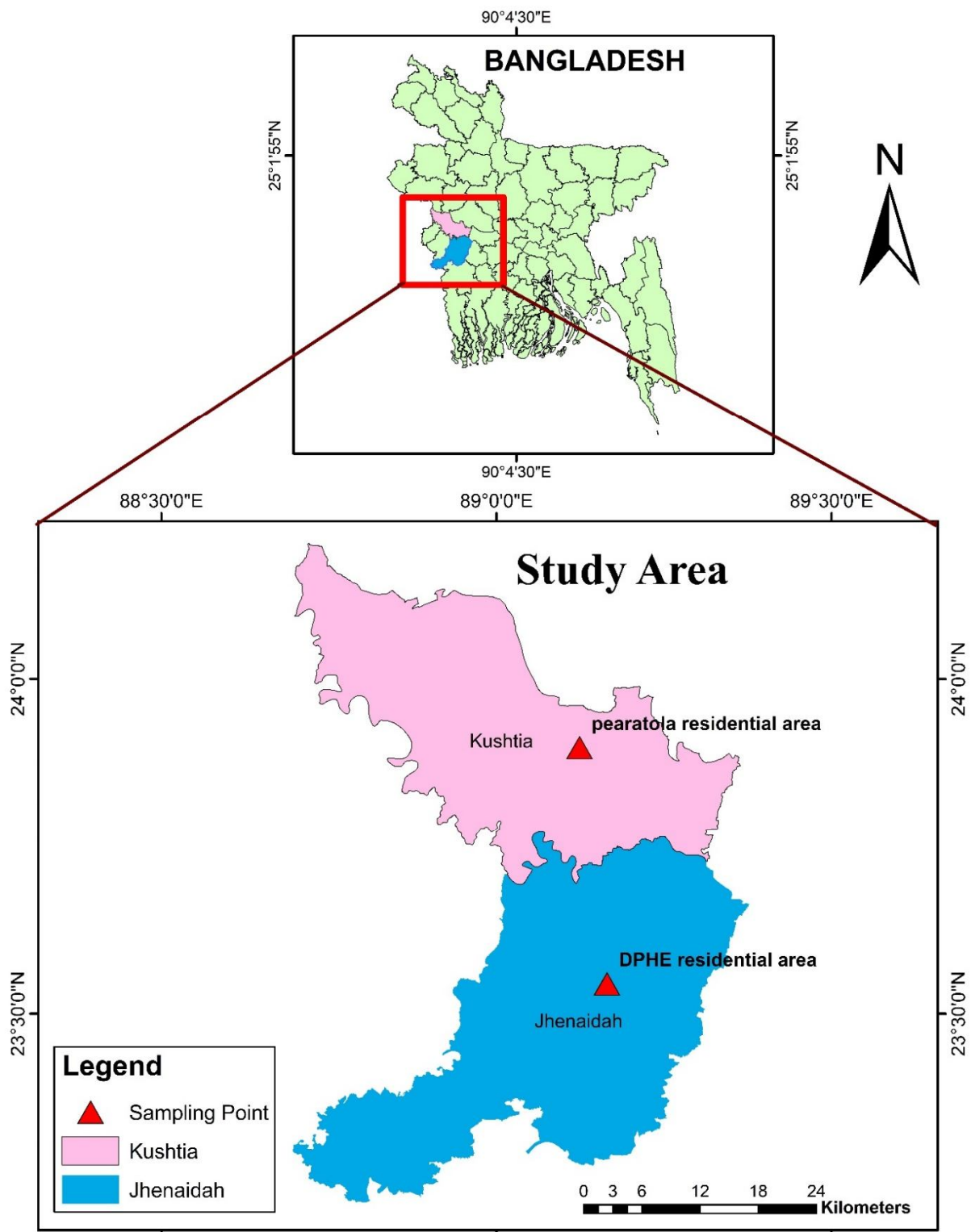


Fig. 1. Sampling point of the municipal area of Kushtia and Jhenaidha districts of Bangladesh.

2.2. Sample Collection and Preservation

Groundwater (tube well water) samples were collected from two sampling points which are Kushtia and Jhenaidah municipal residential areas. All samples were collected in duplicate to analyze the trace elements. Tube well water samples were collected in acid-washed polyethylene (HDPE) bottles. The samples were then preserved with the addition of 5.0 – 6.0 ml ultrapure 1:1 HCl per litre of water sample to minimize the absorption of metals into the walls of the containers. The samples were then transferred to the analytical chemistry laboratory of the ACCE, Islamic University, Kushtia-7003. The analysis was performed accordingly to check repeatability.

3.0 Characterization

“Analysis of trace elements by AAS. AAS is an analytical method for quantifying elements in solution or solid samples. AAS (model: Varian spectra AA220, country of origin: Australia) determined the trace element concentrations in samples using an air-acetylene flame with a digital read-out system. The temperature formed in air-acetylene flame is around 2300.0 °C whereas acetylene-nitrous oxide (dinitrogen oxide) flame is around 3000.0 °C. Generally, with air-acetylene flame Cd, Pb and Zn can be determined by using flame atomic absorption spectrometry” [55]. For analysis of trace elements in water samples, 2.50 ml of concentrated H₂SO₄ and 4.0 ml of concentrated HNO₃ were added. Samples taken in solution form or digested to be detected by FAAS. Typical detection units are around ppm range and sample analysis took 10.0 – 15.0 seconds per element. The Block diagram of FAAS and GFAAS is depicted in Fig. 2 (a) and (b). Generally, hollow cathode lamps as flame or graphite furnaces as an atomizer, grating as a wavelength selector and photomultiplier as a detector are used.

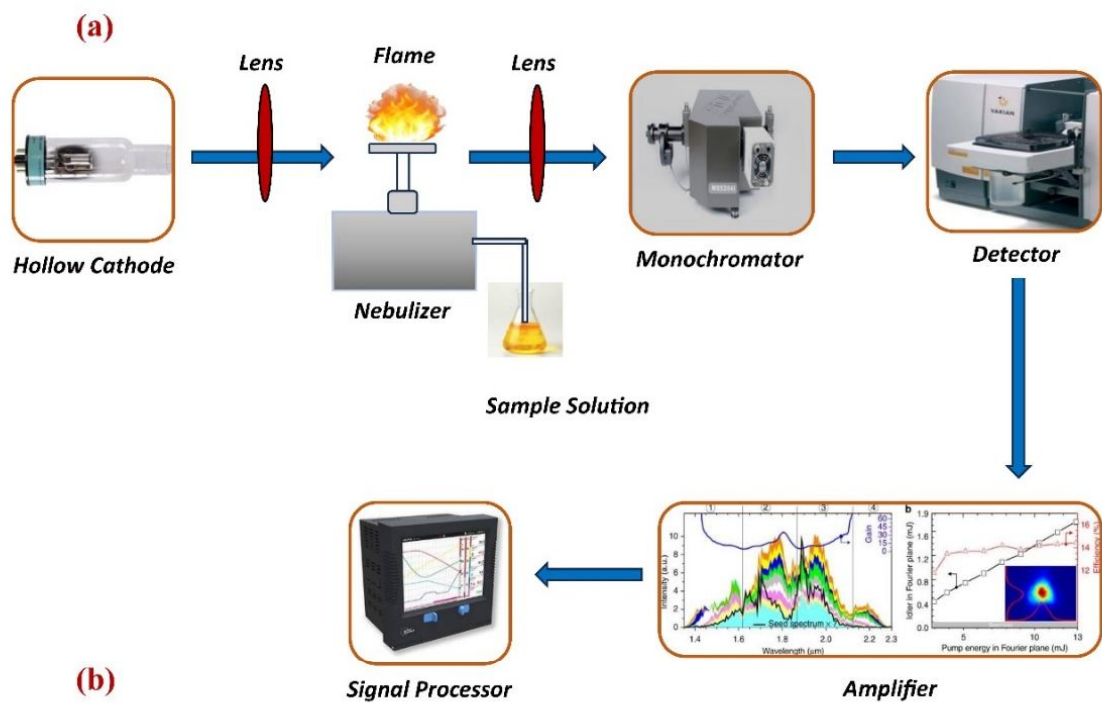


Fig. 2. (a) Block diagram of AAS and (b) instrumental skeleton of AAS.

Analytical conditions for measurement of the Iron (Fe) in aqueous solution using AAS have been reported. The values that were certified and those that were observed agreed well. Reference standard solutions with established concentrations of all measured elements were used as control samples to ensure measurement accuracy. To evaluate the measurement's repeatability, each

sample was measured a minimum of twice. In cases where the measurement's relative standard deviation was higher than 10.0 % and double-distilled water was utilized throughout the inquiry, samples were reanalyzed.

4. Results and Discussion

The experimental results of Fe, Mn, Pb, Cd and Zn presented in various types of groundwater samples of Kushtia and Jhenaidah municipals area are given in Table 2, Fig. 3. and Fig. 4.

4.1 Iron (Fe) in Groundwater

Fe is not considered hazardous to health. Fe is essential for good health because it transports oxygen in our blood. Under Department of Nature Resources (DNR) rules, Fe is considered a secondary or "aesthetic" contaminant. The present recommended limit for iron concentration in drinking water is 0.30 mg/L (ppm) prescribed by WHO [22, 25] and is based on taste and appearance rather than on any detrimental health effect. Bangladesh guideline is also selected 0.30 mg/L [24]. If the Fe concentration in groundwater is found above this range, then this water may have adverse effects on health. The experimental result of the Iron concentration of groundwater in Kushtia and Jhenaidah is given in Table 2 and Fig. 3. Table 2 shows that the groundwater samples contain Iron concentrations of 0.740 mg/L in Kushtia and 0.490 mg/L in Jhenaidah.

Table 2. Trace elements concentration of groundwater samples in the municipals of Kushtia and Jhenaidah districts.

Trace elements concentration in Kushtia					
Sl.	Water Quality Parameters	Analysis Method	Concentration Present	Bangladesh Standard	Unit

(ECR'97)					
1.	Iron (Fe)	AAS-Direct Flame	0.740	0.30 - 1.0	mg/L (ppm)
2.	Lead (Pb)	AAS-Direct Flame	0.040	0.050	mg/L (ppm)
3.	Cadmium (Cd)	AAS-Direct Flame	0.0040	0.0050	mg/L (ppm)
4.	Manganese (Mn)	AAS-Direct Flame	0.370	0.100	mg/L (ppm)
5.	Zinc (Zn)	AAS-Direct Flame	0.0570	5.00	mg/L (ppm)
Trace elements concentration in Jhenaidah					
6.	Iron (Fe)	AAS-Direct Flame	0.490	0.30 - 1.0	mg/L (ppm)
7.	Lead (Pb)	AAS-Direct Flame	0.030	0.050	mg/L (ppm)
8.	Cadmium (Cd)	AAS-Direct Flame	0.0030	0.0050	mg/L (ppm)
9.	Manganese (Mn)	AAS-Direct Flame	0.220	0.10	mg/L (ppm)
10.	Zinc (Zn)	AAS-Direct Flame	0.0310	5.00	mg/L (ppm)

4.2 Manganese (Mn) in Groundwater

“Mn is an essential element for many living organisms, including humans. Adverse health effects can be caused by inadequate intake or overexposure. Mn deficiency in humans appears to be rare because available manganese is present in many common foods. According to WHO guidelines, Mn concentration in drinking water is (0.10 - 0.50) mg/L”[22, 25]. Bangladesh guideline is 0.10 mg/L [24]. The experimental result of the manganese concentration of groundwater in Kushtia and Jhenaidah is given in Table 2. and Fig. 3. From Table 2, it is observed that the amount of Mn concentration is 0.370 mg/L in Kushtia and 0.220 mg/L in Jhenaidah.

4.3 Lead (Pb) in Groundwater

“JECFA established a provisional tolerable weekly intake (PTWI) of 25.0 µg of Pb per kilogram of body weight (equivalent to 3.5 µg/kg of body weight per day) for infants and children which

took into account the fact that Pb is a cumulative poison so that any increase in the body burden of Pb should be avoided. In Bangladesh, the guideline for Pb concentration in water is 0.050 mg/L”[24]. The experimental result of the Pb concentration of groundwater in Kushtia and Jhenaidah is given in Table 2 and Fig. 3. From Table 2, it is observed that the water samples contain Pb concentrations is 0.040 mg/L in Kushtia and 0.030 mg/L in Jhenaidah. So, there is no adverse effect of Pb.

4.4 Cadmium (Cd) in Groundwater

“On the assumption of an absorption rate for dietary Cd of 5.0 % and a daily excretion rate of 0.0050 % of body burden, JECFA concluded that, if levels of Cd in the renal cortex are not to exceed 50.0 mg/kg, the total intake of Cd should not exceed 1.0 µg/kg of body weight per day. The guideline for Cd concentration in water in Bangladesh is 0.0050 mg/L”[24]. The experimental result of the Cd concentration of groundwater in Kushtia and Jhenaidah is given in Table 2 and Fig. 3. Table 2 shows that the water samples contain Cd concentrations of 0.004 mg/L in Kushtia and 0.0030 mg/L in Jhenaidah. So, there is no adverse effect for Cd and these water sources are safe for drinking and other purposes.

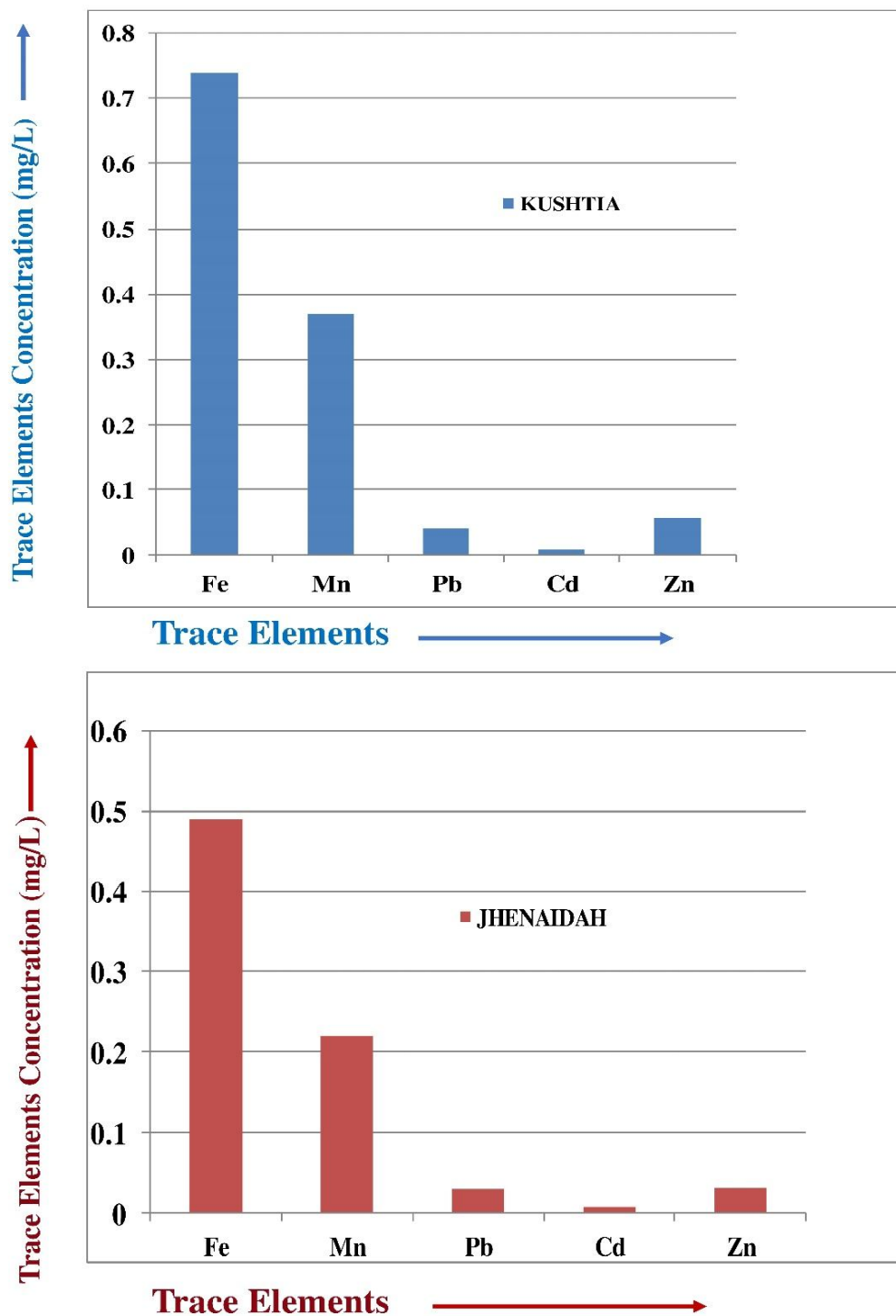


Fig. 3. Trace elements concentration present in groundwater samples of Kushtia and Jhenaidah.

4.5 Zinc (Zn) in Groundwater

Zn is an essential element for humans and most health issues are focused on a deficiency of Zn rather than an excess. Adverse effects of an excess of Zn are centred around gastrointestinal

issues. An excess of Zn in water at concentrations greater than 3.0 mg/L can be detrimental to the appearance of the water with a greasy surface film developing and an unpleasant metallic taste. The USEPA sets a secondary maximum contaminant level (SMCL) for Zn of 5.0 mg/L. Bangladesh has set a 5.0 mg/L [24] standard for Zn. The experimental result of the Zn concentration of groundwater in Kushtia and Jhenaidah is given in Table 2 and Fig. 3. From Table 2, it is observed that the groundwater samples containing Zn concentrations are 0.0570 mg/L in Kushtia and 0.0310 mg/L in Jhenaidah which is below the BD guideline.

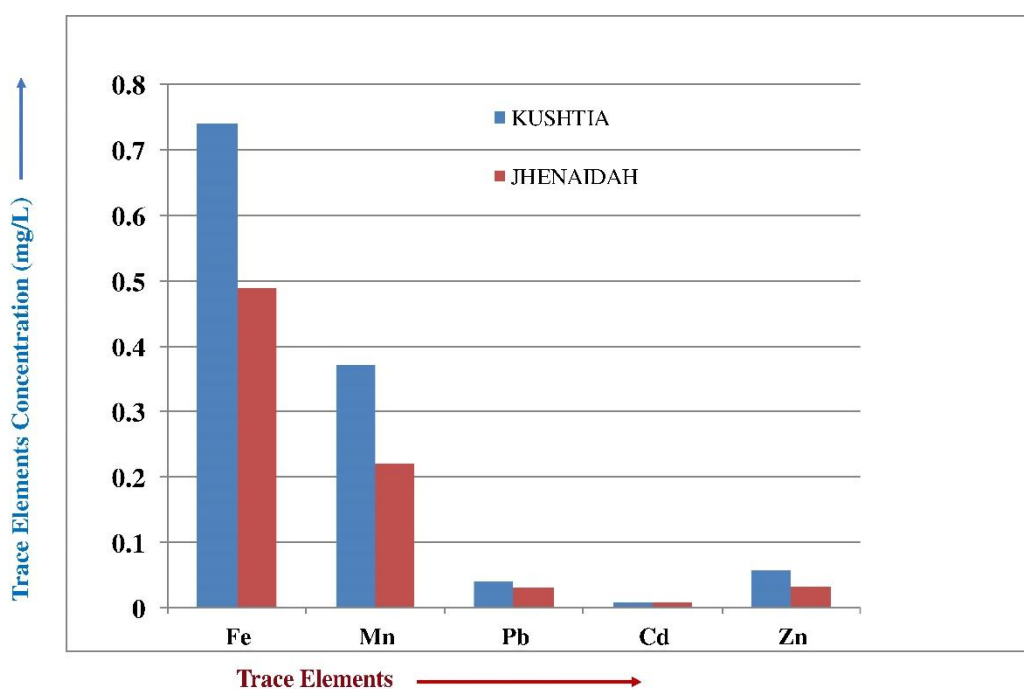


Fig. 4. Comparison between trace elements concentration present in groundwater samples of Kushtia and Jhenaidah.

Fig. 4. shows the relative amounts of trace element concentrations in the groundwater samples of the Kushtia and Jhenaidah municipal areas. the comparison shows that the concentration of trace elements in the Kushtia is higher than in the Jhenaidah. Fe is an important mineral in groundwater. Anaerobic ground waters may contain Fe at concentrations up to several milligrams per litre without discolouration or turbidity in the water when directly pumped from a

well. Taste is not usually noticeable at Fe concentrations below 0.30 mg/L, although turbidity and colour may develop in piped systems at levels above 0.05 - 0.10 mg/L. Fe is an essential element in human nutrition. Concentrations of 1.0 – 3.0 mg/L can be acceptable for people drinking anaerobic well water. The concentration of Fe is 0.740 mg/L in Kushtia and 0.490 mg/L in Jhenaidah. At very high concentrations, Fe can however be toxic with side effects such as rapid and shallow respiration, coma, convulsions, respiratory failure and cardiac arrest being reported. So, everybody should drink water to ensure iron concentration and must avoid water which contains iron overexposure, if it is drunk, then it may cause fatal disease. Mn is also a mineral element that remains in groundwater and it is an important element for all living organisms. But when this Mn concentration in drinking water is overexposed, then it may be harmful to us. So, we should be cognizant of Mn concentration in drinking water before drinking. The concentration of Mn is 0.370 mg/L in Kushtia and 0.220 mg/L in Jhenaidah.

Pb is also found in groundwater. It needs to be recognized that lead is exceptional, in that most Pb in drinking water arises from plumbing in buildings and the remedy consists principally of removing plumbing and fittings containing Pb which requires much time and money. It is therefore emphasized that all other practical measures to reduce total exposure to Pb, including corrosion control, should be implemented. The concentration of Pb is 0.040 mg/L in Kushtia and 0.030 mg/L in Jhenaidah. The regulations for Cd levels in groundwater are sufficient to maintain human intake at low levels. Cd can cause health effects to humans such as kidney, liver and lung damage. The highest Cd exposure to humans is known to come from Cd contaminated food, not drinking water. But care should be taken to the drinking water source. The concentration of Cd is 0.0040 mg/L in Kushtia and 0.0030 mg/L in Jhenaidah. Zn is another element which remains in the water. JECFA proposed a daily dietary requirement of Zn of 0.30 mg/kg of body weight and a provisional maximum tolerable daily intake (PMTDI) of 1.0 mg/kg of body weight. The daily

requirement for adult humans is 15.0 to 22.0 mg/day. The concentration of Zn is 0.0570 mg/L in Kushtia and 0.0310 mg/L in Jhenaidah. It was concluded that in light of recent studies on humans, the derivation of a health-based guideline value is not required at this time. However, drinking water containing Zn at levels above 3.0 mg/L tends to be opalescent, develops a greasy film when boiled and has an undesirable astringent taste.

5.0 Health Effect of the Trace Elements in Groundwater

Some special issues were concerned with the intake of the groundwater that was responsible for major risk factors included in Table 3 and Fig. 5. An excess of iron in the water can result in hemochromatosis, hyperglycemia, nausea and gastrointestinal issues [26, 31]. Mn concentration in older people's hair and the prevalence of neurological symptoms and skin rash of chronic Mn poisoning are correlated with increasing increases in Mn concentration in drinking water [27, 32].

Table 3. Responsible health effect of the trace elements of Fe, Mn, Pb, Cd and Zn.

Serial No.	Elements	Health Effects	References
1.	Iron (Fe)	High iron in water content leads to an overload which can cause diabetes, hemochromatosis, stomach problems and nausea.	[26, 31]
2.	Manganese (Mn)	Progressive increases in Mn concentration in drinking water are associated with progressively higher prevalences of neurological signs of chronic manganese poisoning (CMnP) and Mn concentration in the hair of older persons.	[27, 31]
3.	Lead (Pb)	Lead in drinking water has occurred as a result of	[28, 32, 33]

		contamination from piping and distribution systems contamination has led to acute and chronic toxicity in humans and cirrhosis of the liver.	
4.	Cadmium (Cd)	Chronic exposure to Cd resulted in 'itai-itai' disease in humans. Some correlations were suggested between cadmium levels and the age-adjusted prostate or breast cancer rates distributed in the European countries under study.	[29, 32]
5.	Zinc (Zn)	Excessive levels of zinc are associated with human health effects such as arthralgia and osteomalacia. High levels of Zinc salts in water may cause eye irritation, pain and erythema.	[30, 32]

Humans have been exposed to acute and chronic poisoning as well as liver cirrhosis due to lead pollution in drinking water which resulted from piping and distribution systems [28]. Chronic exposure to Cd resulted in age-adjusted prostate or breast cancer for Cd toxicity [29]. High concentrations of Zn salts in water can irritate, hurt and cause erythema in the eyes and stomach cramps[30, 32]. As well the adverse effect is also dependent on the types of materials [33-42], crystalline properties [43-49] and so other functional applications[50-54].

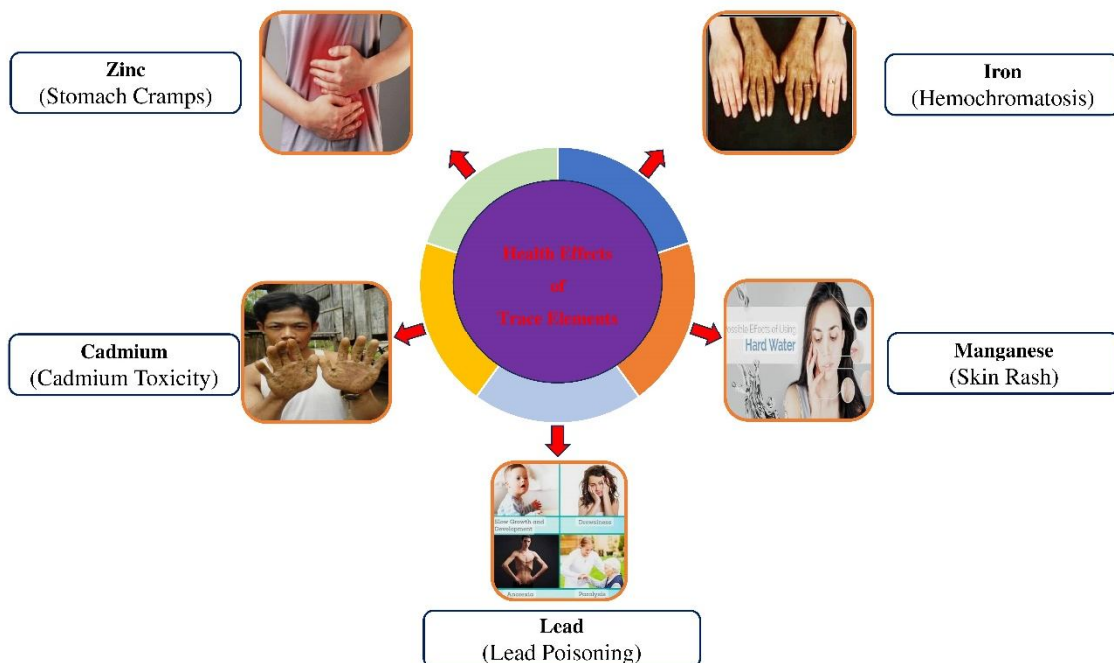


Fig. 5. Health effects of the trace elements (Fe, Mn, Pb, Cd and Zn) in groundwater.

Conclusion

Groundwater samples collected from the municipal areas of Pearatola, Kushtia and DPHE, Jhenaidah districts were analyzed for the determination of trace elements Fe, Mn, Pb, Cd and Zn investigated by AAS with direct flame methods. The evaluated concentrations of Fe, Mn, Pb, Cd and Zn were respectively 0.740 mg/L, 0.370 mg/L, 0.040 mg/L, 0.0040 mg/L and 0.0570 mg/L which were presented in the Kushtia. The absolute concentrations of Fe, Mn, Pb, Cd and Zn were respectively 0.490 mg/L, 0.220 mg/L, 0.030 mg/L, 0.0030 mg/L and 0.0310 mg/L which were presented in Jhenaidah. Fe contamination of examined areas samples in 0.740 ppm and 0.490 ppm of cases exceeded the WHO criteria and 0.30 ppm exceeded BD standards which is a very scary risk factor for human health. Drinking water is essential for any living being. Without water, we cannot go even a single day. Water contains various types of minerals that are indispensable for us. But sometimes these minerals were present at overexposure, then it became

an adverse effect on our health. So, determination of mineral content of Fe, Mn, Pb, Cd and Zn present in drinking water is important. In this respect present work is a tremendous effort. However, the data obtained will be useful for public awareness.

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Credit Authorship Contribution

TanjinaNasrin Eva: Conceptualization, Literature survey, Investigation, Methodology, Data Curation, Formal analysis, writing original draft, Review and editing, Supervision; **KamrunNahar:** Methodology, Supervision; **Md. DurulHoda:** Data Curation; **Md. MazedulHaqueSachchu:** Writing an original draft, Data curation; **Sabrina Afrin:** Formal analysis, Review and editing; **Miss Nushrat Jahan Lima:** Data curation; **Md. Touhid Hasan Shuvo:** Formal analysis, Visualization; **Md. AshrafulAlam:** Writing an original draft, Visualization, Formal analysis, Review and editing.

Conflict of Interest

The authors declared that no personal or financial interest could be influenced in this manuscript.

Data availability

The data is available on request.

Disclaimer (Artificial intelligence)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during the writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] Hassan, W., Faisal, A., Abed, E., Al-Ansari, N., & Saleh, B. (2021). New composite sorbent for removal of sulfate ions from simulated and real groundwater in the batch and continuous tests. *Molecules*, 26(14), 4356.
- [2] Abdulhadi, B. A., Kot, P., Hashim, K. S., Shaw, A., & Khaddar, R. A. (2019, August). Influence of current density and electrode spacing on reactive red 120 dye removal from dyed water using electrocoagulation/electroflotation (EC/EF) process. In *IOP Conference Series: Materials Science and Engineering* (Vol. 584, No. 1, p. 012035). IOP Publishing.
- [3] Megdal, S. B. (2018). Invisible water: the importance of good groundwater governance and management. *NPJ Clean Water*, 1(1), 15.
- [4] Omran, I. I., Al-Saati, N., Hashim, K., Al-Saati, Z., Kot, P., Al Khaddar, R. M., ...&Aljefery, M. (2019). Assessment of heavy metal pollution in the Great Al-Mussaib irrigation channel. *Desalination and Water Treatment*.

- [5] Grönwall, J., & Danert, K. (2020). Regarding groundwater and drinking water access through a human rights lens: Self-supply as a norm. *Water*, 12(2), 419.
- [6] Al-Hashimi, O., Hashim, K., Loffill, E., Marolt Čebašek, T., Nakouti, I., Faisal, A. A., & Al-Ansari, N. (2021). A comprehensive review for groundwater contamination and remediation: occurrence, migration and adsorption modelling. *Molecules*, 26(19), 5913.
- [7] World Water Assessment Programme (United Nations), & UN-Water. (2009). *Water in a changing world*.
- [8] Wang, J., Wang, G., Wu, T., Wang, D., Yuan, Y., Wang, J., ... & Qiu, J. (2018). Quaternary ammonium compound functionalized activated carbon electrode for capacitive deionization disinfection. *ACS sustainable chemistry & engineering*, 6(12), 17204-17210.
- [9] Mahaqi, A., Moheghi, M. M., Mehiqi, M., & Moheghy, M. A. (2018). Hydrogeochemical characteristics and groundwater quality assessment for drinking and irrigation purposes in the Mazar-i-Sharif city, North Afghanistan. *Applied Water Science*, 8, 1-10.
- [10] Wals, A. E. (2012). *Shaping the education of tomorrow: 2012 full-length report on the UN decade of education for sustainable development*. Unesco.
- [11] Shamsudduha, M., Joseph, G., Khan, M. R., Zahid, A., & Ahmed, K. M. U. (2019). Multi-hazard groundwater risks to the drinking water supply in Bangladesh: challenges to achieving the sustainable development goals. *World Bank Policy Research Working Paper*, (8922).
- [12] Islam, A. R. M. T., Al Mamun, A., Rahman, M. M., & Zahid, A. (2020). Simultaneous comparison of modified-integrated water quality and entropy weighted indices: implication for safe drinking water in the coastal region of Bangladesh. *Ecological Indicators*, 113, 106229.
- [13] Gaus, I., Kinniburgh, D. G., Talbot, J. C., & Webster, R. (2003). Geostatistical analysis of arsenic concentration in groundwater in Bangladesh using disjunctive kriging. *Environmental geology*, 44, 939-948.

- [14] Hasan, M. K., Shahriar, A., & Jim, K. U. (2019). Water pollution in Bangladesh and its impact on public health. *Heliyon*, 5(8).
- [15] Flanagan, S. V., Johnston, R. B., & Zheng, Y. (2012). Arsenic in tube well water in Bangladesh: health and economic impacts and implications for arsenic mitigation. *Bulletin of the World Health Organization*, 90, 839-846.
- [16] Benneyworth, L., Gilligan, J., Ayers, J. C., Goodbred, S., George, G., Carrico, A., ...&Piya, B. (2016). Drinking water insecurity: water quality and access in coastal south-western Bangladesh. *International journal of environmental health research*, 26(5-6), 508-524.
- [17] Mukherjee, A. B., & Bhattacharya, P. (2001). Arsenic in groundwater in the Bengal Delta Plain: slow poisoning in Bangladesh. *Environmental Reviews*, 9(3), 189-220.
- [18] Ghosh, G. C., Khan, M. J. H., Chakraborty, T. K., Zaman, S., Kabir, A. E., & Tanaka, H. (2020). Human health risk assessment of elevated and variable iron and manganese intake with arsenic-safe groundwater in Jashore, Bangladesh. *Scientific reports*, 10(1), 5206.
- [19] Zakir, H. M., Sharmin, S., Akter, A., & Rahman, M. S. (2020). Assessment of health risk of heavy metals and water quality indices for irrigation and drinking suitability of waters: a case study of JamalpurSadar area, Bangladesh. *Environmental advances*, 2, 100005.
- [20] Faisal Anwar, A. H. M., &Yunus, A. (2013). Groundwater vulnerability to pesticides in Northwest Bangladesh. *Environmental earth sciences*, 70, 1971-1981.
- [21] Sarker, P., Nahar, S., Begum, R., Reza, S. S., &Rahaman, M. S. (2020). Physicochemical and microbial groundwater quality assessment and evaluation in Noakhali Region, Bangladesh. *Journal of Applied Life Sciences International*, 9-19.
- [22] UNICEF. (2009). Bangladesh National Drinking Water Quality Survey.
- [23] <https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations>

- [24] Chowdhury, A., & Chowdhury, S. A. (2021). Current status of groundwater quality in Naogaon District, Bangladesh. *Journal of Water Resources and Pollution Studies*, 6(1), 35-44.
- [25] Akale, A. T., Dagneu, D. C., Giri, S., Belete, M. A., Tilahun, S. A., Mekuria, W., & Steenhuis, T. S. (2017). Groundwater quality in an upland agricultural watershed in the sub-humid Ethiopian highlands. *Journal of Water Resource and Protection*, 9(10), 1199-1212.
- [26] Ghosh, G. C., Khan, M. J. H., Chakraborty, T. K., Zaman, S., Kabir, A. E., & Tanaka, H. (2020). Human health risk assessment of elevated and variable iron and manganese intake with arsenic-safe groundwater in Jashore, Bangladesh. *Scientific reports*, 10(1), 5206.
- [27] Rahman, M. A., Hashem, M. A., Rana, M. S., & Islam, M. R. (2021). Manganese in potable water of nine districts, Bangladesh: human health risk. *Environmental Science and Pollution Research*, 28, 45663-45675.
- [28] Nordberg, G. F. (1990). Human health effects of metals in drinking water: relationship to cultural acidification. *Environmental Toxicology and Chemistry: An International Journal*, 9(7), 887-894.
- [29] Pan, J., Plant, J. A., Voulvoulis, N., Oates, C. J., & Ihlenfeld, C. (2010). Cadmium levels in Europe: implications for human health. *Environmental geochemistry and health*, 32, 1-12.
- [30] Nriagu, J. (2007). Zinc toxicity in humans. School of Public Health, University of Michigan, 1-7.
- [31] Kobir, M. M., Ali, M. S., Ahmed, S., Sadia, S. I., & Alam, M. A. (2024). Assessment of the physicochemical characteristic of wastewater in Kushtia and Jhenaidah Municipal Areas Bangladesh: A Study of DO, BOD, COD, TDS and MPI. *Asian Journal of Geological Research*, 7(1), 21-30.
- [32] Khatun, M., Kobir, M. M., Miah, M. A. R., Sarkar, A. K., & Alam, M. A. (2024). Technologies for remediation of heavy metals in environment and ecosystem: A critical overview of a comparison study. *Asian Journal of Environment & Ecology*, 23(4), 61-80.

- [33] Sachchu, M. M. H., Hossain, A., Kobir, M. M., Hoda, M. D., Ahamed, M. R., Lima, M. N. J., Eva, T. N., & Alam, M. A. (2024). Heavy Metal Intake by Fishes of Different River Locations in Bangladesh: A Comparative Statistical Review. *Asian Journal of Fisheries and Aquatic Research*, 26(6), 43–67. <https://doi.org/10.9734/ajfar/2024/v26i6775>
- [34] Alam, M. A., Bishwas, R. K., Mostofa, S., & Jahan, S. A. (2024). Crystallographic phase stability of nanocrystalline polymorphs TiO_2 by tailoring hydrolysis pH. *South African Journal of Chemical Engineering*, 49, 73-85.
- [35] Shishir, M. K. H., Sadia, S. I., Ahmed, S., Aidid, A. R., Rana, M. M., Hasan, M. M., ...& Alam, M. A. (2024). Transmission Electron Microscopic and X-ray Diffraction Based Study of Crystallographic Bibliography Demonstrated on Silver, Copper and Titanium Nanocrystals: State of the Art Statical Review. *Asian Journal of Applied Chemistry Research*, 15(3), 1-19.
- [36] Haque, N. N., Alam, M. A., Baidya, A. S., Zenat, E. A., Rahman, M. Z., Roy, C. K., & Munshi, J. L. (2024). Bioremedial capacity of indigenous hydrophytes and microalgae of Bangladesh: A comparative study on their potential in tannery effluent treatment. *Asian Journal of Environment & Ecology*, 23(6), 53-65.
- [37] Ahamed, M. S., Ali, M. S., Ahmed, S., Sadia, S. I., Islam, M. R., Rahaman, M. A., & Alam, M. A. (2024). Synthesis of Silver Nanomaterials Capping by Fruit-mediated Extracts and Antimicrobial Activity: A Critical Review. *International Research Journal of Pure and Applied Chemistry*, 25(1), 45-60.
- [38] Zenat, M., Akther, E., Haque, N. N., Hasan, M. R., Begum, M., Munshi, J. L., ...& Alam, M. A. (2024). Antifungal Activity of Various Plant Extracts against *Aspergillus* and *Penicillium* Species Isolated from Leather-Borne Fungus. *Microbiology Research Journal International*, 34(1), 10-23.
- [39] Sarkar, A. K., Ahmed, S., Sadia, S. I., Kobir, M. M., Tabassum, S., Islam, M. R., & Alam, M. A. (2024). Overview of the skeleton significance of toothpaste formulation, evaluation and

historical perspectives: Insights from Bangladesh's toothpaste industry. *Journal of Materials Science Research and Reviews*, 7(1), 80-101.

[40]Kobir, M. M., Tabassum, S., Ahmed, S., Sadia, S. I., &Alam, M. A. (2024). Crystallographic benchmarking on diffraction pattern profiling of Polymorphs-TiO₂ by WPPF for Pigment and Acrylic Paint. *Archives of Current Research International*, 24(1), 62-70.

[41] Ali, M. S., Ahmed, S., Islam, M. R., Ahamed, M. S., Rahaman, M. A., Khatun, M., &Alam, M. A. (2024). Diabetes mellitus control including fruits in diet: Exhaustive review and meta-analysis. *Asian Journal of Food Research and Nutrition*, 3(1), 43-59.

[42]Tabassum, M., Alam, M. A., Mostofa, S., Bishwas, R. K., Sarkar, D., & Jahan, S. A. (2024). Synthesis and crystallinity integration of copper nanoparticles by reaction medium. *Journal of Crystal Growth*, 626, 127486.

[43] Hasan, M. R., Abdur, R., Alam, M. A., Aziz, S., Sujan, A., Islam, D., ...& Hossain, M. (2024). + Exploring the effects of different parameters on the incorporation of K ions in eggshell derived CaO reveals highly variable catalytic efficiency for biodiesel conversion. *South African Journal of Chemical Engineering*, 47(1), 67-74.

[44]Alam, M. A., Bishwas, R. K., Mostofa, S., & Jahan, S. A. (2024). Low-temperature synthesis and crystal growth behavior of nanocrystal anatase-TiO₂. *Materials Letters*, 354, 135396.

[45] Islam, M. R., Ahmed, S., Sadia, S. I., Sarkar, A. K., &Alam, M. A. (2023). Comprehensive review of phytochemical content and applications from *cestrum nocturnum*: A Comparative Analysis of Physicochemical Aspects. *Asian Journal of Research in Biochemistry*, 13(4), 43-58.

[46]Moulick, S. P., Hossain, M. S., Al Mamun, M. Z. U., Jahan, F., Ahmed, M. F., Sathee, R. A., ...& Islam, F. (2023). Characterization of waste fish bones (*Heteropneustesfossilis* and *Otolithoidespama*) for photocatalytic degradation of Congo red dye. *Results in Engineering*, 20, 101418.

- [47] Rahman, M. M., Maniruzzaman, M., Yeasmin, M. S., Gafur, M. A., Shaikh, M. A. A., Alam, M. A., ...&Quddus, M. S. (2023). Adsorptive abatement of Pb²⁺ and crystal violet using chitosan-modified coal nanocomposites: A down flow column study. *Groundwater for Sustainable Development*, 23, 101028.
- [48]Haque, N. N., Alam, M. A., Roy, C. K., Zenat, M., Akther, E., &Munshi, J. L. (2023). Cyanobacteria Mediated CO₂ Segregation: A Promising Alternative Method for Sustainable Bioremediation and Biomass Production. *Asian Journal of Research in Biochemistry*, 13(3), 28-43.
- [49]Alam, M. A., Tabassum, M., Mostofa, S., Bishwas, R. K., Sarkar, D., & Jahan, S. A. (2023). The effect of precursor concentration on the crystallinity synchronization of synthesized copper nanoparticles. *Journal of Crystal Growth*, 621, 127386.
- [50]Alam, M. A., Mobashsara, M. T., Sabrina, S. M., Bishwas, R. K. B., Debasish, D. S., &Shirin, S. A. J. (2023). One-pot low-temperature synthesis of high crystalline cu nanoparticles. *Malaysian Journal of Science and Advanced Technology*, 122-127.
- [51]Alam, M. A., Munni, S. A., Mostafa, S., Bishwas, R. K., & Jahan, S. A. (2023). An investigation on the synthesis of silver nanoparticles. *Asian Journal of Research in Biochemistry*, 12(3), 1-10.
- [52] Hasan, M. S., Jahan, R., Alam, M. A., Khatun, M., & Al-Reza, S. M. (2016). Study on physicochemical properties of edible oils available in Bangladeshi local market. *Archives of Current Research International*, 6(1), 1-6.
- [53]Alam, M. A., Mostafa, S., Bishwas, R. K., Sarkar, D., Tabassum, M., & Jahan, S. A. Low Temperature Synthesis and Characterization of High Crystalline 3c-Ag Nanoparticle. Available at SSRN 4446717.

[54] Bishwas, R. K., Mostofa, S., Alam, M. A., & Jahan, S. A. (2023). Removal of malachite green dye by sodium dodecyl sulfate modified bentonite clay: Kinetics, thermodynamics and isotherm modeling. *Next Nanotechnology*, 3, 100021.

[55] Vickackaite, V., Tautkus, S., & Kazlauskas, R. (1996). Determination of heavy metals in natural waters by flame atomic absorption spectrometry. *Chemiaanalityczna*, 41, 483-488.

Ifesinachi, Onyenweife Geraldine, and Onyenweife Leonard Chikwado. 2023. "Evaluation of Water Contamination and Its Health Implications on the Residents of Ayamelum Local Government Area, Anambra State, Nigeria". *Asian Journal of Geographical Research* 6 (3):1-8. <https://doi.org/10.9734/ajgr/2023/v6i3184>.

Kanu, Ogonnaya Paul, Ejikeme Ugwoha, Ngozi U. Udeh, and Victor Amah. 2023. "Groundwater Quality Assessment in Aba (Abia State) Using WQI and GIS Techniques". *Asian Journal of Environment & Ecology* 22 (4):1-15. <https://doi.org/10.9734/ajee/2023/v22i4503>.

Foster S, Chilton J, Nijsten GJ, Richts A. Groundwater—a global focus on the 'local resource'. *Current opinion in environmental sustainability*. 2013 Dec 1;5(6):685-95.