INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

OPEN ACCESS
Received: 09-06-2023
Accepted: 05-07-2023
Published: 09-08-2023

Citation: Z, Nongtri ES, Lalnuntluanga , Rai PK (2023) Spatio-Temporal Variations of Physico-Chemical Characteristics and Heavy Metals in Groundwater of an Indo Burma Hotspot Region. Indian Journal of Science and Technology 16(30): 2325-2332. https://doi.org/10.17485/IJST/v16i30.1418

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Funding: Department of Science and Technology (DST)- Nexus project WTI; no. DST/TMD/EWO/WTI/2K19/EWFH/2019(C) for financial assistance

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Spatio-Temporal Variations of Physico-Chemical Characteristics and Heavy Metals in Groundwater of an Indo Burma Hotspot Region

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Abstract

Objective: To monitor and provide the first-hand information on the groundwater quality by assessing spatio-temporal variations of physico-chemical characteristics and heavy metals in Aizawl, Mizoram, an Indo Burma biodiversity hotspot region. **Methods:** Physico-chemical characteristics of groundwater were analyzed through standard methodology following American Public Health Association (APHA) while heavy metals were analyzed using Atomic Absorption Spectrophotometer (AAS). **Findings:** Results revealed that several physico-chemical characteristics were observed within the range of regulatory or prescribed limits, except PO_4^{3-} and N-NH_3. To this end, the ranges of physico-chemical characteristics such as Total Alkalinity ((TA) 9.25 -250.9 mg/L), Total Hardness ((TH)11-242.5 mg/L), Calcium (2.2-71 mg/L), Phosphate ((PO_4^{3-}) 0-0.63 mg/L), Ammonia ((N-NH_3)0.056-1.816 mg/L), Nitrate ((N-NO_2) 0.003- 0.88 mg/L), and heavy metals, specifically Zinc ((Zn)0.2.196 mg/L) and Iron ((Fe)0-1.162 mg/L) were recorded. The present study provides first-hand information on physico-chemical characteristics, especially heavy metals in groundwater sample of Aizawl which is an integral landscape of Indo Burma biodiversity hotspot. **Novelty:** Groundwater pollution can be maintained in Aizawl through regular monitoring and application of green chemicals as well as phytoremediation technology to sustain the potable water quality for human well-being/-health.

Keywords: Monitoring; Groundwater; Water Quality Analysis; PhysicoChemical Characteristics; Human Health; Green Chemical

1 Introduction

Water is one of the most basic necessities of life on earth, required to sustain biotic and abiotic components ofglobal ecosystems [(1)]. The global dependency on groundwater for agricultural, industrial, and domestic needs has grown significantly [(2)]. With increasing global population groundwater has become an extremely vital water resource system for consumption, industrial purposes and irrigation, especially in dry and semi-arid regions where surface water and precipitation are scarce [3]. It is predicted that the approximately one-third of the global population is dependent on groundwater for drinking and other household purposes [4]. However, the excessive and unsanitary usage of groundwater has deteriorated the quality and quantity of groundwater resources [5]. For instance, in India, groundwater is intensively used for irrigation and industrial purposes however, multiple human activities resulted in its deterioration which can be deleterious to human health/well-being [6]. Importantly, ground water can also be contaminated by naturally occurring sources . Monsoon seasons induce the percolation of water into the sub surface of the ground, thereby, carrying with its various components present in the soil and promotes seepage of pollutants into the water table, thereby, deteriorating the groundwater quality [7]. Ground water contamination also can occur due to leakage in sewers, petrol stations, untreated water from industries, effluents from wastewater and sewage. Overuse of pesticides, insecticides, and fertilizers in agriculture are also a major contributor for groundwater contamination through leaching of contaminants into ground water through rainwater surface runoff [8]. Usage of polluted groundwater can cause hazards to public health and can even be the cause of various epidemics [9,10]. Therefore, finding prospective areas for groundwater, monitoring and conserving this resource have become highly crucial for the present civilization

The study site, Aizawl city has water supply through pipeline water supply derived from streams and rivers which is managed by Public Health Engineering Department (PHED) of the State Government. However, as rivers and streams being the pipeline water source, the water supply is insufficient due to seasonal rainfall and other technical issues occurred in the vast network of pipeline in the rough terrain of Aizawl city. Most of the household also depends on rainwater and tuikhur (water storage point fed by water seepages from rock strata) and public bore wells have been drilled and installed by the PHED to meet their daily requirement. However, there exist a research gap on the adequate monitoring of physico-chemical properties and presence of heavy metals in groundwater of Aizawl which is quite pertinent to assess its quality for safe human use. Further, heavy metals such as Iron (Fe) and Zinc (Zn) were not analysed in groundwater samples of Aizawl. The analysis of heavy metals in groundwater is pertinent in view of their interrelationship with public health. The spatio-temporal variations of groundwater quality can further speculate the geographic information about the sources of water pollutants and depicting the seasonal variations which can be helpful in devising the mitigation and control measures of the groundwater pollutions [5,8]. Therefore, proper maintenance of these water source is required and the present investigation aimed to perform spatio-temporal monitoring of the groundwater quality by analysing six physico-chemical properties (Total Alkalinity (TA), Total Hardness (TH), Calcium, Phosphate (PO_4^{3-}), Ammonia ($N\text{-}NH_3$), Nitrate ($N\text{-}NO_2$)), and two heavy metals (Zinc (Zn) and Iron (Fe)) to assess the suitability of the water for consumption and other domestic use. Moreover, frequent monitoring of the groundwater quality can bring into light about the physico-chemical characteristic of the groundwater which can significantly assist in formulation of management strategies mediated through application of green chemicals (such as ferrate) and phytoremediation technology to ameliorate the water quality [11,12].

2 Methodology

In the present investigation, 14 groundwater samples were collected from 14 spatially different localities of Aizawl City under five major zonations viz. North, South, Central, East and West parts of Aizawl City (Figure 1), Temporally/seasonally (January 2018-December 2019) groundwater samples were collected and monitoring was performed. Samples were collected and analysed according to the standard method for the analysis of physico-chemical characteristics of water namely: Total Alkalinity (TA), Total Hardness (TH), Calcium, Phosphate (PO_4^{3-}), Ammonia ($N\text{-}NH_3$), Nitrate ($N\text{-}NO_2$), and two heavy metals (Zinc(Zn) and Iron (Fe)) following the methods as outlined in the 'Standard Methods for Examination of Water and Wastewater' as prescribed by APHA [13] and obtained values were compared with standards given regulatory agencies. Heavy metals such as Zn and Fe were analyzed through Atomic Absorption Spectrophotometer (AAS) lying in Mizoram University.

3 Results and Discussion

3.1 Physico-chemical properties

The analysis of physico-chemical properties provides an insight of the water quality of the groundwater. The findings of different physico-chemical parameters are compared with standard limits and are represented in Table 1.

3.1.1 Total Alkalinity (TA)

Classification based on productivity showed that some sites were highly productive in almost all the seasons in both the years (2018 – 2019), whereas most of the sites were within the range of medium productivity in most seasons in both the years. Present result was in corroboration with past study [14], which stated that the total alkalinity was highest in the dry summer

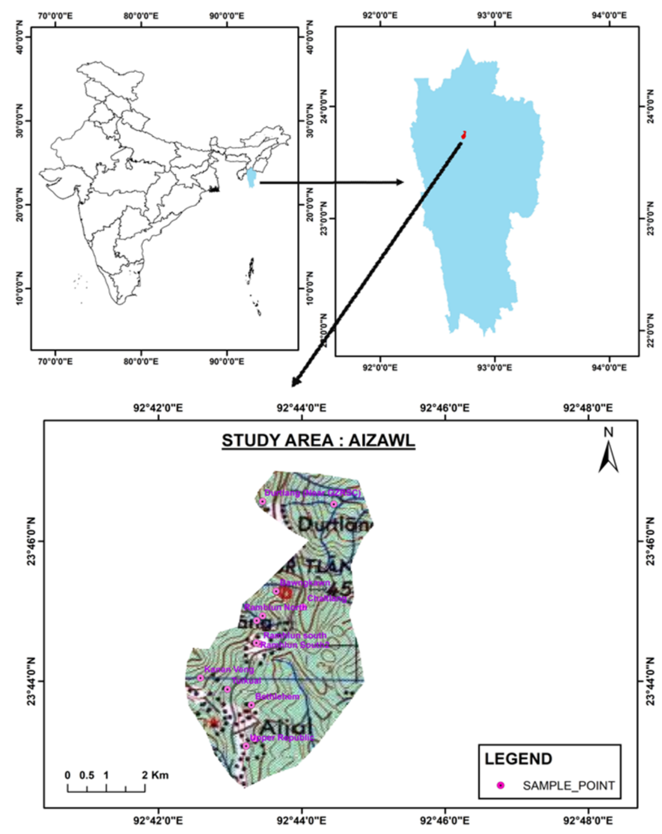

Fig 1. Map showing the study sites

Table 1. Water quality standards for different physico-chemical parameters and heavy metals and range of values

Parameters		Water quality standards				Water quality range during present investigation
		ICMR	BIS	USPH	WHO	
Physico-chemical properties						
1	Total alkalinity (mg/L $CaCO_3$)	200	200	120	200-600	9.25mg/L $CaCO_3$-250.9 mg/L $CaCO_3$
2	Total Hardness (mg/L $CaCO_3$)	300	300	N/A	300	11 mg/L $CaCO_3$-242.5 mg/L $CaCO_3$
3	Calcium (mg/L)	75	200	250	100-200	2.2 mg/L -71 mg/L
4	Phosphate (PO_4^{3-}) (mg/L)	N/A	N/A	0.1	N/A	0 mg/L -0.63 mg/L
5	Ammonia(N-NH_3) (mg/L)	1.5	0.5	1.5	0.5	0.056 mg/L -1.816 mg/L
6	Nitrate-N (mg/L)	150	45	45	50	0.003 mg/L -0.88 mg/L
Heavy metals						
7	Zinc (Zn)	N/A	5	N/A	3	0 -2.196 mg/L
8	Iron (Fe)	1.0	0.3	0.3	0.3	0 mg/L to 1.162 mg/L

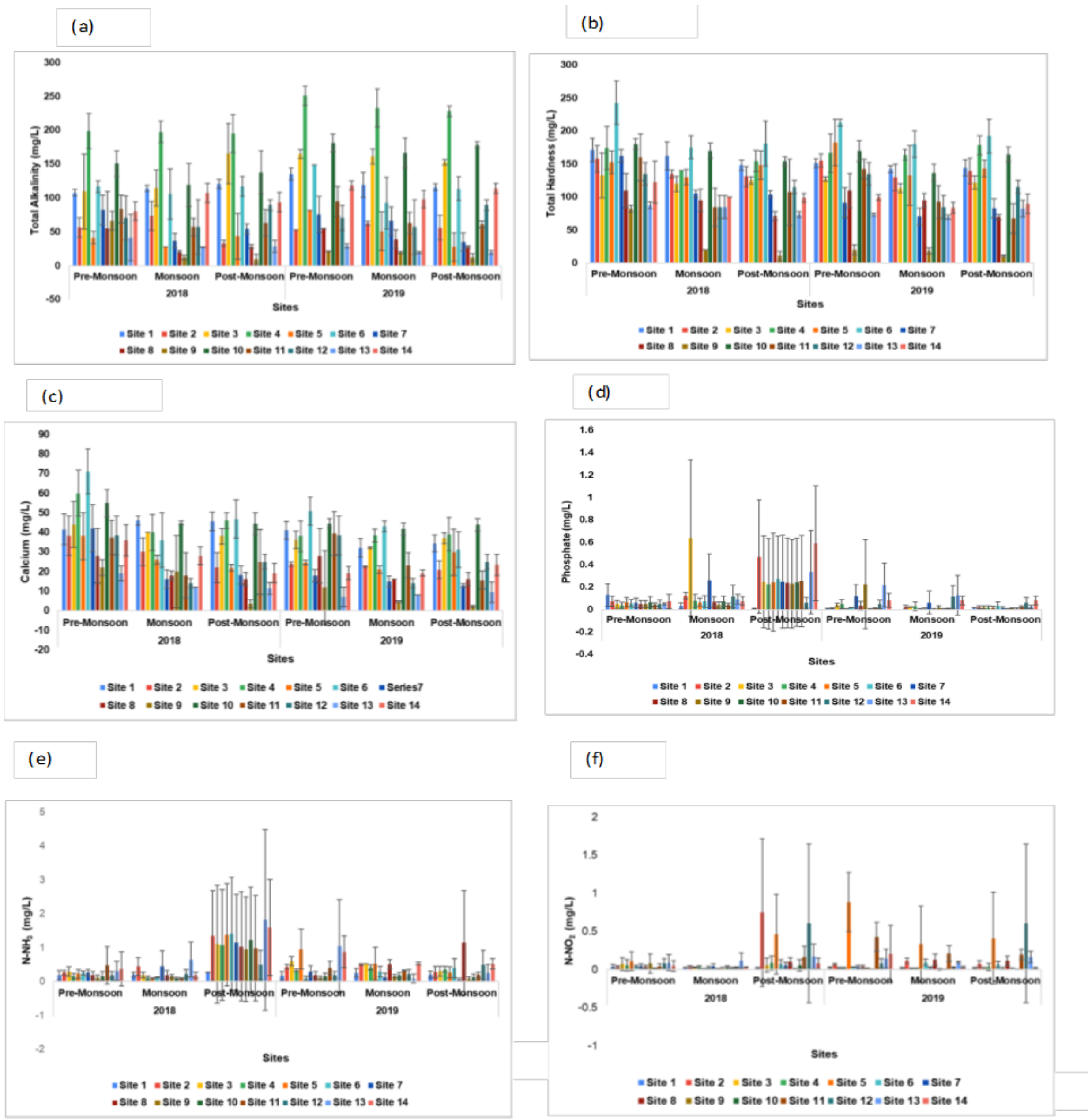

Fig 2. Seasonal variation of physico-chemicalcharacteristic of groundwater in all the study sites; a) Total Alkalinity b)Total Hardness c) Calcium d) Phosphates e) N-NH_3 f) N-NO_2

months while it was recorded lowest during winter season (Figure 2 a). This could be due to the increased seepage of rainwater during the monsoon seasons, which subsequently dilute the water.

Statistically, Two-way ANOVA revealed that the values of total alkalinity recorded in groundwater were significant ($p<0.001$) both between the sites and seasons. A positive and significant correlation of TA was obtained with TH (0.632(39%)), Calcium (0.872(75%)).

3.1.2 Total Hardness (TH)

The total hardness of groundwater at all 14 sites ranged from 11 mg/L to 242.5 mg/L throughout the study period. The total hardness ranged from 11.1 mg/L (site 9 in post-monsoon season) to 242.5 mg/L (site 6 in pre-monsoon season) in 2018. In 2019, however, the range of total hardness was from 11 mg/L (site 9 in post-monsoon season) to 212.5 mg/L (site 6 in pre-monsoon season). The seasonal variations revealed that the total hardness was lowest in post-monsoon season, followed by monsoon season while it was noted highest in pre-monsoon season (Figure 2 b).

The decreased of TH in monsoon could be due to the dilution of water in the monsoon season. During the hot and dry pre-monsoon season, concentration of minerals in groundwater increases due to lack of rain. The results were all within permissible limits set by various regulatory agencies. Nonetheless, based on the classification of hardness, site 9 could be categorised as soft, sites 2, 3, 7, 8, 11, 12, 13 and 14 were considered moderately hard, while sites 1, 4, 5, 6 and 10 were classified as hard in both the years. The present study is in accordance with [15] where the high concentration of TH was observed in the pre-monsoon season when compared with monsoon and post-monsoon seasons. Presence of Magnesium sulphate in groundwater leads to increased total hardness of water. Untreated domestic wastes could also significantly increase the total hardness of water [15].

Two-way ANOVA revealed that the values of total hardness recorded in groundwater were significant ($p<0.001$) both between the sites and seasons. A positive and significant correlation of TH was obtained with TA (0.632(39%), Calcium (0.888(77%)) and Zn (0.619(37%)).

3.1.3 Calcium

The calcium levels ranged from 2.2 mg/L to 71 mg/L in all the samples throughout the study period. In 2018, the range of calcium levels was from 3.6 mg/L (site 9 in post monsoon season) to 71 mg/L (site 6 in pre-monsoon season). However, in 2019, the range of calcium levels was from 2.2 mg/L (site 9 in post-monsoon season) to 50.8 mg/L (site 6 in pre-monsoon season). Seasonal variations revealed that the calcium levels were highest in pre-monsoon season and lowest in post monsoon season (Figure 2 c).

The range of calcium levels were all within permissible limits set by various regulatory agencies. The present result was in accordance with previous study [16] who also concluded that calcium levels were higher in summer than monsoon. The untreated disposal of wastes and wastewater intensifies the contamination of natural water with calcium ions [17].

Two-way ANOVA revealed that the values of Calcium recorded in groundwater were significant ($p<0.001$) both between the sites and seasons. A positive and significant correlation of Calcium was obtained with TA (0.872(75%)), TH (0.888(77%)) and Zn (0.534(28%)).

3.1.4 Phosphate (PO_4^{3-})

The phosphate levels ranged from 0 mg/L to 0.6365 mg/L in the two consecutive years i.e., 2018-19. In 2018, the phosphate levels ranged from 0.007 mg/L (site 1 in post-monsoon season) to 0.6365 mg/L (site 3 in monsoon season). In 2019, however, the phosphate levels ranged from 0 (site 1 in monsoon season) to 0.2155 mg/L (site 13 in pre-monsoon season) (Figure 2d).

Phosphate in water is usually contributed by soil erosion, human and animal wastes, cleaning detergents, and industrial effluents. Phosphate values noted in present study were quite comparable to the past studies [18]. Ecological habitats are vastly limited by phosphate containing materials, which brings the need for managing the input of phosphorus in the aquatic ecosystems. It has also been observed that the presence of phosphate compounds can enhance the discharge of arsenic in the groundwater, thereby increasing the intensity of heavy metal contamination [19]. The agricultural practices of using fertilizers have led to a large concentration of phosphorus in the soil horizons, which in turn can contaminate the groundwater [20]. This study also states that the phosphate contamination has led to worldwide threat on the safety of aquatic organisms and the safe use of water.

Two-way ANOVA revealed that the values of Phosphate recorded in groundwater were significant ($p<0.001$) between the sites. A positive and significant correlation of phosphate was obtained with N-NH_3(0.574(32%)), Fe (0.589(33%)

3.1.5 Ammonia(N-NH_3)

The Ammonia (N-NH_3) levels in all samples from the 14 sites ranged from 0.056 mg/L to 1.816 mg/L during 2018-19. The range of N-NH_3 levels was from 0.091 mg/L (site 5 in monsoon season) to 1.816 mg/L (site 13 in post monsoon season) in the year 2018. The N-NH_3 levels in 2019 ranged from 0.056 mg/L (site 7 in post- monsoon season) to 1.1485 mg/L (site 8 in post-monsoon seasons) (Figure 2 e).

In the year 2018, N-NH_3 values were within permissible limits at all the sites during the pre-monsoon and monsoon season. On contrary, almost all of the sites exceeded the limits set by World Health Organization (WHO) and Bureau of Indian Standards (BIS) in the post monsoon season during the year 2018. In 2019, all sites were within permissible limits of WHO and BIS, with the exception of sites 3, 5, 13 and 14 in pre-monsoon season and site 8 in post monsoon season. All sites except 13 and 14 in post monsoon were within acceptable limits of Indian Council of Medical Research (ICMR) and United State of Public Health (USPH) during the year 2018. The same result was also concluded by[21], who stated that the ammonium levels were higher after precipitation.

Two-way ANOVA revealed that the values of N-NO_2 recorded in groundwater were significant ($p<0.001$) between the sites. A positive and significant correlation of N-NH_3 was obtained with phosphate (0.574(32%)).

3.1.6 Nitrate (N-NO_2)

The N-NO_2 levels of all samples from the 14 sites ranged from 0.00375 mg/L to 0.885 mg/L. In the year 2018, the N-NO2 levels ranged from 0.00775 mg/L (site 9 in the post-monsoon) to 0.745 mg/L (site 2 in post-monsoon season). In the year 2019, however, the N-NO_2 levels ranged from 0.00375 mg/L (site 11 in pre-monsoon season) to 0.885 mg/L (site 5 in pre- monsoon season) (Figure 2 f). The present observations were all found to be under the maximum permissible limits set by the regulatory agencies. Similar result was also observed in previous study[22]. High variations in concentrations were mostly attributed to the influence of anthropogenic factors. High nitrite levels beyond acceptable limits are usually due to the combined influence of ammonium, organic nitrogen, and nitrite compounds[23].

3.2 Heavy metals

3.2.1 Zinc (Zn)

The Zn content ranged from 0 mg/L to 2.196 mg/L during the entire study period of 2018-2019. During 2018, the Zn concentrations in groundwater ranged from 0 mg/L (sites 1, 2, 7, 13 and 14 in pre-monsoon season and site 8 in all seasons, pre-monsoon, monsoon and post monsoon) to 1.7076 mg/L (site 10 in pre-monsoon season). Whereas, in 2019, the Zn levels ranged from 0mg/L (sites 8 in pre-monsoon season and site 9 and 12 in all seasons, pre-monsoon, monsoon and post monsoon) to 2.196 mg/L (site 5 in pre-monsoon season). Seasonal variation revealed that Zn levels was highest in pre-monsoon, followed by monsoon and least in post monsoon seasons respectively (Figure 3 a).

Zn levels in groundwater may vary in different seasons due to changes in rate of percolation, increased runoffs, evaporation rate and humidity. The decrease in Zn content during monsoon and post monsoon could be due to dilution of groundwater from increased rainfall. The present findings were in accordance with the past study[24]. Zn can be harmful to human population when present in excess concentrations with-in groundwater. Excessive Zn in groundwater can have adverse effects on human health such as nausea, vomiting, and diarrhoea. High consumption of Zn from water or its intake from the atmosphere and troposphere for a long period may have serious health impacts, causing a variety of problems related to the digestive tract, respiration, and nervous system[25]. Zn contamination can also impact aquatic ecosystems by affecting the growth and reproduction of aquatic organisms. A positive and significant correlation of Zn was obtained with TH (0.619(37%)) and Calcium (0.534(28%))

3.2.2 Iron (Fe)

The Fe levels in the groundwater of all the 14 sites ranged from 0 mg/L to 1.162 mg/L. In the year 2018, the total range of Fe concentration was found to be from 0 mg/L (sites 1, 4, 6, 9, 11, 12, 13 and 14 in pre-monsoon season, sites 1, 4, 6, 9, 12 and 13 in monsoon season, and sites 1, 4, 9, 12 and 13) to 1.162 mg/L (site 7 in pre-monsoon season). In 2019, the range of Fe levels was from 0 mg/L (sites 1, 2, 4, 5, 8, 9, 10, 12 and 13 in pre-monsoon season, sites 1, 4, 9, 12 and 13 in monsoon season and sites 2, 4, 6, 9, 12 and 13 in post monsoon season) to 0.7496 mg/L (site 1 in post monsoon season). The total range observed in the two years was from 0 mg/L to 1.162 mg/L. The Fe level seems to be highest in pre-monsoon and lowest in post monsoon (Figure 3 b).

Seasonal changes in temperature, humidity and rainfall can have huge impacts on the levels of Fe. The heavy precipitation in the area, causing increased leaching can be the main reason for this. Site 7 in pre-monsoon season has exceeded the acceptable

(a)

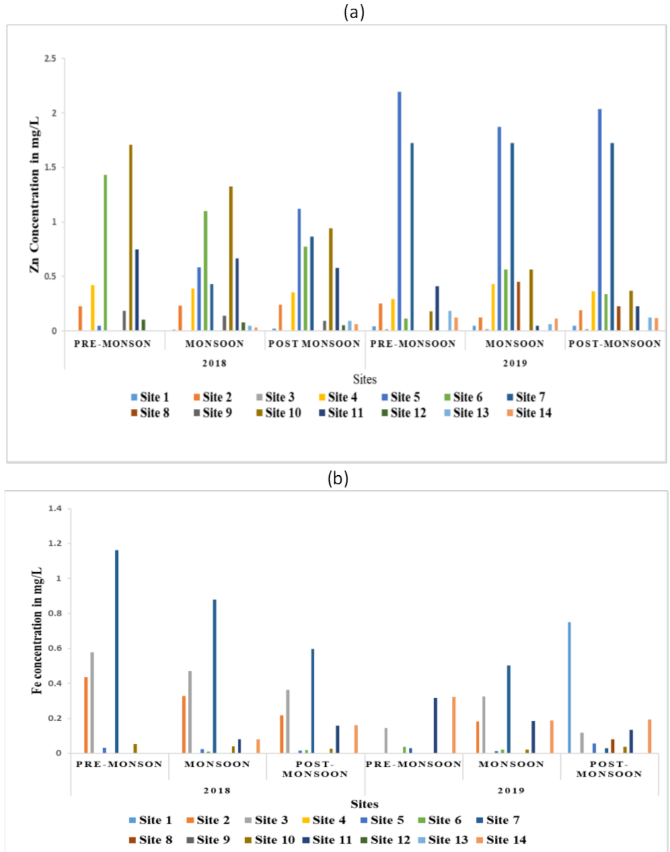

Fig 3. Seasonal variation of heavy metals in all the study sites; a) Zinc; b) Iron

standards set by various scientific agencies. This could be attributed to the rusting of Fe associated with the hand pumps and further seepage to groundwater. Similar results on Fe concentrations in groundwater were recorded in past studies[24].

Consumption of Fe contaminated water may pose a significant health risk and can have adverse effects on the aesthetic qualities of the water such as cancer, cardiac disorders and problems related to nerves, liver, and methemoglobinemia which results when Fe in the blood existing in ferrous form get oxidised to ferric form. A positive and significant correlation of Fe was obtained with and phosphate (0.589(33%)). Application of green chemicals such as ferrate and phytotechnologies can ameliorate the heavy metals for human well-being/-health[11,12].

4 Conclusion

The present study provided first-hand information on groundwater quality, especially in relation to heavy metals which are intimately linked with human health. The spatio-temporal monitoring of the physico-chemical properties of groundwater in Aizawl demonstrated that the majority of values pertaining to the physico-chemical parameters were high in the pre-monsoon season at distinct sites, except PO_4^{3-}(0.6365 mg/L at site 3) and N-NH_3 (1.816 mg/L at site 13) which were high in monsoon and post-monsoon seasons, respectively and also exceeded the permissible limit. However, heavy metals like Zn and Fe were present below the regulatory agency. The present study concluded that the sustained groundwater quality monitoring of Aizawl is necessary for safe human use. The presences of high concentration of PO_4^{3-} and N-NH_3 can deteriorate the water quality and can also lead to eutrophication if stored in microcosm water system with potential to perturb the aquatic ecosystem health. Therefore, it is important to frequently monitor the groundwater quality. Application of green chemicals and phytoremediation can be sustainable technology can help reduce the groundwater contaminants to safeguard the public health.

Acknowledgement

Authors are grateful to the Department of Science and Technology (DST)- Nexus project WTI; no. DST/TMD/EWO/WTI/2K19/EWFH/2019(C) for financial assistance.

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