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Research Article

Assessment of physicochemical characteristics and identification of groundwater quality indicator parameters in Aizawl, Mizoram, Northeast India

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Abstract
The increase in population and rapid industrial development have resulted in surface water pollution that stresses groundwater resources to ensure sustainable consumption and human well-being. The present study was aimed to assess the physico-chemical characteristics and heavy metal concentration of groundwater in Aizawl city. The study also seeks to determine the indicator parameters of water quality through analysis of variance (ANOVA) and correlation coefficient in relation to physico-chemical properties. The results revealed that all physico-chemical parameters were within the regulatory standards, except turbidity (80.9 NTU) and phosphate (0.6365 mg/L). Trace amounts of Zinc (Zn) and Copper (Cu) were also present; however, Iron (Fe) and Manganese (Mn) slightly exceeded (Fe: 1.162 mg/L; Mn: 0.6892 mg/L) the permissible limit. Statistically, two-way ANOVA revealed that temperature, chloride, total alkalinity (TA), total hardness (TH), calcium, and dissolved oxygen (DO) were significant ($p<0.001$) both between sites and seasons. Further, TH showed positive and significant correlation with total dissolved solid (TDS) (R^2=0.792), chloride (R^2=0.52), TA (R^2=0.62), calcium (R^2=0.88), and Zn (R^2=0.61). Conversely, DO demonstrated negative and significant correlation with turbidity (R^2=-0.73), chloride (R^2=-0.52), phosphates (R^2=-0.70), ammonia (R^2=-0.81), and Mn (R^2=-0.58). These results indicate that the analysis of TH and DO can serve function as proxies for indirectly indicating the presence and concentrations of the other correlated water quality parameters. Thus, TH and DO act as indicator parameters for water quality in holistic groundwater monitoring in Aizawl. The identification of water quality indicator parameters can play a key role in future research for cost-effective, rapid, and seasonal groundwater monitoring to ensure the sustainable management of this resource.

Keywords: Arsenic, groundwater, Heavy metals, Human health, Physico-chemical parameters, Water quality indicator

INTRODUCTION

Water is one of the most important basic necessities of life on Earth and a vital natural resource for environmental sustainability (Giri, 2020; Rai *et al.,* 2023). In recent decades, the global dependence on groundwater for agricultural, industrial, and domestic purposes has increased dramatically as the quality of surface water has declined significantly worldwide (Zhang *et al*., 2021; Das *et al*., 2021). With the growing global population, groundwater has become an extremely important resource for consumption, industrial purposes, and irrigation, especially in dry and semi-arid regions where surface water and precipitation are scarce (Li *et al*. 2017; Chakraborty *et al*., 2022). Approximately one-third of the world's population relies on groundwater for drinking and domestic use (International Association of Hydrogeologists, 2020). It is estimated that about 50% of total water utilized for domestic purposes comes from groundwater resources (UNESCO, 2022). According to the United Nations Environment Program (UNEP, 1999), developing countries, particularly China and India, use more groundwater resources for drinking purposes. On the contrary, Central Asian countries such as Kyrgyzstan, Tajikistan, Kazakhstan, Uzbekistan, and Turkmenistan used the utilized abundant groundwater resources for various several domestic and other purposes (Liu *et al*., 2020). However, in a more recent scenario, low groundwater availability (i.e., about 2.5 %) in countries such as Turkmenistan limits its use for essential domestic purposes only and deprives other important sectors such as agriculture (Liu *et al*., 2020).

Groundwater is a significant component of the global water cycle and plays a crucial role in supporting various ecosystems, agriculture, and human needs (Lalawmpuii and Rai, 2023). Further, groundwater resources are integral sources of clean drinking water and their sustenance is intimately linked with United Nations sustainable development goals (UNSDGs) (specifically, SDG 6 i.e.,'clean water and sanitation') (Gao, 2020). In this respect, SDG 6 includes targets related to improving access to safe and affordable drinking water, sanitation facilities, and the sustainable management of water resources. Also, the sustainable management of groundwater quality is the need of the hour given its inextricable linkage with human health and well-being (SDG 3) (Rai *et al.,* 2022). However, increasing population, urbanization, industrialization, and wide adoption of modern agricultural practices in recent decades have led to contamination of groundwater (Saleh *et al.,* 2018). Water pollutants especially heavy metals/-metalloids occur naturally and therefore they easily enter into groundwater through the weathering of rocks, limestone, and minerals (Thambidurai *et al.,* 2012; Sankoh *et al*., 2023). However anthropogenic sources like domestic waste, metals from factories, and accidental oil spills also find their way into groundwater (Sankoh *et al*., 2023; Zonunthari *et al.,* 2023a). Arsenic (As) contamination in aquifer systems is ascribed to the weathering of rocks and agricultural runoff which can perturb the groundwater quality (Singh *et al.,* 2004; Kapesa and Raju, 2007 Shaji *et al*., 2021).

Heavy metals and As contamination in groundwater systems have been reported in several Indian cities (Ravindra and Mor, 2019; Shaji *et al*., 2021).ji For instance, several villages of Chandigarh were reported to be contaminated with heavy metals/-metalloids such as Cadmium (Cd), Nickel (Ni), Lead (Pb) and Zinc (Zn) (Ravindra and Mor, 2019). In addition to urban cities, surface and groundwater resources in pristine landscapes of the north eastern region are also reported with excess concentrations of heavy metals and As (Zonunthari *et al.,* 2023a; Zonunthari *et al.,* 2023b; Laishram and Kshetrimayum, 2019; Lahkar and Bhattacharyya, 2019). The ingestion of these heavy metals/-metalloids contaminated groundwater can cause various human health hazards like immunodeficiency, osteoporosis, neurotoxicity, kidney and other organ failures, and cancer (Ravindra and Mor, 2019; Gupta *et al.,* 2023). Therefore, extensive study is needed to monitor the groundwater quality in India, especially in the mountainous landscape of Aizawl (Mizoram, North East (NE) India). The evaluation of groundwater quality in Aizawl is necessary to safeguard the public health of traditional indigenous society.

Physicochemical characteristics of water can interact with and influence heavy metal concentrations in groundwater, therefore advocated to be analyzed simultaneously (Rai, 2010). Several studies have reported that parameters like TDS, pH, electrical conductivity (EC), chemical oxygen demand (COD), biological oxygen demand (BOD), phosphates, sulphates, and heavy metals (e.g., copper, cobalt, cadmium and lead) were positively correlated (Popoola *et al*., 2019; Qureshi *et al*. 2021). Therefore, the analysis and identification of certain physico-chemical characteristics can help determine the other correlated parameters (Singh *et al*., 2004). Mountainous regions are subjected to high rise in temperature which leads to a decline in surface water availability through increased evapotranspiration. Moreover, mountainous regions receive less availability to surface water because of the high altitudes which makes them over-dependent on groundwater resources. However, groundwater can provide adequate water supply in such hilly landscapes (Somers *et al*., 2019; Somers and McKenzie, 2020).

The majority of the studies reported in Aizawl were based on surface water resources like rivers and spring water, however, there are scanty studies on seasonal groundwater quality and heavy metals monitoring. The present study is novel as it attempts to statistically identify salient water quality indicator parameters which can act as a proxy for other physico-chemical characteristics to depict the health of groundwater. Analyzing all physico-chemical characteristics of groundwater is in fact time consuming and labour intensive. Therefore, the identification of water quality indicator parameters can be a cost-effective and sustainable approach for long-term monitoring.

The major source of drinking water in Aizawl City is the groundwater and domestic water supply through pipeline. Pipeline water supply is usually the treated water that is managed by the Public Health Engineering Department (PHED) of the Mizoram. However, the pipeline water supply is insufficient to meet the needs of the people. Additionally, since rivers are the only water source for pipeline connections, the amount of water supplied through this connection is highly variable due to seasonal variations in rainfall and several geographical constraints of Aizawl City. Therefore, many households depend on secondary water sources like rainwater and groundwater. Groundwater in Aizawl is extracted from hand pumps and bore wells constructed by the Mizoram government. Safe utilization of groundwater is necessary to safeguard the human health and well-being of local residents in Aizawl. Consequently, there is a need for proper monitoring and maintenance of the groundwater resources in the Aizawl district. Therefore, the present study aimed to monitor the physico-chemical properties and heavy metals present in the groundwater of Aizawl City. Also, the study further attempted to identify water quality indicator parameters through correlation coefficient and analysis of variance (ANOVA).

MATERIALS AND METHODS

Groundwater samples were collected seasonally (i.e., pre-monsoon (February-May), monsoon (June-September), and post- monsoon (October-January) seasons) from 14 different localities of Aizawl City under five major zonation i.e., North, South, Central, East and West parts of Aizawl City, for a time duration of 2 years (i.e., January 2018-December 2019). Fig. 1 represents the location of sampling sites in Aizawl. Samples were collected as per the standard sampling method. Physico-chemical characteristics of water such as temperature (°C; centigrade thermometer with a precision of 0.1°C), pH (pH meter), turbidity (NTU; turbidity meter), TDS (mg/L; evaporation and filtration method), chloride (mg/L; argentometric titration method), total alkalinity (TA) (mg/L; potentiometric titration method), total hardness (TH) (mg/L; EDTA titration method), calcium (mg/L; titration method), phosphate-P (mg/L; stannous chloride method), nitrogen ammonia ($N\text{-}NH_3$) (mg/L; calorimetric method), nitrite ($N\text{-}NO_2$) (mg/L; phenol disulphonic acid method), and dissolved oxygen (DO) (mg/L; Winkler's Azide method) were analyzed following the methods as outlined in the 'Standard Methods for Examination of Water and Wastewater' as prescribed by "American Public Health Association (APHA, 2005)". The results were compared with standards given by as United States Public Health Service (USPH) and Bureau of Indian Standards (BIS) of the year 1962 and1983, respectively. Estimation of heavy metals (Zn, Cu, Fe, and Mn) was done in the present study. Groundwater samples were acid digested as described elsewhere (APHA, 2005; Singh and Rai, 2016; Rai, 2021). Heavy metals were analyzed using an Atomic Absorption Spectrophotometer (AAS) (Model: Shimadzu AA-7000) available in the Department of Chemistry, Mizoram University.

RESULTS AND DISCUSSION

Physical properties

In the present investigation, the average temperature of all the sites in the given study period was 23.57 ± 2.37□ with the highest temperature recorded at site 14 (26°C) during monsoon and post-monsoon period (Table 1). The reason for moderate temperature can be associated with the unavailability of sunlight due to the depth of groundwater. Temperature varies according to a number of factors, including latitude, sun angle, season, wind, water depth, waves, and gain or loss of heat in shallow surface water near the shore (Saad *et al*.,

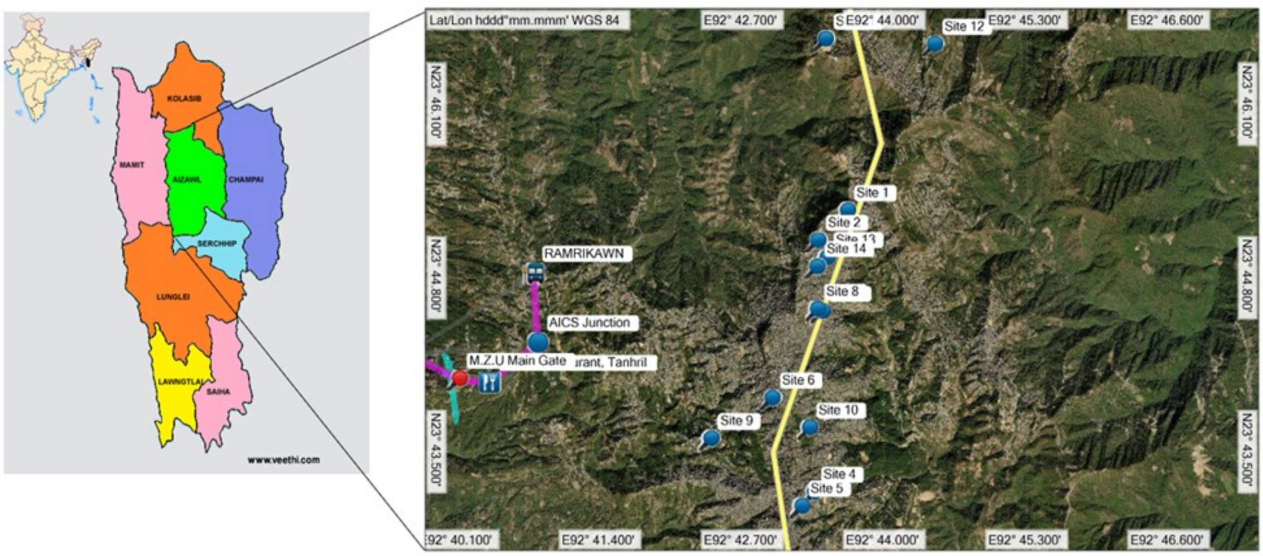

Fig 1. *Map showing different locations of study sites in Aizawl district, Mizoram*

Table 1. Comparison of water quality characteristics results observed in the present study with the scientific standards set by various regulatory agencies

Sl. No	Parameters	Water quality standards				Range of water quality characteristics during the study period
		BIS	USPH	WHO	ICMR	
1	Temperature	-	-	30	N/A	23.57 ± 2.37
2	pH	6.5 – 8.5	6-8.5	6.5-9.2	6.0-8.5	6.80 ± 0.45
3	Turbidity	1	-	5	2.5	4.58 ± 7.67
4	TDS	500	500	1000	500	155.75 ± 19.16
5	Chloride	250	250	250	200	38.21 ± 8.55
6	Total Alkalinity	200	-	200-600	200	88.85 ± 24.55
7	Total Hardness	200	-	300	300	122.06 ± 23.45
8	Calcium	75	100	100-200	75	28.00 ± 9.48
9	Phosphate	-	0.1	N/A	N/A	0.09 ± 0.19
10	$N\text{-}NH_3$	45	-	0.5	1.5	0.45 ± 0.67
11	$N\text{-}NO_2$	45	-	50	150	0.10 ± 0.16
12	DO	-	4-6	4.0-6.0	N/A	4.27 ± 1.17

2017). However, in groundwater, the temperature changes can be ascribed to seasonal variations (Zonunthari *et al.,* 2023c). Two-way ANOVA revealed that the values of temperature recorded in groundwater were significant (p<0.001) both between sites and seasons (Table 2). However, temperature showed a positive and significant correlation with TDS whereas it was negatively correlated with copper (Table 3).

The average pH value at all the sites in the given study period was 6.80 ± 0.45 with the highest pH (7.9) recorded at Site 9 during the pre-monsoon period during the year 2019. This implies that the water is slightly alkaline which may be due to the presence of minerals at the bottom sediment. The lowest pH (5.7) at site 13 during the monsoon period shows that the water is acidic and can cause detrimental effects on human health when consumed without treatment. The low pH of groundwater during monsoon may be ascribed to run-off or seepage of acidic leachates into aquifers. Two-way ANOVA revealed that the values of pH recorded in groundwater were significant (p<0.001) only between the sites (Table 2). This explains the significant variation of pH when compared between the sites, however, there was no significant variation when compared with seasons (Table 3). A negative and significant correlation was obtained with, $N\text{-}NH_3$ and Mn revealing that a decrease in pH will significantly increase their levels in groundwater (Zonunthari *et al.,* 2023b).

In the present study, the average turbidity of all the sites was 4.58 ± 7.67 NTU and the highest value (80.9 NTU) was recorded at site 11 during post monsoon season 2019 while the lowest (0.1 NTU) at site 10 during post-monsoon of the year 2018. Furthermore, turbidity is the cloudiness of water due to the presence of inorganic matter and other dissolved particulate matter. It is one of the important parameters for the analysis of drinking water. Two-way ANOVA revealed that the values of turbidity recorded in groundwater were significant (p<0.001) only between the seasons A positive and significant correlation of turbidity was obtained with phosphate-p and $N\text{-}NH_3$. On the contrary, a negative and highly significant correlation was obtained with DO (Table 3).

In the present investigation, the average TDS at all the selected sites was 155.75 ± 19.16 mg/L with highest TDS (268 mg/L) found at site 6 during the monsoon season of the year 2018 while the lowest value (16 mg/L) was recorded at site 9 during the pre-monsoon and monsoon season of the same study period. The presence of high TDS can be attributed to anthropogenic sources such as domestic sewage, septic tanks, agricultural activities, and runoff during the rainy season. Additionally, TDS mostly consist of carbonates, bicarbonates, chlorides, sulphate, phosphate, silica, calcium, magnesium, sodium, and potassium (Kumar *et al*., 2016). Two-way ANOVA revealed that the values of TDS recorded in groundwater were significant (p<0.001) only between the sites (Table 2). A positive and significant correlation of TDS was obtained with temperature, Chloride, TH, and Calcium (Table 3).

Chemical properties

The present study showed that a high amount (86.025 mg/L) of chloride was found at site 6 during pre-monsoon 2018 and the lowest (3.1625 mg/L) at site 9 during post monsoon season of the year 2019. Chloride in groundwater can originate from a variety of sources, including weathering, leaching of sedimentary rocks and soil, and home and municipal effluents (Sarath Prasanth *et al*., 2012; Kumar *et al*., 2014). Presence of chloride in water indicates sewage pollution

Table 2. Two-way ANOVA for all the physico-chemical parameters of groundwater

Source of Variation	SS	df	MS	F	P-value	F crit
Temperature						
Between Sites	111.857887	13	8.604453	8.024222	2.87E-09	1.87388
Between Seasons	159.289435	5	31.857887	29.709587	1.42E-15	2.356028
Error	69.700149	65	1.07231			
Total	340.84747	83				
pH						
Between Sites	16.359127	13	1.258394	12.152584	7.75E-13	1.873879951
Between Seasons	0.699874	5	0.139975	1.351766	0.254139	2.356027822
Error	6.73072	65	0.10355			
Total	23.789721	83				
Turbidity						
Between Sites	1611.847329	13	123.988256	1.481609	0.148591	1.87388
Between Seasons	2433.683787	5	486.736757	5.816304	0.000169	2.356028
Error	5439.517359	65	83.684882			
Total	9485.048475	83				
TDS						
Between Sites	180564.2329	13	13889.55638	47.277972	5.25E-28	1.87388
Between Seasons	739.801339	5	147.960268	0.503635	0.772431	2.356028
Error	19096.02158	65	293.784947			
Total	200400.0558	83				
Chloride						
Between Sites	27485.0218	13	2114.232446	56.055966	3.67E-30	1.87388
Between Seasons	861.068012	5	172.213602	4.566007	0.001248	2.356028
Error	2451.569727	65	37.716457			
Total	30797.65954	83				
Total Alkalinity						
Between Sites	246623.5111	13	18971.03932	74.998462	6.29E-34	1.87388
Between Seasons	6484.706252	5	1296.94125	5.127215	0.000503	2.356028
Error	16441.90466	65	252.952379			
Total	269550.122	83				
Total Hardness						
Between Sites	143661.0963	13	11050.85356	51.09376338	5.52E-29	1.87388
Between Seasons	15295.86086	5	3059.172173	14.14412183	2.35E-09	2.356028
Error	14058.57455	65	216.2857624			
Total	173015.5318	83				
Calcium						
Between Sites	11124.62551	13	855.740424	28.554103	6.89E-22	1.87388
Between Seasons	2721.898839	5	544.379768	18.164709	3.09E-11	2.356028
Error	1947.990744	65	29.969088			
Total	15794.51509	83				
Phosphates						
Between Sites	0.135739	13	0.010441	1.210491	0.2925	1.87388
Between Seasons	0.554791	5	0.110958	12.863547	1.06E-08	2.356028
Error	0.560676	65	0.008626			
Total	1.251206	83				
$N-NH_3$						
Between Sites	1.70003	13	0.130772	2.384317	0.011025	1.87388
Between Seasons	8.150679	5	1.630136	29.721764	1.41E-15	2.356028
Error	3.565025	65	0.054847			
Total	13.415733	83				
$N-NO_2$						
Between Sites	0.820228	13	0.063094	3.419144	0.000485	1.87388
Between Seasons	0.244376	5	0.048875	2.64859	0.030603	2.356028
Error	1.199464	65	0.018453			
Total	2.264067	83				
DO						
Between Sites	37.292917	13	2.868686	7.244156	1.73E-08	1.87388
Between Seasons	30.429853	5	6.085971	15.368611	5.91E-10	2.356028
Error	25.740002	65	0.396			
Total	93.462772			83		

(Shrivastava *et al*., 2010). Two-way ANOVA revealed that the values of chloride recorded in groundwater were significant ($p<0.001$) both between the sites and seasons (Table 2). A positive and significant correlation of chloride was obtained with TDS and TH. On the contrary, a negative and significant correlation was obtained with pH and DO (Table 3).

The average alkalinity of all the sites in the present investigation was 88.85 ± 24.55 mg/L (Table 1). Highest alkalinity (250.9 mg/L) was observed at site 4 during pre-monsoon season of 2019 while lowest alkalinity (9.25 mg/L) was found at site 9 during post-monsoon season of the year 2018. Alkalinity is often associated with the presence of hydroxide, carbonates, and bicarbonate (Boyd *et al.,* 2016). Statistically, Two-way ANOVA revealed that the values of TA recorded in groundwater were significant ($p<0.001$) both between the sites and seasons (Table 2). A positive and significant correlation of TA was obtained with TH and Calcium (Table 3).

The average TH of the present investigation was 122.06 ± 23.45 mg/L, where the highest (242.5 mg/L) is observed at site 6 during pre-monsoon period and the lowest (11 mg/L) at site 9 during post-monsoon period. Hardness of water is due to the presence of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ion in the water (Abd Aziz, 2019). The degree of hardness has been classified as temporary or permanent. Temporary hardness can be decreased by boiling, whereas permanent hardness requires special chemical treatment (MacAdam and Jarvis, 2015). Two-way ANOVA revealed that the values of TH recorded in groundwater were significant ($p<0.001$) both between the sites and seasons. A positive and significant correlation of TH was obtained with TDS, chloride, TA, calcium, and Zn. This observation signifies that high TH in water can be attributed to the presence of calcium, dissolved solids, and some metals emanating from weathering of fragile rocks (Thambidurai *et al.,* 2012; Zonunthari *et al.,* 2023c). The TH in groundwater of present study site can therefore be attributed to the weathering of limestone, rocks, and calcium-bearing minerals. Thus, the contaminants in the groundwater of study area are mostly geogenic due to the the lack of industries and modern intensive agriculture in Mizoram (Singh *et al.,* 2004; Kapesa and Raju, 2007; Rai, 2012). Analysis of TH can therefore indirectly indicate the concentration of the other parameters such as TDS, chloride, TA, calcium, and Zn, thereby signifying their role as water quality indicator parameters (Table 3).

The average calcium content observed in the present study was 28.00 ± 9.48 mg/L with the highest (71 mg/L) at site 6 during pre-monsoon and the lowest (2.2 mg/L) at site 9 during post-monsoon period. The present result was in accordance with Ahouansou *et*

Table 3. Correlation coefficient of physico-chemical properties of water with heavy metals

	Temperature	pH	Turbidity	TDS	Chloride	TA	TH	Calcium	Phosphate	N-NH3	N-NO2	DO	Zinc	Copper	Fe	Mn
Temperature	1															
pH	-0.409	1														
Turbidity	0.29	-0.212	1													
TDS	0.542*	-0.239	0.198	1												
Chloride	0.181	-0.513*	0.303	0.791**	1											
TA	0.385	0.412	0.082	0.367	-0.131	1										
TH	0.345	0.031	0.064	0.792**	0.522*	0.633*	1									
Calcium	0.373	0.272	-0.023	0.580*	0.161	0.872**	0.888**	1								
Phosphate	0.451	-0.205	0.576*	0.064	0.068	0.061	-0.049	-0.016	1							
N-NH3	0.384	-0.549*	0.558*	0.213	0.397	-0.292	-0.125	-0.322	0.574*	1						
N-NO2	-0.17	-0.305	-0.058	0.118	0.413	-0.361	-0.007	-0.276	0.025	0.166	1					
DO	0.298	0.457	-0.735*	-0.307	-0.529*	0.057	-0.07	0.116	-0.701*	-0.810**	-0.362	1				
Zinc	0.057	0.343	-0.132	0.458	0.261	0.295	0.619*	0.534*	-0.192	0.042	-0.162	0.088	1			
Copper	-0.539*	0.242	-0.184	-0.186	-0.055	-0.081	-0.092	-0.157	-0.297	-0.33	0.560*	0.113	-0.195	1		
Fe	0.05	0.128	0.298	0.177	0.144	-0.058	0.024	-0.055	0.589*	0.228	-0.021	-0.305	-0.068	-0.142	1	
Mn	0.494	-0.557*	0.344	0.139	0.208	-0.133	-0.006	-0.15	0.462	0.647*	0.306	-0.582*	-0.022	-0.292	0.096	1

al., (2018) who recorded higher calcium levels in summer than in monsoon. The range of calcium levels was all within permissible limits set by various regulatory agencies. The untreated disposal of wastes and wastewater intensifies the contamination of natural water with calcium ions (Sudarshan *et al*., 2019). Two-way ANOVA revealed that the values of calcium recorded in groundwater were significant ($p<0.001$) both between the sites and seasons (Table 2). A positive and significant correlation of calcium was obtained with TDS, TA, TH, and Zn (Table 3).

The average phosphate contents in the present investigation ranged from 0.09 ± 0.19 mg/L. Presence of phosphates in groundwater can be attributed to dissolved organic carbon derived from microorganisms-mediated mineralization (Neidhardt *et al*., 2018; Liu *et al*., 2023). Two-way ANOVA revealed that the values of phosphate recorded in groundwater were significant ($p<0.001$) only between the sites (Table 2). A positive and significant correlation of phosphate was obtained with turbidity, N-NH_3, and Fe (Table 3).

The average ammonia content in the present study was 0.45 ± 0.67mg/L. The N-NH_3 levels were found lowest (0.056 mg/L) at site 5 during monsoon season and highest (1.816 mg/L) at site 13 during post monsoon season in the year 2018 whereas, it was lowest at site 7 during post- monsoon season while highest at site 8 during post-monsoon seasons in the year 2019. Two-way ANOVA revealed that the values of N-NH_3 recorded in groundwater were significant ($p<0.001$) only between the seasons. A positive and significant correlation of N-NH_3 was obtained with turbidity, Mn and phosphate. On the contrary, a negative and significant correlation was obtained with pH and DO (Table 3).

The average nitrate content of groundwater in the present investigation was recorded 0.10 ± 0.16 mg/L. The NO_2 content was present within the permissible set by various regulatory agencies. NO_2 in groundwater could be released from the nitrogen-based fertilizers, sewage and animal waste break down in the soil which eventually seeps into the groundwater (Gao *et al*., 2012). Exposure to high concentrations of NO_2 causes respiratory diseases known as methaemoglobinaemia or blue baby syndrome which often occur in infants (Kanmani and Gandhimathi, 2013). 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-NO_2 was obtained with Cu (Table 3).

The DO of groundwater in the present study was recorded 4.27 ± 1.17 mg/L. Two-way ANOVA revealed that the values of DO recorded in groundwater were significant ($p<0.001$) both between the sites and seasons (Table 2). A negative and significant correlation was obtained with turbidity, chloride, phosphate, N-NH_3, and Mn which depicts that DO was inversely proportional to turbidity, chloride, phosphate, N-NH_3, and Mn. The analysis of DO can indirectly display the presence and the concentration of the other parameters without analyzing them. Therefore, in the present study DO can be considered as water quality indicator parameter to potentially facilitate the rapid and cost-effective monitoring of groundwater. Herein, DO and TH are observed as indicator parameters for groundwater quality because of their statistical correlation with other physico-chemical characteristics. However, DO values can remarkably be influenced by the microbial community and geology of the aquifer (Rai, 2010). The analysis of groundwater quality requires time and labour to analyse all the physicochemical parameters which makes regular monitoring of groundwater difficult. Past studies have also reported rapid evaluation of water quality through multivariate statistical analysis (Singh *et al*., 2004; Mamun *et al*., 2021; Gyimah *et al*., 2021).

Heavy metals

Heavy metals analysis revealed the presence of trace amounts of heavy metals like Zn and Cu at selected sampling sites of Aizawl city. However, Iron (Fe) and Manganese (Mn) were recorded slightly above (Fe: 1.162 mg/L; Mn: 0.6892 mg/L) permissible limit (Table 4). The terrain of Mizoram is hilly and rocky, with most of the land covered by dense forests. The environmental attributes such as climate, topography and geology of Mizoram have a significant influence in the weathering of rocks which can influence the release of metals/-metalloids (Rai, 2012). The presence of Fe in groundwater could be ascribed to their release from the earth's crust and through anthropogenic activities like

Table 4. Comparison of heavy metals in present investigation scientific standards set by various regulatory agencies (2018-2019)

Sl. No.	Parameters	Water quality standards				Water quality range during present investigation (average of three samples)
		WHO	BIS	USPH	ICMR	
1	Iron (Fe) mg/L	0.3	0.3	0.3	1.0	0 mg/L to 1.162 mg/L
2	Zinc (Zn) mg/L	3	5	N/A	N/A	0 -2.196 mg/L
3	Manganese (Mn) mg/L	0.4	0.1	N/A	N/A	0- 0.6892 mg/L
4	Copper (Cu) mg/L	2	2	N/A	N/A	0 -0.0189 mg/L

untreated waste discharge (Rai *et al.,* 2018). Metallic contaminants in the groundwater of Mizoram and other Northeastern states are mostly geogenic with aquifer type being sandstone and shale (Singh, 2004; Kapesa and Raju, 2007; Thambidurai *et al.,* 2012). Although Fe is an essential element for human health, however when present in excess concentration can poses threats to human health by causing various diseases such as cancer, cardiac disorders, neurological and the liver problems (Kumar *et al*., 2017; Rai *et al.,* 2019). Further, excessive consumption Mn contaminated water can cause damage to the nervous system, especially in children (Therdkiattikul *et al*., 2020).

Conclusion

Monitoring the physico-chemical characteristics of groundwater provides the information about the quality and potability of water for safe human consumption. The present investigation revealed that all the physico-chemical parameters were within acceptable limits, except turbidity, phosphates, and ammonia. The concentration of heavy metals like Fe and Mn were also recorded above the permissible limit. Statistically, the two-way ANOVA showed that there were significant variations between sites and seasons for most of the physico-chemical parameters. In addition TH showed a positive correlation with TDS, chloride, TA, Calcium and Zn, whereas DO was negatively correlated with turbidity, chloride, phosphates, ammonia, and Mn. Among the twelve physico-chemical parameters analyzed, two parameters namely, TH and DO were observed to be correlated with several parameters and therefore could potentially serve function as water quality indicator parameters for cost-effective, rapid, and regular long-term monitoring of groundwater. Thus, the analysis of TH and DO can indirectly serve as a proxy for the intensity of other physicochemical parameters. The indicator parameters for water quality will reduce the efforts and cost of groundwater monitoring and assessment to facilitate sustainable management and support achievement of the UNSDGs. Identifying water quality indicator parameters will facilitate the seasonal monitoring of groundwater in Aizawl to ensure sustainable safe consumption and human well-being.

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Conflict of interest

The authors declare that they have no conflict of interest.

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