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Hydrogeochemical assessment of groundwater quality: a case study of Federal College of Education (Technical), Omoku, Rivers State

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ABSTRACT

This study was carried out to assess the suitability of groundwater for drinking and irrigation purposes by interpreting the hydrochemical species of groundwater samples. Six water samples were collected and assess to determine the concentration of some ions, pollution load index (PLI), contamination factor (CF), water quality index (WQI), sodium adsorption ratio (SAR), magnesium hazard (MH), Kelly ratio (KR) and percentage sodium (%Na). The result revealed that most of the ions have concentrations within the WHO permissible limit for drinking water except biological oxygen demand (BOD), chemical oxygen demand (COD) and Fe^{2+}, which exceeded the WHO standard in some samples. The mean abundance of the cations is $K^{+} > Na^{+} > Ca^{2+} > Fe^{2+} > Mg^{2+} > Mn^{2+}$, while that of the anions is $Cl^{-} > SO_4^{2-} > HCO_3^{-}$. The result reveals that K^{+} and Cl^{-} are the most abundant cation and anion respectively. CF reveals a low concentration (<1) of So_4^{2-}, Cl^{-} K^{+}, Na^{2+}, Ca^{2+}, Mg^{2+}, and Mn^{2+} and high concentration (>1) of Fe^{2+}. The values of PLI were very low indicating no pollution. The WQI reveals the samples with excellent (<50) rating, while those above 100 (>100) were rated as poor. The SAR, MH, KR and %Na reveal the groundwater status for irrigation based on the ratings of the indices.

Key words: contamination factor, hydrochemical species, irrigation, pollution load index, water quality index

HIGHLIGHTS

- Groundwater repository was assessed using the geochemical parameters.
- Concentrations of the ions were compared with the WHO standard for drinking water.
- Water quality indices (PLI, CF and WQI) were determined.
- Irrigation indices (SAR, MH, %Na and KR) were computed.
- The results reveal the status of groundwater for domestic and irrigation purposes.

INTRODUCTION

Water plays an essential role in many processes/activities in our society and provides both environmental and economic benefits. Contaminated groundwater poses a serious threat to humans as it may lead to water-borne diseases, which are dangerous to health. Also, agricultural productivity depends on the suitability of the groundwater, which will boost crop yield. Groundwater is an essential natural asset that supports domestic and agricultural purposes and its suitability is of great concern for its sustainability and effective use (George *et al.* 2015; Obiora *et al.* 2015; Ekanem *et al.* 2020). A greater percentage of water supplies for domestic, agricultural and industrial uses are tapped from groundwater, due to its availability and proximity (Ibe *et al.* 2020; Akakuru *et al.* 2021). Groundwater quality depends not only on natural factors such as aquifer lithology, groundwater velocity, quality of recharge waters and interaction with other types of water or aquifers but also on human activities and the environment. The quality of groundwater is affected by contaminants such leachates, oil pollution etc, which emanates from different sources and infiltrates into the aquifer units through the pores and crevices of rocks or soils after decomposition and becomes a point source of groundwater pollution (Hossain *et al.* 2014; Ganiyu *et al.* 2015; Ibuot *et al.* 2019). Rocks and sediments contain contaminants, solutes and groundwater flowing through them dissolves these substances thus changing the chemistry of groundwater repositories. Groundwater suitability depends on the hydrogeochemical properties and susceptibility of the aquifer layers to pollution (Wang *et al.* 2010; Okolo *et al.* 2018; Ekanem *et al.* 2020). Also, the aquifer susceptibility depends

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on porosity, permeability and overburden thickness of geologic formation (George *et al.* 2014; Obiora *et al.* 2015; Ibuot *et al.* 2017; Oni *et al.* 2017; Ibe *et al.* 2020).

The groundwater repositories are continuously overstretched by processes such as saltwater intrusion, movement of leachates, oil spillage, surface and subsurface leakages, and leakage from septic tanks (Umar & Igwe 2019; Akakuru *et al.* 2021). The quality of groundwater is largely controlled by discharge-recharge pattern, nature of host and associated rocks as well as contaminated activities (Mishra *et al.* 2013; Ibuot *et al.* 2019). Groundwater contains a high level of dissolved solids due to its contact with aquifer geologic materials. According to Rawat *et al.* (2018), groundwater quality degradation may be due to geochemical reactions in the aquifers and soils and, also when it is supplied through improper canals/drainages for irrigation. The suitability of groundwater for agriculture depends on the nature of the mineral elements in the water and their impacts on both the soil and plants (Singh *et al.* 2013; Rawat *et al.* 2018; Thomas *et al.* 2020).

Groundwater pollution happens mostly due to percolation of pluvial water and the infiltration of contaminants through the soil (George *et al.* 2014; Hossain *et al.* 2014; Ganiyu *et al.* 2015). The degradation in groundwater quality has been a serious issue in both human health and agriculture sector as it affects agricultural productivity. The excess amount of dissolved elements affect human health when its concentration exceeds the World Health Organization (WHO) permissible limits and also affects plants growth by changing the uptake power of plant due to complex changes that arise out of the osmotic processes. The concentration and toxicity of contaminants determine the extent of threats. The chemicals in the wastes are usually disposed without appropriate measures leaches and percolate into the aquifer layer, which have the potential to change the groundwater chemistry and thus pollute groundwater resources.

Pollution in coastal aquifers is connected to numerous factors such as: hydraulic gradient, groundwater recharge and discharge rate and nature of geological formation (Mosuro *et al.* 2017; Yetiş *et al.* 2019). Going by the debilitating effects of contaminated groundwater in the Federal College of Education (Technical), Omoku, this work is designed to evaluate groundwater quality by assessing the physicochemical properties and water quality indices of groundwater samples in the study area and its environs.

Location and geological setting of the study area

The study area is the Federal College of Education (Technical), Omoku, which is located in the coastal town of Omoku in Rivers State, Nigeria. The community is known for its rich oil and gas deposits, with the presence of many multinational oil companies operating in the community. It lies within the Niger Delta Basin, which is underlain by the Benin Formation Agbada Formation, and Akata Formation. The Akata Formation, which is mainly shale and clay, and the Agbada Formation, which is generally fluviatile and fluviomarine, are of primary interest to the petroleum industry (Abam & Nwankwoala 2020). The Akata and Agbada formations provide hydrocarbon source rock and reservoir and account for almost all the hydrocarbons in the region. The Benin Formation, which occurs at shallower horizons, consists of a continental deposit of sand and gravel (Abam & Nwankwoala 2020), and is important in groundwater exploration. Figure 1 is the map of the study area showing sample (borehole) location points.

MATERIALS AND METHOD

Hydrogeochemical and physical properties of water samples

Groundwater from boreholes located within the vicinity of the study were considered for this study. A total of six water samples were collected from six different boreholes across the area without contamination in the month of February, 2022. The borehole locations were: BH 1, BH 2, BH 3, BH 4, BH 5 and BH 6. The water samples were split into two containers, one for anions and the other for cations to determine their concentration in milligrammes per litre (mg/L). The values of pH and alkalinity were measured using a multi-parameter analyser. Alkalinity is a property of water that depends on the presence in the water of some chemicals such as carbonates, bicarbonates and hydroxides (Thomas *et al.* 2020). The values of electrical conductivity (EC) of the water samples was measured at the point of collection using a Wissenschaftlich-Technische Werkstätten LF91 (Ec) meter. The total dissolved solids (TDS) and dissolved oxygen (DO) were determined at the point collection. The DO was measured with the aid of a dissolved oxygen meter and sensor. The values of the chemical oxygen demand (COD) and biological oxygen demand (BOD) were determine in the laboratory using standard procedures. These containers were initially washed with 0.05 M HCl and filtered through membranes of 0.45 μm pores and then rinsed with ionized water. The water samples were acidified with concentrated nitric acid (HNO_3) to

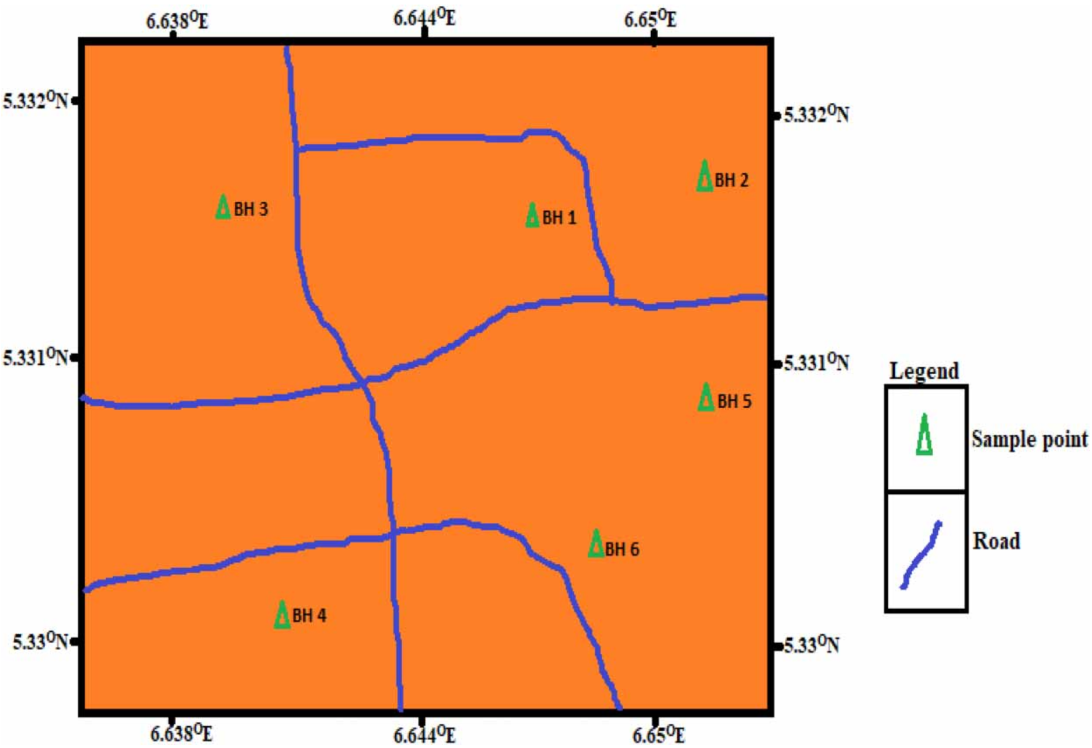

Figure 1 | Map showing the sample location points.

homogenize and prevent metallic ions from sticking to the walls. The analysis of the bicarbonates (HCO_3^-) was carried out using a standard technique of titration to obtain their concentrations. The concentrations of the cations (K^+, Na^{2+}, Ca^{2+}, Mg^{2+} Mn^{2+} and Fe^{2+}) were determined using the Atomic Adsorption Spectrometer model AA-7000 Shimadzu, Japan ROM version 1.01, while the anions (SO_4^{2-}, Cl^-, HCO_3^-) were determined in the laboratory using the standard procedure of titrimetric method.

Pollution, water quality and irrigation water quality indices

Assessing drinking water quality and pollution level

This study makes use of different indices to assess the water quality of the study area. The indicators include: water quality index (WQI), contamination factor (CF) and pollution load index (PLI).

WQI

This index was computed employing the method of weighted arithmetic index. The sample concentration (C_i) in mg/L of each is divided by each respective WHO standard (S_i) in mg/L to obtain the quality rating scale (q_i). The ratio of C_i/S_i is then multiply by a factor of 100 to give a mathematical expression given in Equation (1) (Verma *et al.* 2020; Akakuru *et al.* 2022).

$$q_i = \frac{C_i}{S_i} \times 100 \tag{1}$$

The inverse of the WHO standard corresponding to each of the analysed parameters gives the relative weight (W_i) of each sample as expressed in Equation (2);

$$W_i = \frac{1}{S_i} \tag{2}$$

The WQI is then expressed mathematically in Equation (3) as the product of Equations (1) and (2);

$$WQI = \sum q_i W_i \tag{3}$$

CF

This index defines the range of contamination or pollution of metals and according to Hakanson (1980) it is expressed as in Equation (4);

$$CF = \frac{C_n}{B_n} \tag{4}$$

where C_n is the concentration of metal in the area while B_n is the background/target, which is a reference value for the maximum allowable concentration of metals (Yahaya & Fatima 2021; Akakuru *et al.* 2022).

PLI

This index is computed using CF. It is calculated by obtaining the n-root from the n-CFs obtained for all the metals considered. This index helps in comparing the pollution status of different places (Rabee *et al.* 2011) and provides useful information about metal toxicity (Yang *et al.* 2011). It was computed using Equation (5) according to Tomlinson *et al.* (1980).

$$PLI = \sqrt[n]{CF1 \times CF2 \times \ldots \times CFn} \tag{5}$$

where CF is the contamination factor, n is the number of metals considered.

Assessing irrigation water quality

The suitability of groundwater quality for irrigation was determine by utilizing the concentrations of sodium, calcium and magnesium (Raju *et al.* 2009; Sisir & Anindita 2012). The indicators sodium adsorption ratio (SAR), magnesium adsorption ratio (MAR), Kelly's ratio (KR), sodium percentage (Na%) and magnesium hazard (MH) will be estimated.

SAR

This parameter gives the relative ratio of Na^+, Ca^{2+} and Mg^{2+} ions contained in water sample. It is estimated using Equation (6). It is also noted that SAR influences the percolation time of water in the soil (Rawat *et al.* 2018). The classification is based on the following classes: $< 10 =$ Ideal or excellent; $10 - 18 =$ good; $18 - 20 =$ doubtful; $> 26 =$ unsuitable

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \tag{6}$$

MH

The soil quality is affected by excess concentration of magnesium in groundwater, since a high value of Mg^{2+} in water increases soil pH and leads to a decrease in the availability of phosphorus (Al-Shammiri *et al.* 2005). MH is estimated using Equation (7). $MH > 50$ is not recommended for irrigation (Khodapanah *et al.* 2009).

$$MH = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100 \tag{7}$$

KR

This is based on the concentration of Na^+ against Mg^{2+} and Ca^{2+}. It is estimated using Equation (8). $KR > 1$ indicates an excess level of Na^+ in waters. Therefore, water having $KR \leq 1$ is recommended for irrigation while water with $KR \geq 1$ is not recommended due to alkali hazards (Karanth 1987; Ramesh & Elango 2012).

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \tag{8}$$

%Na

This factor assesses groundwater suitability for irrigation purposes, it gives the percentage composition of Na^{+} in water. It is estimated using Equation (9). When %Na is $<$ 20%, it is excellent, 20–40% is good, 40–60% is permissible, 60–80% is doubtful and $>$ 80% is unsuitable (Khodapanah *et al.* 2009).

$$\%Na = \frac{Na^{+} \times 100}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} \tag{9}$$

where Na^{+}, Mg^{2+} K^{+} and Ca^{2+} are sodium, magnesium, potassium and calcium ions respectively.

RESULTS AND DISCUSSION OF RESULTS

Results in Table 1 show the concentrations of both the physical and chemical parameters considered in the water samples collected from six different boreholes within the vicinity of the study area.

Table 1 | Results of chemical composition of groundwater samples from boreholes

S/N	Parameters	BH 1	BH 2	BH 3	BH 4	BH 5	BH 6	WHO (2017)
1	pH	7.7	7.4	7.5	7.3	7.5	7.8	6.5–8.5
2	EC ($\mu s/cm$)	19.10	53.00	14.70	23.40	36.80	27.40	500
3	TDS (mg/L)	82.31	99.94	76.79	105.90	83.6	74.15	500
4	Alkalinity (mg/L)	0.10	0.05	0.06	0.06	0.18	0.07	200
5	DO (mg/L)	8.00	11.20	6.40	5.80	11.50	7.05	-
6	BOD (mg/L)	9.60	12.80	8.00	6.08	8.30	7.50	2
7	COD (mg/L)	32.00	42.40	26.40	28.40	23.80	36.50	10
8	SO_4^{2-} (mg/L)	7.01	4.03	5.57	4.25	7.53	6.45	250
9	Cl^{-} (mg/L)	24.14	45.44	19.88	26.85	18.37	37.72	250
10	HCO_3^{-} (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	200
11	Na^{+} (mg/L)	0.52	0.98	0.27	0.62	0.34	0.73	200
12	K^{+} (mg/L)	1.70	4.72	3.56	1.58	6.81	5.06	200
13	Ca^{2+} (mg/L)	BDL	1.33	0.03	0.27	1.20	0.46	7.5
14	Mg^{2+} (mg/L)	0.07	0.12	0.11	0.21	0.18	0.06	50
15	Mn^{2+} (mg/L)	BDL	BDL	0.07	0.06	0.03	0.07	0.5
16	Fe^{2+} (mg/L)	0.49	0.03	0.25	0.18	0.23	0.09	0.3

BDL: Below detectable limit.

Physical and oxygen-related parameters

The physical and oxygen-related parameters considered were pH, EC, TDS, alkalinity, DO, BOD and COD. The pH has a range of 7.3–7.8 with a mean of 7.5 within the WHO standard for drinking water. The mean pH value suggests that the water quality is close to neutrality level (George *et al.* 2014; Olofinlade *et al.* 2018). pH controls the solubility and biological availability of chemical constituents of nutrients and metals. The concentration of HCO_3^{-} was below detectable limit (BDL) in all water samples analyzed, which suggests a low concentration of carbonate-rich compounds in the study area (George *et al.* 2014; Ibuot *et al.* 2017). The EC of water informed us of the amount of dissolved substances, chemicals and minerals present in water, in this study, EC ranges from 14.7–53 $\mu s/cm$ with an average of 29.07 $\mu s/cm$. These values were below the WHO standard, which may be due to a lower concentration of dissolved solutes in water. TDS has values ranging from 74.15–105.90 mg/L with an average of 87.12 mg/L, which is below the WHO standard, and these values fall within the excellent and palatable class (Rahman *et al.* 2015). According to Yetiş *et al.* (2019) and Akakuru *et al.* (2021) variation of TDS is greatly controlled by the anthropogenic activities and geochemical processes taking place within the groundwater repositories, and also the residence time of groundwater in a hydrogeologic unit (Alsuhaimi *et al.* 2019). The alkalinity, which measures the ability of water to neutralize acids and bases range from 0.05–0.18 mg/L and its average value is 0.09 mg/L, and below the WHO standard. The low concentration of alkalinity may be caused by the absent/low concentration of carbonate in the subsurface rocks. The DO ranges from 5.8–11.5 mg/L with an average of 8.32 mg/L, BOD, which determines the quantity of DO required for the decomposition of organic matter, ranges from 6.08–12.8 mg/L with an average value of 8.71 mg/L. The COD, which measures, the quantity of oxygen that can be consumed per unit volume of water, ranges from 23.8–42.4 mg/L with an average value of 31.58 mg/L. The values of BOD and COD exceeded the WHO standard in all the water samples, which may be attributed to dumping of municipal and industrial wastes, which decompose and percolate into the groundwater repositories. The high concentrations of BOD and COD indicate a greater amount of oxidizable organic material in the water samples, which will reduce DO. The concentration of DO according to Thomas *et al.* (2020) suggests oxic condition (DO $> 5\,mg/L$). Figure 2 shows the spatial variations of the physical and oxygen-related parameters in the study area.

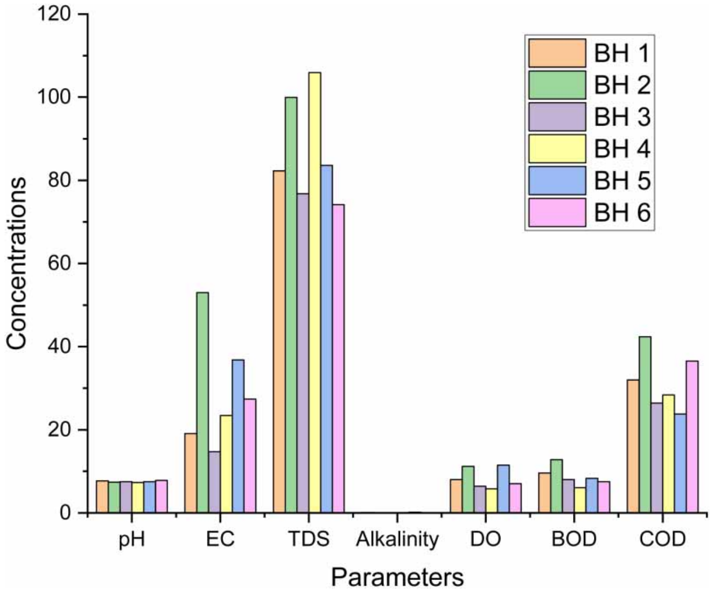

Figure 2 | Distributions of the physical and oxygen-related parameters.

Hydrogeochemical parameters

The geochemical results (Table 1), the anions in order of abundance are $Cl^- > SO_4^{2-} > HCO_3^-$. The values of SO_4^{2-} ranged from 4.03–7.53 mg/L with a mean of 5.81 mg/L and with the WHO standard for drinking water. High concentration of SO_4^{2-} may increase the levels of hardness in groundwater repositories, and may corrode plumbing done with copper. A high concentration of SO_4^{2-} can lead to irritation of the lungs which cause serious disease of the lung. The Cl^- has values ranging from 18.37–45.44 mg/L and a mean value of 26.94 mg/L, which were within the WHO permissible limit of 250 mg/L. If Cl^- exceeds 250 mg/L, it will produce a salty taste, which is not good for human consumption (Rahman *et al.* 2015). The Cl^-concentration in groundwater may be due to the presence of chlorides from rocks, seawater intrusion, or contamination by industrial waste or domestic sewage (Saha *et al.* 2019). The low concentration of Cl^- is attributed to low salinity of the groundwater of the study area.

The order of abundance of cations is given in the following order: $K^+ > Na^+ > Ca^{2+} > Fe^{2+} > Mg^{2+} > Mn^{2+}$. The values of K^+ in the water samples ranged from 1.58–6.81 mg/L with a mean of 3.91 mg/L, the concentration of potassium is within the WHO permissible limit of 200 mg/L. Potassium and sodium are monovalent ions and as such do not cause hardness of water. The absence of potassium will affect the normal functioning of the body cells. Potassium produces positively charged ions when dissolved in water, which allow it to conduct electricity, which is important for many processes throughout the body. The sodium (Na^+) concentration ranged from 0.27–0.98 mg/L and its average value of 0.58 mg/L were within the WHO permissible limit of 200 mg/L. According to Rahman *et al.* (2013), the mixing of freshwater with saline water due to marine transgression can increase the concentration of sodium in water. Ca^{2+} ranged from 0–1.33 mg/L with an average value of 0.55 mg/L. The values of calcium in all the water samples did not exceed the WHO standard for drinking water. Calcium is a significant determinant of water hardness, and because of its buffering qualities, it also functions as a pH stabilizer. Mg^{2+} with values within the WHO standard for drinking water ranged from 0.06–0.21 mg/L with an average of 0.13 mg/L. Both calcium and magnesium are found in groundwater that has come in contact with certain rocks and minerals, especially limestone and gypsum. When these materials are dissolved, they release calcium and magnesium. The amount of dissolved CO_2 in groundwater influences the reaction of magnesium in solution (Saha *et al.* 2019). Fe^{2+}ranged from 0.03 to 0.49 mg/L and its average value of 0.21 mg/L is within the WHO permissible limit for drinking water except BH 1, whose value exceeded the WHO standard. The high concentration of Fe^{2+} in BH 1 may be as a result of the ferrigenous Benin sands, which contain the minerals haematite, limonite and goethite, and also the leaching of the shales of Niger delta in the groundwater repositories (Akakuru *et al.* 2015; Ibuot *et al.* 2017; Urom *et al.* 2021). Mn^{2+} is the least abundant, having values thats range from 0–0.07 mg/L with a mean of 0.04 mg/L. These are within the WHO standard for drinking water. Iron and manganese occur naturally in groundwater as a result of weathering of iron- and manganese-bearing minerals and rocks. Figure 3 shows the ions' distribution in the water samples across the study area.

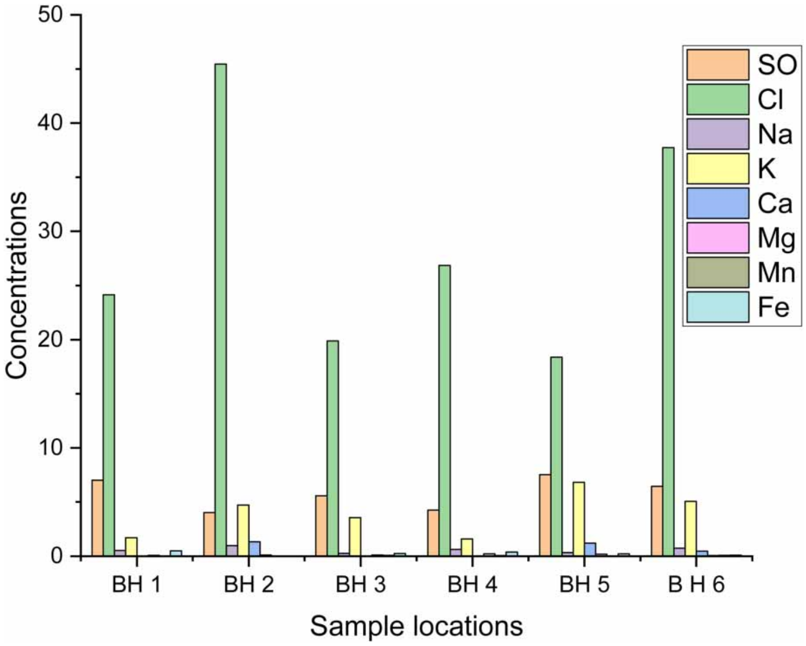

Figure 3 | Concentration of ions in the study area.

CF

The CF of the groundwater samples was computed and the results presented in Table 2 while Figure 4 shows its distribution. The results reveal that SO_4^{2-}, Cl^-, K^+, Na^{2+}, Ca^{2+}, Mg^{2+} and Mn^{2+} have low CF values (<1) in all the water samples analysed, but Fe^{2+} BH 1 and BH 6 have CF values greater 1 (>1). According to the ratings of

Table 2 | Results of CF, PLI and WQI

		Contamination Factor (CF)									
S/N	**Sample No.**	**SO_4^{2-}**	**Cl^-**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**Mn^{2+}**	**Fe^{2+}**	**PLI**	**WQI**
1	BH 1	0.0280	0.0966	0.0026	0.0085	0	0.0014	0	1.6333	0	544.4482
2	BH 2	0.0161	0.1818	0.0049	0.0236	0.1773	0.0024	0	0.1067	0	38.00885
3	BH 3	0.0223	0.0795	0.0014	0.0178	0.004	0.0022	0.14	0.8333	0.000002	305.8579
4	BH 4	0.0170	0.1074	0.0031	0.0079	0.036	0.0042	0.12	1.2667	0.000006	224.5218
5	BH 5	0.0301	0.0735	0.0017	0.0341	0.1600	0.0036	0.06	0.7667	0.000015	269.7245
6	BH 6	0.0258	0.1509	0.0037	0.0253	0.0613	0.0012	0.14	1.6333	0.000008	128.8933

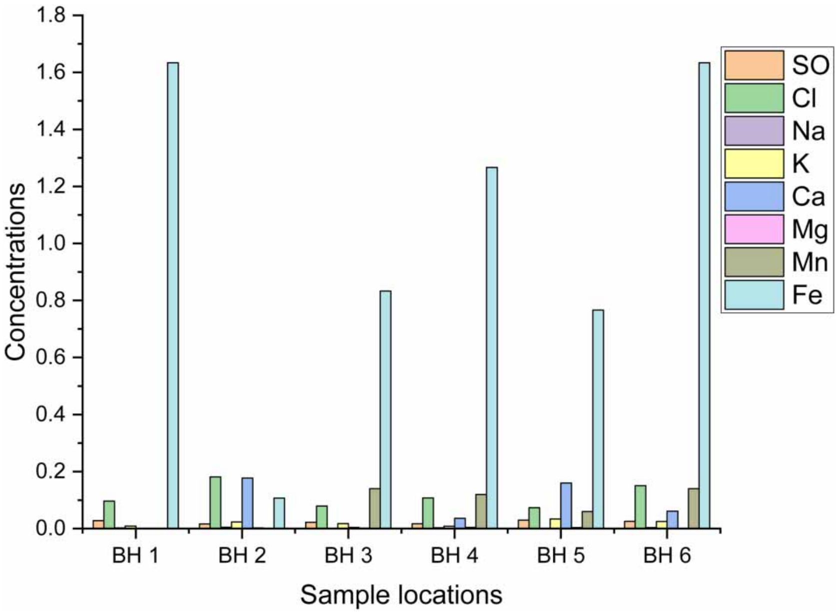

Figure 4 | CF in the water samples.

Bhutian *et al.* (2017) and Akakuru *et al.* (2021), SO_4^{2-}, Cl^- K^+, Na^{2+}, Ca^{2+}, Mg^{2+} *and* Mn^{2+} fall within the class of low contamination ($CF < 1$), while Fe^{2+} in BH 1 and BH 6 falls within the class of moderate contamination ($1 \leq CF \geq 3$). This may be attributed to the influence of contaminants from industrial activities, agricultural runoff and other anthropogenic inputs as pointed out by Rabee *et al.* (2011).

Pollution load index (PLI)

This index was computed using Equation (5) and the result presented in Table 2, the values of PLI were very low (<1) in all the samples analysed indicating no pollution. This agrees with the work of Yahaya & Fatima (2021) and Akakuru *et al.* (2022). Generally, the variation in the indices may be attributed to changes in sensitivity of these indices towards sediments pollutants (Rabee *et al.* 2011). The variation of this parameter is presented in Figure 5.

WQI

The WQI was determined for all the samples and the results (Table 2) and Figure 5 shows the variation of WQI across the study area. This index helps in the classification of the water samples to know its status and the rating

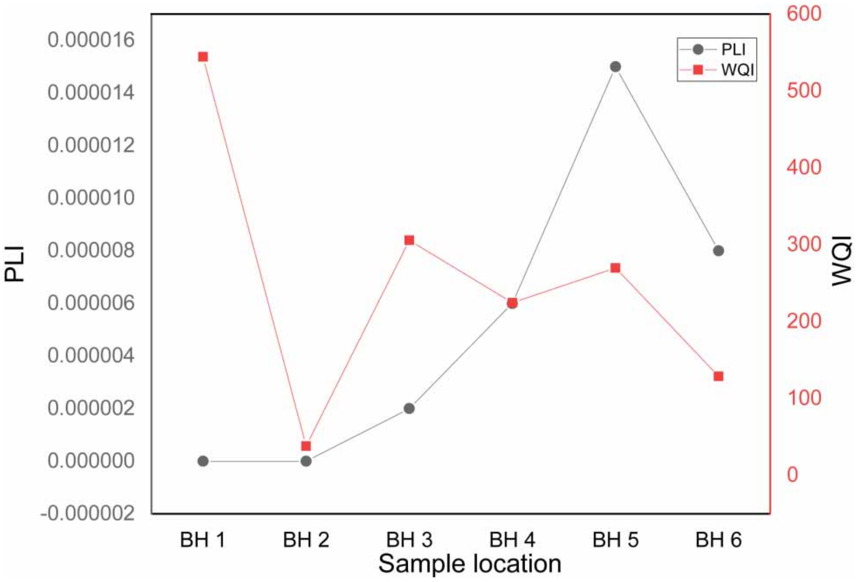

Figure 5 | PLI and WQI Variation.

was done according to Akakuru *et al.* (2022). BH 2 with a WQI value of 38.00885 was rated as being in the excellent class (<50), which implies that the water can be utilized for drinking, irrigation and industrial uses. The water sample from BH 6 was rated as poor (100–200), so it will useful for industrial and irrigation purposes. BH 4, and BH 5 were rated as very poor (200–300), which can be utilized for irrigation purposes. BH 1 with values greater than 300 (>300) was rated as unsuitable and thus needs proper treatment before any use.

SAR

The results in Table 1 were employed in estimating the SAR as presented in Table 3. Sodium is important in irrigation water as it can help improve soil structure, but will have a negative effect on plant growth and crop yield when in excess. Also, alkaline soils may be form when sodium combines with carbonates. The study reveals that SAR concentration varies from 0.41–2.78 with a mean of 1.47. Considering the classification of Todd (1980) and Raju *et al.* (2009), SAR values that are less than 10 (<100) indicate that all the water samples have excellent water quality for irrigation.

Table 3 | Classification of groundwater samples for irrigation

Sample No.	SAR	MH	KR	%Na
BH 1	2.78	100.00	7.43	22.71
BH 2	1.15	8.28	0.68	13.71
BH 3	1.15	100.00	2.46	6.85
BH 4	1.91	100.00	2.95	25.73
BH 5	0.41	13.04	0.25	3.99
BH 6	1.43	11.54	1.40	11.57

MH

Magnesium is important in irrigation water as it is essential in the formation of chlorophyll molecules in plant tissue and also in activation of specific enzymes. Availability of magnesium in soil depends on factors such as rock constituents, amount of weathering, climate of the area etc. The values of MH ranged from 8.28–100 with a mean of 55.48, according the rating of Khodapanah *et al.* (2009), BH 1, BH 3 and BH 4 have values greater than 50 (MH > 50) and consequently are not recommended for irrigation purposes.

KR

This index also helps in assessing the suitability of groundwater for irrigation purposes. The results in Table 3 show the values of KR ranging from 0.25–7.48 with a mean value of 2.53. BH 1, BH 3, BH 4 and BH 6 have values greater than 1 (>1), thus are rated as not suitable for irrigation purpose due to alkali hazard. BH 2 and BH 5 with values of 0.68 and 0.25 respectively are suitable for irrigation.

%Na

Sodium affects the soil by closing up the pores and this leads to poor water infiltration and wetting of the soil and can cause permeability problems. The %Na index is important in determining groundwater suitability for irrigation purpose. The results in Table 3 show %Na values ranged from 3.99–25.73% with a mean value of 14.09%. This implies that BH 2, BH 3, BH 5 and BH 6 are within the permissible category of excellent (<20%) while BH 1 and 4 are within the good class (20–40%) for irrigation (Khodapanah *et al.* 2009).

The irrigation indices (SAR, MH, KR and %Na) varies across the study area, the variations may due to geogenic and anthropogenic impacts on the earth subsurface. The distribution of this parameters is shown in Figure 6.

CONCLUSION

The analysis of physical and hydrogeochemical parameters of water samples was carried out within the study area and its environs. The study reveals the concentrations of the physical parameters from which water quality and irrigation indices like WQI, PLI, CF, SAR, MH, %Na and KR were estimated. The concentrations of physical

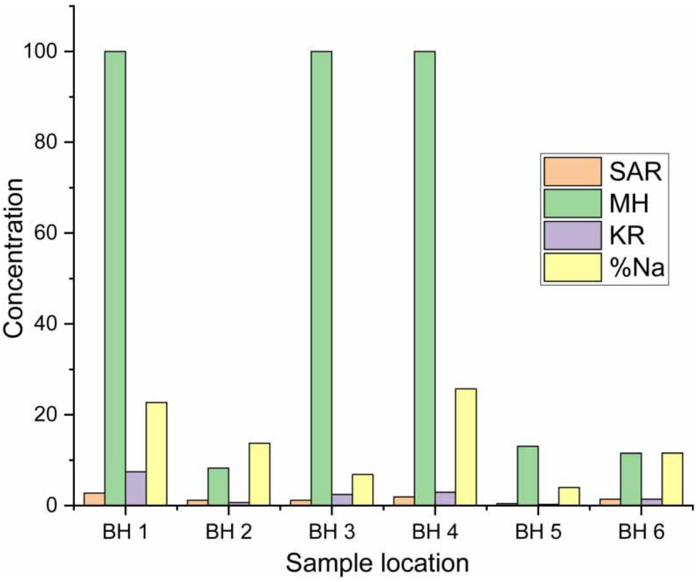

Figure 6 | Distribution of SAR, MH, KR and %Na.

and chemical parameters were within the WHO permissible limit for drinking water except BOD and COD which exceeded WHO standard in all the water samples, and Fe^{2+}, which also exceeded the WHO standard in sample BH 1. The observed DO values suggest oxic condition (DO$>$ 5 mg/L). The order of abundance of the cations and anions is $K^{+} > Na^{+} > Ca^{2+} > Fe^{2+} > Mg^{2+} > Mn^{2+}$ and $Cl^{-} > SO_4^{2-} > HCO_3^{-}$ respectively. Contamination factor reveal that So_4^{2-}, Cl^{-} K^{+}, Na^{2+}, Ca^{2+}, Mg^{2+} and Mn^{2+} have low concentration ($<$1) while Fe^{2+} is high ($>$1) in two of the samples. The values of PLI were low in all the water samples which signifies no pollution. The WQI reveal that water sample with value less than 50 (excellent class) as good for drinking, irrigation and industrial uses. The values of SARS estimated reveals that all the water samples have excellent water quality for irrigation. MH KR and %Na, based on their ratings, reveal the status of the suitability of the water samples for irrigation purpose. We can infer the chemistry of the sediments and the hydrogeologic units, which are controlled by different processes that affect the groundwater status of the area. The various plots displayed the variability of the concentration of the parameters. These indices can serve as tools for predicting the suitability of groundwater for drinking, irrigation and industrial purposes. It is recommended that future research work be carried out to consider and evaluate the concentration of heavy metals, salinity hazard, alkalinity, soluble sodium percentage, residual sodium bicarbonate and permeability index.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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