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ORIGINAL ARTICLE

The hydrogeochemical signatures, quality indices and health risk assessment of water resources in Umunya district, southeast Nigeria

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Abstract

The hydrogeochemical characteristics, water quality and health risk statuses of waters in Umunya district, southeastern Nigeria were studied, in attempt to evaluate their suitability for drinking and domestic purposes. Twelve groundwater and 3 surface water samples were analyzed for 26 physicochemical and hydrogeochemical parameters, using standard techniques. Results show that dominance of cations and anions is in the order $Ca^{2+} > Na^{+} > K^{+} > Mg^{2+}$ and $HCO_3^{-} > Cl^{-} > NO_3^{-} > SO_4^{-}$, respectively. Order of dominance of the heavy metals is Pb > Zn > Fe > Ni > Mn > Cr > Ba. Eight water types were identified, with Ca–Na–HCO_3 (26.66%) and Na–Cl–HCO_3 (20%) dominating the study area. All the water types characterize five major facies. Further, the result revealed that the physical properties and chemical ionic concentrations in the waters are well below standard maximum permissible limits, although majority of the samples have pH values off the allowable limits of 6.5–8.5, classing the waters as slightly acidic. Generally, the water quality in the study area is deteriorated due to the presence of high levels of heavy metals. Water quality index results show that 46.67% of the water samples are in excellent and good categories. 13.33% are in poor water category, whereas 40% are in category unsuitable for drinking purposes. A good percentage of the waters predispose users to health risks. Stoichiometric and statistical analyses revealed that the variations in chemistry and quality of the waters are due to combined influence of human activities and geogenic processes (silicate weathering and ionic exchanges). Treatment of contaminated waters before use is, therefore, recommended.

Keywords Hydrogeochemistry · Water contamination · Water quality index (WQI) · Water resources · Umunya

Introduction

Surface water and groundwater are the two major resources very important for sustainability of life and environment. Although it is generally believed that about 71% of Earth's resources are water, access to quality water for drinking, domestic and industrial purposes is limited, especially in developing countries. The limited availability of quality water, both in rural and urban areas, is usually caused by anthropogenic factors more than natural processes. The anthropogenic factors which are eminent sources of water systems contamination span from domestic, agricultural and industrial activities to poor waste management (Barzegar et al. 2016, 2017a; Tziritis et al. 2017; Ezenwaji and Ezenweani 2018; Egbueri 2018). On the other hand, the natural factors that determine how far a water system is contaminated include amount and chemistry of contaminants, topography, mobility of contaminants, toxicity of contaminants, rainfall intensity, hydrogeological conditions, the residence time and the reactions that occur within the aquifer, etc. (Ahamed et al. 2015; Barzegar et al. 2016, 2018a; Tziritis et al. 2017; Kalaivanan et al. 2017; Prasanna et al. 2017; Ezenwaji and Ezenweani 2018; Egbueri 2018).

Undesirable water quality reduces the economy and restrains the improvement in the living conditions of people (Batabyal and Chakraborty 2015). Contamination or pollution of water resources remains a big threat to many communities in different parts of the world. However, in any attempt to sustain public health and the environment, continuous assessment and monitoring of the quality of water resources and adoption of appropriate measures for protection are inevitable. The determination of water quality is important to ascertain its suitability for a particular use. Assessing

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and monitoring of water quality often require knowledge of hydrogeochemistry, statistics and water quality index as special tools. Hydrogeochemistry reveals the ions distributed in water, which are pointers to its type and quality. An understanding of the geochemical components in water, as well as the physical ones, is important in determining its origin and suitability for drinking and several other purposes (Saba and Umar 2016; Tiwari et al. 2017; Mostafa et al. 2017; Kalaivanan et al. 2017). Water quality index (WQI) depicts the influence of natural and anthropogenic activities based on several key parameters on water chemistry (Batabyal and Chakraborty 2015; Ahamed et al. 2015). On the other hand, statistical methods are very useful and efficient for assessing the quality of water and for communicating the information on overall quality of water (Tiwari et al. 2017).

The study area is a fast-growing suburban district where inhabitants depend on both surface water and groundwater resources for drinking and domestic purposes. Recently, Egbunike (2018) assessed the water types and suitability of groundwater resources in Umunya area for drinking purpose using limited approach. Nevertheless, the literatures reporting on the hydrogeochemistry and quality of water resources in Umunya district are very scarce. This makes it necessary and compelling that a more sophisticated approach be employed to examine both natural (geogenic) and anthropogenic factors that influence and govern the hydrogeochemistry and quality of water resources (surface and groundwater) in this district. It is, therefore, in line with this conviction that the aim of this work was built. To that end, this study evaluates the hydrogeochemistry, quality and suitability of these natural resources for drinking and domestic purposes, using a more integrated, sophisticated approach. Moreover, this study also examines the various natural and anthropogenic factors that affect the hydrogeochemistry, quality and suitability of the water resources. The methods integrated to achieve the aim of this work included geochemical investigations, stoichiometry, WQI, multivariate statistical analyses (correlation matrix analysis and principal component analysis) and health risk analysis. This research is important because the information provided in it would help government and policy makers in the water resources planning and management for the Umunya district.

Study area description

Location, physiography and economy

The study area lies within latitudes 06°10′N to 6°15′N and longitudes 06°54′E to 07°00′E (Fig. 1). Umunya is a suburban district proximal to a megacity, Onitsha, in Anambra State, southeastern Nigeria. Abagana, Ifite-Ukpo, Awkuzu and Umunnachi are some communities identified around Umunya town, all of which make up the Umunya district

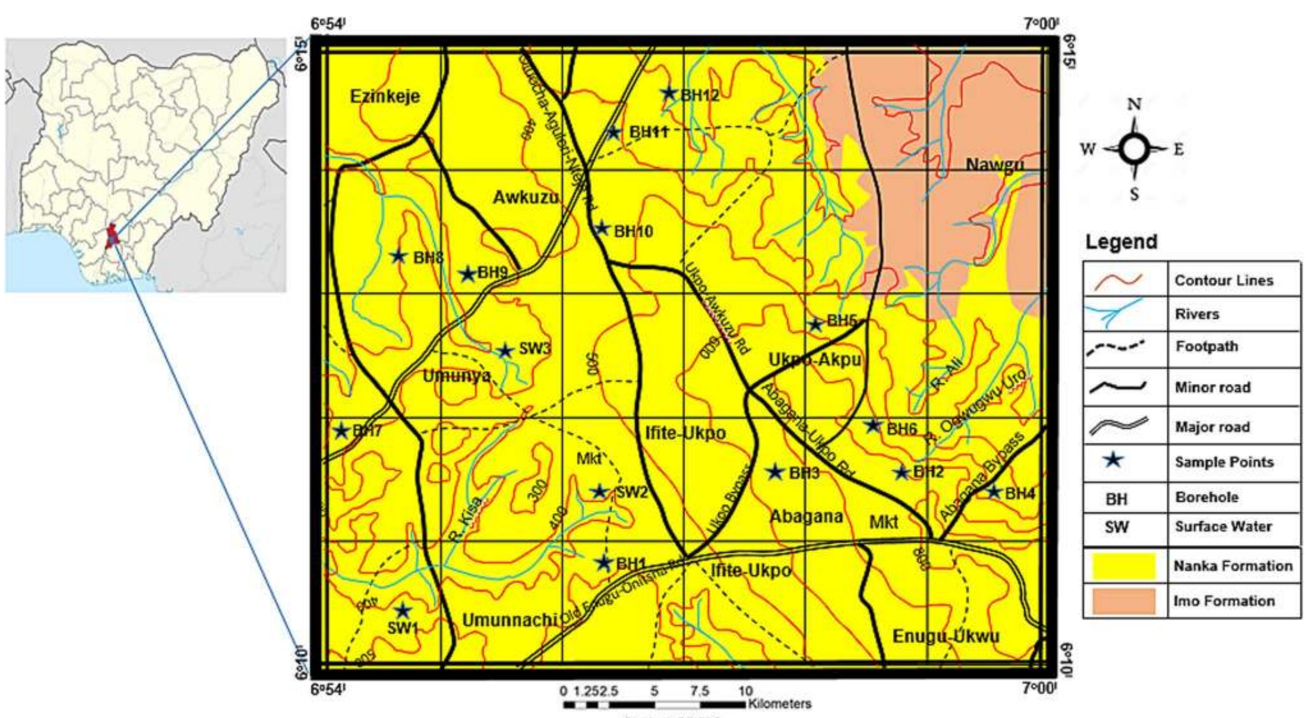

Fig. 1 Map showing the location, geology, accessibility and drainage of the study area

in this study. Because of overcrowded nature of the Onitsha city (westerly to the study area), inhabitants and migrants are gradually settling down in this district for shelter and livelihood. The position of this area makes it possible for the sun to be always overhead for the greater part of each year. The area experiences a wet season that spans April to November, leading to abundance of luxuriant trees and shrubs (Ofomata 2002). Annual rainfall in the area varies between 1500 to 2000 mm, with the driest month usually recording less than 30 mm of rainfall (Inyang and Monanu 1975). The physiography of this area is defined by uneven topography. Pertinent to note is the Awka-Orlu highland which runs NW–SE in the Abagana and Ifite-Ukpo communities, where it attains a maximum height of about 800 m.

The drainage system within the area is grossly influenced by the topographic nomenclature (prominence of sandstone ridges). Most of the rivers derive their sources from this nomenclature and move downslope at various speeds determined by the gradients of the ridges with adjoining lowlands. The Ali and Ogwugwu-Ulo rivers which drain the Abagana and Ukpo-Akpu communities together with the rivers north of the study area (draining Nawgu) are all major tributaries of Mamu River System (Fig. 1). Southwest of the study area, Kisa River and other co-tributaries of larger Idemili River drain the Umunya and Umunnachi communities. In addition, Nkisi River also takes its source from this ridge and drains the Awkuzu and Umunya areas as it flows into Niger River, which in turn empties into the Atlantic Ocean.

Because of high slope of areas east of the study area, rivers and surface runoffs tend to descend the ridges at great speeds, leading to the scourge of intense gullying within this region. Many of the gullies in the area are used as dumpsites. Wastes disposed in these gullies span from organic (mainly from households and markets) to inorganic (mainly from industries in neighboring urban areas) wastes. Livestock market at Umunya is believed to significantly contribute to the quantity of potential water contaminants (abattoir waste runoff in form of rumen, fecal waste, blood and fatty materials). A study carried out by Ogbonnaya (2008) has shown that contaminants from abattoir waste can increase the total dissolved solids and suspended solids in water. Moreover, inhabitants of this suburban district have their primary occupation in agriculture. Especially in the Awkuzu and Umunnachi communities, the use of chemical fertilizers rich in NPK (nitrogen, phosphorus and potassium) is a potential source of nutrient pollution.

Geology and hydrogeology

The study area is underlain by the Eocene Nanka Formation, one of the formations within the Ameki Group (Nwajide 1979, 1980) (Fig. 1). The formation is composed of very friable, flaser-bedded units of fine-medium-grained sands, with intervals of light gray mudrocks and ironstones (Nwajide 2006; Okoro et al. 2010a; Nwajide 2013; Oguadinma et al. 2014; Obi and Okekeogbu 2017). The highly porous and permeable Nanka Formation forms the major aquifer in this area (comprising over 60 m sandstone interval), while the underlying Imo Shale acts as the aquitard (Okoro et al. 2010b). Information about the aquifer properties of the Nanka Formation, such as pumping test estimates, hydraulic conductivity and transmissivity, have been reported by Okoro et al. (2010a). The presence of a major ridge, which acts as a water divide in this area, creates groundwater flow patterns running southwards and eastwards away from the divide (Nfor et al. 2007).

Materials and methods

Field sampling and physicochemical analysis

Fifteen freshwater samples comprising of borehole, stream and spring waters were collected from the study area and analyzed within 48 h of collection to avoid reactivity and algal growth. These samples were collected in clean polyethylene bottles which were labeled appropriately and sent to laboratory for analysis. Twenty-six water quality parameters were analyzed in the samples. These parameters were subdivided into three, physical properties, chemical ions and heavy metals. The physical parameters include temperature (Temp), color, pH, total dissolved solids (TDS), electrical conductivity (EC), total hardness (TH), calcium hardness (Ca H), magnesium hardness (Mg H), total suspended solids (TSS), total solids (TS) and turbidity (TDY). The chemical ions are Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}, HCO_3^- and NO_3^-. Seven heavy metals were analyzed, including Fe, Zn, Mn, Pb, Ba, Cr and Ni. Test methodology followed the recommended standards of the American Public Health Association (APHA 2005). The TDS was determined by gravimetric analysis. Cl^- was determined using a chloridometer, while titration of water with H_2SO_4 was used to determine HCO_3^-. Also, phenanthrolin was employed in determining the total Fe in the samples. For other trace elements, an atomic absorption spectrophotometer (AAS) was used.

Statistical analysis

Statistics is a very important tool used in presenting hydrogeochemical characteristics of water resources. AquaChem software (version 2014) was used in studying the hydrogeochemical signatures (facies and types) of the 15 water samples. Different hydrogeochemical diagrams, including Piper diagram, Durov diagram, Radial diagram and

Schoeller diagrams, were plotted using the AquaChem software. Pearson's correlation analysis and principal component factor analysis (PCFA) were performed with the use of the statistical software package, SPSS (version 22). Chart showing the distribution of heavy metals in the waters was produced using Microsoft Excel (version 2016).

Water quality evaluation

Potability of the waters was assessed by comparing their physicochemical and hydrogeochemical properties with the set maximum allowable limits, for each of the quality parameters, of the World Health Organization (WHO 2017) and Nigerian Industrial Standard (NIS 2007). Water quality index (WQI) was also calculated for all the samples. This was done in order to get a comprehensive summary of quality status of the water samples. Three steps were taken in evaluating the WQI of all the water samples. First, weights (ranging from 1 to 5) were assigned to the physicochemical parameters (with exception of temperature, TSS and TS, because they have no WHO (2017) standard values) according to the parameters' relative importance in the overall quality of water for drinking purposes (Ahamed et al. 2015). With the assigned weights, the relative weight of each parameter was calculated using the formula:

$$W_i = w_i / \sum_{i=1}^{n} w_i \quad (1)$$

where W_i is relative weight, w_i is weight of parameter and n is the total number of parameters.

Secondly, quality rating scale for parameters was calculated. This was done by dividing each parameter's concentration in each water sample by its respective WHO (2017) standards and multiplying the results by 100. The equation is given below as:

$$q_i = (C_i / S_i) \times 100 \quad (2)$$

where q_i is quality rating, C_i is the concentration of each parameter and S_i is the WHO (2017) standard value for the parameter.

The last step in the evaluation of WQI involved the determination of subindex for each parameter and then the summation of all subindices for each sample.

$$\mathrm{SI}_i = W_i \times q_i \quad (3)$$

$$\mathrm{WQI} = \sum \mathrm{SI}_{i-n} \quad (4)$$

where SI_i is the subindex of ith parameter, q_i is the quality rating based on concentration of ith parameter and n is the number of parameters.

Health risk assessment

The non-carcinogenic risk associated with consumption of groundwater which is contaminated with metals was calculated according to the guidelines of US Environmental Protection Agency (USEPA 1989). The risk for children and adults was separately evaluated using the function:

$$\mathrm{CDI} = \frac{C_\mathrm{W} \times \mathrm{IRW} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \quad (5)$$

where CDI represents the Chronic Daily Intake or exposure dose (mg/kg/day), C_w represents the contaminant concentration in water (mg/L), IRW denotes the ingestion rate (for adults IRW is 2 L/day while for children it is 1 L/day), EF denotes the Exposure Frequency (equivalent to 365 days/year), ED is the exposure duration (for adults and children, ED is 70 and 6 years, respectively), BW represents the body weight (for adults and children, BW is 70 and 15 kg, respectively), AT represents the average exposure time (AT for adults is 25,550 days while for children, it is 2190 days) (Bortey-Sam et al. 2015; Duggal et al. 2017; Barzegar et al. 2018b).

To evaluate the non-carcinogenic risk imposed by individual elements, the hazard quotient (HQ) as outlined by Li et al. (2016) and Zhang et al. (2018) was calculated as follows:

$$\mathrm{HQ} = \frac{\mathrm{CDI}}{\mathrm{RfD}} \quad (6)$$

where RfD signifies the reference dose of a specific element (mg/kg/day). According to Duggal et al. (2017) and Barzegar et al. (2018b), RfD for different elements is equivalent to 0.7 (Fe), 1 (Al), 0.3 (Zn), 0.046 (Mn), 0.0035 (Pb), 0.02 (Ni), 0.0003 (As), 0.2 (Ba) and 0.04 (Cu). Finally, to calculate the hazard index (HI) of the water samples, the summation of HQ values for the elements is computed, i.e.,

$$\mathrm{HI} = \sum \mathrm{HQ} \quad (7)$$

Values of HI and HQ greater than 1 indicate the non-carcinogenic risk of the specific element exceeds the limit of

Table 1 USEPA (1989) classification of non-carcinogenic risk

Risk level	Hazard index (HI)	Chronic risk
1	<0.1	Negligible
2	$\geq 0.1 < 1$	Low
3	$\geq 1 < 4$	Medium
4	≥ 4	High

acceptance (HI = 1), while values less than 1 indicate that the non-carcinogenic risk is within limits of acceptance (USEPA 1989; Su et al. 2017). Table 1 shows USEPA (1989) classification of non-carcinogenic risk as presented by Bortey-Sam et al. (2015), Barzegar et al. (2017b, 2018b).

Results and discussion

Physicochemical and hydrogeochemical signatures

Statistical summary of physicochemical and hydrogeochemical parameters of water resources in the study area is presented in Table 2. Also, the obtained values were compared with those of the WHO (2017) and NIS (2007). The results revealed that about 46% of the water quality parameters possessed a wide range of standard deviation which indicates groundwater quality might be affected by a set of hydrogeochemical processes rather than one process (Rahman et al. 2017). Contrary to this view about the wide-range standard deviation, Ezenwaji and Ezenweani (2018) reported that where the standard deviation is above the mean, the implication is that there are values that lie outside the mean and the mean is not a true representative of the sample from which it was computed. It was, however, observed that those parameters having standard deviations greater than their means have minimum values of zero and that a number of parameters recorded zero (Table 2).

In a general note, the physical properties and chemical ion concentrations in the waters are well below the maximum permissible limits of the WHO and NIS (Table 2). However, majority of the samples have pH values off the allowable limits of 6.5–8.5 (Fig. 2), classing the waters as slightly acidic. The moderate acidity of the waters could be linked to use of chemical fertilizer in the area, leaching of dissolved constituents into aquifer systems, etc. In addition, with respect to color, only a stream sample (SW3) recorded 57TCU against the standard threshold of 15TCU. That said, it is pertinent to note that the samples which have lower color values are not necessarily pure, because they have TDS. In other words, clarity of the waters does not mean purity of the water.

Table 2 Statistical summary of analyzed physicochemical and hydrogeochemical parameters in Umunya

Parameter group	Parameter	Total no. of samples	Min.	Max.	Mean	Standard deviation	WHO (2017)	NIS (2007)
Physical parameters	Color (TCU)	15	0.00	57.00	4.73	14.69	15	15
	Temp (°C)	15	25.70	28.10	26.55	0.81	–	Ambient
	pH	15	4.61	6.53	5.56	0.65	6.5–8.5	6.5–8.5
	TDS (mg/L)	15	10.49	105.56	34.19	26.81	600–1000	1000
	EC (µS/cm)	15	16.14	162.40	52.36	41.24	1000	1000
	TH (mg/L $CaCO_3$)	15	2.00	150.00	46.67	45.40	100–300	150
	Ca H (mg/L $CaCO_3$)	15	2.00	134.00	42.00	40.11	100–300	150
	Mg H (mg/L $CaCO_3$)	15	0.00	26.00	5.33	7.66	100–300	150
	TSS (mg/L)	15	0.00	18.00	1.73	4.56	–	–
	TS (mg/L)	15	11.49	106.60	35.93	26.84	–	–
	Turbidity (NTU)	15	0.00	27.00	2.60	6.80	5	5
Chemical ions	Na^+ (mg/L)	15	7.00	33.97	14.36	6.71	200	200
	K^+ (mg/L)	15	1.00	12.00	5.33	2.82	12	–
	Mg^{2+} (mg/L)	15	0.00	6.35	1.30	1.87	50	0.20
	Ca^{2+} (mg/L)	15	0.22	53.60	16.76	16.09	75	–
	SO_4^{2-} (mg/L)	15	0.00	10.00	3.07	3.15	250	100
	Cl^- (mg/L)	15	8.00	120.00	38.40	42.59	200–300	250
	HCO_3^- (mg/L)	15	36.00	86.00	54.00	14.68	250	–
	NO_3^- (mg/L)	15	0.00	21.10	6.40	6.86	50	50
Heavy metals	Fe (mg/L)	15	0.00	0.54	0.13	0.179	0.3	0.3
	Zn (mg/L)	15	0.01	0.54	0.22	0.174	4	3
	Mn (mg/L)	15	0.00	0.11	0.02	0.040	0.4	0.2
	Pb (mg/L)	15	0.00	3.09	0.82	1.082	0.01	0.01
	Ba (mg/L)	15	0.00	0.01	0.001	0.003	1.3	0.7
	Cr (mg/L)	15	0.00	0.01	0.001	0.003	0.05	0.05
	Ni (mg/L)	15	0.00	0.34	0.084	0.124	0.07	0.02

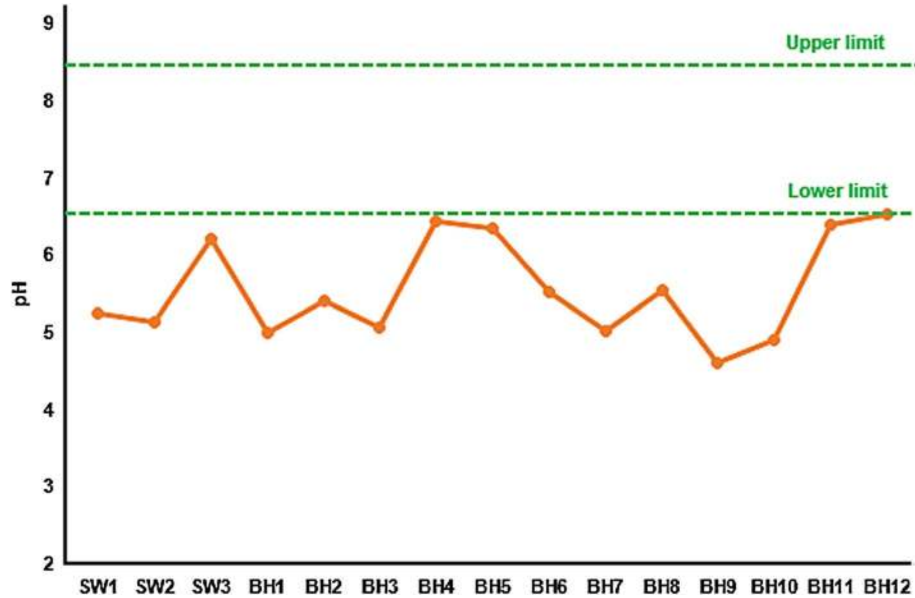

Fig. 2 pH values of the samples graphically compared to the WHO (2017) and NIS (2007) limits

Table 3 Classification of water resources based on EC (Langenegger 1990), TDS (Davis and De Wiest 1966) and TH (Sawyer and McCarthy1967)

Electrical conductivity (µS/cm)	Category	% of samples in category
0–333	Excellent	100
333–500	Good	–
500–1100	Permissible	–
1100–1500	Brackish	–
1500–10,000	Saline	–
TDS (mg/L)	Water quality	% of samples in category
< 500	Desirable for drinking	100
500–1000	Permissible for drinking	–
< 3000	Useful for irrigation	–
> 3000	Unfit for drinking and irrigation	–
Total hardness as $CaCO_3$ (mg/L)	Water type	% of samples in category
< 75	Soft	80
75–150	Moderately hard	20
150–300	Hard	–
> 300	Very hard	–

The EC, TDS and TH are very important physical properties of water used in measuring its quality status. Table 3 shows that based on EC, 100% of the water samples are classified as excellent drinking water. Likewise, 100% of the samples classify into "desirable for drinking" based on TDS. However, on the basis of TH, 80% of the samples are soft and very suitable for drinking and domestic (food preparation, washing and bathing) purposes. Meanwhile, 20% represent samples with moderate hardness, which are only fairly suitable for drinking and other domestic purposes (Sawyer and McCarthy 1967) (Table 3). The low values of EC and TH confirm the low concentrations of dissolved solids in the water samples. TSS and TS have no standard limits by WHO (2017) and NIS (2007).

Schoeller diagram plotted for the samples shows the graphical distribution of the major chemical ions (Fig. 3). The hydrogeochemistry of the water resources in Umunya district is characterized by the prevalence of calcium and bicarbonate as dominant cation and anion. The dominance of cations and anions is in the order $Ca^{2+} > Na^{+} > K^{+} > Mg^{2+}$ and $HCO_3^{-} > Cl^{-} > NO_3^{-} > SO_4^{-}$, respectively. The alkaline earth content (Ca^{2+}) reflects the dissolution of Ca-bearing minerals. On the other hand, the alkali element (Na^{+}) is probably due to dissolution of alkali feldspar minerals in the aquifer systems. The Na and Cl concentrations are generally low, indicating there is no seawater intrusion process in the area and that no evaporite deposits underlie the area. HCO_3 occurrence exceeded that of SO_4, indicating that carbonic acid weathering is dominating in the area more than sulfide oxidation, thereby significantly influencing the geochemistry of the waters, among other factors. Probably, the bicarbonates were derived from weathering of silicate rocks and minerals, and/or atmospheric and soil CO_2 gas. Chloride concentrations could be attributed to domestic wastes, poor sanitary conditions, leaching from soil layers or natural geochemical processes. Nitrate concentration was found to be well below standard limits set for drinking water. This indicates that agricultural activities in the Umunya district have not had severe impact on water quality. The decreased potential of nitrate pollution in the area could be linked to abundance of greenish vegetation and trees, which can expedite denitrification processes. Studies have shown that low nitrate concentration in waters in agricultural provinces could be due to dilution from precipitation, denitrification and uptake by plants (Hubbard and Sheridan 1989; Nemcic-Jurec et al. 2017). Based on the Mg limit by NIS (2007), majority (66.67%) of the samples are magnesium contaminated. But, judged by WHO (2017) limit, all the waters are very safe and desirable for drinking.

AquaChem aided the identification of the various water types and facies. Table 4 presents a summary of the classification of the waters according to types and facies. Radial and Stiff diagrams are two major tools used in picturizing water types. In this study, Radial diagrams were plotted for the fifteen water samples (Figs. 4, 5). Eight water types were identified, with Ca–Na–HCO_3 (26.66%) and Na–Cl–HCO_3 (20%) dominating the study area, as opposed to the five water types with the dominance of Ca–Na–K–HCO_3 and Na–K–HCO_3 water types reported by Egbunike (2018). However, in their shortest forms the dominant water groups can be summed as Ca–HCO_3 and Na–HCO_3 for both studies. Moreover, in this study, all the water types characterize five major facies. Piper trilinear diagram (Fig. 6) was created to picturize the distribution of the samples into various facies fields. It was observed that 40% of the water samples belong to alkaline earth-alkali-bicarbonate facies while 33.33% constitute alkali-bicarbonate-chloride facies. These two facies dominate the area. The positions of the water samples on the trilinear diagram confirm that the area is dominated by weak acids (HCO_3, 60%) than strong acids ($Cl + SO_4$, 40%) (Tiwari et al. 2017).

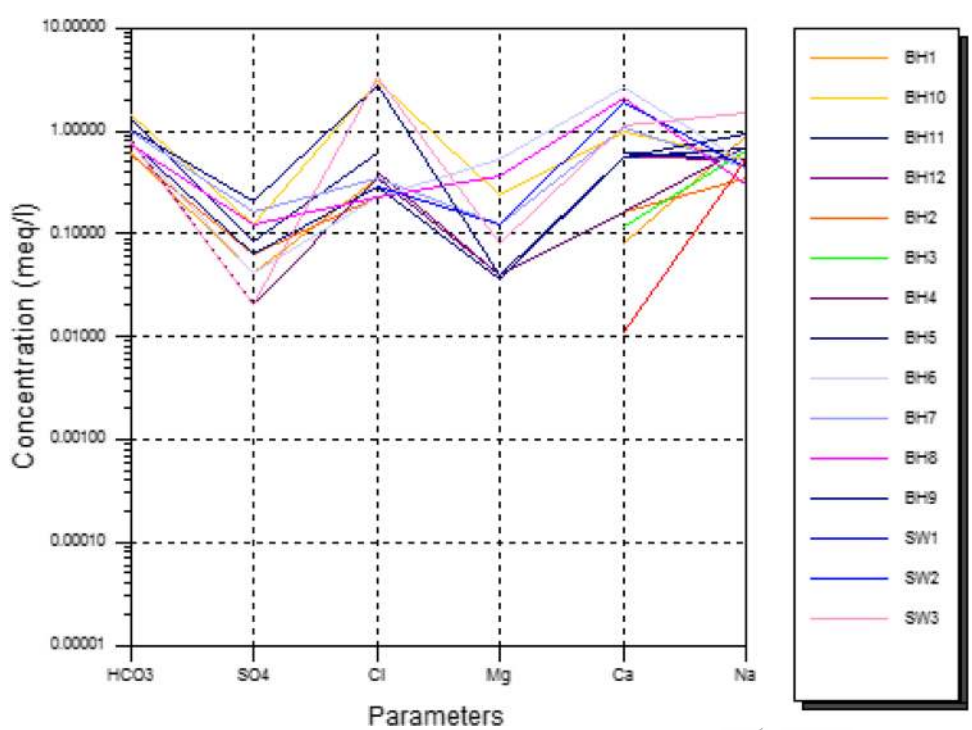

Fig. 3 Schoeller diagram showing the concentrations of major ions

Table 4 Hydrogeochemical classifications of the water resources

Water type	Sample in water type		Dominant water facies and their percentages
	No. of sample	%	
1. Na–HCO_3–Cl	2	13.33	1. Alkali-bicarbonate-chloride (33.33%)
2. Ca–Cl–HCO_3	1	6.67	2. Alkaline earth-chloride-bicarbonate (6.67%)
3. Ca–Na–HCO_3	4	26.66	3. Alkaline earth-alkali-bicarbonate (40%)
4. Na–Cl–HCO_3	3	20.00	4. Alkaline earth-bicarbonate (13.33%)
5. Na–Ca–HCO_3	2	13.33	5. Alkali-alkaline earth-chloride-bicarbonate (6.67%)
6. Ca–Mg–HCO_3	1	6.67	
7. Ca–HCO_3	1	6.67	
8. Na–Ca–Cl–HCO_3	1	6.67	

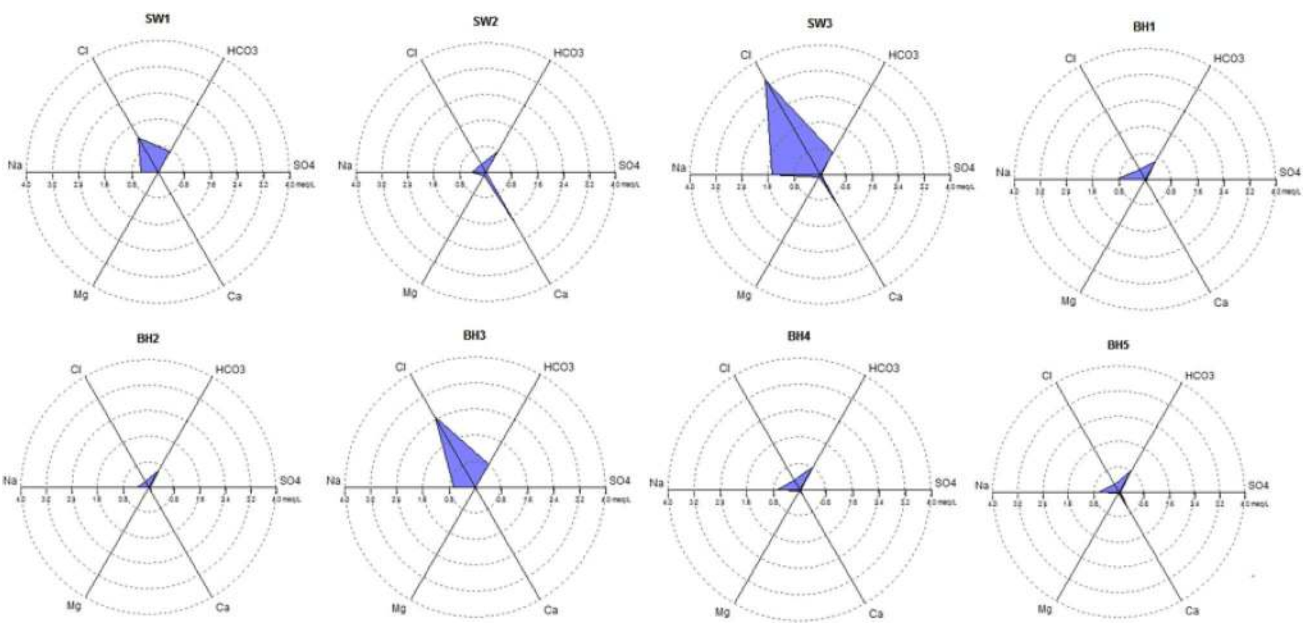

Fig. 4 Radial diagrams for samples SW1, SW2, SW3, BH1, BH2, BH3, BH4 and BH5

It was also necessary to plot Durov diagram. This diagram is important in depicting the hydrogeochemical processes or trends dominating aquifer systems. The Durov diagram confirmed the distinctions shown in the cation and anion fields of the Piper diagram. The samples generally seem to have similar geochemical trend. Figure 7 shows that majority of the samples concentrated in the fields marked by simple dissolution or mixing and ion exchange (Lloyd and Heathcote 1985; Onwuka et al. 2018). Further, in order to ascertain the rock-water equilibrium of the waters, it was necessary to plot their ionic values in a Giggenbach triangle. The triangle (Fig. 8) shows that both the surface waters and the groundwaters plotted at the base of the triangle, suggesting that the waters are not equilibrated and immature. This implies that the waters had not had long-time interaction with surrounding rocks/soils (having short residence time) when the samples were collected. This correlates well with the physicochemical values (especially for TDS, TSS, TH and EC) obtained.

Prevalent geogenic processes (factors) influencing the supply of ions in the waters

Various reactions are usually responsible for the hydrogeochemical characteristics of aqua systems. These reactions also impact the quality of waters. The major chemical processes and factors (potential sources of the ions) prevailing in the analyzed water resources were studied by using different ionic ratios and bivariate diagrams. Forward and reverse ion exchanges are part of the common processes that govern the evolution of water geochemistry. On the first hand, forward ion exchange is represented by the displacement of the Na ion at mineral surfaces (e.g., clay) by other cations in the water, such as Ca and Mg (Barzegar et al. 2018a). On the

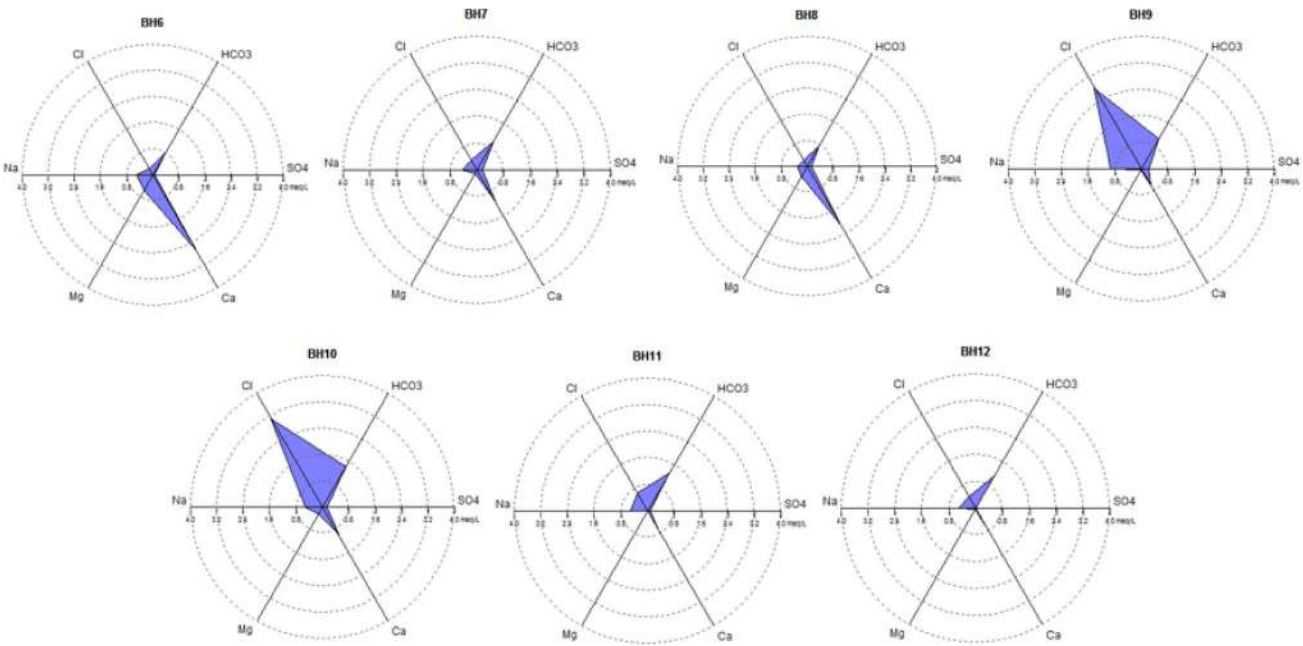

Fig. 5 Radial diagrams for samples BH6, BH7, BH8, BH9, BH10, BH11 and BH12

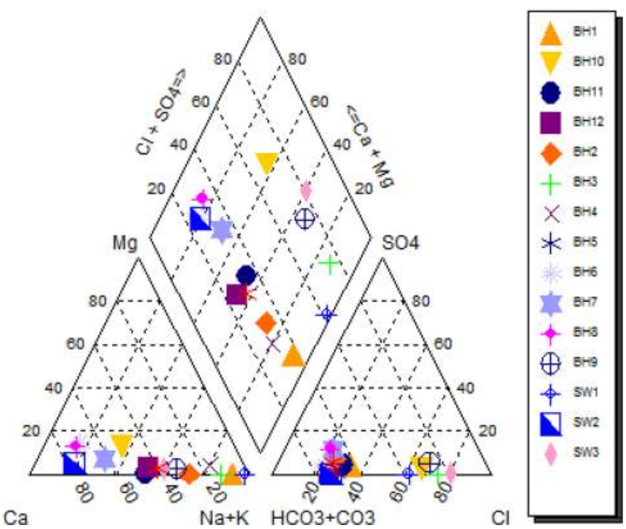

Fig. 6 Piper diagram plotted for the samples

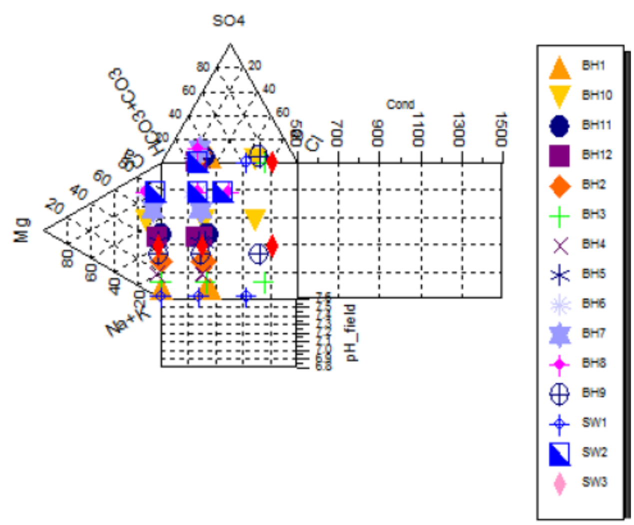

Fig. 7 Durov diagram plotted for the samples

other hand, reverse ion exchange is defined by the exchange of Ca and Mg ions on clay minerals by Na ions in the water (Barzegar et al. 2018a).

Figure 9a shows the Na^+ versus Cl^- diagram. From the plot, it can be deduced that forward ion exchange is the predominating process releasing sodium ion in the waters (Eq. 8) (Appelo and Postma 2005; Barzegar et al. 2018a). Moreover, Meyback (1987), Kumar et al. (2009) and Barzegar et al. (2016) reported that Na/Cl ratio greater than 1 typically indicates that sodium ions were derived from silicate weathering. However, Fig. 9b shows that only four samples have Na/Cl ratio greater than 1, whereas the majority were less than 1, suggesting that there could be significant reduction of Na^+ concentration in water due to reverse ion exchange process (Eq. 9) (Appelo and Postma 2005; Barzegar et al. 2018a). This process releases more calcium ions, rather than sodium ions, in water. This assumption is consistent with the major ion chemistry, with calcium concentration higher than that of the sodium ($Ca^{2+} > Na^+ > K^+ > Mg^{2+}$). However, if halite dissolution or evaporation process was to be responsible for the sodium ion concentration in the samples, majority of Na/Cl ratio could be approximately equal to 1 (Meyback 1987; Kumar et al. 2009;

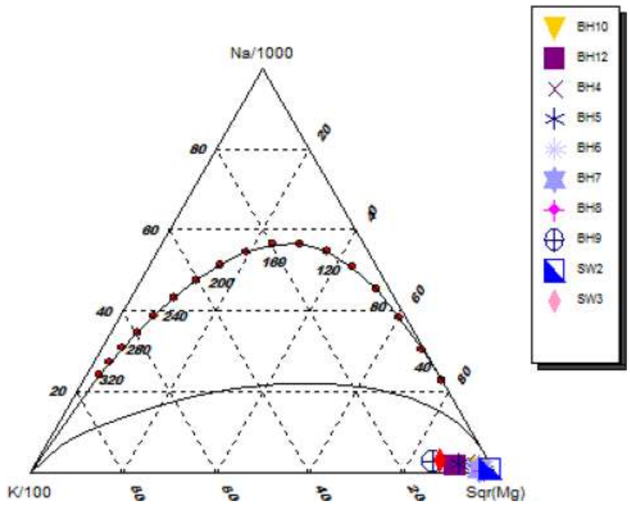

Fig. 8 Rock-water equilibrium of the samples plotted on Giggenbach diagram

Barzegar et al. 2016). In addition, this could be more reason the waters generally have relatively low EC values (Fig. 9b).

$$2NaX + Ca^{2+} \rightarrow 2Na^{+} + CaX_2 \quad (8)$$

$$CaX_2 + 2Na^{+} \rightarrow Ca^{2+} + NaX. \quad (9)$$

Ca versus HCO_3 scatter diagram and that of Ca versus SO_4 were also plotted. Figure 9c indicates that carbonic acid weathering also plays a major role in the release of Ca ions into the waters, rather than carbonate mineral (calcite) dissolution. In other words, silicate weathering by carbonic acid and cationic exchange releases Ca^{2+} into the waters. In addition, Fig. 9d also shows that silicate weathering, rather than anhydrite or gypsum dissolution, is a predominant process that governs the major ion chemistry and the hydrogeochemical evolution of the study area (Tziritis et al. 2017; Barzegar et al. 2017a). Moreover, it confirms the low concentration of SO_4 ions ($HCO_3^{-} > Cl^{-} > NO_3^{-} > SO_4^{-}$), which in turn points to anoxic hydrogeological conditions of the study area (Barzegar et al. 2017a). It is further indicated in Fig. 10a that sodium ions in the waters are majorly released by forward ion exchange process. On the other hand, Fig. 10b signifies and confirms that Ca^{2+} and Mg^{2+} in water were not derived from carbonate mineral dissolution but from silicate weathering.

In attempt to further investigate the sources of some ions in the analyzed waters, chloro-alkaline indices (CAI-1, CAI-2) were calculated. The indices are used to confirm the occurrence and type of ion exchange in water, which in most cases regulates the transportation of chemicals and pollutants in soil and water (Li et al. 2013). CAI-1 was calculated using Eq. 10, while CAI-2 was got by Eq. 11. According to Schoeller (1977), a negative CAI-1 and CAI-2 values indicate dominance of forward ion exchange, while positive values indicate reverse ion exchange. In this study, the CAI-1 (Fig. 11a) and CAI-2 (Fig. 11b) identified and confirmed the prevalence of forward ion exchange over reversed ion exchange in releasing the alkali metals (Na + K).

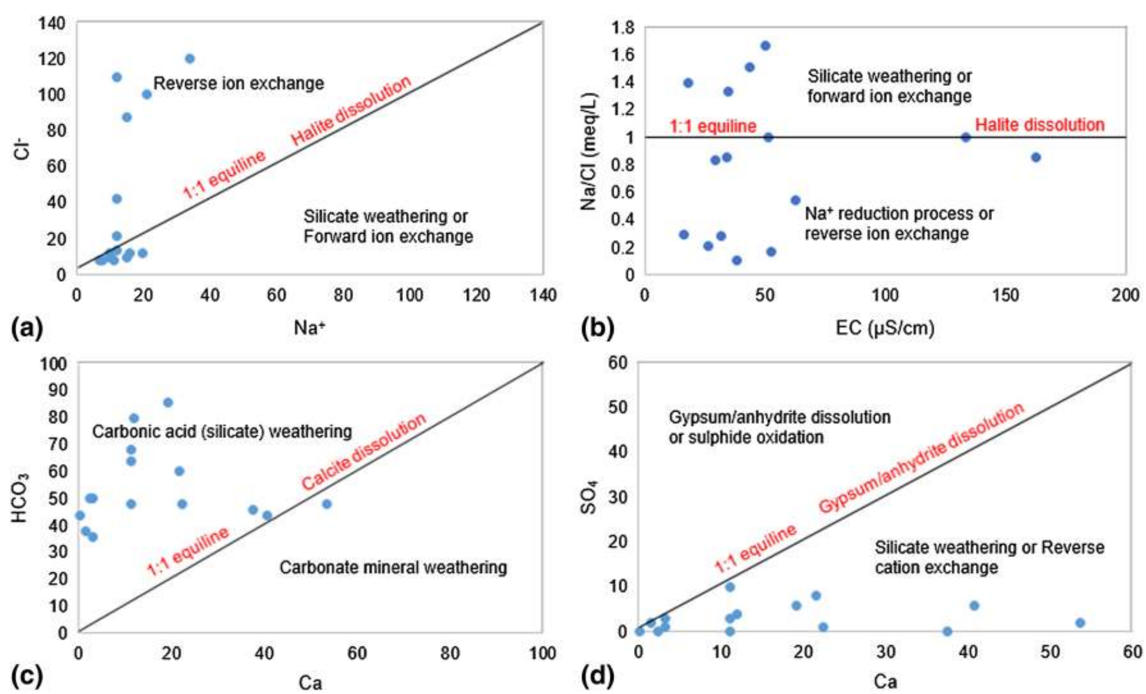

Fig. 9 Scatter plots (mg/L) for: **a** Na versus Cl, **b** Na/Cl versus EC, **c** Ca versus HCO_3, **d** Ca versus SO_4

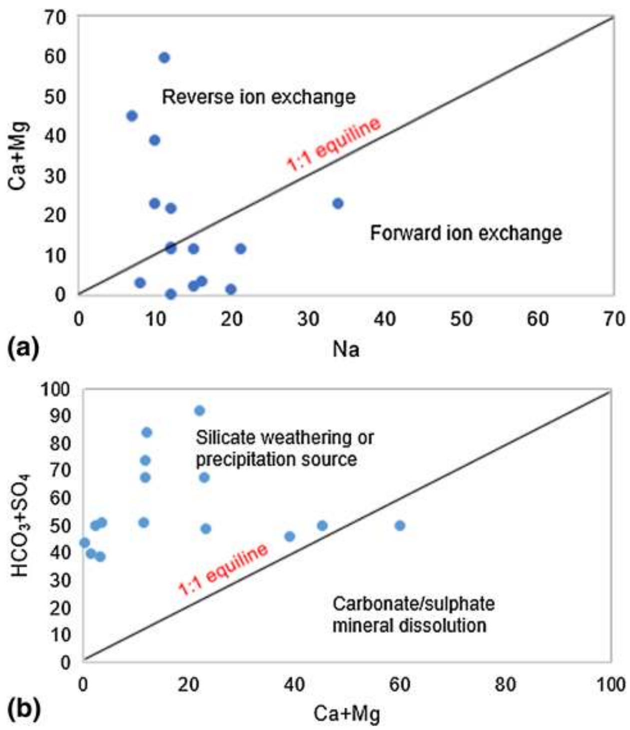

Fig. 10 Scatter plots for: **a** Na versus (Ca + Mg) (mg/L), **b** (Ca + Mg) versus ($HCO_3 + SO_4$)

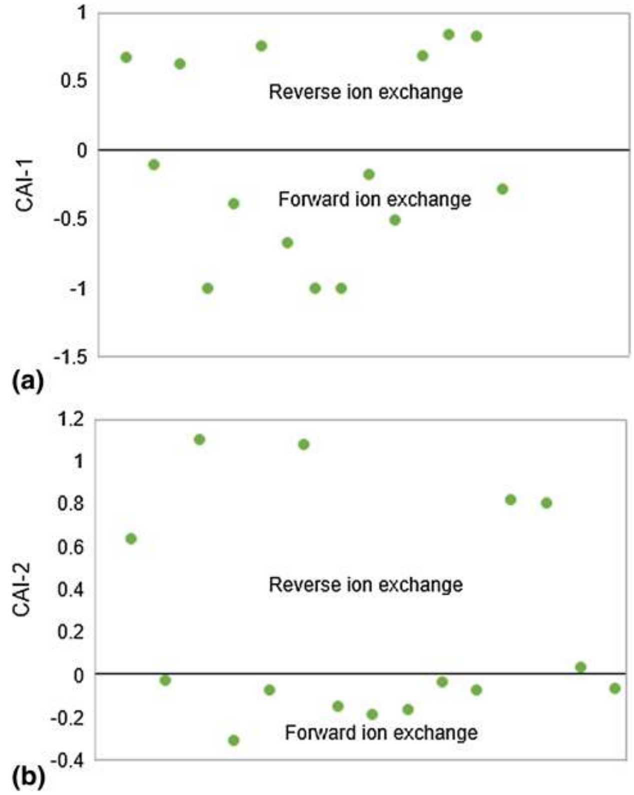

Fig. 11 **a**, **b** Chloro-alkaline indices (CAI-1, CAI-2) depict the dominance of forward ion exchange in releasing the alkali metals and chlorides

$$\text{CAI-1} = [\text{Cl}-(\text{Na}+\text{K})/\text{Cl}] \tag{10}$$

$$\text{CAI-2} = [\text{Cl}-(\text{Na}+\text{K})/(\text{SO}_4+\text{HCO}_3+\text{NO}_3)] \tag{11}$$

Heavy metal concentrations

Trace metals Fe, Zn, Mn, Pb, Ba, Cr and Ni were also studied in the water samples of the study area to examine their suitability as drinking water. Figure 12 shows the graphical representation of the heavy metal constituents in the water resources. Except for Zn, all other metals recorded minimum values below the detection limit of 0.001 mg/L in some samples. Such minimal values were recorded as zero. Based on their mean values, the order of dominance of the heavy metals is Pb > Zn > Fe > Ni > Mn > Cr > Ba (see Table 2 too). The results of the heavy metal analysis indicate that the water quality of the study area is vulnerable to trace metals pollution. The concentration of Pb, Zn, Ba, Cr, Mn and Ni is attributed to dumpsite and anthropogenic sources, rather than natural geogenic sources (Tiwari et al. 2017; Egbueri 2018). This follows the fact that the geology of the study area is made of lithologies (sandstones and mudrocks) deficient in heavy (trace) metal mineralogy (Nwajide 1979, 1980, 2013; Oguadinma et al. 2014). However, it is believed that Fe concentration came from the interaction of rainwater during infiltration with the iron-rich sediments (Batabyal and Chakraborty 2015).

Pearson's correlation matrix

In this study, the interrelationships among different water quality parameters of the study area were studied by running Pearson's correlation analysis. This was done to further analyze the factors that govern the hydrogeochemistry and quality of the water resources in Umunya district. The correlation matrix of the 26 variables was computed using SPSS software. Correlation coefficients greater than 0.5 were considered significant. At the end of the analysis, 45 significant positive correlation pairs were identified (Table 5). The pairs are: Color/TSS (0.981), Color/TDY (0.992), Color/Na (0.752), Color/K (0.650); TDS/EC (1.000), TDS/TS (0.986), TDS/Zn (0.534), TDS/Pb (0.718), TDS/Ni (0.712), EC/TS (0.986), EC/Zn (0.534), EC/Pb (0.712), EC/Ni (0.699); TH/Ca H (0.998), TH/Mg H (0.913), TH/Mg (0.914), TH/Ca (0.998), TH/Zn (0.699); Ca H/Mg H (0.891), Ca H/Mg (0.891), Ca H/Ca (1.000), Ca H/Zn (0.713); Mg H/Mg (1.000), Mg H/Ca (0.890), Mg H/Zn (0.584); TSS/TDY (0.982), TSS/Na (0.762), TSS/K (0.596), TSS/Cl (0.502); TS/Zn (0.515), TS/Pb (0.691), TS/Ni (0.686), TDY/Na (0.793), TDY/K (0.659), Mg/Ca (0.891), Mg/Zn (0.585); Ca/Zn (0.714), SO_4/Fe (0.845), Cl/NO_3 (0.803), HCO_3/NO_3 (0.608), HCO_3/Fe (0.587),

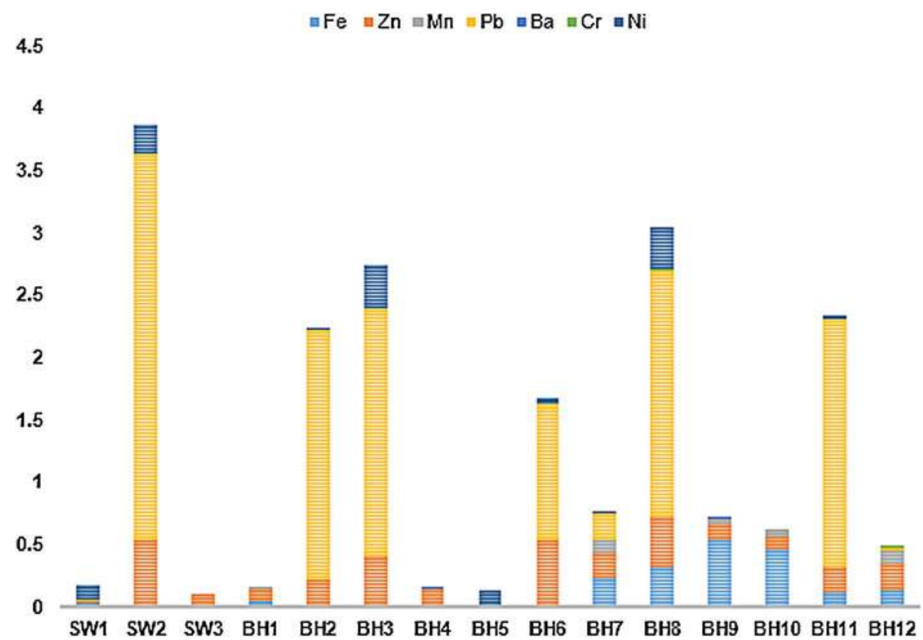

Fig. 12 Heavy metal concentrations (distribution) in the water samples

HCO_3/Mn (0.524); Zn/Pb (0.762), Zn/Ni (0.547), and Pb/Ni (0.627).

With respect to these pairs, it can be deduced that:

1. Temperature and pH have no significant correlation with all other parameters, suggesting that temperature has little or no influence on the geochemistry of the waters and that the pH is influenced by several factors other than the parameters analyzed.
2. The pairs with significant correlation have the same source (origin), and their linearity is directly proportional. Those with correlation coefficients greater than 0.9 have the strongest linearity. Among the heavy metals, Zn appears to have more associations with other parameters, indicating it has variety of sources.
3. Cr and Ba recorded no significant relationship with other parameters. This suggests that they have different waste source or origin. Although all the heavy metals were generally classified to have dumpsite (anthropogenic) sources in the correlation analysis, Cr and Ba are thought to have peculiar waste source(s) (different leachate makeup), different from where others were leached from. Cr and Ba could be leached from metallurgical waste sources, whereas Zn, Ni, Pb could be leached from automobile batteries, tires and electronic wastes.
4. TS has good correlation with heavy metals Pb, Zn and Ni. These three trace metals have good correlation with TDS and EC, indicating their presence significantly influence them (TDS and EC).

Factor analysis

Principal component factor analysis (PCFA) is very useful in water resource management as it helps to relate the distribution of various quality parameters to different possible sources, which usually have different chemical signatures. In attempt to further investigate the potential processes and sources (factors) that drive the hydrogeochemical characteristics of the water resources, PCFA was used to identify the most significant hydrogeochemical factor loadings. The exact number of factors was chosen by Kaiser (1958, 1960) criterion in which factors with eigenvalues less than one (<1) are not considered. Considering the loadings in this study, factor loadings greater than 0.50 were defined as significant, and loadings of less than 0.50 were considered insignificant. In addition, factor loadings above 0.75 are classed as high, those between 0.50 and 0.75 as medium, and those below 0.50 as weak (Panda et al. 2006; Tziritis et al. 2017). Moreover, this follows the fact that the higher a factor loading of a parameter is, the greater its participation to the examined factor group (Tziritis et al. 2017). Table 6 shows the results of the factor analysis (the components, their loadings, interrelationships and variability). Seven principal components (PCs) were extracted for the study area. This explains the reason for the variation in geochemical composition of the waters (Krishna-Kumar et al. 2014). The PCFA of the water quality variables indicated that the chemistry of the water resources in the study area is majorly controlled by geogenic processes and anthropogenic activities.

The total components' variance was explained at 90.026% (Table 6). PC1 explains 28.827% variability and has significant loadings for TDS, EC, TH, Ca H, Mg H, Na, Mg,

Table 5 Pearson's correlation matrix for different physicochemical and hydrogeochemical parameters

	Color	Temp	pH	TDS	EC	TH	Ca H	Mg H	TSS	TS	TDY	Na^+	K^+	Mg^{2+}	Ca^{2+}	SO_4^{2-}	Cl^-	HCO_3^-	NO_3^-	Fe	Zn	Mn	Pb	Ba	Cr	Ni
Color	1																									
Temp	0.166	1																								
pH	0.261	0.205	1																							
TDS	−0.021	−0.233	−0.059	1																						
EC	−0.019	−0.245	−0.055	**1.000**	1																					
TH	0.162	0.190	−0.072	0.422	0.428	1																				
Ca H	0.172	0.199	−0.059	0.418	0.424	**0.998**	1																			
Mg H	0.031	0.261	−0.126	0.233	0.238	**0.913**	**0.891**	1																		
TSS	**0.981**	0.137	0.206	−0.080	−0.078	0.120	0.137	−0.046	1																	
TS	0.146	−0.209	−0.024	**0.986**	**0.986**	0.442	0.441	0.225	0.090	1																
TDY	**0.992**	0.150	0.319	−0.065	−0.062	0.112	0.126	−0.033	**0.982**	0.102	1															
Na^+	**0.752**	0.102	0.135	−0.370	−0.371	−0.222	−0.206	−0.282	**0.762**	−0.240	**0.793**	1														
K^+	**0.650**	0.234	0.123	−0.282	−0.285	−0.015	−0.015	−0.022	**0.596**	−0.180	**0.659**	**0.753**	1													
Mg^{2+}	0.032	0.262	−0.129	0.234	0.239	**0.914**	**0.891**	**1.000**	−0.045	0.226	−0.032	−0.281	−0.022	1												
Ca^{2+}	0.172	0.201	−0.058	0.419	0.425	**0.998**	**1.000**	**0.890**	0.138	0.443	0.127	−0.204	−0.012	**0.891**	1											
SO_4^{2-}	−0.103	−0.231	−0.424	0.014	0.020	0.162	0.140	0.197	−0.133	−0.009	−0.155	−0.088	0.279	0.198	0.142	1										
Cl–	0.494	0.035	−0.291	−0.290	−0.297	−0.147	−0.157	−0.113	**0.502**	−0.204	0.486	**0.626**	**0.745**	−0.111	−0.157	0.187	1									
HCO^{3-}	−0.137	−0.054	0.074	−0.204	−0.203	0.005	−0.006	0.025	−0.149	−0.230	−0.112	−0.062	0.318	0.025	−0.005	0.399	0.367	1								
NO^{3-}	0.449	0.200	0.043	−0.156	−0.160	−0.019	−0.034	0.021	0.410	−0.086	0.442	0.461	**0.700**	0.022	−0.032	0.256	**0.803**	**0.608**	1							
Fe	−0.125	−0.407	−0.457	0.061	0.065	0.129	0.095	0.201	−0.170	0.032	−0.165	−0.078	0.335	0.202	0.097	**0.845**	0.411	**0.587**	0.378	1						
Zn	−0.139	0.419	−0.175	**0.540**	**0.534**	**0.699**	**0.713**	**0.584**	−0.146	**0.515**	−0.172	−0.403	−0.216	**0.585**	**0.714**	−0.161	−0.263	−0.164	−0.220	−0.150	1					
Mn	−0.152	−0.192	−0.101	−0.300	−0.297	−0.045	−0.054	−0.032	−0.127	−0.321	−0.133	−0.155	0.068	−0.032	−0.053	0.351	0.039	**0.524**	−0.063	0.465	−0.173	1				
Pb	−0.171	0.185	−0.107	**0.718**	**0.712**	0.339	0.359	0.153	−0.157	**0.691**	−0.203	−0.478	−0.344	0.155	0.360	−0.172	−0.283	−0.186	−0.134	−0.225	**0.762**	−0.425	1			
Ba	−0.139	−0.066	−0.010	−0.207	−0.204	−0.179	−0.180	−0.131	−0.126	−0.228	−0.112	0.227	0.215	−0.130	−0.178	0.272	0.130	0.084	0.050	0.323	−0.154	−0.006	−0.282	1		
Cr	−0.136	0.077	0.283	0.223	0.218	0.138	0.139	0.099	−0.188	0.191	−0.113	−0.311	−0.003	0.098	0.140	−0.284	−0.223	0.127	−0.275	−0.030	0.404	0.436	0.196	−0.187	1	
Ni	−0.098	0.085	−0.189	**0.712**	**0.699**	0.252	0.247	0.169	−0.150	**0.686**	−0.157	−0.336	−0.225	0.169	0.245	−0.199	−0.081	−0.336	−0.166	−0.121	**0.547**	−0.367	**0.627**	−0.275	0.266	1

Significant positive correlation (≥ 0.500) are in bold

Table 6 Communalities, variabilities and principal components' loadings of water quality parameters

Quality parameter	Communality (initial at 1.00)	Principal components (initial eigenvalue = 1)						
		PC 1	PC 2	PC 3	PC 4	PC 5	PC6	PC 7
Color	0.978	−0.224	**0.853**	−0.382	0.060	0.062	−0.205	−0.075
Temp	0.834	0.085	0.295	−0.161	**−0.560**	−0.001	**0.630**	0.065
pH	0.899	−0.127	0.096	−0.406	−0.343	0.492	−0.142	**0.574**
TDS	0.987	**0.775**	0.022	−0.221	**0.550**	0.104	−0.097	0.122
EC	0.987	**0.775**	0.023	−0.216	**0.548**	0.102	−0.115	0.128
TH	0.988	**0.762**	**0.513**	0.272	−0.224	−0.050	−0.132	0.019
Ca H	0.976	**0.760**	**0.514**	0.243	−0.235	−0.047	−0.131	0.023
Mg H	0.938	**0.660**	0.425	0.419	−0.351	−0.144	−0.040	−0.001
TSS	0.953	−0.269	**0.810**	−0.401	0.044	0.022	−0.212	−0.131
TS	0.989	**0.729**	0.159	−0.289	**0.557**	0.108	−0.133	0.099
TDY	0.991	−0.280	**0.828**	−0.408	0.033	0.105	−0.215	−0.038
Na^+	0.880	**−0.622**	**0.623**	−0.283	0.056	−0.128	−0.060	0.048
K^+	0.863	−0.457	**0.737**	0.116	0.141	0.169	0.188	0.112
Mg^{2+}	0.939	**0.661**	0.426	0.419	−0.349	−0.146	−0.038	−0.002
Ca^{2+}	0.976	**0.759**	**0.516**	0.243	−0.234	−0.045	−0.130	0.026
SO_4^{2-}	0.788	−0.044	0.129	**0.755**	0.379	−0.185	−0.127	0.075
Cl^-	0.920	−0.490	**0.585**	0.167	0.351	−0.031	0.358	−0.240
HCO_3^-	0.821	−0.234	0.118	**0.648**	0.128	0.481	0.256	0.143
NO_3^-	0.858	−0.358	**0.621**	0.207	0.291	0.088	0.446	0.099
Fe	0.974	−0.064	0.143	**0.827**	**0.508**	0.045	−0.063	0.025
Zn	0.872	**0.848**	0.133	−0.025	−0.158	0.054	0.326	−0.029
Mn	0.883	−0.217	−0.119	**0.589**	−0.099	**0.560**	−0.268	−0.282
Pb	0.842	**0.736**	−0.084	−0.301	0.243	0.032	0.378	0.021
Ba	0.690	−0.295	−0.055	0.271	0.092	−0.273	0.024	**0.665**
Cr	0.810	0.311	−0.125	−0.010	−0.145	**0.820**	0.032	−0.056
Ni	0.770	**0.646**	−0.055	−0.315	0.360	0.020	0.301	−0.173
	Total	7.495	5.119	3.834	2.658	1.725	1.510	1.065
	% variance	28.827	19.690	14.747	10.223	6.634	5.809	4.097
	Cumulative %	28.827	48.516	63.263	73.486	80.120	85.929	90.026

Significant component loadings are in bold

Ca, Zn, Pb and Ni. This group of factor loadings indicates the prevalence of weathering and mineralization (geogenic processes), except for (Zn, Pb and Ni), which is a common group attributable to anthropogenic activities. The lithology of the study area confirms that these heavy metals could not have originated from rock weathering. PC2 explains 19.690% of the total variance and has pronounced factor loadings for TH, Ca H, TSS, TDY, Na, K and NO_3, suggesting geogenic sources. However, the NO_3 in this group is linked to anthropogenic source(s). PC3, PC4, PC5, PC6 and PC7 explained different percentages of total variance (Table 6) and have loadings for (SO_4, HCO_3 and Mn), (Temp, TDS, EC, TS and Fe), (Mn and Cr), (Temp) and (pH and Ba), respectively. Parameters in PC3 are suggestive of waste sources and oxidation processes, whereas those in PC4 are indicative of weathering and dissolution origin. Mn and Cr with high loadings in PC5 are indicative of sources from heavy chemical wastes, like automobile wastes and paints. PC6 and PC7 show that temperature, pH and Ba somewhat influence the quality of the water resources in the Umunya district.

Water quality index (WQI)

WQI is defined as a rating reflecting the composite influence of different quality parameters on the overall quality of water (Batabyal and Chakraborty 2015). It is an important tool that gives a clear picture about the usability of water for drinking and other purposes. A water quality index denotes the integrated effect of the various parameters that are relevant and significant to a particular use (Saba and Umar 2016). Tables 7, 8 and 9, respectively, show the relative weight of all the parameters, the water classification based on WQI and the WQI classification for the individual water samples. The calculated WQI ranges from 8.97 to 2047. Results show that 40% of the water

Table 7 Relative weight of water quality parameters

Parameter	WHO (2017) standard	Weight (w_i)	Relative weight (W_i) $W_i = w_i / \sum_{i=1}^{n} w_i$
Color	15	1	0.013
pH	6.5–8.5	4	0.052
TDS	600–1000	5	0.065
EC	1000	3	0.039
TH	100–300	3	0.039
Ca H	100–300	3	0.039
Mg H	100–300	3	0.039
TDY	5	4	0.052
Na^+	200	3	0.039
K^+	12	2	0.026
Mg^{2+}	50	2	0.026
Ca^{2+}	75	2	0.026
SO_4^{2-}	250	4	0.052
Cl^-	200–300	3	0.039
HCO_3^-	250	3	0.039
NO_3^-	50	5	0.065
Fe	0.3	4	0.052
Zn	4	2	0.026
Mn	0.4	4	0.052
Pb	0.01	5	0.065
Ba	1.3	4	0.052
Cr	0.05	5	0.065
Ni	0.07	5	0.065
		$\sum w_i = 77$	$\sum W_i = 1.027$

Table 8 Water quality classification based on WQI and % of samples in each class

WQI range	Water type	% of sample in category
< 50	Excellent water	40
50–100	Good water	6.67
100–200	Poor water	13.33
200–300	Very poor water	0
> 300	Water unsuitable for drinking	40

samples are in excellent category and suitable for drinking and domestic purposes. 6.67% and 13.33% of the samples are in good water and poor water categories, respectively. The remaining 40% of the samples are in category unsuitable for drinking purposes. A spring sample and five groundwater samples fell into the unsuitable category. The high-quality indices of the samples in this last category are attributed to high concentrations of heavy metals in them. Being contaminated with heavy metals, the waters can serve domestic purposes that do not require them for food processing.

Table 9 Water quality index (WQI) classification for the individual water samples

S/no	Sample ID	Source	WQI	Water type
1	SW1	Spring	19.08	Excellent water
2	SW2	Spring	2047	Water unsuitable for drinking
3	SW3	Stream	52.65	Good water
4	BH1	Borehole	8.97	Excellent water
5	BH2	Borehole	1310	Water unsuitable for drinking
6	BH3	Borehole	1331	Water unsuitable for drinking
7	BH4	Borehole	10.94	Excellent water
8	BH5	Borehole	24.18	Excellent water
9	BH6	Borehole	732.82	Water unsuitable for drinking
10	BH7	Borehole	157.88	Poor water
11	BH8	Borehole	1349	Water unsuitable for drinking
12	BH9	Borehole	25.09	Excellent water
13	BH10	Borehole	103.72	Poor water
14	BH11	Borehole	1319	Water unsuitable for drinking
15	BH12	Borehole	32.12	Excellent water

Table 10 Health risks of the analyzed heavy metals (NIS 2007; WHO 2017)

Heavy metal	Health impact
Fe	No health-based guideline
Zn	No health-based guideline
Cr	Cancer
Pb	Cancer, mental retardation, toxic to nervous systems, inhibits vitamin D metabolism
Ba	Hypertension
Mn	Neurological disorder
Ni	Carcinogenic

Health risk assessment

Having evaluated the hydrogeochemistry and quality of these water resources, it is necessary to discuss the health implications associated with their uses. Although the physical properties and chemical ionic concentrations of the waters are within the set limits, many are laden with heavy metals. The consumption of heavy metal contaminated waters has a lot of health risks, as shown in Table 10. Since Pb has the highest contamination factor among the heavy metals, the residents are more predisposed to health risks associated with lead poisoning (Table 10). In use for domestic purposes, other than drinking, these heavy metals in water can cause undesirable taste in beverages, stains on wares and laundry, slimy coatings and depositions in water distribution pipes (WHO 2017). Although there is no health-based guideline for temperature, it has been observed that high water temperature enhances the growth of microorganisms, which may be toxic

Table 11 Non-carcinogenic risk of heavy metals in terms of hazard quotient (HQ) and hazard index (HI) for children and adults in Umunya district

Sample ID	Sample source	Fe (A*)	Fe (C*)	Zn (A*)	Zn (C*)	Ni (A*)	Ni (C*)	Cr (A*)	Cr (C*)	Mn (A*)	Mn (C*)	Pb (A*)	Pb (C*)	Ba (A*)	Ba (C*)
SW1	Spring	0.0012	0.0029	0.0010	0.0022	0.1714	0.0333	0.0000	0.0000	0.0062	0.0145	0.0082	0.0191	0.0000	0.0000
SW2	Spring	0.0000	0.0000	0.0514	0.1200	0.3429	1.8000	3.81E−05	8.89E−05	0.0000	0.0000	25.2000	58.8000	0.0002	0.0003
SW3	Stream	0.0000	0.0000	0.0095	0.0222	0.0000	0.3333	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
BH1	Borehole	0.0016	0.0038	0.0095	0.0222	0.0000	0.3333	0.0000	0.0000	0.0062	0.0145	0.0000	0.0000	0.0000	0.0000
BH2	Borehole	0.0008	0.0019	0.0191	0.0444	0.0286	0.6667	1.9E−05	4.44E−05	0.0000	0.0000	16.3265	38.0952	0.0000	0.0000
BH3	Borehole	0.0004	0.0010	0.0381	0.0889	0.4857	1.3333	7.62E−05	0.0002	0.0000	0.0000	16.1633	37.7143	0.0000	0.0000
BH4	Borehole	0.0008	0.0019	0.0114	0.0267	0.0000	0.4000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0014	0.0033
BH5	Borehole	0.0000	0.0000	0.0010	0.0022	0.1714	0.0333	0.0000	0.0000	0.0000	0.0000	0.0082	0.0191	0.0000	0.0000
BH6	Borehole	0.0000	0.0000	0.0514	0.1200	0.0571	1.8000	3.81E−05	8.89E−05	0.0000	0.0000	8.8735	20.7048	0.0002	0.0003
BH7	Borehole	0.0094	0.0219	0.0191	0.0444	0.0286	0.6667	1.9E−05	4.44E−05	0.0683	0.1594	1.7143	4.0000	0.0000	0.0000
BH8	Borehole	0.0131	0.0305	0.0390	0.0889	0.4856	1.3333	7.62E−05	0.0002	0.0000	0.0000	16.1633	37.7143	0.0000	0.0000
BH9	Borehole	0.0220	0.0514	0.0114	0.0267	0.0000	0.4000	0.0000	0.0000	0.0249	0.0580	0.0000	0.0000	0.0014	0.0033
BH10	Borehole	0.0188	0.0438	0.0095	0.0222	0.0000	0.3333	0.0000	0.0000	0.0373	0.0870	0.0000	0.0000	0.0000	0.0000
BH11	Borehole	0.0045	0.0105	0.0191	0.0444	0.0286	0.6667	1.9E−05	4.44E−05	0.0000	0.0000	16.3265	38.0952	0.0000	0.0000
BH12	Borehole	0.0053	0.0124	0.0200	0.0467	0.0000	0.7000	0.0002	0.0004	0.0689	0.1609	0.1714	0.4000	0.0002	0.0003
	Minimum	0.0000	0.0000	0.0010	0.0022	0.0000	0.0333	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Maximum	0.0220	0.0514	0.0514	0.1200	0.4857	1.8000	0.0002	0.0004	0.0689	0.1609	25.2000	58.8000	0.0014	0.0033
	Mean	0.0053	0.0121	0.0206	0.0482	0.1200	0.7222	3.17E−05	7.41E−05	0.0141	0.0330	6.7303	15.7041	0.0002	0.0005
	HI	0.0780	0.1819	0.3095	0.7222	1.8000	10.8333	0.0005	0.0011	0.2118	0.4942	100.9551	235.5619	0.0033	0.0077

*A**adult; *C** children

to human systems, and may increase problems related to taste, odor, color and corrosion (WHO 2017).

Moreover, the results of hazard quotients (HQ) (for the heavy metals) presented in Table 11 were estimated to assess the non-carcinogenic risk posed by the ingestion of water containing trace metals for both children and adult population groups within the study area. Mean values show that the HQ order for both the children and adult population group is Pb > Ni > Zn > Mn > Fe > Ba > Cr, confirming Pb to have the highest pollution factor in the water resources. According to Table 11, Pb is the only trace metal with mean HQ values for both adult and children population groups above 1, having 46.7% of samples investigated falling above unity. In addition, 26.7% of the Ni health quotient (HQ) values for the children population group were also above the acceptable limit. Seven samples recorded ≥ 4 HQ values of Pb for adult population, which going by Bortey-Sam et al. (2015) classification, poses high chronic risk when ingested (Table 11). Furthermore, results of hazard index (HI) show that elevated HI values for Ni and Pb for both adult and children population group within the studied area pose high chronic risks, whereas HI values for other trace metals are within acceptable limits and as such pose no health risk.

Conclusions

The hydrogeochemical characteristics and quality indices of water resources in Umunya district have been evaluated for drinking and domestic purposes. Moreover, the non-carcinogenic health risks associated with the use of these resources were assessed. The dominance of cations and anions is in the order $Ca^{2+} > Na^{+} > K^{+} > Mg^{2+}$ and $HCO_3^{-} > Cl^{-} > NO_3^{-} > SO_4^{-}$, respectively. Eight water types were identified, with Ca–Na–HCO_3 (26.66%) and Na–Cl–HCO_3 (20%) dominating the study area. All of the water types fall within five major facies, namely alkali-bicarbonate-chloride (33.33%), alkaline earth-chloride-bicarbonate (6.67%), alkaline earth-alkali-bicarbonate (40%), alkaline earth-bicarbonate (13.33%) and alkali-alkaline earth-chloride-bicarbonate (6.67%). Further, the result revealed that the physical properties and chemical ionic concentrations in the waters are well below the maximum permissible limits of WHO (2017) and NIS (2007). However, the water quality is deteriorated due to the presence of high levels of heavy metals, especially Pb, Fe and Ni. Consumption of high concentration of these heavy metals has negative health impacts such as cancer, nervous system disorder, mental disorder, etc. WQI results show that 46.67% of the water samples are in excellent and good categories and, thus, suitable for drinking and domestic purposes. 13.33% of the samples are in poor water category, whereas the remaining 40% of the samples are in category unsuitable for drinking purposes. Stoichiometric and statistical analyses revealed that the variations in chemistry and quality of the waters are due to combined influence of human activities and geogenic processes. Based on the results of health risk assessment, a good percentage of the water samples predisposes users to health risks. The results of the human health risk assessment show that Pb and Ni are the most dominant heavy metals inducing high non-carcinogenic, chronic risk among all the heavy metals. It is, therefore, advised that residents of the study area should treat these waters before consumption. Also, it is recommended that high sanitary measures be adopted, especially in homes and waste disposal sites.

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