



Hydrochemistry and an appraisal of surface water and groundwater quality for domestic and irrigation use in parts of Southern Benue Trough, Nigeria

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Abstract

This research attempts to assess the hydrochemistry of major ions, the quality of surface and subsurface water, as well as its suitability for domestic and agricultural uses, in parts of the Southern Benue Trough. A total of thirty water samples were collected and analyzed in the laboratory using standard practices. Results revealed that the concentration of major cations for both surface and groundwater is in the order: $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$, while major anionic constituents are, respectively, present in the order: $\text{Cl}^- > \text{HCO}_3^- > \text{CO}_3^{2-} > \text{NO}_3^- > \text{SO}_4^{2-}$ and $\text{HCO}_3^- > \text{Cl}^- > \text{CO}_3^{2-} > \text{NO}_3^- > \text{SO}_4^{2-}$ for surface and groundwater. The water quality index (WQI) model revealed that 100% of the surface water is of good quality for domestic and other uses, while 29.17% and 70.83% of the groundwater are of excellent and good quality, respectively. Three water types were identified, namely Na–Cl, Ca–Mg– HCO_3 , and Na– HCO_3 . Lastly agricultural indices (total hardness, TH, percent sodium, %Na, sodium absorption ratio, SAR, residual sodium carbonate, RSC, permeability index, PI and magnesium hazard, MH) computed along with various plots, revealed that the analyzed surface and subsurface water are suitable for irrigation purposes. The application of plots, tables, and models based on the major ionic constituents, gives fast and effective visualization of the quality and chemistry of surface water and groundwater.

Keywords Surface water · Groundwater · Irrigation · Major ions · Water quality · Hydro-chemical facies

Introduction

The importance of water to mankind is indispensable because it is utilized in households, farms, and in the industries (Musa et al. 2014; Tiwari et al. 2017; Roşca et al. 2020). About three-quarters of the earth's surface area is covered by water, and ninety-seven percent of the earth's water resources which are locked in the sea and ocean are saline (Cidu et al. 2011). Fresh water occurs in the form of surface and groundwater, and they constitute the remaining three percent. Within the study area, surface water sources include; rivers, streams, and ponds, while groundwater is located within subterranean (shallow and deep) aquifers.

Shallow aquifers are explored by means of open wells, usually below twenty meters deep, and boreholes which are generally below 60 m deep. The deep aquifer is usually tapped using boreholes greater than sixty meters (Edet 2018).

Most rural communities in Nigeria depend on water resources to meet their daily requirements. It is believed that groundwater in terms of quality, is more reliable compared to surface water which is continuously contaminated by human activities (Ayuba et al. 2017; Khudair et al. 2022). However, some groundwater sources could also be contaminated through geogenic and anthropogenic processes. Owing to the seasonal nature of most surface water bodies, there is greater dependence on groundwater particularly in the dry period as the level of water lowers within the subsurface reservoirs, and surface water bodies dry up. Generally, about 52% of households in Nigeria have access to improved sources of drinking water (NBS 2014). Further, according to a report by NBS (2017) about 42.9% of the households in Cross River State depend on groundwater while 43% depends on surface water. Both surface and groundwater are exposed to anthropogenic impacts arising from waste

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disposal into surface water, infiltration into shallow sub-surface water, poor construction of wells, and agricultural activities. These activities alter the natural chemistry of major ionic constituents and the quality of water. Major ionic constituents are those whose concentration is greater than 0.5 mg/l in water, they include SO_4^{2-} , HCO_3^- , Cl^- , Na^+ , K^+ , Ca^{2+} , and Mg^{2+} (Merkel and Planer-Freidrich 2002). These ions together with physical factors like pH, total dissolved solids (TDS), and electrical conductivity (EC), are used to effectively evaluate water sources and predict changes within their environment (Edmunds et al. 2006; Li et al. 2016). As groundwater flows, its quality gets altered over time and space (Moral et al. 2008; Egbueri et al. 2019; Ifediegwu et al. 2019; Ochelebe et al. 2020), through the hydrological cycle and operations of geogenic and anthropogenic processes.

There is often a misconception that clean water is of good quality (Akter et al. 2016). This assertion has ignored the fact that the presence of chemical and ionic constituents in water impacts its chemistry. Several factors that affect water chemistry may include; rainfall, groundwater flow configurations, percolation rate, quality of recharge water, geological settings, saline intrusion, mining, excessive irrigation activities, rate of weathering, and inputs from other sources (Okiongbo and Douglas 2015; Srinivas et al. 2017; Egbueri et al. 2019; Bhat et al. 2022).

Several investigations have been carried out in other part of the southern Benue Trough to assess the quality of water (Offiong and Edet 1998; Edet and Okereke 2005, 2022; Edet et al. 2012; Ekwere and Edet 2012; Adamu et al. 2014). The water quality index (WQI) model has also been used as an effective tool to assess the suitability of water resources based on their physicochemical characteristics (Shankar 2022), although it provides little evidence in terms of the sources of deterioration. Specific work on the quality of water and ionic composition in terms of their sources, types, and their suitability for domestic and agricultural purpose in Okpoma and its surrounding area is limited. And with the on-going infrastructural developments, the impact of anthropogenic activities on groundwater and surface water is bound to change. Hence, the need to evaluate the hydro-chemistry and appraise the surface and groundwater quality within Okpoma and its environs is very important, especially during this COVID-19 pandemic when the demand for quality water has increased tremendously.

Furthermore, farming is predominant in the area, just as in most rural communities in Nigeria. Farmers depend on groundwater and surface water for their agricultural activities during the dry season especially, towards achieving food sufficiency for the growing population. Major ions have also been employed in evaluating water resources for agricultural use (Edet 2016). Water quality is therefore pivotal for plant growth in addition to the nature and quality of the soil. According to Ghalib (2017), mineral dissolution may

be responsible for the release of ionic constituents in water. Also, Tak et al. (2012) noted that poor water quality may affect crop productivity. Other practices that have a significant effect on water quality may include intense agricultural practices, and the use of chemical fertilizers, pesticides and insecticides. The aim of this research is, therefore, to assess the chemistry and quality of surface and subsurface water within Okpoma and its environs for its major ion composition, as well as domestic and agricultural use. It is envisaged that the present study forms baseline information for sustainable utilization of water resource in future development.

The study area

The area under investigation lies within longitudes $8^\circ 30'$ E to $8^\circ 50'$ E and latitudes $6^\circ 30'$ N to $6^\circ 50'$ N (Fig. 1) in the southern Benue Trough. It is accessed through the major road that connects Ogoja to Abakaliki which runs across the study area, and a network of other minor roads, footpaths, and farm tracts that provided access routes. The study area is characterized by distinct wet and dry seasons which normally span the months April to September, and October to March, respectively. The area typified by the presence of tall grasses, bushes, and isolated short trees. The precipitation ranges from 200 to 250 cm, which recharges the heavily fractured jointed aquifer (Ekwere and Ukpong 1994).

The Onwu and Aya Rivers with a network of other smaller seasonal rivers and streams drain the entire area. These rivers are structurally controlled and characterized by dendritic drainage patterns (Olade 1975). A common feature of the area is the predominance of alluvial plains which encourage the cultivation of swamp rice and other agricultural produce during the wet period, and irrigation farming in the dry period.

Geology

Geologically, the Okpoma area is characteristic of a Cretaceous folded basin (Peters 1991), and typical rock types found here include; shales, sandstones, and basaltic intrusion (Fig. 2). The evolution of the basin is attributed to direct responses to plate tectonic process in the south Atlantic, concomitant to the parting of Africa and America continents in the Early Cretaceous era (Benkhelil 1987). According to Fairhead and Green (1989), the area had experienced compressional deformation which resulted in the Santonian–Early Campanian folding, and this is contemporaneous with the dextral rebirth of shear zones in central Africa. Also, Peters (1991) stated that alkaline magmatism associated with rifting and initial sedimentation within the basin, particularly in the Abakaliki Sub-basin around the Wankande area, was accompanied by contact metamorphism.

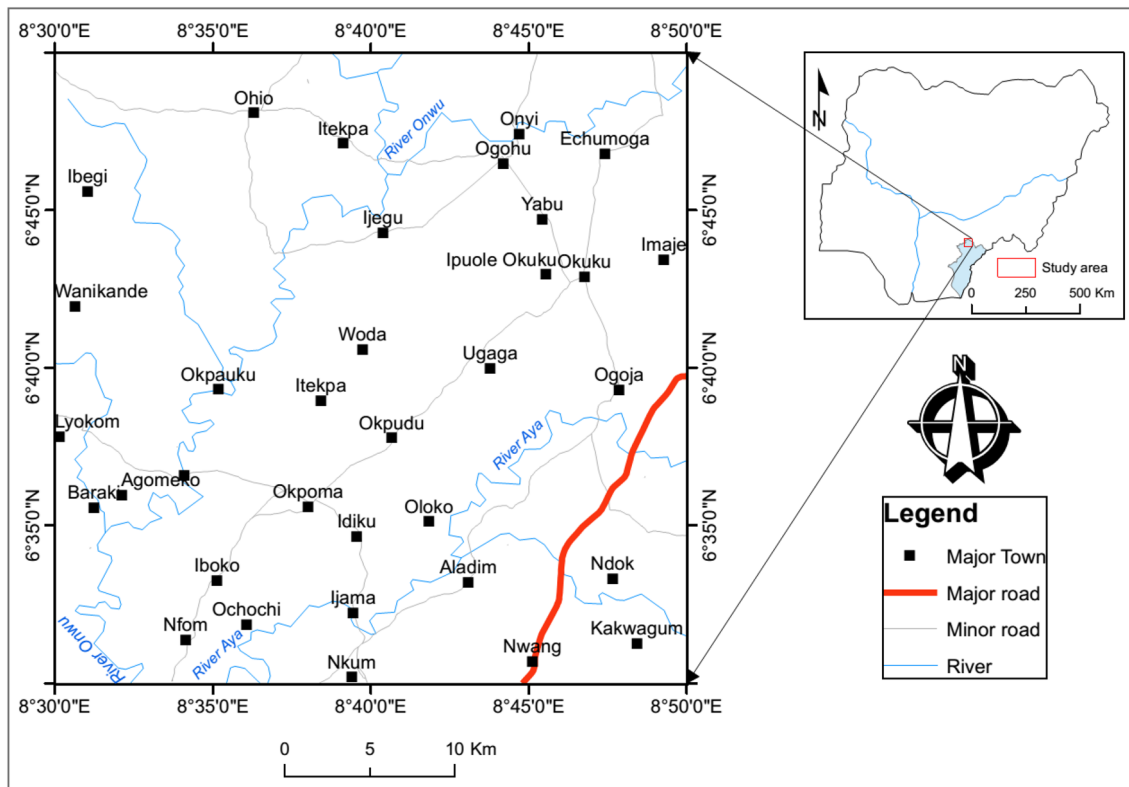


Fig. 1 Map of Okpoma and environs

High-stand and low-stand cycles before the mid-Albian characterized sequence of sedimentation and stratigraphy within the southern Benue Trough, while sediments of the Asu-River Group (ARG) are the oldest, and overlie the basement rocks. They were deposited under a sub-anoxic, shallow water environment of low energy as indicated by the carbonaceous and pyretic nature of the shales. Typical lithologies represented by this Group are shales and sandy shales, calcareous sandstone, and siltstone with lenses of limestone. Turonian–Early Santonian Eze-Aku Formation (EAF) overlies the ARG, while lithologic units within the Formation are variable in thickness comprising shales and siltstones with limestone and sandstone which are calcareous (Dessauvage 1975; Mbiptom et al. 1990). Minor basic intrusions invaded the pre-Santonian EAF (Obiora and Umeji 1995).

Studies by Uma and Lohnert (1992) revealed that compressional movement led to the formation of folds and subsequent uplift around Abakaliki. These events were characterized by intruding bodies, such as the accompanying lead–zinc mineralization. They further stated that sediment of the southern Benue Trough has been estimated to be over 6000 m in thickness. Findings on the stratigraphic as well as tectonic and sedimentologic development of the basin have been documented in existing literature (Benkhelil 1982;

Petters and Ekweozor 1982; Hoque and Nwajide 1984; Ofoegbu 1984; Nwachukwu 1985; Tijani et al. 1996).

Hydrogeology

The main aquiferous unit is the fractured baked shales and sandstones which are recharged majorly through precipitation. The hydraulic properties vary across the area, with the static water level around 15.00 m from the ground surface, and a yield of about 30.00–67.00 m³/h for the sandstones (Edet and Ekpo 2008). There is a high fluctuation in the groundwater level due to the seasonality of rainfall in the area. This normally results in the drying up of some wells in the dry seasons.

Edet (2018) identified two aquifer media in the area, the first is sandstone with a static water level in the range of 5.29–13.05 m, hydraulic conductivity (K) of 0.55–17.0 m/day, and transmissivity (T) ranging between 10.30 and 598.57 m²/day around the southeastern part of the area. The second consists mostly of fractured shales with T in the range of 10.20–26.20 m²/day. The general direction of regional groundwater flows is northeast towards the Benue basin (Ekwere and Ukpong 1994).

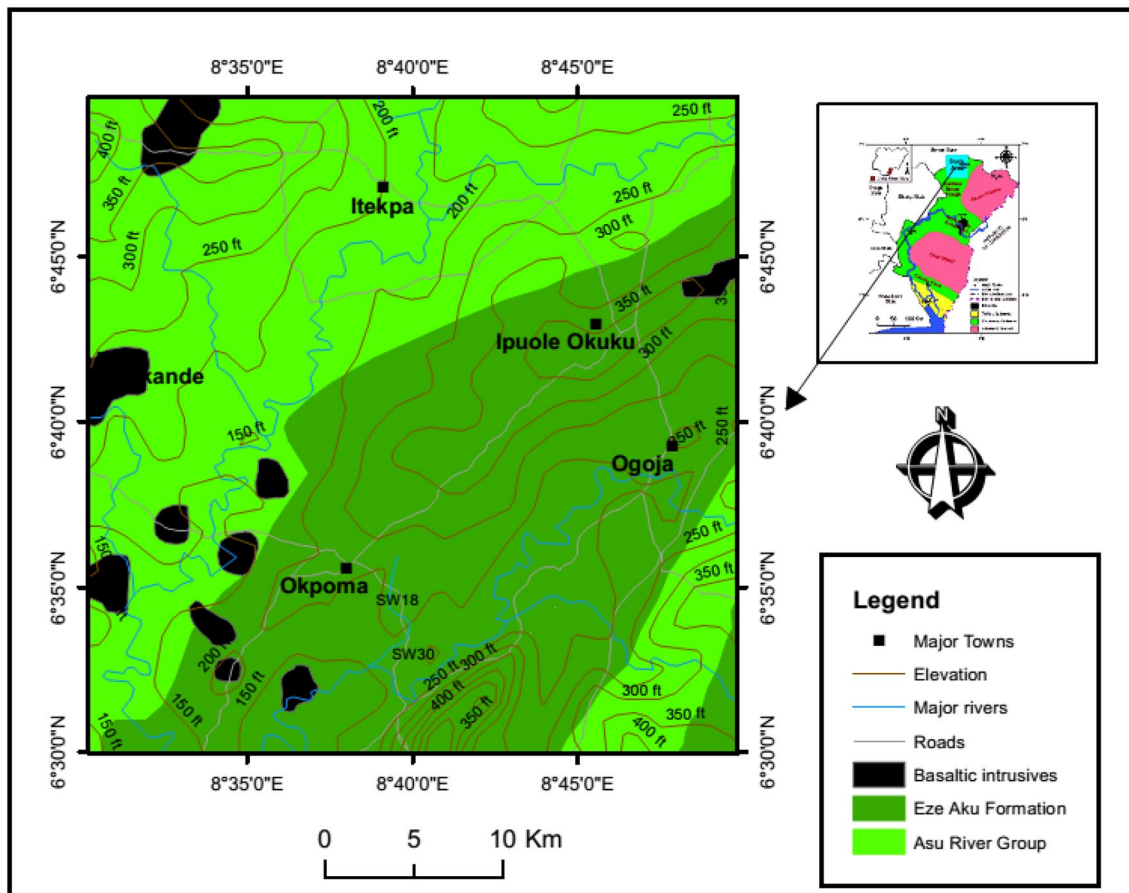


Fig. 2 Geological map of Okpoma and environs

Materials and methods

Sampling and laboratory analysis

A total of thirty (30) water samples were obtained for the study (Fig. 3). From this amount, six (6) samples were from surface water (SW) sources while twenty-four (24) samples were collected from groundwater (GW) sources. The sampling was done during the dry period when the concentration of the ions is expected to be high. The groundwater sources from which water was sampled comprise shallow hand-dug wells (HW) and deeper bore-holes (BH). For each sampling point, sampled water is kept in clean polyethylene bottles that are previously rinsed thoroughly about 2–3 times with the sample. After this, the water sample is then stored in a polyethylene sample bottle at each respective sample point. At the point of sample collection physical parameters (pH, electrical conductivity—EC, and total dissolved solid—TDS) of the sampled water was measured in situ using standard HANA multi-parameter field conductivity equipment, with model number HI 9813. For emphasis, and concerning groundwater sampled from boreholes, the borehole

was left pumping water for about 10–15 min before samples were taken.

Samples collected were strained using a 0.45 μm -size cellulose nitrate membrane, then taken for chemical analysis in the laboratory. Two samples were taken from each location for major cation and anion analysis. At the point of sample collection, a few drops of diluted nitric acid (HNO_3) were added to the samples used for cation analysis to attain a pH of ≤ 2 . In the laboratory, major cations and some anions were determined with the use of an inductively coupled plasma mass spectrophotometer, while other anions were analyzed through titration.

Data interpretation

The concentration of ionic constituents in both surface and groundwater was analyzed and presented by the use of various tables, plots, and numerical equations. Statistical summaries (minimum, maximum, mean, and standard deviation values) used in the analysis of results obtained from the laboratory were performed with a *Microsoft Excel spreadsheet*. Also, correlation matrix analysis was

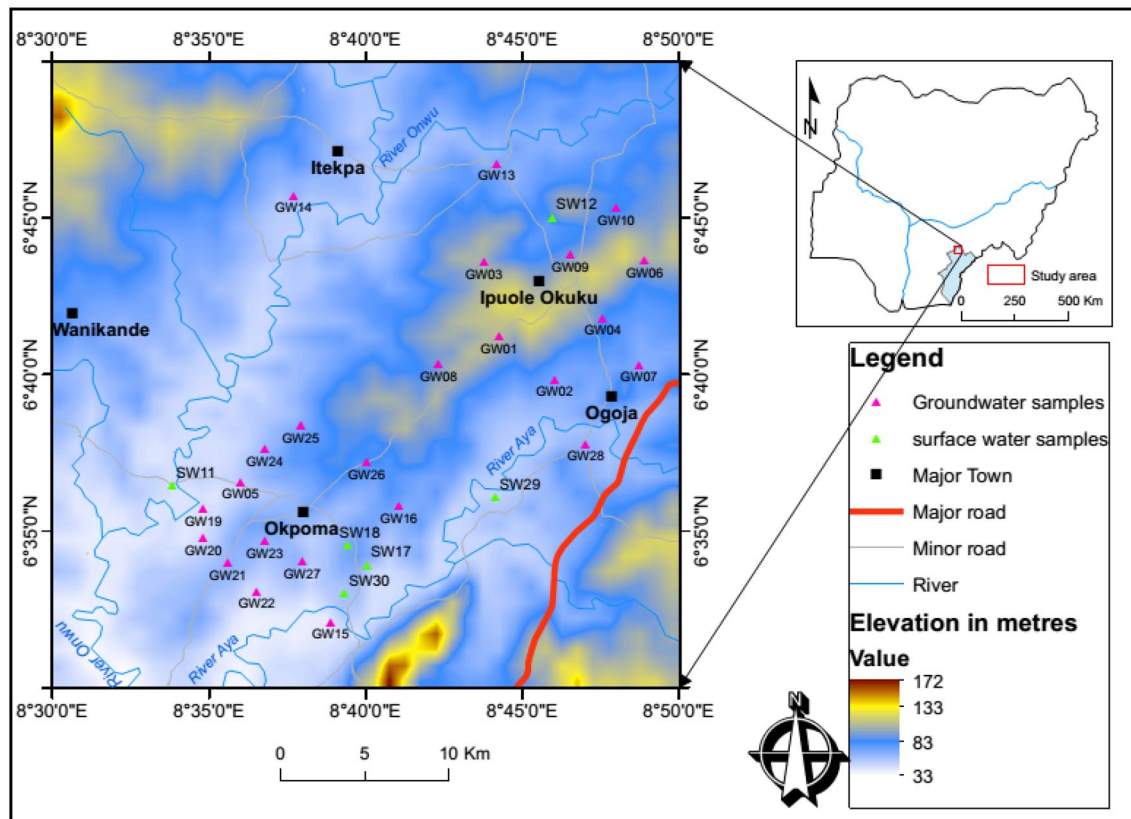


Fig. 3 Location of sampling points

employed to express the relationships between major ionic constituents present in the water samples. In this study, the Pearson correlation coefficient according to Bahar and Reza (2010) was employed to explain the relationships between variables using *MINITAB-16* software. Strength of the relationship between the analyzed parameters include; poorly correlated ($r^2 < \pm 0.5$), moderately correlated ($\pm 0.5 \leq r^2 < \pm 0.7$), strongly correlated ($\pm 0.7 \leq r^2 < \pm 0.9$), very strongly correlated ($\pm 0.9 \leq r^2 \leq 1$) and perfectly correlated ($r^2 = 1$).

Rock-ware 15.0 software was used to prepare the Piper plot which classified hydro-chemical facies of the water samples from the study area. First, the concentrations of major ionic constituents were converted to meq/l units and then plotted using a Piper trilinear diagram. This was done to ascertain the hydro-chemical facies in surface- and groundwater and to further envisage the hydro-chemical trends. Gibbs plot was produced using the software *Aquachem 4.0* and *Grapher 10*, from which interpretation of ion sources was derived.

Computation using Water quality index, WQI model, and agricultural indices

Appraisal of surface water and groundwater quality for domestic purposes was possible by computing the water quality index (WQI) and comparing computed mean values of major ion concentration with world health organization (WHO) standard values. The weighted arithmetic WQI model (Yisa and Jimoh 2010; Etim et al. 2013; Tyagi et al. 2014) were employed to reveal the influence of individual quality parameters. Water quality score, comparative weight, and the general WQI were computed using the model equations that follow:

$$q_i = \frac{C_i}{S_i} \times 100 \quad (1)$$

and

$$w_i = \frac{1}{S_i}, \quad (2)$$

where q_i is the quality rating of the i th parameter within the given number of samples, n ; C_i is the measured concentration of respective ions; S_i is the standard value of the i th

parameter within the given number of samples, n , and w_i represents the relative weight of the i th parameter within the given number of samples, n .

Finally, the overall WQI was computed using the following:

$$WQI = \frac{\sum_i^n q_i w_i}{\sum_i^n w_i} \quad (3)$$

The WQI values computed in this study were compared with the classification according to Akter et al. (2016).

Several other indices were employed to measure the appropriateness of water from the study area for agricultural purposes. The indices are; total hardness (TH), percent sodium (%Na), sodium absorption ratio (SAR), residual sodium carbonate (RSC), permeability index (PI), and magnesium hazard (MH). Computed values of the respective indices and statistical summaries were presented for interpretation. The units of TH are expressed in mg/l, while %Na, SAR, RSC, PI, and MH were all expressed in meq/l. Empirical equations employed in the computation of these indices are as follows:

Total hardness, TH

Total hardness was determined according to Sawyer and McCarthy (1967) by the following equation:

$$TH \text{ as } CaCO_3, \frac{mg}{l} = 2.5Ca^{2+} + 4.1Mg^{2+}. \quad (4)$$

Percent sodium, %Na

The amount of sodium expressed in percentage, that is capable of replacing Mg^{2+} , Ca^{2+} and K^+ existing in water samples were computed using the equation after Todd (1980) as follows:

$$\%Na = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100. \quad (5)$$

Sodium absorption ratio, SAR

SAR is used to estimate alkali hazards in irrigation water, and it is associated with the absorption of Na^+ by soil. The SAR was computed using the equation according to Richards (1954) as follows:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (6)$$

Residual sodium carbonate, RSC

Eaton (1950) developed an equation to quantify RSC in water with high HCO_3^- , because they tend to precipitate as carbonates of Ca^{2+} and Mg^{2+} . The equation is as follows:

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}). \quad (7)$$

Permeability index, PI

Doneen (1964) developed the concept of PI which is used to evaluate water quality for irrigation purposes. It is computed using:

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100. \quad (8)$$

Magnesium hazard, MH

Excess Mg^{2+} and Ca^{2+} will adversely impact the soil by making it more alkaline, thus decreasing crop output (Ravikumar et al. 2011). This can be estimated in terms of the MH by the following equation:

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100. \quad (9)$$

Results

The results obtained from the physicochemical analysis of surface water, and groundwater samples are presented here-with (Table 1). These data form the basis for all interpretations in the discussion section.

Discussion

Physico-chemical factors

A statistical summary of physicochemical factors analyzed for water samples in this study is presented (Table 2). EC in surface water ranges from 21.50 to 520.00 $\mu S/cm$, and an average of $169.42 \pm 175.15 \mu S/cm$. The pH values are in the range of 6.50–7.90, and an average of 7.17 ± 0.42 . It is noted that mean values of the physical parameters measured in situ from the samples obtained fall below WHO (2011) standard. The amount of Ca^{2+} and Mg^{2+} , respectively, varies between 4.00 and 27.27 mg/l with an average value of $9.30 \pm 8.19 \text{ mg/l}$, and 0.74–15.80 mg/l with an average value of $3.61 \pm 5.46 \text{ mg/l}$. Na^+ varies between 16.10 and

Table 1 Results obtained from the analyses of surface water and groundwater samples

S/n	Code	EC, $\mu\text{S/cm}$	pH	Concentrations in mg/l									
				Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	Cl ⁻	CO ₃ ²⁻	HCO ₃ ⁻	SO ₄ ²⁻	NO ₃ ⁻	
1	GW01	11.00	6.50	2.00	1.24	18.40	0.60	28.40	3.05	40.40	0.06	0.92	
2	GW02	215.00	5.70	7.60	2.15	36.80	1.10	56.80	2.70	35.90	0.00	2.95	
3	GW03	104.50	5.90	3.20	0.75	25.30	0.80	39.05	2.35	31.40	0.00	3.45	
4	GW04	40.50	8.30	42.50	24.50	18.40	0.60	28.40	26.45	354.70	0.04	1.70	
5	GW05	202.70	6.80	8.40	0.48	32.20	1.00	49.10	4.00	53.90	0.00	2.10	
6	GW06	136.00	7.10	8.40	0.48	32.20	1.00	49.70	4.00	53.90	0.00	2.10	
7	GW07	438.00	6.20	12.00	5.85	75.90	2.35	117.15	3.05	40.40	0.00	3.15	
8	GW08	19.00	5.90	3.20	0.24	18.40	0.60	28.40	3.05	40.40	0.01	1.60	
9	GW09	311.50	5.40	29.70	8.75	23.00	0.70	35.50	16.55	224.50	0.02	0.42	
10	GW10	730.50	9.10	14.00	25.25	41.40	1.25	63.90	25.15	336.50	0.04	0.76	
11	SW11	520.00	6.94	27.27	15.80	75.90	2.35	117.15	7.05	94.30	0.03	3.45	
12	SW12	48.00	7.90	8.80	0.74	16.10	0.50	24.85	5.05	6.35	0.02	0.38	
13	GW13	611.00	7.40	27.27	15.80	75.90	2.35	117.15	7.05	94.30	0.03	3.45	
14	GW14	414.00	6.80	15.60	6.80	64.40	2.00	99.40	4.05	53.85	0.01	3.20	
15	GW15	240.00	6.90	3.60	1.50	16.10	0.50	24.85	3.05	40.40	0.00	2.10	
16	GW16	9.50	6.10	2.40	1.95	16.10	0.50	24.85	2.35	31.40	0.01	0.87	
17	SW17	21.50	6.50	4.40	1.45	18.40	0.60	28.40	3.05	40.40	0.01	0.48	
18	SW18	22.00	7.30	4.00	0.95	23.00	0.70	35.50	4.00	53.90	0.02	0.43	
19	GW19	125.50	7.50	7.60	2.70	29.90	0.95	46.15	4.70	62.90	0.27	0.45	
20	GW20	432.50	9.00	8.80	2.90	16.10	0.50	24.85	24.80	332.25	0.14	0.26	
21	GW21	45.50	7.10	6.00	0.75	20.70	0.65	31.95	4.70	62.90	0.09	0.35	
22	GW22	258.50	6.70	8.00	5.55	50.60	1.55	78.10	2.35	31.40	0.03	2.85	
23	GW23	71.00	6.10	2.80	1.24	25.30	0.80	39.05	2.70	35.90	0.03	1.90	
24	GW24	201.00	8.20	9.40	5.15	35.50	1.05	53.25	9.40	125.70	0.01	0.64	
25	GW25	819.50	10.40	3.10	2.00	27.60	0.85	42.60	45.90	615.10	0.03	0.44	
26	GW26	202.00	7.90	12.80	8.30	27.60	0.90	42.60	10.40	139.15	0.01	1.80	
27	GW27	541.00	8.40	30.90	30.80	55.20	1.45	85.20	20.80	278.35	0.04	1.50	
28	GW28	265.00	7.10	31.70	3.70	65.86	2.20	68.90	5.90	34.20	0.35	108.00	
29	SW29	220.00	7.30	5.10	1.20	22.00	2.20	35.55	9.50	28.50	0.08	2.50	
30	SW30	185.00	7.10	6.20	1.50	21.00	1.80	33.50	10.55	31.50	0.05	1.50	

Table 2 Statistical summary of physicochemical parameters analyzed

Parameters	Surface water				Groundwater				WHO (2011)
	Min	Max	Mean	SD	Min	Max	mean	SD	
EC $\mu\text{S/cm}$	21.50	520.00	169.42	175.15	9.50	819.50	268.53	224.13	1500
pH	6.50	7.90	7.17	0.42	5.40	10.40	7.19	1.20	6.50–8.50
Ca ²⁺	4.00	27.27	9.30	8.19	2.00	42.50	12.54	11.08	100
Mg ²⁺	0.74	15.80	3.61	5.46	0.24	30.80	6.62	8.46	50
Na ⁺	16.10	75.90	29.40	20.92	16.10	75.90	35.37	18.75	200
K ⁺	0.50	2.35	1.36	0.78	0.50	2.35	1.09	0.58	12
Cl ⁻	24.85	117.15	45.83	32.13	24.85	117.15	53.14	27.43	250
CO ₃ ²⁻	3.05	10.55	6.53	2.77	2.35	45.90	9.94	10.86	600
HCO ₃ ⁻	6.35	94.30	42.49	27.21	31.40	615.10	131.24	146.66	600
SO ₄ ²⁻	0.01	0.08	0.03	0.02	0.00	0.35	0.05	0.08	250
NO ₃ ⁻	0.38	3.45	1.46	1.17	0.26	108.00	6.12	21.27	50

All concentrations of ionic species are measured in mg/l

75.90 mg/l with a mean of 29.40 ± 20.90 mg/l, while K^+ varies from 0.5 to 2.35 mg/l with a mean of 1.36 ± 0.78 mg/l. Cl^- ranges between 24.85 and 117.15 mg/l with an average value of 45.83 ± 32.13 mg/l. The amount of CO_3^{2-} ranges from 3.05 to 10.55 mg/l with a mean of 6.53 ± 2.77 mg/l, while HCO_3^- ranged between 6.35 and 94.30 mg/l with a mean concentration of 42.49 ± 27.21 mg/l. The concentration of SO_4^{2-} ranged from 0.01 to 0.08 mg/l with mean value of 0.03 ± 0.02 mg/l, while NO_3^- varied between 0.38 and 3.45 mg/l with mean value of 1.46 ± 1.17 mg/l. Therefore, one can infer that the relatively weak acid to alkaline pH values recorded in surface and groundwater could be a result of the higher chloride, carbonate, and bicarbonates ions, as asserted previously in the Enugu area according to Abugu et al. (2021).

Physical parameters measured from groundwater reveal that EC ranges from 9.50 to 819.50 $\mu S/cm$, and an average value of 268.13 ± 224.13 $\mu S/cm$. pH ranging from 5.40 to 10.40 is classified as weak acid to weak alkaline (Merouche et al. 2020), with an average value of 7.19 ± 1.2 . The concentration of cationic constituents in groundwater showed that Ca^{2+} varies between 2.00 and 42.50 mg/l with an average value of 12.54 ± 11.08 mg/l. Mg^{2+} varies between 0.24 and 30.80 mg/l, and the average value is 6.62 ± 8.46 mg/l. Na^+ ranges between 16.10 and 75.90 mg/l with average value 35.37 ± 18.75 mg/l, while K^+ ranges from 0.50 to 2.35 mg/l with mean concentration of 1.09 ± 0.58 mg/l, respectively. Of the major anions analyzed from the groundwater samples collected, Cl^- ranges between 24.85 and 117.15 mg/l, with mean values of 53.14 ± 27.43 mg/l. The levels of HCO_3^- present ranged between 31.40 and 616.10 mg/l and a mean value of 131.24 ± 146.66 mg/l, while CO_3^{2-} it ranges between 2.35 and 45.90 mg/l and an average value of 9.94 ± 10.86 mg/l. It is observed that SO_4^{2-} concentration in the groundwater varies between 0.00 and 0.35 mg/l, with a mean of 0.05 ± 0.08 mg/l. NO_3^- levels range between 0.26 and 108.00 mg/l, with a mean concentration of 6.12 ± 21.27 mg/l.

The result showed that HCO_3^- and CO_3^{2-} are fairly present in the surface water and groundwater samples. However, in comparison with WHO (2011) standards for drinking water quality, are not concerns for human health. Egbueri et al. (2019) and Abugu et al. (2021) noted that the dissolution of atmospheric CO_2 in precipitating natural water forms H_2CO_3 , which dissociates into HCO_3^- and H^+ . The study further revealed that EC values are < 1000 $\mu S/cm$, indicating 'very weakly mineralized water' (Detay and Carpenter 1997). Also, it is slightly lower in surface water samples than the groundwater samples. The variation in EC may be attributed to those factors which according to Danbatta (2006), Ramesh and Elango (2012), and Edet et al. (2013) include ion-exchange, precipitation, dissolution, evaporation, silicate weathering, carbonate weathering,

redox processes, and anthropogenic activities. The basis of pH values obtained for surface water and groundwater samples revealed that they are weakly acidic to alkaline in nature. Also, physicochemical parameters obtained from the analyzed samples fall below the WHO (2011) water quality guideline. Only pH and NO_3^- are an exception to this, where values above the permissible limits were obtained in some locations. The mean levels of all the measured parameters in the groundwater samples are higher than in the surface water samples except for Na^+ , K^+ and Cl^- . The mean concentration indicates that the major cation constituents in the order of dominance from both surface water and groundwater sources are; $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. The anion dominance in surface water is in the order; $Cl^- > HCO_3^- > CO_3^{2-} > NO_3^- > SO_4^{2-}$, while for the groundwater it is $HCO_3^- > Cl^- > CO_3^{2-} > NO_3^- > SO_4^{2-}$. Although Abugu et al. (2021) observed the trend; $Na^+ > K^+ > Ca^{2+} > Mg^{2+}$ for the cations, while the anions were $HCO_3^- > SO_4^{2-} > Cl^- > NO_3^- > CO_3^{2-} > PO_4^{3-}$. These showed a slightly different order of major ions abundance within similar geological settings.

Water quality for domestic use

In this study, the water quality index (WQI) was computed using data obtained from surface water and groundwater samples utilizing the weighted arithmetic index method of about eleven physicochemical parameters (EC, pH, TDS, Ca^{2+} , Mg^{2+} , Na^+ , K^+ , SO_4^{2-} , NO_3^- , Cl^- , CO_3^{2-} and HCO_3^-). The WQI model adopted was precise in revealing the quality status of all the samples. The order of dominance for the ion constituents and computed WQI with their classification are presented (Table 3), while the summary of percentages is shown in Table 4. The observed ranges of WQI are from 50.11 to 61.81 and 44.55 to 80.39 for surface water and groundwater, respectively. The lowest and highest WQI values observed were from groundwater sources at GW09, and GW25, respectively. Excellent water quality was obtained from groundwater sources only (GW01 to GW03, GW08, GW09, GW16, and GW23), while the remaining locations comprises of surface and groundwater (GW04 to GW07, GW10, SW11, SW12, GW13 to GW15, SW17, SW18, GW19 to GW22, GW24 to GW28, SW29, and SW30) were observed to have good water quality.

The results from the analysis of physicochemical factors showed that surface water and groundwater from the study area are fit for consumption and other domestic uses (Table 2) because the concentration levels all lie below the permissible limit according to WHO (2011). This is further supported by the fact that computed WQI values were classified as good to excellent (Fig. 4; Table 3). The values obtained showed that 100% of surface water samples were of good water quality. About 20.82% and 8.34% of

Table 3 Order of ion dominance and water quality index values at various locations

Water source	Code	Water type	Order of dominance for major ions		WQI	Class
			Cation	Anion		
SURFACE WATER	SW11	SW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	Cl ⁻ > HCO ₃ ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	61.81	Good
	SW12	SW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	Cl ⁻ > HCO ₃ ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	60.15	Good
	SW17	SW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	50.11	Good
	SW18	SW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	56.26	Good
	SW29	SW	Na ⁺ > Ca ²⁺ > K ⁺ > Mg ²⁺	Cl ⁻ > HCO ₃ ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	60.11	Good
	SW30	SW	Na ⁺ > Ca ²⁺ > K ⁺ > Mg ²⁺	Cl ⁻ > HCO ₃ ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	57.69	Good
GROUNDWATER	GW01	HW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	49.99	Excellent
	GW02	HW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	Cl ⁻ > HCO ₃ ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	46.06	Excellent
	GW03	HW	Na ⁺ > Ca ²⁺ > K ⁺ > Mg ²⁺	Cl ⁻ > HCO ₃ ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	46.19	Excellent
	GW04	BH	Ca ²⁺ > Mg ²⁺ > Na ⁺ > K ⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	68.41	Good
	GW05	HW	Na ⁺ > Ca ²⁺ > K ⁺ > Mg ²⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	53.62	Good
	GW06	HW	Na ⁺ > Ca ²⁺ > K ⁺ > Mg ²⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	55.82	Good
	GW07	HW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	Cl ⁻ > HCO ₃ ⁻ > NO ₃ ⁻ > CO ₃ ²⁻ > SO ₄ ²⁻	54.3	Good
	GW08	HW	Na ⁺ > Ca ²⁺ > K ⁺ > Mg ²⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	45.48	Excellent
	GW09	BH	Ca ²⁺ > Na ⁺ > Mg ²⁺ > K ⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	44.55	Excellent
	GW10	BH	Na ⁺ > Mg ²⁺ > Ca ²⁺ > K ⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	75.51	Good
	GW13	HW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	Cl ⁻ > HCO ₃ ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	65.21	Good
	GW14	HW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	Cl ⁻ > HCO ₃ ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	57.92	Good
	GW15	HW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	52.78	Good
	GW16	HW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	46.86	Excellent
	GW19	HW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	58.89	Good
	GW20	BH	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	68.97	Good
	GW21	HW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	54.68	Good
	GW22	HW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	Cl ⁻ > HCO ₃ ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	55.3	Good
	GW23	BH	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	Cl ⁻ > HCO ₃ ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	47.71	Excellent
	GW24	HW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	HCO ₃ ⁻ > Cl ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	64.88	Good
	GW25	BH	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	HCO ₃ ⁻ > CO ₃ ²⁻ > Cl ⁻ > NO ₃ ⁻ > SO ₄ ²⁻	80.39	Good
	GW26	HW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	HCO ₃ ⁻ > CO ₃ ²⁻ > Cl ⁻ > NO ₃ ⁻ > SO ₄ ²⁻	62.77	Good
GW27	BH	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	HCO ₃ ⁻ > CO ₃ ²⁻ > Cl ⁻ > NO ₃ ⁻ > SO ₄ ²⁻	72.42	Good	
GW28	HW	Na ⁺ > Ca ²⁺ > Mg ²⁺ > K ⁺	Cl ⁻ > HCO ₃ ⁻ > CO ₃ ²⁻ > NO ₃ ⁻ > SO ₄ ²⁻	61.16	Good	

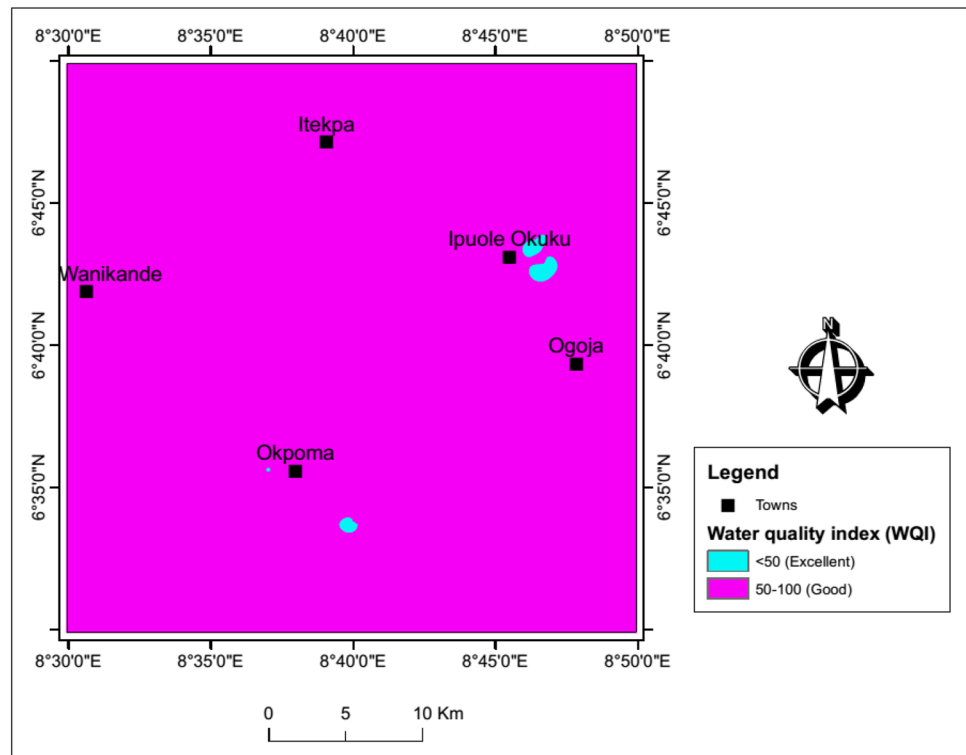
Table 4 Summary of WQI classes and their respective percentages

Index	Range of values	Remark	No. of samples				Percentage (%)			
			SW		GW		SW		GW	
			HW	BH	Total	HW	BH	Total		
WQI (after Akter et al. 2016)	< 50	Excellent	–	5	2	7	–	20.83	8.34	29.17
	50–100	Good	6	12	5	17	100	50	20.83	70.83
	101–200	Poor	–	–	–	–	–	–	–	–
	201–300	Very poor	–	–	–	–	–	–	–	–
	> 300	Unsuitable	–	–	–	–	–	–	–	–

groundwater analyzed had excellent water quality from hand wells and boreholes respectively, while 50% and 20.83%

were classified to have good water quality from hand wells and boreholes, respectively.

Fig. 4 Spatial representation of WQI in the study area



SW, surface water; GW, groundwater; HW, hand well, BH, borehole

Hydro-chemical facies and correlation analysis

Variations in the hydro-chemical facies of natural water sources may be due to anthropogenic and geogenic processes occurring within a given area. The Piper diagram (Fig. 5) revealed three hydro-chemical facies for this study, namely; Na–Cl, Ca–Mg–HCO₃, and Na–HCO₃ water types. Na–HCO₃ facies is the most dominant water type from the borehole (relatively deep groundwater source) samples analyzed, while Na–Cl facies is the most dominant water type present in surface water and hand-dug wells (shallow groundwater source). This explains that the saline nature of water in the area is an indication that the mineralization of water is a result of the probable dissolution of halite (Appelo and Postma 1993). A study by Tijani et al. (1996) showed that the salinization within and around the area is from brines of marine origin, and this assertion was corroborated by Edet and Okereke (2022). Other means could probably be a result of weathering, leaching, and cation exchange (Farid et al. 2015). The presence of Na–HCO₃ water type implies recently recharged water of meteoric origin due to dissolution of alumino-silicate minerals, as was stated by Musa et al. (2014) and Edet and Okereke (2022) in separate previous studies they carried out. The dominance of Na⁺ over Ca²⁺ resulting from ion exchange could be linked to

weathering of ferromagnesian minerals of intrusive rocks (Akanbi 2016), similar to those found in the area. These minerals particularly the feldspars are rich in calcium, sodium, and potassium.

The Gibbs diagram (Fig. 6) showed that the dominant factor responsible for the ions present in water from the study area is weathering (Xu et al. 2019; Edet and Okereke 2022) due to rock-water interaction. The majority of the samples analyzed plotted within the rock dominance field, suggesting that enrichment of ion constituents in surface and groundwater is predominantly through rock weathering and dissolution processes, in soils or aquiferous materials along the groundwater flow path. About four (4) samples were plotted within the precipitation/rainfall dominance field, two (2) each from surface water and groundwater sources, respectively. Generally, HCO₃⁻ and CO₃²⁻ were from carbonate rocks such as limestone and dolomite of atmospheric origin (Singhal and Gupta 1999). The contribution of rainfall to the chemistry of water suggests that these anions may result from the dissolution of carbon IV oxide within the soil zone and in the atmosphere (Singh et al. 2013; Abugu et al. 2021; Edet and Okereke 2022). Therefore, the outcome substantiates that the chemistry of groundwater is greatly influenced by weathering and cation exchange processes.

Correlation values obtained for all the parameters analyzed for this study are presented in Table 5. The main contributing ions in surface water that have a very strong positive correlation with EC are Mg²⁺ (+0.90), Na⁺ (+0.91),

Fig. 5 Piper plot for surface and groundwater samples obtained in the present study

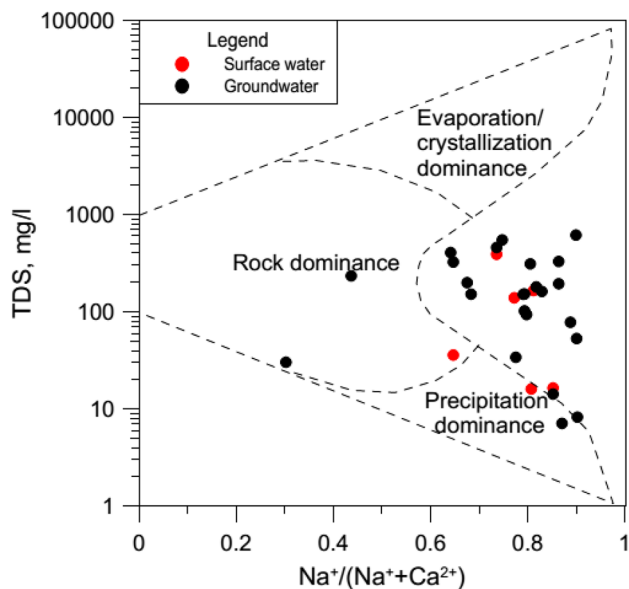
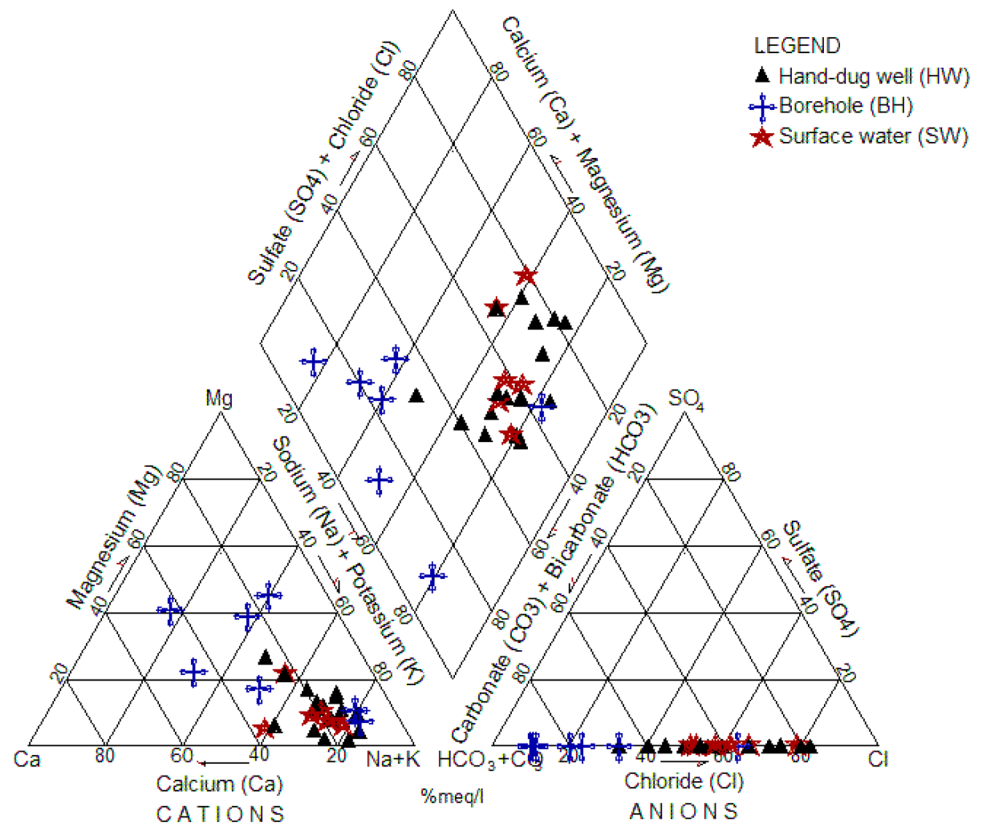


Fig. 6 A Gibbs plot for surface water and groundwater samples

Cl^- (+0.92) and NO_3^- (+0.96); those with a positive strong correlation with EC are Ca^{2+} (+0.88), K^+ (+0.87) and HCO_3^- (+0.71); while it has a positive moderate correlation with CO_3^{2-} . Also, EC in groundwater samples, showed a moderate positive correlation with pH (+0.62), Na^+

(+0.51), Cl^- (+0.54), HCO_3^- (+0.64) and CO_3^{2-} (+0.64). This indicates that the ions were likely sourced from the chemical disintegration of underlying host rocks through the process of dissolution, and human activities as suggested by Tahmasebi et al. (2018); Abugu et al. (2021); Edet and Okereke (2022). Surface water samples showed that pH had a negative moderate correlation with HCO_3^- (-0.53), while groundwater samples showed a strong correlation with CO_3^{2-} (+0.82) and HCO_3^- (+0.81). This according to the authors (Singh et al. 2013; Khudair et al 2022), is in tandem with the assertion which indicates carbonate dissolution processes in groundwater.

In surface water analyzed, Ca^{2+} showed a very strong positive correlation with Mg^{2+} (+0.98), Na^+ (+0.96), and Cl^- (+0.96) contrary to studies by Adamu et al. (2022) within the shales of the Calabar Flank; strong correlation with HCO_3^- (+0.74) and NO_3^- (+0.73); and positive moderate correlation with K^+ (+0.54). Mg^{2+} showed a positive strong correlation with Ca^{2+} (+0.73) in groundwater, indicating ion exchange processes. Similarly, Mg^{2+} displayed a very strong positive correlation with Na^+ (+0.99) and Cl^- (+0.99); a strong positive correlation with HCO_3^- (+0.86) and NO_3^- (+0.77); and a moderate positive correlation with K^+ (+0.59) in surface water, and poorly correlated with other ions in the groundwater sources. Surface water showed Na^+ had a strong positive correlation

Table 5 Pearson matrix for surface- and groundwater

	E. C	pH	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	Cl ⁻	CO ₃ ²⁻	HCO ₃ ⁻	SO ₄ ²⁻	NO ₃ ⁻	
SW	E. C	1.00										
	pH	-0.19	1.00									
	Ca ²⁺	0.88	-0.11	1.00								
	Mg ²⁺	0.90	-0.29	0.98	1.00							
	Na ⁺	0.91	-0.27	0.96	0.99	1.00						
	K ⁺	0.87	-0.18	0.54	0.59	0.62	1.00					
	Cl ⁻	0.92	-0.27	0.96	0.99	1.00	0.63	1.00				
	CO ₃ ²⁻	0.50	0.13	0.11	0.10	0.12	0.80	0.14	1.00			
	HCO ₃ ⁻	0.71	-0.53	0.74	0.86	0.89	0.47	0.89	-0.06	1.00		
	SO ₄ ²⁻	0.36	0.21	-0.08	-0.07	-0.02	0.74	-0.01	0.87	-0.16	1.00	
	NO ₃ ⁻	0.96	-0.20	0.73	0.77	0.79	0.95	0.80	0.61	0.61	0.57	1.00
GW	E. C	1.00										
	pH	0.62	1.00									
	Ca ²⁺	0.23	0.17	1.00								
	Mg ²⁺	0.46	0.42	0.73	1.00							
	Na ⁺	0.51	0.01	0.40	0.33	1.00						
	K ⁺	0.48	-0.02	0.40	0.27	0.99	1.00					
	Cl ⁻	0.54	0.01	0.34	0.36	0.98	0.95	1.00				
	CO ₃ ²⁻	0.64	0.82	0.31	0.47	-0.13	-0.16	-0.12	1.00			
	HCO ₃ ⁻	0.64	0.81	0.29	0.47	-0.15	-0.18	-0.13	0.99	1.00		
	SO ₄ ²⁻	-0.04	0.17	0.25	-0.06	0.15	0.20	-0.02	0.02	-0.03	1.00	
	NO ₃ ⁻	-0.01	-0.04	0.36	-0.07	0.37	0.43	0.15	-0.10	-0.16	0.72	1.00

SW, surface water sources; GW, groundwater sources

with HCO₃⁻ (+0.89) and NO₃⁻ (+0.79); moderate positive correlation with K⁺ (+0.62) and perfect correlation with Cl⁻ (+1.00), while from the groundwater sources it showed a positive very strong correlation with K⁺ (+0.99) and Cl⁻ (+0.98). A very strong to perfect correlation was expressed between Na⁺ and Cl⁻ for surface and groundwater and this may signal salinization processes from geogenic and anthropogenic processes (Paliwal 1972). K⁺ concentration in the surface water is strongly correlated with CO₃²⁻ (+0.80), SO₄²⁻ (+0.74), and NO₃⁻ (+0.95); moderately correlated with Cl⁻ (+0.64), while in groundwater it is very strongly correlated with Cl⁻ (+0.95).

Cl⁻ showed a positive strong correlation with HCO₃⁻ (+0.89) and NO₃⁻ (+0.80). This is a possible indication of anthropogenic inputs in exposed surface water within the study area, thereby imparting both temporary and permanent hardness therein (Wali et al. 2019). Also, a strong to moderate correlation between NO₃⁻ and all the major ions analyzed further revealed anthropogenic contamination (Eldaw et al. 2021). It may arise from indiscriminate open defecation which is the predominant practice in mostly rural areas, and also the application of fertilizers and pesticides on farmlands. Furthermore, it was observed that HCO₃⁻ in surface water alone revealed a positive moderate correlation with NO₃⁻, and this is an indication of anthropogenic influences (Edet and Okereke 2022). CO₃²⁻ within the surface

water samples analyzed displayed a strong positive correlation with SO₄²⁻ (+0.87) and a moderate positive correlation with NO₃⁻ (+0.61). However, CO₃²⁻ in the groundwater samples only showed a very strong positive correlation with HCO₃⁻ (+0.99), which is indicative of mineral dissolution processes (Abugu et al. 2021). In both surface water and groundwater sources, SO₄²⁻ showed a positive moderate correlation (+0.57) and a strong correlation (+0.72) with NO₃⁻.

Water suitability for irrigation

It is observed that physical and chemical parameters may disrupt plant metabolism and lower soil permeability (Sahinci 1991). Hence indices such as TH, %Na, SAR, RSC, PI, and MH were used to evaluate the suitability of surface and groundwater for agricultural purposes within the area of study (Table 6).

Sawyer and McCarthy (1967) have defined classes for TH based on their range of values. Surface water and groundwater investigated showed that 76.67% of the water sample were classified as soft water, 16.67% were moderately hard while only 6.67% were found to be hard. The outcome suggests that water resources from this study are predominantly soft water, suggesting that the water does not contain excess

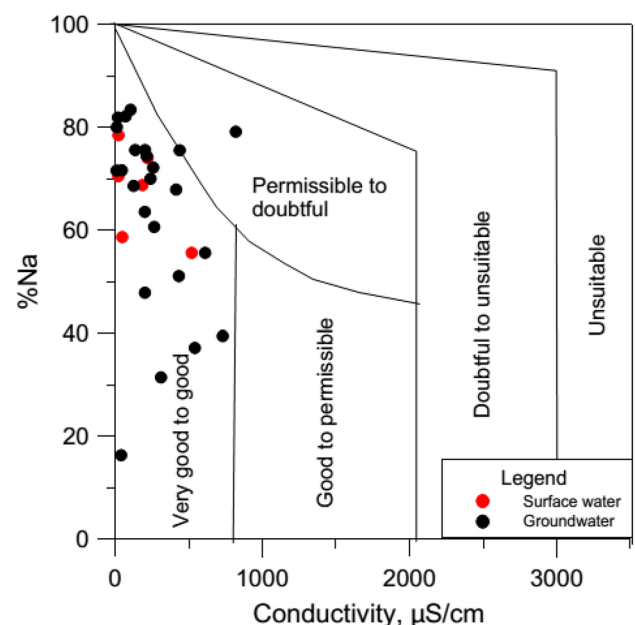
Table 6 Irrigation indices assessment for water within the study area

Indices	Sources	Range	Class	No. of sample	Percentage (%)
Total hardness (TH)	Sawyer and McCarthy (1967)	< 75	Soft	23	76.67
		75–150	Moderately hard	5	16.67
		150–300	Hard	2	6.67
		> 300	Very hard	0	0.00
Percent sodium (%Na)	Todd (1980)	< 20	Excellent	1	3.33
		20–40	Good	3	10.00
		40–60	Permissible	5	16.67
		60–80	Doubtful	17	56.67
		> 80	Unsuitable	4	13.33
Sodium adsorption ratio (SAR)	Richard (1954)	< 10	Excellent	30	100.00
		(10–18)	Good	0	0.00
		18–26	Doubtful	0	0.00
		> 26	Unsuitable	0	0.00
Residual sodium Carbonate (RSC)	Eaton (1950)	< 1.25	Good	23	76.67
		1.25–2.5	Doubtful	3	10.00
		> 2.5	Unsuitable	4	13.33
Permeability index (PI)	Doneen (1964)	< 25	Not suitable	0	0.00
		25–75	Moderate	2	6.67
		> 75	Suitable	28	93.33
Magnesium hazard (MH)	Ravikumar et al. (2011)	< 50	Suitable	23	76.67
		> 50	Not suitable	7	23.33

chloride and sulphate salts of alkaline earth metals (Gopinath et al. 2015), making it more suitable for agricultural purposes.

Another important parameter used in evaluating water for irrigation is the percentage of sodium. About 3.33% of the water samples were excellent, 10% were good, 16.67% were permissible, 56.67% are doubtful and 13.33% are unsuitable for irrigation purposes (Table 6). To adequately classify irrigation water quality, an important parameter to be considered is the EC (Nematollahi et al. 2016; Tahmasebi et al. 2018). Thus, the Wilcox diagram (Fig. 7) was employed to classify the water samples analyzed for agricultural purposes. The diagram revealed that nearly all water sources are plotted under a 'very good to good' field except one groundwater sample that is classified to be 'permissible to doubtful' for irrigation purposes. The values of EC show a low presence of sodium salts in the water, which when in excess limits air and water movement during the soil in the wet season (Saleh et al. 1999; Ravikumar et al. 2011). This indicates that water from Okpoma and its environs is suitable for agricultural purposes.

SAR is also significant in assessing irrigation water because an increased concentration of sodium is capable of reducing the permeability of soil structure (Todd 1980). Table 6 showed that SAR is less than 10 for all water samples, indicating that 100% of the analyzed water samples are excellent for irrigation based on this index. Salinity, on

**Fig. 7** Classification of irrigation water quality after Wilcox (1955)

the other-hand, is an expression of EC, and in turn a measure of the leaching of dissolved salts in water (Nematollahi et al. 2016). Therefore a plot of SAR against salinity hazard (Fig. 8) after USSS (1954), showed that 83.33% and 66.67%

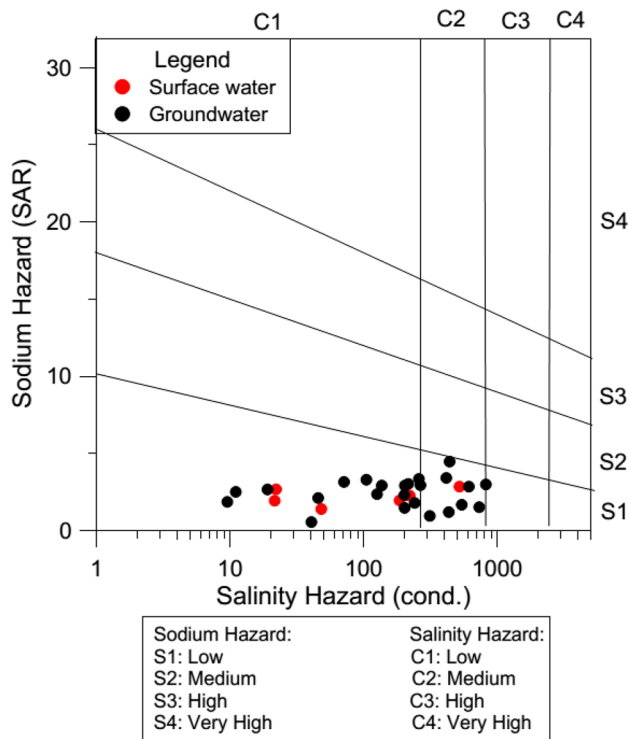


Fig. 8 Plot of sodium adsorption ratio versus salinity hazard (after USSL 1954)

of the surface water and groundwater, respectively were classified in the low salinity–low sodium hazard (C1S1) field. Also, about 16.67% and 33.33% of the surface water and groundwater, respectively, fall in medium salinity–low sodium hazard (C2S1) field. This is an indication that most of the water sampled belongs to C1S1 and C2S1, and it is, therefore, suitable for use as irrigation water on all types of soils devoid of the possible impact of exchangeable sodium (Bian et al. 2018).

RSC was used for classifying water for irrigation purposes, and the values obtained are thus presented (Table 6). These values showed that 76.67% of the water sample is good, 10% is doubtful and 13.33% is unsuitable for irrigation purposes. Extended use of irrigation water influenced by the amount of Na^+ , Ca^{2+} , Mg^{2+} , and HCO_3^- in soils, affects the soil permeability (Ghalib 2017). Therefore, PI was applied to evaluate the suitability of water sources for irrigation purposes. Based on this, about 93.33% of the samples analyzed were suitable, and 6.67% are moderate for irrigation. Lastly, MH which is a ratio of magnesium over calcium and magnesium in water was used to assess the impact on the quality of soils, as they may impact the overall agricultural output. According to Ravikumar et al. (2011), $\text{MH} > 50\%$ would negatively impact crop output as the soil becomes alkaline. In this study, MH values obtained showed that 76.67% of the

water sampled is suitable for irrigation, while about 23.33% were classified as not suitable for irrigation.

Conclusion

Both surface and groundwater are important resources, and therefore the routine assessment of its quality is germane towards its sustainable utilization for domestic and irrigational purposes. The study showed that average values of all the parameters assessed in the study area were within the WHO standard value for drinking water. Water from the area is slightly acidic to slightly alkaline. The following sequence were observed for cations present; $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ in both water sources while the anionic composition was $\text{Cl}^- > \text{HCO}_3^- > \text{CO}_3^{2-} > \text{NO}_3^- > \text{SO}_4^{2-}$ and $\text{HCO}_3^- > \text{Cl}^- > \text{CO}_3^{2-} > \text{NO}_3^- > \text{SO}_4^{2-}$ for surface water and groundwater, respectively. WQI computed indicates that both surface and groundwater are suitable for domestic purposes, as they were classified to generally have good to excellent water quality. Three hydro-chemical facies/water types were identified namely; Na-HCO_3 , Ca-Mg-HCO_3 , and Na-Cl . It was observed that halite dissolution, weathering, cation exchange, and leaching of ions from the host rock were the possible processes regulating the ionic constituents in the water sources as evidenced by Gibb's plot and correlation analysis. Indices such as TH, %Na, RSC, PI, SAR, and MH, indicate that water sources from Okpoma and environs are adequate for irrigation. Furthermore, the Wilcox plot revealed that both surface water and groundwater were classified to be 'very good to good' for agricultural purposes, except for one location where the groundwater sample was classified as 'permissible to doubtful'. The plot of sodium hazard (SAR) against salinity hazard (EC) showed that 83.33% and 66.66% of the surface water and groundwater respectively were classified to be suitable, while 16.66% and 29.1% were respectively classified to have medium salinity to low sodium hazard for agriculture and irrigation practices.

However, the result of this investigation is limited to the dry period sampling alone, in other to assess future variation of these ions in time and space. It is therefore recommended that periodic assessments of these ions be carried out.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

- Abugu HO, Egwuonwu PF, Ihedioha JN, Ekere NR (2021) Hydrochemical evaluation of River Ajali water for irrigational application in agricultural farmland. *Appl Water Sci* 11:71. <https://doi.org/10.1007/s13201-021-01395-4>
- Adamu CI, Nganje T, Edet A (2014) Hydro-chemical assessment of pond and stream water near abandoned barite mine sites in parts of Oban Massif, Southeastern Nigeria. *Environ Earth Sci* 71:3793–3811. <https://doi.org/10.1007/s12665-013-2757-5>
- Adamu CI, Oyetade OP, Ekwere AS, Kudamnya EA, Adebayo KI, Uyok IA, Nganje TN (2022) Mineralogical and physico-chemical properties of the Cretaceous shales of the Calabar Flank, south-eastern, Nigeria: implication for paleo-weathering conditions, provenance and industrial applications. *Solid Earth Sci* 7(2022):167–183. <https://doi.org/10.1016/j.sesci.2021.10.001>
- Akanbi OA (2016) Use of vertical electrical geophysical method for spatial characterization of groundwater potential of crystalline crust of Igboora area, southwestern Nigeria. *Int J Sci Res Publ* 6(3):399–406
- Akter T, Jhohura FT, Akter F, Chowdhury TR, Mistry SK, Dey D, Barua MK, Islam MA, Rahman M (2016) Water quality index for measuring drinking water quality in rural Bangladesh: a cross-sectional study. *J Health Popul Nutr* 35:4. <https://doi.org/10.1186/s41043-016-0041-5>
- Appelo CAJ, Postma D (1993) *Geochemistry, groundwater and pollution*, 2nd edn. Balkema, Rotterdam, p 321
- Ayuba R, Tijani MN, Omonona OV (2017) Hydro-chemical characteristics and quality assessment of groundwater from shallow wells in Gboloko Area, Central Nigeria. *Global J Geol Sci* 15:15
- Bahar MM, Reza MS (2010) Hydro-chemical characteristics and quality assessment of shallow groundwater in a coastal area of southwest Bangladesh. *Environmental Earth Sciences* 61:1065–1073
- Benkhelil J (1982) Benue trough and Benue chain. *Geol Mag* 119:155–168
- Benkhelil J (1987) Cretaceous deformation, magmatism and metamorphism in the Lower Benue Trough, Nigeria. *Geology J* 22:467–493
- Bhat SU, Nisa AU, Sabha I, Mondal NC (2022) Spring water quality assessment of Anantnag district of Kashmir Himalaya: towards understanding the looming threats to spring ecosystem services. *Appl Water Sci* 12:180. <https://doi.org/10.1007/s13201-022-01691-7>
- Bian J, Nie S, Wang R, Wan H, Liu C (2018) Hydrochemical characteristics and quality assessment of groundwater for irrigation use in central and eastern Songnen Plain, Northeast China. *Environ Monit Assess* 190:1–16. <https://doi.org/10.1007/s10661-018-6774-4>
- Cidu R, Frau F, Tore P (2011) Drinking water quality: comparing inorganic components in bottled water and Italian tap water. *J Food Compos Anal* 24(2):184–193
- Danbatta UA (2006) A baseline study of hydrochemistry of River Adankole around Obajana, Kogi State. *ChemClass J* 3:10–17
- Dessauvagie TFJ (1975) Explanatory notes to the geological map of Nigeria. *J Min Geol* 19:11–28
- Detay M, Carpenter M (1997) *Water wells: implementation, maintenance and restoration*. Wiley, London
- Doneen LD (1964) Notes on water quality in agriculture. Published as a water science and engineering paper 4001. Department of Water Sciences and Engineering, University of California
- Eaton FM (1950) Significance of carbonates irrigation waters. *Soil Sci* 39:123–133
- Edet A (2016) Hydrogeology and groundwater evaluation of a shallow coastal aquifer, southern Akwa Ibom State (Nigeria). *Appl Water Sci* 7:2397–2412. <https://doi.org/10.1007/s13201-016-0432-1>
- Edet A (2018) Seasonal and spatio-temporal patterns, evolution and quality of groundwater in Cross River State, Nigeria: implications for groundwater management. *Sustain Water Resour Manag* 5(2):667–687. <https://doi.org/10.1007/s40899-018-0236-6>
- Edet AE, Okereke CS (2005) Hydrogeological and Hydro-chemical character of the regolith aquifer, northern Obudu Plateau, southern Nigeria. *Hydrogeol J* 13(2):391–415
- Edet A, Okereke C (2022) Investigation of hydrogeological conditions of a fractured shale aquifer in Yala Area (SE Nigeria) characterized by saline groundwater. *Appl Water Sci* 12:194. <https://doi.org/10.1007/s13201-022-01715-2>
- Edet A, Worden R (2009) Monitoring of Physical parameters and evaluation of the chemical composition of river and groundwater in Calabar (South-eastern Nigeria). *Environ Monit Assess* 157:243–258
- Edet AE, Worden RH, Mohammed EA, Preston MR (2012) Hydrogeochemical processes in a populated shallow Coastal Plain Sand Aquifer south-eastern Nigeria. *Environ Earth Sci* 65:1933–1953
- Edet A, Ukpong A, Nganje T (2013) Hydro-chemical studies of Cross River Basin (Southeastern Nigeria) river systems using cross plots, statistics and water quality index. *Environ Earth Sci* 70:3043–3056
- Edet AE, Ekpo BO (2008) Hydrogeochemistry of a fractured aquifer in the Ogoja/Obudu area of SE Nigeria. In: Adelana S, MacDonald A (eds) *Applied groundwater studies in Africa*. IAH selected papers on hydrogeology, vol 13, pp 391–403
- Edmund W, Ma J, Aeschbach-Hertig W, Kipfer R, Danbyshire D (2006) Groundwater recharge history and Hydro-chemical evolution in the Minqin Basin, Northwest China. *Appl Geochem* 21:2148–2170
- Egbueri JC, Mgbenu CN, Chukwu CN (2019) Investigating the hydrogeochemical processes and quality of water resources in Ojoto and environs, using integrated classical methods. *Model Earth Syst Environ*. <https://doi.org/10.1007/s40808-019-00613-y>
- Ekwere AS, Edet A (2012) Hydrogeochemical signatures of different aquifer layers in the crystalline basement of Oban Area (SE Nigeria). *J Geogr Geol*. <https://doi.org/10.5539/jgg.v4n1p>
- Ekwere SJ, Ukpong EE (1994) Geochemistry of saline groundwater in Ogoja, Cross River State of Nigeria. *J Min Geol* 29:277–282
- Eldaw E, Huang T, Mohamed AK, Mahama Y (2021) Classification of groundwater suitability for irrigation purposes using a comprehensive approach based on the AHP and GIS techniques in North Kurdufan Province, Sudan. *Appl Water Sci* 11:126. <https://doi.org/10.1007/s13201-021-01443-z>
- Etim EE, Odoh R, Itodo AU, Umoh SD, Lawal U (2013) Water quality index for the assessment of water quality from different sources in the Niger Delta region of Nigeria. *Front Sci* 3(3):89–95. <https://doi.org/10.5923/j.fs.20130303.02>

- Fairhead JD, Green CM (1989) Controls on rifting in Africa and the regional tectonic model for the Nigeria and East Niger Rift Basin. *J Afr Earth Sci* 8:231–249
- Farid I, Zouari K, Rigane A, Beji R (2015) Origin of the groundwater salinity and geochemical processes in detrital and carbonate aquifers: case of Chougafiya Basin (Central Tunisia). *J Hydrol* 530:508–532
- Ghalib HB (2017) Groundwater chemistry evaluation for drinking and irrigation utilities in east Wasit Province, central Iraq. *Appl Water Sci* 7:3447–3467. <https://doi.org/10.1007/s13201-017-0575-8>
- Gopinath S, Srinivasamoorthy K, Saravanan K, Prakash R, Suma CS, Khan F, Senthilnathan D, Sarma VS, Devi P (2015) Hydrogeochemical characteristics of coastal groundwater in Nagapattinam and Karaikal aquifers: implications for saline intrusion and agricultural suitability. *Coast Sci J*. <https://doi.org/10.6084/m9.figshare.1512790.v1>
- Hoque M, Nwajide CS (1984) Tectono-sedimentological evolution of an elongate intracratonic basin (aulacogen): the case of the Benue Trough of Nigeria. *J Min Geol* 21:19–26
- Ifediegwu IS, Onyeabor CF, Nnamani CM (2019) Geochemical evaluation of carbonate aquifers in Ngbo and environs, Ebonyi State, southeastern, Nigeria. *Model Earth Syst Environ* 5:1893–1909. <https://doi.org/10.1007/s40808-019-00646-3>
- Khudair MY, Kamel AH, Sulaiman SO, Al-Ansari N (2022) Groundwater quality and sustainability evaluation for irrigation purposes: a case study in an Arid region, Iraq. *Int J Sustain Dev Plan* 17(2):413–419
- Li P, Zhang Y, Yang N, Jing L, Yu P (2016) Major ion chemistry and quality assessment of groundwater in and around a mountainous tourist town of China. *Expo Health* 8:239–252. <https://doi.org/10.1007/s12403-016-0198-6>
- Mbipom EW, Okon-Umoren OE, Umoh JU (1990) Geophysical investigation of salts Pond in Okpoma Area, south-eastern Nigeria. *J Min Geol* 26:285–290
- Merkel BJ, Planer-Friedrich B (2002) Groundwater geochemistry. In: Nordstrom DK (ed) a practical guide to modeling of natural and contaminated aquatic systems. Springer, Berlin, pp 1–191
- Merouche A, Selvam S, Imessaoudene Y, Maten CN (2020) Assessment of dam water quality for irrigation in the northeast of catchment Chelif-Zahrez, Central Algeria. *Environ Dev Sustain* 22:5709–5730. <https://doi.org/10.1007/s10668-019-00447-9>
- Moral F, Cruz-Sanjulian JJ, Olias M (2008) Geochemical evolution of groundwater in the carbonate aquifers of Sierra de Segura, Betic Cordillera, Southern Spain. *J Hydrol* 360:281–296
- Musa OK, Kudamnya EA, Omali AO, Akuh TI (2014) Physico-chemical characteristics of surface and groundwater in Obajana and its environs in Kogi State, central Nigeria. *Afr J Environ Sci Technol* 8(9):521–531. <https://doi.org/10.5897/AJEST2014.1708>
- National Bureau of Statistics NBS (2014) Summary Findings of National nutrition and Health Survey. Abuja, Nigeria, p 41
- National Bureau of Statistics NBS (2017) Nigeria Multiple Indicator Cluster Survey: 2016–2017 Survey Findings Report. Abuja, Nigeria, p 212
- Nematollahi MJ, Ebrahimi P, Razmara M, Ghasemi A (2016) Hydrogeochemical investigations and groundwater quality assessment of Torbat-Zaveh plain, Khorasan Razavi, Iran. *Environ Monit Assess* 188:1–21. <https://doi.org/10.1007/s10661-015-4968-6>
- Nwachukwu JL (1985) Petroleum prospect of Benue Trough Nigeria. *AAPG Bull* 69:601–609
- Obiora SC, Umeji AC (1995) Alkaline intrusive and extrusive rocks west of Anyim River, southeastern Benue Trough. *J Min Geol* 31:9–19
- Ochelebe I, Kudamnya EA, Nkebem GE (2020) An assessment of heavy metals concentration in water around quarries and barite mine sites in part of central Cross River State, southeastern Nigeria. *Global J Geol Sci* 18(2020):89–95
- Offiong OE, Edet AE (1998) Water quality assessment in Akpabuyo, Cross River basin, South-Eastern Nigeria. *Environ Geol* 34(2/3):167–174
- Ofoegbu CO (1984) An aeromagnetic study of part of the Benue Trough Nigeria. *Geol Rundt* 73:1007–1018
- Okiongbo KS, Douglas RK (2015) Evaluation of major factors influencing the geochemistry of groundwater using graphical and multivariate statistical methods in Yenagoa city, Southern Nigeria. *Appl Water Sci* 5(1):27–37
- Olade MA (1975) Evolution of Nigeria's Benue Trough (aulacogen): a re-interpretation. *J Min Geol* 13: 20–27
- Paliwal KV (1972) Irrigation with saline water. Water Technology Centre, Indian Agriculture Research Institute, New Delhi, p 198
- Peters SW (1991) Regional geology of Africa. Springer, Berlin
- Petters SW, Ekweozor CM (1982) Petroleum geology of the Benue Trough and southeastern Chad Basin Nigeria. *AAPG Bull* 66:1141–1149
- Ramesh K, Elango L (2012) Groundwater quality and its suitability for domestic and agricultural use in Tondiar River basin, Tamil Nadu, India. *Environ Monit Assess* 18:3887–3899
- Ravikumar P, Venkatesharaju K, Prakash KL, Somashekar RK (2011) Geochemistry of groundwater prospects evaluation, Anekal Tuluk, Bangalore Urban District, Karnataka, India. *Environ Monit Assess* 179:93–112
- Richards LA (1954) Diagnosis and improvement of saline alkali soils. US Department of Agriculture, Hand book
- Roşca OR, Dippong T, Marian M, Mihali C, Mihalescu L, Hoaghia M, Jelea M (2020) Impact of anthropogenic activities on water quality parameters of glacial lakes from Rodnei mountains, Romania. *Environ Res* 182:109136. <https://doi.org/10.1016/j.envres.2020.109136>
- Sahinci A (1991) Geochemistry of natural waters (in Turkish). Izmir: reform printing office, p 548
- Saleh A, Al-Ruwah F, Shehata M (1999) Hydrogeochemical processes operating within the main aquifers of Kuwait. *J Arid Environ* 42:195–209
- Sawyer GN, McCarthy DL (1967) Chemistry of sanitary engineers, 2nd edn. McGraw Hill, New York
- Shankar K, Elangovan G, Balamurugan P, Saravanan R (2022) Spatial distribution of Groundwater quality assessment using Water Quality Index and GIS techniques in Thanjavur Taluk, Thanjavur District, Tamil Nadu, India. *Int J Civ Environ Agric Eng* 4(2): 32–58
- Singh AK, Raj B, Tiwari AK, Mahato MK (2013) Evaluation of hydrochemical processes and groundwater quality in the Jhansi District of Bundelkhand Region. *Environ Earth Sci India*. <https://doi.org/10.1007/s12665-012-2209-7>
- Singhal BBS, Gupta RP (1999) Applied hydrogeology of fractured rocks. Kluwer Academic Publishers, Dordrecht
- Srinivas Y, Aghil TB, Hudson OD, Nithya NC, Chandrasekar N (2017) Hydro-chemical characteristics and quality assessment of groundwater along the Manavalakurichi coast, Tamil Nadu, India. *Appl Water Sci* 7(3):1429–1438
- Tahmasebi P, Mahmudy-Gharaie MH, Ghassemzadeh F, Karouyeh AK (2018) Assessment of groundwater suitability for irrigation in a gold mine surrounding area, NE Iran. *Environ Earth Sci* 77:766. <https://doi.org/10.1007/s12665-018-7941-1>
- Tak IH, Bakhtiyar Y, Ahmad F, Inam A (2012) Effluent quality parameters for save use in agriculture. In: Lee TS (ed) Water quality, soil and managing irrigation of crops. InTtech, pp 23–36
- Tijani MN, Leohnert EP, Uma KO (1996) Origin of saline groundwater in the Ogoja Area, Lower Benue Trough, Nigeria. *Journal of Africa Earth Sciences* 23:237–252
- Tiwari AK, Ghione R, Maio MG, Lavy M (2017) Evaluation of hydrogeochemical processes and groundwater quality for suitability for

- drinking and irrigation purposes: a case study in Aosta Valley region, Italy. *Arab J Geosci* 10(12):264
- Todd DK (1980) *Groundwater hydrology*. Wiley International Edition. Wiley, New York
- Tyagi S, Singh P, Sharma B, Singh R (2014) Assessment of water quality for drinking purpose Pauri district of Uttarkhand. *India Appl Ecol Environ Sci* 2(4):94–99
- Uma KO, Lohnert EP (1992) Research on the saline groundwater in the Benue Trough, Nigeria: preliminary results and projection. *Zbl Geol Pal J Stuttg* 11:2751–2756
- USSL (1954) *Diagnosis and improvement of saline and alkali soil*. USDA handbook no. 60, Washington
- Wali SU, Kabiru Jega Umar KJ, Abubakar SD, Ifabiyi IP, Dankani IM, Shera IM, Yauri SG (2019) Hydrochemical characterization of shallow and deep groundwater in Basement Complex areas of southern Kebbi State, Sokoto Basin, Nigeria. *Appl Water Sci* 9:169. <https://doi.org/10.1007/s13201-019-1042-5>
- Wilcox LV (1955) *Classification and use of irrigation waters*. US Department of Agriculture Circular, p 969
- World Health Organization WHO (2011) *Guidelines for drinking water quality*, 2nd edn. WHO, Geneva
- Xu P, Feng W, Qian H, Zhang Q (2019) Hydrogeochemical characterization and irrigation quality assessment of shallow groundwater in the central-western Guanzhong Basin, China. *Int J Environ Res Public Health* 16:1492. <https://doi.org/10.3390/ijerph16091492>
- Yisa J, Jimoh T (2010) Analytical studies on water quality index of river Ladzu. *Am J Appl Sci* 7:453–458

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