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ORIGINAL ARTICLE

Groundwater Quality Assessment in Ondo City, Southwestern Nigeria

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Abstract

Groundwater is an important source for drinking water supply in the hard rock terrain of Ondo town, southwestern Nigeria. Groundwater quality was investigated in Ondo town to determine its suitability for domestic use and human consumption. To achieve this aim, twenty-five groundwater samples were collected and analyzed for physiochemical parameters. Water quality was classified using the Water Quality Index (WQI). Except for phosphate, the results demonstrate that the groundwater characteristics were below the World Health Organization's allowed range. The dominance of main ions was Na $^{+}$> Ca2+ > K+ > Mg2+ $Na^{+}> Ca^{2+\,>}\ K^{+}> Mg^{2+}$ for cations and $HCO_3{}^{-}> Cl^{-} > NO_3{}^{-\,>}\ PO_4{}^{2-\,>}\ SO_4{}^{2-}$ for anions. Within the research region, the WQI varies from 52.69 to 118.07. With the exception of a few isolated regions in the study area, WQI shows that the bulk of the samples are of good quality, implying that the groundwater is safe for consumption and other household applications. Groundwater in places where the quality of the water is declining has to be treated before being used.

Keywords Groundwater · Physiochemical parameters. Water quality index · Human consumption

1 Introduction

The survival of human, food production, well-being, as well as socioeconomic growth all depend on having access to clean and safe water (Adimalla et al. 2020; Boateng et al. 2016; Gugulothu et al. 2022). The variety uses of water are significantly influenced by its quality. Water often derived from two main natural sources: surface water from streams, rivers and groundwater such as well and borehole water (Boateng et al. 2016; Houatmia et al. 2016; Punna et al. 2022). An estimated 1.5 billion people depend on groundwater for residential use, either directly or indirectly (Carrard et al. 2019). Because of a dearth of surface water, need for groundwater resources has soared globally during the last twenty years, particularly for drinking and irrigation (Adimalla 2019; Adimalla et al. 2018a; Awosika et al. 2020; Dasho et al. 2017; Li et al. 2018). Contamination of groundwater has increased rapidly in many geological terrains where there has been massive population growth, rapid urbanization and industrialization, significant agricultural development, excessive fertilizer usage, poor rainfall and large evaporation (Adimalla et al. 2018b; Boateng et al. 2016; Kumar and Sangeetha 2020; Subba Rao 2017). Studies have shown that groundwater contamination poses environment risk and have a huge effect on human health (Adebayo et al. 2021; Adimalla 2019; Akakuru et al. 2021a, b; Akinola et al. 2018; Aromolaran et al. 2019; Mgbenu and Egbueri 2019). Poor water quality causes a variety of health issues, including kidney stones, gout, and water-borne illnesses (Khatri et al. 2020). According to study carried out by the World Health Organization (WHO), 1.7 million

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children under the age of five (5) die each year as a result of groundwater pollution (WHO 2017). As a result, monitoring groundwater quality is critical to ascertain the suitability of water for drinking and agricultural uses (Eyankware and Akakuru 2023; Khalid 2019). Hydrogeochemical processes that regulate the amounts of main and minor ions in groundwater ranges from, dissolution, weathering to ion exchange (Adimalla et al. 2020; Houatmia et al. 2016). Studies on the suitability of groundwater for irrigation and drinking, as well as the determination of the primary sources of groundwater contamination have been carried out worldwide (Adebayo et al. 2021; Aghaei et al. 2023; Akakuru et al. 2021a, b; Akinola et al. 2018; Nsabimana and Li 2023; Onwe et al. 2023; Sunkari et al. 2023; Tegegne et al. 2023). (Emenike et al. 2018) found that the main processes influencing the groundwater chemistry in Abeokuta, Southwest Nigeria, are the weathering of rocks and the dissolving of minerals from the soil and aquifer. The research conducted by (Egbueri 2019) in Ogbaru farming district in southeastern Nigeria found that both anthropogenic (mostly agricultural) and geogenic factors affect the ion concentrations and quality of drinkable water in the studied area. (Mgbenu and Egbueri 2019) conducted a groundwater quality study in the Umunya district of southeast Nigeria and discovered that human activities and geogenic processes are the primary variables affecting changes in groundwater chemistry and quality.

In Ondo town, groundwater is a significant source of water for drinking, residential use, and agriculture purposes. As a result of the recently established and the existing institutions in the study area, the region population has increased significantly, consequently increasing the withdrawals and consumption of groundwater. For a better knowledge of state of groundwater quality and the evolution of hydrogeochemical processes of groundwater systems, related health hazards and suitability for drinking purpose, an evaluation of groundwater quality is essential. The objectives of this study were to determine the physical properties, concentrations of cations, and anions in the drinking water (groundwater) samples in Ondo town and evaluate the quality of groundwater used for drinking and domestic purposes in Ondo City. The findings of this study can serve as a guide for future policies governing the development, operation, and maintenance of groundwater resources in the studied region.

2 Materials and Methods

2.1 Study Area, Climate, Hydrogeology and Geology

With an estimated 275,917 residents, Ondo metropolis is the second-largest metropolis in Ondo State, Nigeria (NPC 2010). The overall area of the city is 970 km^2. The area falls within the humid tropical climatic zone which has prominent dry and wet seasons. A typical wet season extends from April to October, while the dry season extends from November to March. The climate is influenced by rainfall, humidity, temperature and vegetation. Annual rainfall varies between 100 and 1500 mm, with average wet days of about 100 (Iloeje 2001). The almost seven (7) months long wet season ensures aquifer recharge and high humidity. Ondo town is situated inside the Basement Complex area part of Ondo State (Fig. 1). According to Ako and Olorunfemi (1989) and Afolayan et al. (2004), the weathered and fractured basement aquifers are the two main aquifer units that set distinct the Basement Complex region of southwest Nigeria. In contrast to the fractured basement aquifer, which is the outcome of tectonic action, the weathered aquifer unit is created by chemical processes. In the same site, the fractured aquifer and the weathered layer aquifer may coexist.

3 Sample Collection and Analysis

Water samples from twenty-five (25) manually dug wells were collected from different locations (Fig. 2) in February 2020 using double-distilled water pre-cleaned high quality polyethylene plastic bottles, which were also rinsed four times with sampling water. The samples were then analyzed for a variety of hydro-chemical variations of water quality parameters. Total dissolved solids (TDS), pH and electrical conductivity (EC) were determined in-situ.

The in situ measurement was performed using a laboratory calibrated multi-parameter Hanna edge HI 9813–6 pH/EC/TDS/°C probe. Depending on the characteristics of interest, several analytical techniques were utilized for the water samples, and all field and laboratory results were made in accordance with the accepted practices prescribed by American Public Health Association (APHA 2005). Titrimetric techniques were used to determine Cl^-, $PO_4{}^{3-}$, and HCO^{3-}. Na^+ and K^+ were determined using a flame photometric method, while Ca^{2+} and Mg^{2+} were determined using an Ethylenediaminetetraacetic acid (EDTA) titrimetric approach (APHA 2005).

4 Statistical Analyses

The SPSS 16.0 version of the statistical software for social sciences was used to conduct descriptive statistical analysis on laboratory data. The R package software cor plot was used to investigate the relationship between the elements while multiple regression analysis was performed to determine the element with the maximum contribution to overall water quality.

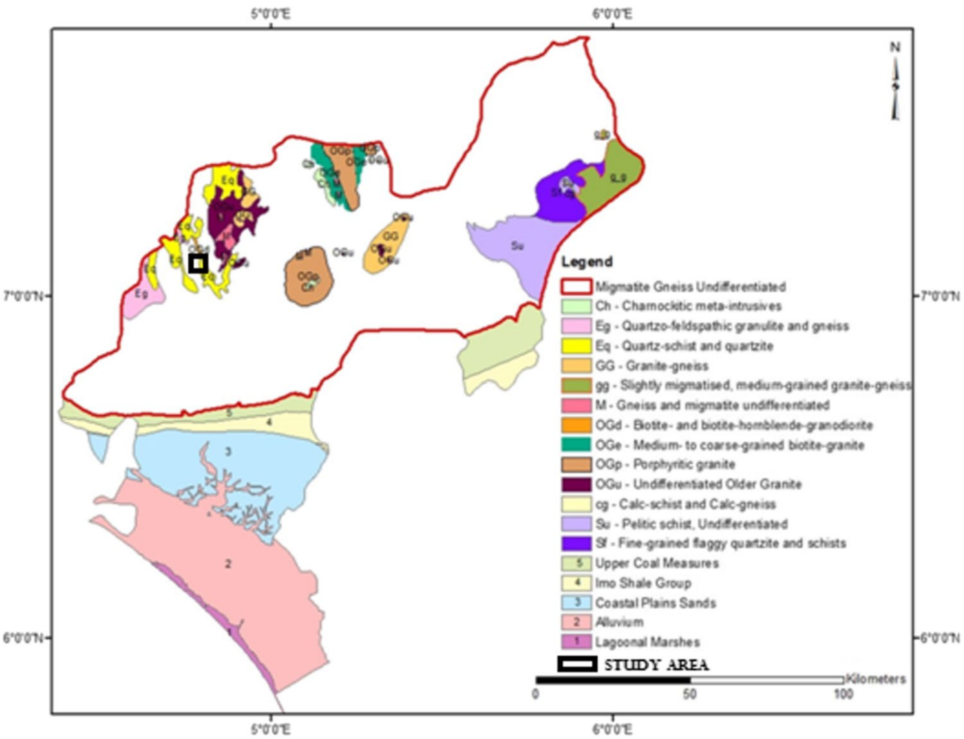

Fig. 1 Geology map of Ondo State

5 Multiple Linear Regression

Regression models is one of the effective statistical methods for investigation of relationship between dependent and independent variables (Abyaneh 2014; Akakuru et al. 2022; Omokungbe et al. 2020). MLR is used to model the linear relationship of dependent variables and one or more independent variables (Agbasi and Egbueri 2023; Omokungbe et al. 2020). MLR equation is given in Eq. (1) as:

$$y = c_o + c_1x_1 + c_2x_2 + c_3x_3 \ldots c_ix_i \tag{1}$$

where y is the predicted, x_1, x_2, and x_3 are the predictors or descriptors, c_o is the intercept and c_1, c_2, and c_3 are regression coefficients for predictors. The independent contributions of each independent variable to the dependent variable's prediction are shown by regression coefficients (Akakuru et al. 2022; Akakuru et al. 2023; Omokungbe et al. 2020). The MLR algorithm was employed in this work to simulate and forecast indices and parameters related to water quality. Physicochemical parameters $(HCO_3^-, Cl^-, NO_3^-, PO_4^{2-}, SO_4^{2-}, Na^+, Ca^{2+}, K^+, Mg^{2+})$ analyzed were used as predictors for WQI. Coefficient standardization function in MLR model was used to evaluate the effectiveness of the MLR simulations. MLR was run in R package software.

6 Principal components analysis (PCA)

PCA can be used in data reduction to examine similarities/clustering in data and to identify the sources of variance across variables (Akakuru et al. 2022; Boateng et al. 2016). Principal component analysis (PCA) with Varimax with Kaiser Normalization was applied to the data in order to determine the sources of the physiochemical parameters in the samples (Adebayo et al. 2022; Eyankware et al. 2022; Ogundele et al. 2020), which reduced the amount of variables with an elevated loading on each component, making PCA results easier to comprehend.

6.1 Water Quality Index Method (WQI)

The WQI is a useful tool for determining the whole quality of groundwater and its appropriateness for drinking (Adimalla et al. 2018a; Agidi et al. 2022; Khan and Jhariya 2017). It basically simplifies a lot of groundwater data into a single value and makes information about the quality of the water easier to understand. Weight (wi) was assigned to physiochemical parameters according to their importance for the overall quality of drinking water in order to calculate WQI.

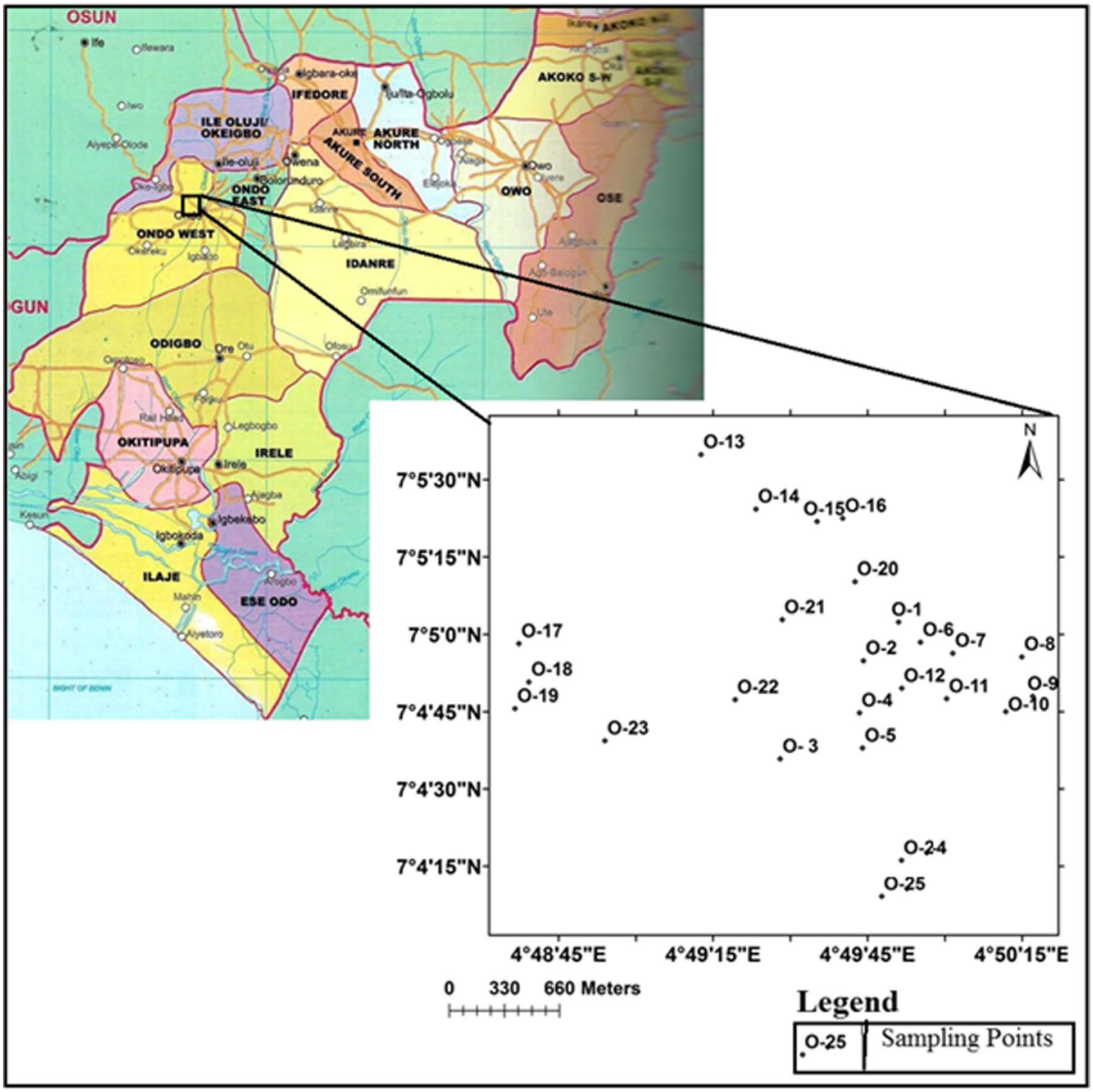

Fig. 2 Data acquisition map of the sampling locations

The WHO standards, relative weight (W_i), and assigned weight (w_i), for each parameter are shown in Table 1. A maximum weight of 5 was assigned to variables including nitrate, total dissolved solids, chloride, and sulfate due to their importance in assessing water quality (Khan and Jhariya 2017). Because bicarbonate and phosphate play minimal roles in water quality assessment, they were assigned a minimum weight of 1. Other characteristics, such as calcium and magnesium, were assigned weights ranging from 1 to 5 based on their importance in the overall quality of drinking water (Boateng et al. 2016).

The relative weight is determined using Eq. (2)

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{2}$$

n represents the number of parameters, w_i represents the weight of each parameter, and W_i represents the relative weight.

The quality rating scale of each parameter was calculated according to WHO (2011) using Eq. (3)

$$q_i = \frac{C_i}{S_i} \times 100 \tag{3}$$

where S_i represents the WHO (2011) guideline for each parameter, C_i represents the concentration (mg/L) of each

Table 1 Relative weight of parameters and water quality standard (Adimalla et al. 2020)

parameters	WHO standards (2011)	Weight (w_i)	Relative weight $W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}$
Ca^{2+}	50	3	0.075
Mg^{2+}	500	3	0.075
K^{+}	12	2	0.050
Na^{+}	200	2	0.050
Cl^{-}	250	5	0.125
HCO_3^{-}	500	1	0.025
NO_3^{-}	45	5	0.125
PO_4^{2-}	0.5	1	0.025
SO_4^{2-}	250	5	0.125
pH	6.5–8.5	4	0.100
EC	500	4	0.100
TDS	500	**5**	0.125
		$\sum w_i = 40$	$\sum W_i = 1.125$

chemical parameter, and qi represent the quality rating. For each chemical parameter, sub-index of *ith* parameter (SI_i) was calculated using Eq. (4). SI_i was then utilized to compute the WQI using Eq. (5)

$$SI_i = W_i \times q_i \tag{4}$$

$$WQI = \sum SI_i \tag{5}$$

7 Result and Discussion

Table 2 showed the physicochemical properties of groundwater samples and WHO guideline values for drinking water. As noticed, the average pH value of 5.23 indicates that the groundwater is mildly acidic, with all samples falling below the permissible range of 6.5–8.5. This low pH value may be related to the oxidation and hydrolysis of pyrite found in groundwater sediment and the weathering of complex subsurface rocks in southwest Nigeria (Egbueri 2019). According to reports, acidic water may cause salts in the aquifer rocks to dissolve and raise the metal and TDS levels in the groundwater (Shakerkhatibi et al. 2019). The results of this study are similar to several other studies conducted in other parts of the country (Egbueri 2019; Emenike et al. 2018). Except for S3, the TDS values for the groundwater at the study sites were within the WHO (2011) permissible limits. High value of TDS in S3 sample may be as a result of rich geogenic deposits of minerals. (Freeze and Cherry 1979) classification showed that all groundwater samples of the study site are classify as freshwater (TDS < 1000 mgL^{-1}). The groundwater EC values at the study sites were below WHO's acceptable limit. The decomposition of minerals in groundwater due to water rock interaction often cause higher EC concentration (Baig et al. 2010). High EC values in groundwater have a huge effect is the physiological drought condition because it prevent plants from competing with the ions in the soil solution (Naseem et al. 2010). The concentrations of all the cations were discovered to be below WHO's acceptable limits (WHO 2017) and (NSDWQ, 2007). The average concentration of the cations in the samples decreased in the following trend Na^{+} (28.50) $> Ca^{2+}$ (16.28) $> K^{+}$ (6.13) $> Mg^{2+}$+(5.59). The dissolution of the limestone and shale are the possible sources of calcium and magnesium that may be present in the water samples from the study area (Mgbenu and Egbueri 2019). Similarly, potassium is considered to come via agricultural waste leaching and silicate rock weathering (Egbueri 2019; Ezugwu et al. 2019). The order of anion enrichment in the groundwater decreased in the following trend HCO_3^{-}(42.79)> Cl^{-}(21.67) > NO_3^{-}(18.01)

Table 2 The analyzed major ions and physical parameters

Parameter	Min	Max	Mean	Std dev	Variance	Skewness	Kurtosis	WHO (2011)
Ca^{2+}	0.90	46.64	16.28	12.04	144.94	1.24	1.17	50
Mg^{2+}	0.60	15.85	5.59	3.62	13.11	0.98	1.13	500
K^{+}	1.80	15.23	6.13	4.02	16.13	1.10	0.40	12
Na^{+}	2.13	83.33	28.50	18.61	346.35	1.20	2.08	200
Cl^{-}	5.67	42.54	21.67	10.19	103.89	0.62	-0.41	250
HCO_3^{-}	2.40	213.60	42.79	55.93	3127.74	2.08	4.04	500
NO_3^{-}	1.08	31.10	18.01	8.11	65.76	-0.75	-0.21	45
PO_4^{2-}	6.84	13.20	9.95	1.48	2.18	-0.03	0.40	0.5
SO_4^{2-}	5.85	19.00	8.95	2.76	7.64	1.95	6.40	250
pH	4.10	6.20	5.23	0.57	0.33	-0.22	-0.50	6.5–8.5
EC	20.00	840.00	295.20	193.65	37,501.00	1.27	2.09	500
TDS	20.00	651.00	217.44	142.25	20,236.09	1.48	2.98	500

$> PO_4^{2-}$(9.95) $> SO_4^{2-}$ (8.95). Except for phosphate, none of the anions have concentrations beyond their respective maximum allowed limits for drinking water, which is similar to the results of the cations concentration in the groundwater samples. Ondo is known for intensive agricultural activities, majority of nitrate pollution may be attributed to percolating of inorganic and organic fertilizers from agricultural land via irrigation water and infiltration of rain, biological fixation and atmospheric precipitation weathering (Egbueri 2019; Ezugwu et al. 2019). High phosphate level could be as a result of sewage materials rich in phosphate from the communities (Boateng et al. 2016). It could also be attributed to drain rich in detergents. According to Collins et al.(2020), the presence of Nitrate in water lowers the pH consequently forming weak acids through process of hydration and oxidation. The formation of bicarbonates in groundwater is mainly from the CO_2 dissolution in soil, the environment and organic matter (Egbueri et al. 2019). Chloride is thought to be derived from the onsite septic contamination, animal wastes and leachates from organic agricultural waste dumps (Egbueri 2019). The occurrence of sulphate and phosphate in the groundwater sample maybe related to fertilizer applications in the vicinity of the study region and wastewaters from agricultural operations.

The reported results (Table 3) for Ca^{2+} and Cl^{-} in this study were shown to be lower than the previously reported data from Akoko, Abeokuta, Abakaliki and Umunya (Agidi et al. 2022; Eyankware 2022; Afuye et al. 2015; Emenike et al. 2018). Except for pH, the concentrations of major ions (Akakuru et al. 2021a; Akakuru et al. 2021b) were lower than in the present study.

The reported concentrations of Ca^{2+}, NO_3^{-} and K^{+} from Benue were lower than the present reported concentrations, while Cl^{-}, HCO_3^{-}, and K^{+} concentrations were reported higher than the present reported concentrations (Agidi et al. 2022). Comparatively, Abeokuta, Abakaliki, Umunya and Benue groundwater were found to contain higher concentrations of Ca^{2+}, Cl^{-}, and HCO_3^{-}, respectively.

7.1 Water Quality Index Result

The spatial distribution of groundwater quality status of studied groundwater samples is presented in Fig. 3. According to Adimalla and Qian (2019), there are five types of groundwater quality rating based on WQI values. The rating are excellent water quality ($WQI < 50$), good quality type ($WQI : 50 - 100$), poor quality type ($WQI : 100 - 200$), very poor quality type ($WQI : 200 - 300$) and water not suitable for drinking type ($WQI > 300$). As can be seen from Fig. 3, high water quality index was found at Q2—Q4 indicating that the groundwater greatly is impaired. Low water quality index was at the vicinities well location Q10. Q13 and Q25, According

Table 3 Mean concentration of major ions from previously published works compared with the present study

Locations	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Cl^{-}	HCO_3^{-}	NO_3^{-}	PO_4^{2-}	SO_4^{2-}	pH	EC	TDS	References
Ondo City Nigeria	16.28	5.59	6.13	28.50	21.67	42.79	18.01	9.95	8.95	5.23	295.2	217.44	Present Study
Akoko, Nigeria	74.67	0.27	-	64.19	77.55	-	27.90	-	75.77	7.34	258.45	230.27	Afuye et al. 2015
Abeokuta, Nigeria	78.48	89.91	5.80	193.46	181.32	411.27	3.43	-	298.29	6.76	1573.57	1135.86	Emenike et al. 2018
Asaba Nigeria	1.28	0.99	0.65	5.86	1.67	32.15	0.74	-	3.02	7.19	0.40	21.95	Akakuru et al. 2021a
Owerri Nigeria	4.45	1.54	0.96	4.57	2.05	18.56	-	-	1.84	7.16	30.86	30.70	Akakuru et al. 2021b
Abakaliki, Nigeria	48.67	3.65	12.45	7.41	352.3	99.56	23.55	-	12.17	6.00	344.59	6.00	Eyankware et al. 2022
Benue, Nigeria	8.41	3.64	7.43	10.94	53.48	148.44	12.69	-	2.35	4.49	19.05	13.04	Agidi et al. 2022
Umunya, Nigeria	42.00	1.30	5.33	14.36	38.40	54.00	6.40	-	3.07	5.56	41.24	34.19	Mgbenu and Egbueri 2019

Dash (-) implies data not available

Fig. 3 Spatial distribution of groundwater quality index

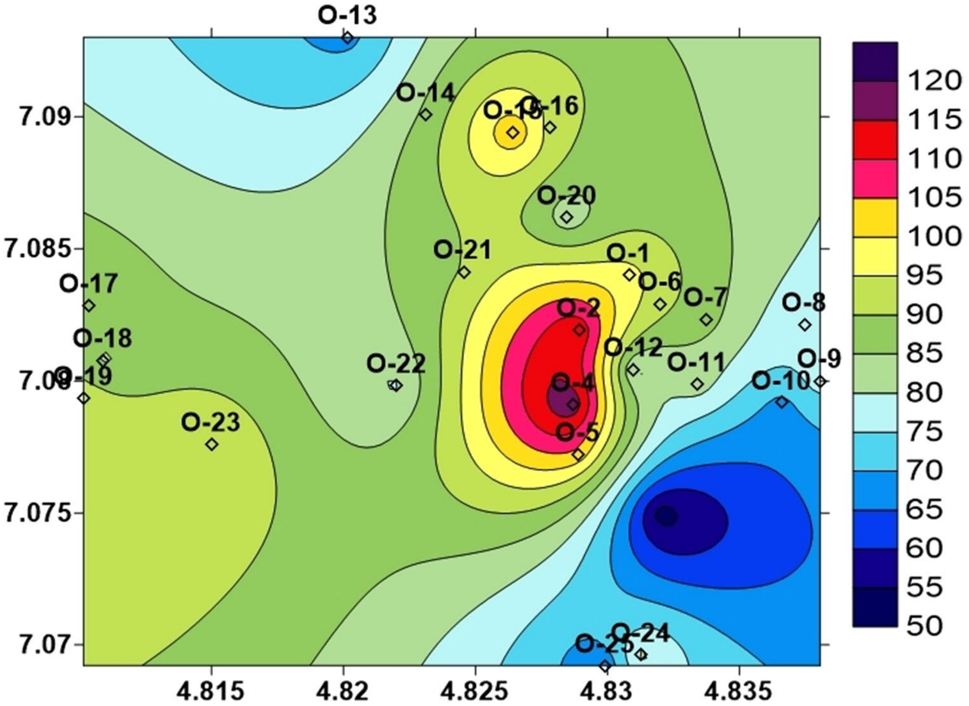

Table 4 Standardized beta in MLR model was used to identify the parameters that contribute to the water quality index

parameters	B coefficient	standardized beta	Standard error	p value
Ca^{2+}	0.111	**0.879**	4.31E-09	0.002
Mg^{2+}	0.167	**0.405**	1.97E-09	0.002
K^{+}	-7.167	-1.933	1.08E-09	0.518
Na^{+}	3.283	0.201	5.60E-10	0.569
Cl^{-}	5.556	0.301	3.91E-10	0.002
HCO_3^{-}	5.556	0.286	1.57E-19	0.002
NO_3^{-}	3.086	0.168	5.36E-10	0.002
PO_4^{2-}	5.556	**0.551**	1.65E-09	0.002
SO_4^{2-}	5.56	0.132	9.08E-10	0.002
pH	1.587	0.224	6.49E-09	0.002
EC	2.222	0.289	2.00E-10	0.002
TDS	0.278	**0.652**	2.65E-10	0.002

to the WQI classification, 22(88%) of the total groundwater samples had good water quality for domestic purposes, approximately three (3) samples, or 12% of all groundwater samples, had low-quality water. Conclusively, except for a few sampling places (Q2—Q4), the WQI results revealed that the groundwater in the examined area is of good drinking quality.

To ascertain the parameters which had the greatest influence on the WQI, multiple regression analysis where coefficient standardization was utilized. The result showed that Phosphate, Calcium, *TDS*, and Magnesium have the greatest impact due to the higher standardized beta coefficients. As a result, magnesium, calcium, and *TDS* are critical markers in the determination of groundwater quality Table 4.

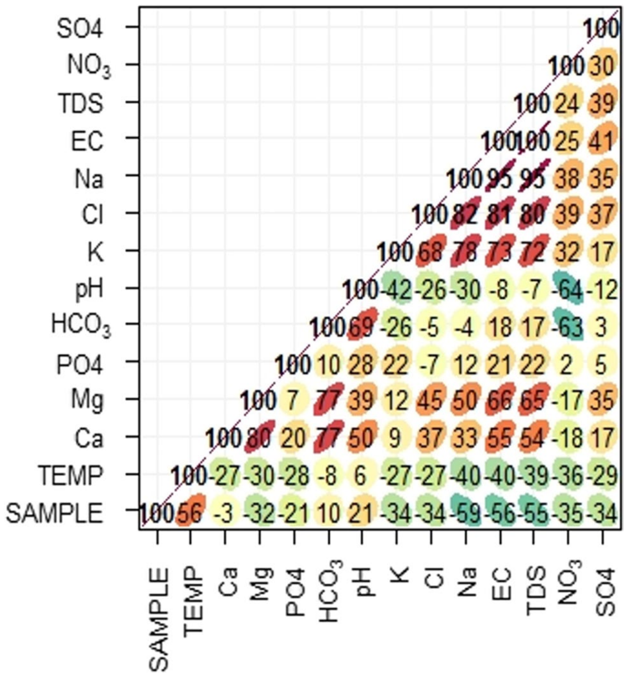

Fig. 4 Correlation plots of physiochemical parameters from sampling points in Ondo

Table 5 PC analysis result of the study area

Variables	Component 1	2	3
Ca^{2+}	0.455	**0.777**	0.047
Mg^{2+}	**0.582**	-0.745	-0.146
K^{+}	**0.764**	-0.322	0.320
Na^{+}	**0.957**	-0.075	**0.080**
Cl^{-}	**0.893**	-0.065	-0.141
HCO_3^{-}	0.038	**0.964**	-0.035
NO_3^{-}	0.418	**0.658**	-0.079
PO_4^{2-}	0.109	**0.909**	0.127
SO_4^{2-}	0.493	0.030	-0.272
pH	-0.266	-0.245	. **0.826**
EC	**0.966**	0.162	0.128
TDS	**0.958**	0.162	0.143
Eigen Values	5.261	3.352	1.125
% of Variance	43.841	27.936	9.376
% of Cumulative	43.291	71.519	81.154

Bold indicate high loadings

7.2 Correlation Between Physiochemical Parameters

Figure 4 depicts the Cor plot of the parameters. The plot showed that the bulk of the parameters have a statistically significant correlation with one another, showing a close relationship between these parameters. Except for NO_3^{-}, SO_4^{2-}, PO_4^{2-} and HCO_3^{-} significant positive correlations were observed between essential ion, TDS and EC, with correlation coefficient (r) ranging from (0.54 – 0.95) suggesting that ions are affected by ion exchange, mineral dissolution and solubility, topographical features and anthropogenic activities. Significant positive correlation was also observed between Mg^{2+} and Ca^{2+} (r = 0.80), an indication of water hardness, Na^{+} strongly correlated with TDS ($r = 0.95$) while pH has no strong link with TDS or the principal ions studied, indicating that pH does not play a vital role in determining groundwater chemistry. The most significant positive associations of bicarbonate and calcium ($r = 0.77$), bicarbonate and magnesium ($r = 0.77$) are related to the breakdown of carbonates rocks (dolomite) found in sedimentary rocks (Houatmia et al. 2016).

7.3 Sources Identification

The result of factor analysis is shown in Table 5. The components PCA analysis yielded three factors. TDS, EC, Ca^{2+}, Cl^{-}, Mg^{2+}, and Na^{+} show strong positive factor loadings in $PC1$, which explains 43.84% of the variance, according to the extracted factor data. The factor may be caused by host rock weathering and leaching. $PC2$ which describes 27.94% of the total variance was positively loaded with HCO_3^{-}, NO_3^{-} and PO_4^{2-}. Factor 2, can thus be linked to the influence of human-induced activities from the communities. In $PC3$, pH and Na^{+} have elevated positive loading coefficient and it has 9.37% as variance percentage explained. Chloride is assumed to be from the dissolution of top layers of the soil that collect wastewater and sewage from residential activities (Boateng et al. 2016).

7.4 Limitations and Uncertainties of the Study

In this study, the metal content of the groundwater was analyzed and compared to permitted limit values, the water quality index was calculated, and the suitability of the groundwater for human consumption was examined. The limitation of this study was that naturally occurring radionuclides materials (NORMs) and heavy metals are not observed. This may underestimate the overall water quality level in the study area.

8 Conclusion

Unmanaged groundwater extraction due to a surge in population may cause a serious water imbalance problem in Ondo City, Ondo State. This study, therefore, was conducted to clarify the groundwater quality conditions and its suitability for residential use. The mean concentration values of Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Cl^{-}, HCO_3^{-}, NO_3^{-}, and SO_4^{2-} in the sampled groundwater were within their respective permissible limits. The sequence of ions in the groundwater was $Na^{+} > Ca^{2+}$ ˃ $K^{+}> Mg^{2+}$ for cations and $HCO_3^{-}> Cl^{-} > NO_3^{-}$ ˃ PO_4^{2-} ˃ SO_4^{2-} for anions. Groundwater quality is mostly influenced by anthropogenic activities, weathering of the rocks, and leaching of surface soil, according to the PCA results. The calculated WQI values of the ions vary from 52.69 —118.07 with a mean of 86.44, implying that the groundwater is safe for consumption and other household applications. Therefore, it can be concluded that the sampled groundwater is unpolluted and safe for domestic consumption.

Author's Contribution Ayodele P. Olufemi: conceptualized, carried out the experiment; and wrote the original manuscript. Adebiyi S. Adebayo, Opeyemi R. Omokungbe: designed and conducted the experiments; data analysis and interpretation; revised the manuscript. Oghenenyovwe Ovie, Adekunle B. Toyeje, Oladimeji A. Babatunde, Juliet O. Ogede Conducted the experiments; site selection, data analysis and interpretation; revised the manuscript.

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Declarations

Competing Interests The authors declare no competing interests.

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