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GIS-based groundwater quality assessment for domestic and irrigation purposes in Ogbia local government area of Bayelsa State, Nigeria

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***Abstract*---**Groundwater is germane to human existence. The study assessed the physicochemical attributes of groundwater for domestic and irrigation applications. This was conducted by collecting and subjecting thirty (30) groundwater samples to physicochemical analysis. Thirteen parameters such as pH, electrical conductivity, total dissolved solids, total hardness, magnesium, calcium, sodium, iron, fluoride, chloride, sulphate, nitrate, and phosphate were used to compute water quality index (WQI). While chloride, electrical conductivity, magnesium adsorption ratio (MAR) and sodium adsorption ratio (SAR) were used to characterise the groundwater for irrigation purposes. Inverse distance weighted (IDW) interpolation method was used to develop spatial variation maps for both the WQI and the irrigation indices. Except for iron and fluoride, the results of the physicochemical parameters were within the WHO permissible limits. The WQI values for the boreholes range between 23.53 and 393.72 with a mean value of 108.69. The WQI was classified into excellent water (7.89%), good water (40.00%), poor water (43.34%), very poor water (5.44%) and unsuitable water (3.33%). The results for irrigation indices show that chloride and EC fall within the suitable groundwater status, MAR classified into suitable (46.67%) and unsuitable (53.33%), and SAR delineate the groundwater status into suitable (43.33%) and marginally suitable (56.67%). Groundwater potability will demand proper treatment for those within poor and very poor classes while for irrigation, overall water treatment is inevitable to avert further soil degradation and crop failure.

***Keywords*---**groundwater, quality assessment, WQI, potability, irrigation indices.

Introduction

Water is one of the most important resources for man's survival on this planet (Lalitha, 2017). It is essential for both chemical and biological reactions in all living things as a universal solvent. While the composition changes from location to place, Hamdy et al. (2003) reported that water makes up over 75% of the Earth surface. Furthermore, the majority of the water on Earth is salty (97%) while only 3% is freshwater in rivers and groundwater forms (Bureau of Reclamation, 2017). Water availability on earth has also been influenced by the rapid growth of urban cities due to over exploitation and anthropogenic influence (Ferry et al., 2003).

Water has long been used for a variety of purposes, including drinking, residential, irrigation, industrial, and ecological uses. Nearly half of the world's population relies on groundwater for drinking water, and it accounts for a significant portion of all irrigation water used in agriculture (FAO, 2010). Around 2.5 billion people worldwide rely on groundwater for their daily needs (UNESCO, 2000). The general reliance on groundwater is primarily due to its inherent quality. Groundwater, on the other hand, is considered the cleanest type of water when compared to surface water (Arslan, 2012). This is owing to natural filtering, anaerobic decomposition, and ion exchange processes that purify groundwater in the soil column. This is one of the reasons for the rapid increase in groundwater usage among most rural and urban residents (Yammani, 2007; Akakuru et al., 2022). Groundwater importance and fragility, necessitated the need for careful management to enhance quality, usability, and sustainability.

According to research, the value of groundwater is determined not by its availability or broad occurrence in nature, but by its quality, which makes it suitable for the desired objectives (Chapman, 1996; WHO, 2011; Mohamed et al. 2020; Magha et al., 2021; Akakuru et al., 2022). As a result, contamination of groundwater is defined as when the quality features of the water have changed beyond their natural expected attributes as a result of the direct or indirect introduction of particular contaminants (Ramesh, 2001; Magha et al., 2021). The geochemistry of the soil through which water infiltrates or flows before reaching the water-bearing strata determines the nature and extent of such chemical alterations or changes (De Zuane, 1990; Pashaeifar et al., 2021). Odigie et al. (2021) attributed major changes in groundwater modification or contamination to contact with effluent from industries, seepages from underground waste tanks, and saltwater intrusion among others. The presence of such contaminants in groundwater, both for domestic and agricultural purposes, is a major concern; as a result, quality assessment data on the quantity and quality of water resources is crucial when planning development projects. Drinking contaminated water has been connected to a variety of illnesses and severe problems, while irrigation with contaminated water has been associated to soil deterioration and poor yield.

Ogbia local government area is one of the most populated and agrarian settlements in Bayelsa State, Delta areas of Nigeria. Associated challenges in the State include much water everywhere but less water for drinking and essential farming activities. This is due to crude oil spillage and iron contamination among others. Previous studies in the area established that growing urbanization (industrialization), exploding population and intensive agriculture as contributing factors to groundwater quality deterioration (Nwankwoala, 2011; Udom et al., 2013; Oyinkuro and Rowland, 2017; Akakuru et al., 2022). This study used integrated hydro-chemical and geographic information system (GIS) techniques in delineating groundwater quality distribution while water quality index (WQI) and irrigation indices in order to estimate the overall suitability of the groundwater resource for public utilization and agricultural irrigation. This method has recently proven beneficial in assessing water quality and monitoring geographical information about water resources. WQI is one of the most useful methods for assessing the quality of drinking water very effectively and efficiently (Boyd, 2000; Magha et al., 2021; Akakuru et al., 2022) and it can be computed in a variety of ways (Saha and Paul 2020). Regardless of the methods, the aggregate of several water quality parameters is obtainable in a single dimensionless digit expressing the drinking water quality that has a connection to human health (Tiwari et al., 2014). Geo-informatics techniques can contribute to refining the estimates and can potentially fill the gaps of knowledge about the effects of urbanization (industrialization) on groundwater quality. GIS is therefore a veritable platform for assimilating geo-information in order to create solutions such as water quality assessment, river and flooding delineation, desertification and drought mapping, watershed analysis, groundwater potential investigation, earth resources exploration, and natural resources management all at local, regional and global scale (Ferry et al., 2003). GIS is therefore the hardware, software, personnel and administrative procedure for data capturing, processing, analysing, manipulating and integrating spatial data sets. Therefore, combination of GIS and statistical methodologies are effective in communicating water quality solutions for decision makers (Sinha and Shrivastava, 1994). Thus, in demystifying groundwater characteristics in Ogbia and its environs, this study assessed physicochemical characteristics of groundwater and gave the spatial distribution of water quality in relation to potability and irrigation application. It will also offer water resources managers the characteristics of groundwater quality available for domestic and irrigation purposes.

Material and Methods

Study Area

The study area is Ogbia and its environs situated in Bayelsa State, Southern Nigeria (Figure 1). The part lies within Latitudes 4^{o}35’30”N and 4^{0}60’0”N and Longitudes 6^{o}10’0”E and 6^{0}25’0”E. It has an approximated area of 695 km^{2} and with a population of about 179,926 (NPC, 2007). The topography is generally low-lying with elevations ranging from below sea level in the south western border of the expanse to about 40 m further inland. The area is equally drained with creeks and tributaries and situated within the freshwater swamp and saltwater zone. Geological characteristics show tertiary subsurface litho-stratigraphic entities of quaternary formation. The climate of the area is typical tropical climate with heavy cloud formation, rainfall and sunshine intensity throughout the year.

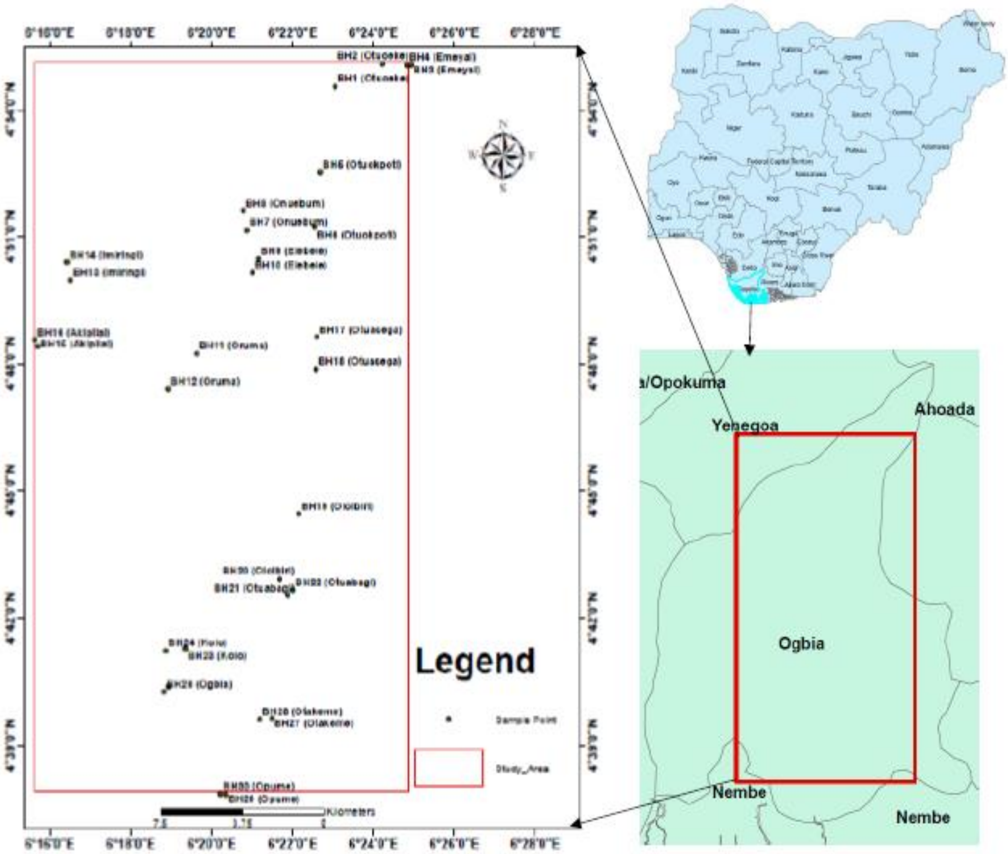


Fig. 1 Map of the study area

Sample Collection Techniques and Analysis

Groundwater sampling was conducted according to the number of boreholes available in the study area. A total of 30 groundwater samples spread over the study area were collected (Figure 2) in polypropylene plastic bottles after pumping for few minutes to minimize the impacts of iron pipes and homogenize the sample. Sampling locations were recorded using global positioning system (Garmin GPS). The pH, total dissolved solids (TDS), and electrical conductivity (EC) of the water samples were measured onsite using portable pH, and EC electrodes (Oakton Z5227807) and TDS meter (HANNA 4855733). While total hardness (TH) was determined by complexometric titration. The samples were acidified using nitric acid (50 %) pH<2 for cations analysis. The samples were stored in ice cool condition, carried to the laboratory and kept at 4°C for further chemical analysis. Immediately after the water samples were transported to the laboratory, the major cations: magnesium, Mg^{2+}; calcium, Ca^{2+}; sodium, Na^{+}; and Fe^{2+} were analysed using atomic absorption spectrometer (Thermo Fisher Scientific M series), and the major anions: fluoride, F^{-}; chloride, Cl^{-}; sulphate, $SO4^{2-}$; nitrate, $NO3^{-}$;

phosphate, PO_4^- were analysed using ion chromatograph (DionexLC20). Thereafter, results from the in-situ measurements and laboratory analysis were entered into excel spreadsheet and imported into ArcGIS 10.3 to produce spatial distribution maps for each of the physicochemical parameters, water quality index (WQI), and irrigation parameters such as Cl^-, EC, MAR (magnesium adsorption ratio) and SAR (sodium adsorption ratio) which were compared with standards for domestic and irrigation agriculture purposes. For spatial interpolation, inverse distance weighted (IDW) function in ArcGIS 10.3 was used to delineate the distribution of natural and subsurface anthropogenic groundwater contaminants.

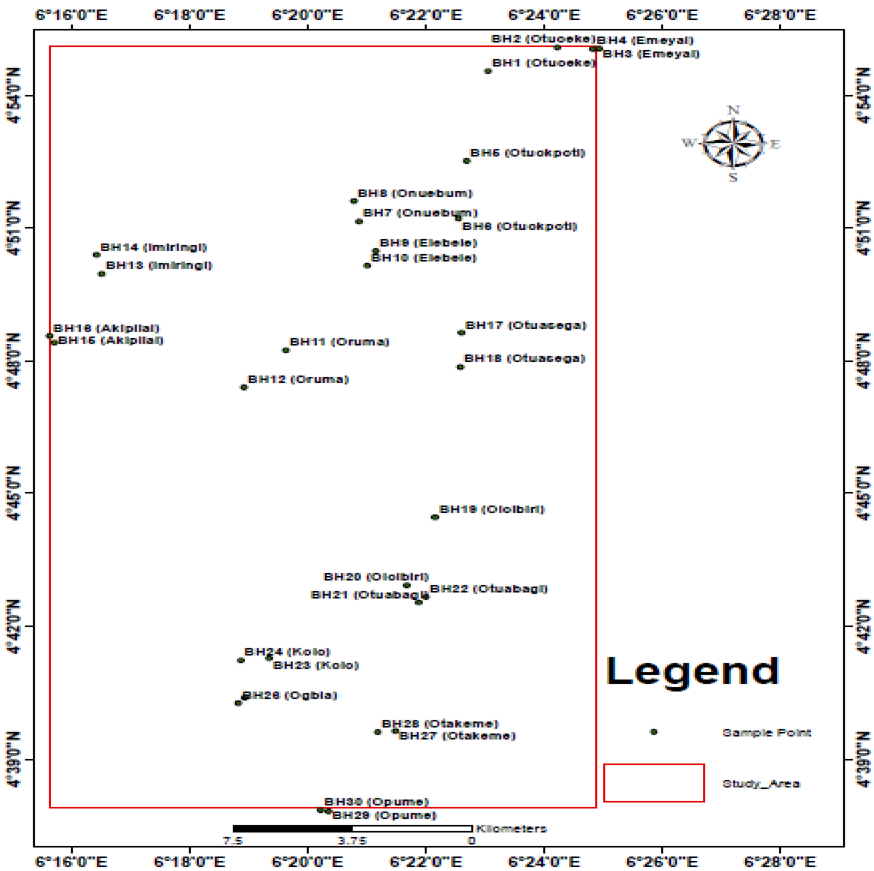


Fig. 2 Map of the sampling points in the study area

Water Quality Index

The computation of the water quality index (WQI) was employed for the assessment of groundwater portability and was carried out by weighted arithmetic index method. The statistical analysis was used for correlation and the water quality index calculated in three stages. In stage 1, each of the parameters was assigned a weight (w_i) according to its relative importance in the overall quality of water for drinking purposes. Take for instance, maximum weight of five (5) were assigned to the parameter phosphorus due to its irrelevance in water quality assessment. Calcium was given the minimum weight of three (3) because it is not harmful. In stage 2, the relative weight (W_i) is computed using a weighted arithmetic index method given below (Horton, 1965; Tiwari and Mishra, 1985) in the following steps:

$$W_i = \frac{\mathrm{wi}}{\sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{wi}} \quad (1)$$

where, W_i is the relative weight (dimensionless), w_i is the weight of each parameter and n is the number of parameters.

In the third step, a quality rating scale, q_i for each parameter was assigned by dividing its concentration in each groundwater sample by the World Health Organization (WHO, 2011) standard for drinking water and the result multiplied by 100.

$$q_i = \left(\frac{C_i}{S_i}\right) * 100 \quad (2)$$

where, q_i is the quality rating, C_i is the concentration of each parameter in each water sample in mg/l and S_i is the WHO (2011) drinking water quality standard for each parameter in mg/l.

For computing water quality index(WQI), the SI_i is first determined for each chemical parameter which is then used to determine the(WQI), as indicated by the following equations:

$$SI_i = W_i * q_i \quad (3)$$

$$WQI = \sum_{i=1}^{n} SI_i \quad (4)$$

where, SI_i is the sub-index of i^{th}parameter, q_i is the rating based on concentration of i^{th} parameter and n is the number of parameters.

The computed WQI values were categorised into five classes, excellent water, good water, poor water, very poor water and unsuitable water for drinking (Sarkar and Abassi, 2006). The results from the WQI calculated, was then added as a column to the attribute table of the location data of the sampling points and was used to produce the water quality map of the study area through inverse distance weighted (IDW) in the Geo-statistics analyst extension of ArcGIS 10.3.

Irrigation Water Quality

Irrigation water quality parameters such as sodium adsorption ratio (SAR), and magnesium adsorption ratio (MAR) were computed by employing the equations from 5 to 7. These parameters were evaluated in order to depict the suitability of groundwater for irrigation purposes.

The SAR value for irrigation water was calculated as expressed by Ragunath (1987) and shown in equation (5). The concentration of the ions was stated in mg/L.

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+}+Mg^{2+})/2}} \quad (5)$$

Irrigation water quality of the groundwater was categorized based on the MAR according to Ragunath (1987) indicated by equation (6), whereby the concentration of each cation was presented in mg/L.

$$MAR = \frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}} * 100 \quad (6)$$

Results and Discussion

Physicochemical Properties of Groundwater

The statistical analysis of physicochemical parameters obtained from boreholes BH1 to BH30 and along with the WHO standard is tabulated in Table 1 and the spatial distribution of analysed physicochemical parameters are shown in Figures 3 to 15.

pH is a vital parameter for measuring water quality and pollution. The quantity of hydrogen ion in water is measured by its pH range. Water exhibits neutral pH in its unpolluted state (Bauder et al., 2010). In this study, pH concentration varies from

Table 1: Physiochemical parameters of groundwater in the study area

BOREHOLE	pH	EC uS/cm	TDS mg/l	TH mg/l	NO_3^- mg/l	Cl^- mg/l	SO_4^{2-} mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^+ mg/l	Fe^{2+} mg/l	F^- mg/l	PO_4^- mg/l
BH1	7	76	106	17.1	1.2	15	3.5	10	7.1	96.1	2.5	0.28	0.02
BH2	7.1	74	100	16.07	1.1	20	4	9	7.07	90	2.01	0.28	0.02
BH3	6.5	101	150	14.6	2.4	10	5	5.5	6.1	96	1.5	0.29	0.15
BH4	6.9	76	96	13.5	2.6	15	4.8	7.5	6	100	1.4	0.2	0.16
BH5	6.4	100	100	21.2	2.4	25	10	12.2	9	95	4.2	0.31	0.19
BH6	6.5	100	1.02	20	2.4	25	10	12	5	98	3.8	0.31	0.19
BH7	7	77	110	19.1	2.5	25	0.29	10.1	9	100	2.9	25	15
BH8	7	76	79	20.1	2.3	27	19	10.1	7	100	2.5	1	0.11
BH9	6.8	100	59	15.7	0.9	30	16	12.6	6.1	105	2.3	0.19	0.09
BH10	6.9	54	92	17.9	1.2	35	15	10.9	7	106	2.56	0.17	0.1
BH11	7	74	56	13.1	1.6	10	9.6	10.1	3	94	0.56	0.06	0.11
BH12	6.7	100	100	19.1	0.6	15	16	13.1	6	95	1.6	0.09	0.12
BH13	6.8	76	100	16.7	2	25	19	10.7	6	100	0.96	0.07	0.14
BH14	7	74	24	6.4	0.6	16	12	4	2.41	100	0.1	0.06	0.07
BH15	6.5	74	100	15.1	1.7	28	15	10	5.1	98	0.71	0.09	0.15
BH16	7	55	59	5.9	1.6	15	10	3.9	2	95	0.1	0.07	0.02
BH17	6.9	75	99	10.1	0	25	20	6	4.1	100	2.53	0.3	0.15
BH18	6.5	100	99	13.5	0.01	27	27	9	4.5	106	2.55	0.4	0.17
BH19	7	54	100	4.8	0	20	96	3	1.8	86	0.2	0.2	0.1
BH20	6.8	100	100	6.41	0.5	26	20	4	2.14	10	2.3	0.04	0.16

BH21	6.9	74	68	20	0.1	30	15	12	8	102	1.56	0.06	0.15
BH22	6.5	110	70	21	0.01	29	17	12	9	110	2.2	0.1	0.07
BH23	7	76	59	8.1	0.01	26	18	5.1	3	103	0.75	0.7	0.15
BH24	6.9	74	64	9.2	0.01	27	20	6.2	3	106	0.92	0.87	0.16
BH25	7	72	96	13.1	0.01	28	22	9	4.1	110	2.45	0.64	0.17
BH26	7	68	97	14.6	0.06	39	21	8.5	6.1	110	2.3	1.2	0.19
BH27	6.5	100	110	20.6	0.1	25	20	12.6	8	106	3.2	0.09	0.15
BH28	7	57	56	4.9	0.1	15	4.8	3	1.9	92	0.07	0.28	0.15
BH29	6.9	55	97	18.7	0.6	29	50	10	8.7	100	2.53	0.28	0.17
BH30	6.5	59	99	17.7	0.15	30	21	10	7.7	110	2.49	0.28	0.15
Min	6.4	54	1.02	4.8	0	10	0.29	3	1.8	10	0.07	0.04	0.02
Max	7.1	110	150	21.2	2.6	39	96	13.1	9	110	4.2	25	15
Mean	6.81	78.70	84.86	14.48	0.96	23.73	18.03	8.74	5.53	97.30	1.86	1.13	0.62
WHO (2011)	6.5-8.5	1000	500	100	10	250	100	70	10	200	0.3	1.5	0.05

6.4 to 7.1 with a mean value of 6.81, which is within 6.5 and 8.5, the recommended range of pH set by the WHO (Table 1). Figure 3 shows the spatial distribution of pH in the study area.

EC is a measure of the ability of any material to transmit electrical current in soluble state and directly proportional to dissolved materials in a liquid state. EC concentration in this study ranges between 54 and 110 μS/cm with a mean value of 78.70 μS/cm, which is lower than 1000 mg/L, the acceptable limit stated by the WHO (Table 1). However, the spatial distribution map of EC is shown in Figure 4.

TDS is used to provide dissolved estimate of inorganic and organic matter in a liquid. Though, it is not supposed to be associated with any health implication. It is a parameter for describing the aesthetic features of drinking water (Boyd, 2000). TDS concentration in this study varies from 1.02 to 150.00 mg/L with a mean value of 84.86 mg/L, which is lower than 500 mg/L, the WHO permissible limit (Table 1). The spatial variation map of TDS is illustrated in Figure 5.

TH is the quantity of calcium and magnesium that dissolved in a liquid. This is manifested in water by the dissolution of natural occurring minerals moving through soil and rock. This describes the sum of the temporary and permanent hardness. TH concentration ranges from 4.80 mg/L to 21.20 mg/L with a mean value of 14.48 mg/L, which is lower than the WHO stipulated limit of 100 mg/L (Table 1). Figure 6 illustrates the spatial distribution of TH in the study area.

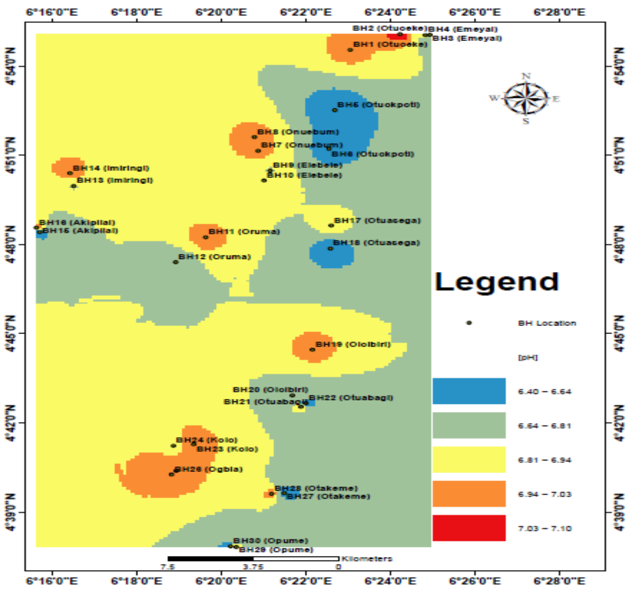


Fig. 3 Spatial distribution map of pH

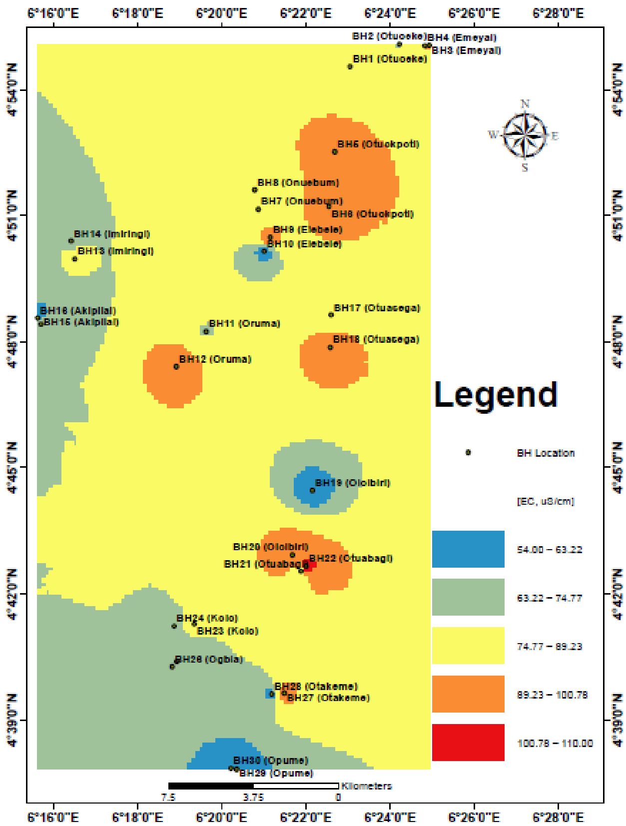


Fig. 4 Spatial distribution map of electrical conductivity

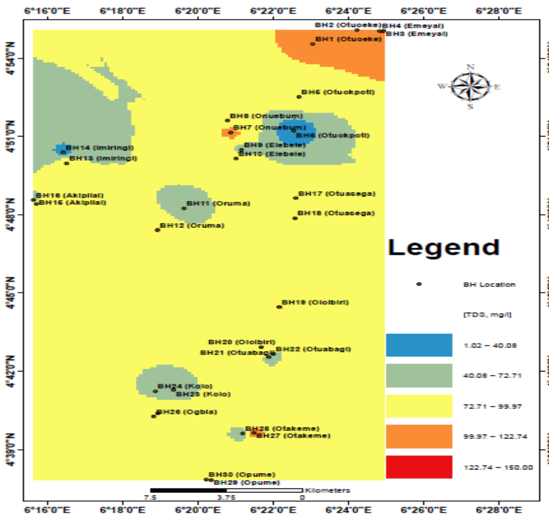


Fig. 5 Spatial distribution map of total dissolved solids

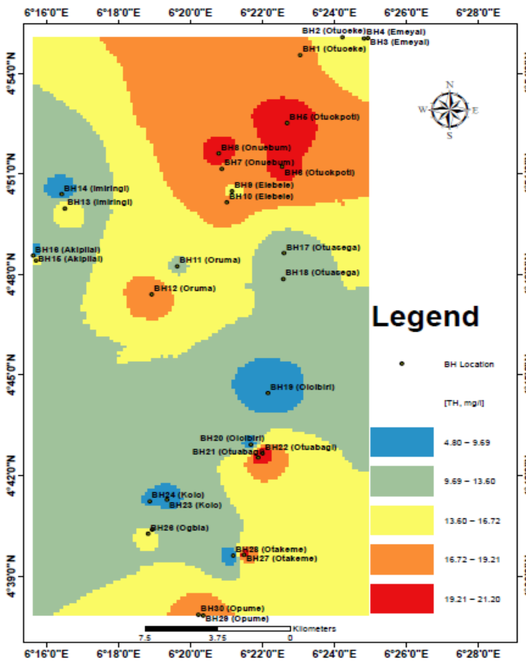


Fig. 6 Spatial distribution map of total hardness

Nitrate is a vital constituent of the nitrogen cycle and occurs in a natural state. Nitrate occurrence in groundwater is usually due to aerobic decomposition of nitrogen from organic matter and other sources like fertilizers, industrial effluents and septic waste. Its concentration varies between 0.00 mg/L and 2.60 mg/L with a mean value of 0.96 mg/L which is lower than 10 mg/L, the WHO acceptable value (Table 1). However, the spatial distribution map of nitrate is depicted in Figure 7.

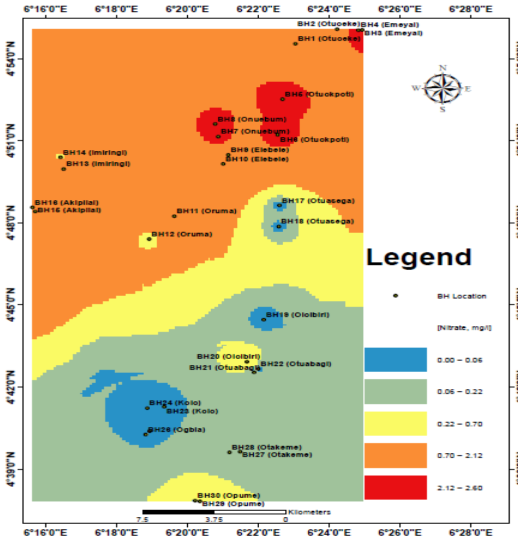


Fig. 7 Spatial distribution map of nitrate

Chloride concentrations vary widely in natural water and it is directly related to mineral content of the water. The presence of chloride is not hazardous but its high frequency of association with elevated sodium is of great concerns (Thlakma et al., 2018). In this study, chloride concentration varies from 10.00 mg/L to 39.00 mg/L with a mean value of 23.73 mg/L, which is lower than the WHO permissible limit of 250 mg/L (Table 1). Figure 8 depicts the spatial distribution of chloride in this study.

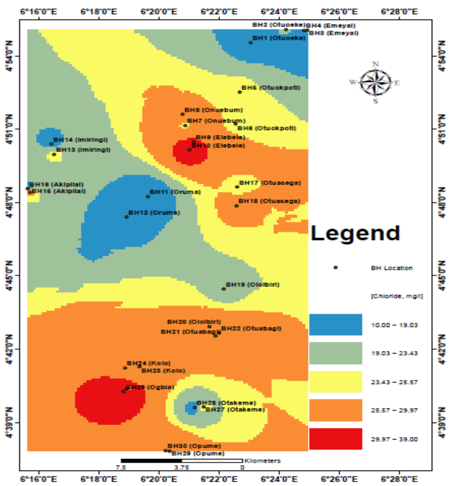


Fig. 8 Spatial distribution map of chloride

Sulphate may occur naturally by the dissolution and percolation of rocks in the form of iron sulphides, gypsum and other types of sulphur composites. It may also enter the aquifer system through industrial effluent and waste discharge (Sagnak, 2010). Sulphate concentration ranges between 0.29 mg/L and 96.00

mg/L with a mean value of 18.03 mg/L, which is lower than 100 mg/L, the acceptable limit specified by the WHO (Table 1). However, the sulphate spatial distribution map is shown in Figure 9.

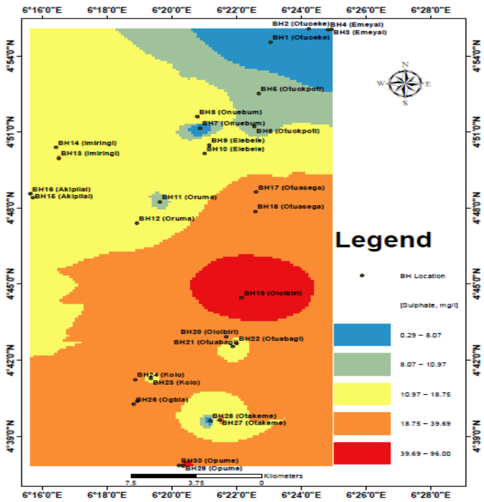


Fig. 9 Spatial distribution map of sulphate

Calcium may find its way into groundwater from the leaching of calcium bearing mineral deposits. In this study, calcium concentration varies from 10.00 mg/L to 39.00 mg/L with a mean value of 8.74 mg/L, which is lower than 70 mg/L, the recommended WHO limit (Table 1). This fulfils the process for chemical weathering and fluoride dissolution which may lead to an upsurge in the concentration of fluoride due to the lower quantity of calcium. However, the spatial distribution map of calcium is shown in Figure 10.

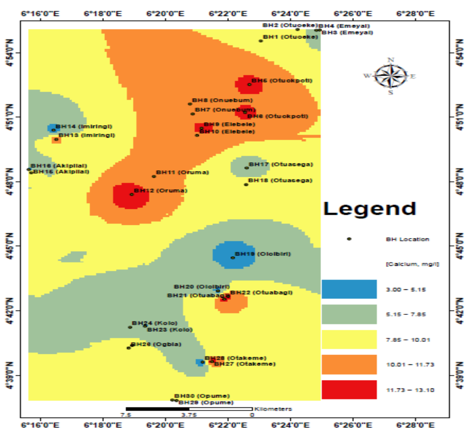


Fig. 10 Spatial distribution map of calcium

Magnesium is a prime cause of hardness in water. Magnesium, often leached from geological sources into water. Magnesium concentration ranges between 1.80 mg/L and 9.00 mg/L with a mean value of 5.53 mg/L, which is lower than

10 mg/L, the WHO permissible limit (Table 1). However, the map of magnesium characterising its spatial distribution is represented in Figure 11.

Many sodium salts are highly soluble in water. Many rocks and soils, water treatment chemicals, effluents from sewage, water softener, etc are some of its sources (Hassan et al., 2019). Sodium concentration varies from 10.00 mg/L to 110 mg/L with a mean value of 97.30 mg/L (Table 1). High values of sodium are usually found in the groundwater affected by saline water intrusion, though the mean value estimated in this study is lower than 200 mg/L, the WHO acceptable limit (Table 1). Figure 12 reveals the spatial distribution of sodium in the study area. In general, sodium salts are not actually harmful but too much can be bad for persons with controlled quantity.

Iron is an abundant metal found in the Earth's crust. It is naturally present in water and may also be released into water from corrosion of steel and cast-iron pipes, effluent discharge, natural mineral deposits, and iron minerals processing. The concentration of iron ranges from 0.07 mg/L to 4.20 mg/L with a mean value of 1.86 mg/L, which is higher than the WHO recommended limit of 0.3 mg/L (Table 1). However, the spatial distribution map of iron is shown in Figure 13. Though iron is an essential element in human nutrition, concentration above the parametric value will turn water brown, turbid or deposit solids on clothes washed in the water or food cooked using water (Nwankwola and Udom, 2011).

Fluoride is mainly from fluoridation of public water supplies and sometimes from industrial waste, though its presence in groundwater may be due to release from geological processes (Hassan et al., 2019). Fluoride concentration varies between 0.04 mg/L and 25.00 mg/L with a mean value of 1.13 mg/L, which is lower than the WHO recommended limit of 1.5 mg/L (Table 1). However, the spatial distribution of map of fluoride is shown in Figure 14. Health studies have shown that the addition of fluoride to water supplies at levels above 0.6 mg/L leads to a reduction in tooth decay in growing children (Hassan et al. 2019).

The presence of phosphorus may come from untreated discharges from domestic, agricultural and industrial sources. Phosphorus concentration ranges between 0.02 mg/L and 15.0 mg/L with a mean value of 0.62 mg/L, which is higher than the WHO permissible limit of 0.05 mg/L (Table 1). Figure 15 shows the spatial distribution of phosphorus. High concentration of phosphorus cause eutrophication and make water unsuitable for drinking and industrial usage (Nwankwola and Udom, 2011).

Water Quality Index (WQI)

Water quality index (WQI) of Ogbia groundwater was established from a range of physicochemical parameters. The values of the various parameters for the calculation of WQI are illustrated in Tables 2 and 3.
Table 2: Relative weight of groundwater physicochemical parameters
Table 3: Water quality classification based on WQI

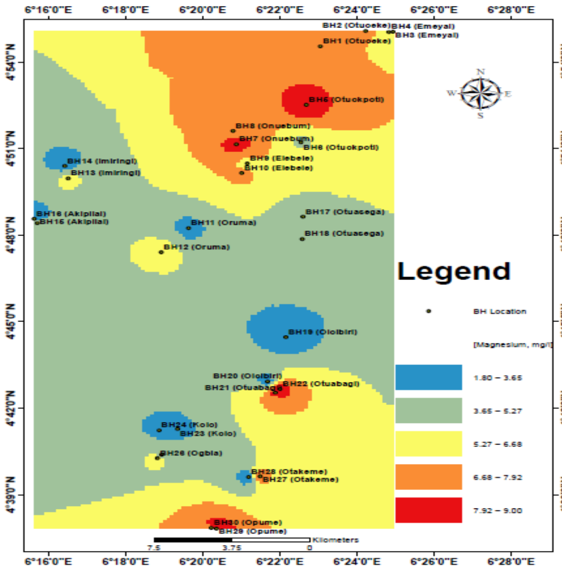


Fig. 11 Spatial distribution map of magnesium

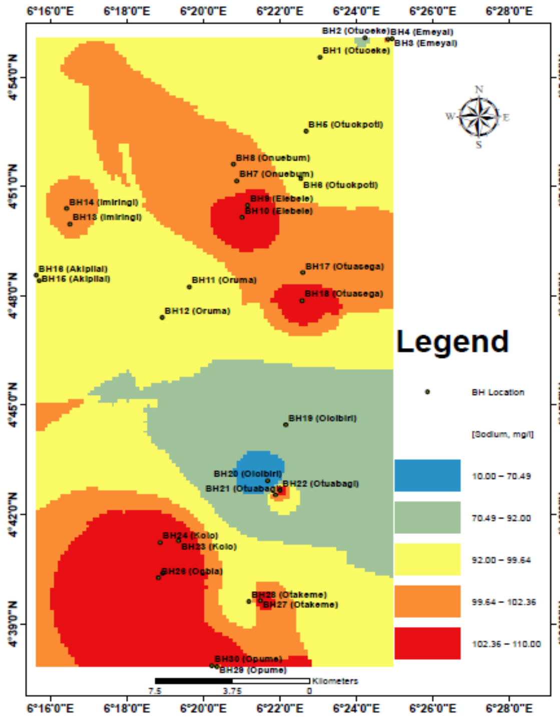


Fig. 12 Spatial distribution map of sodium

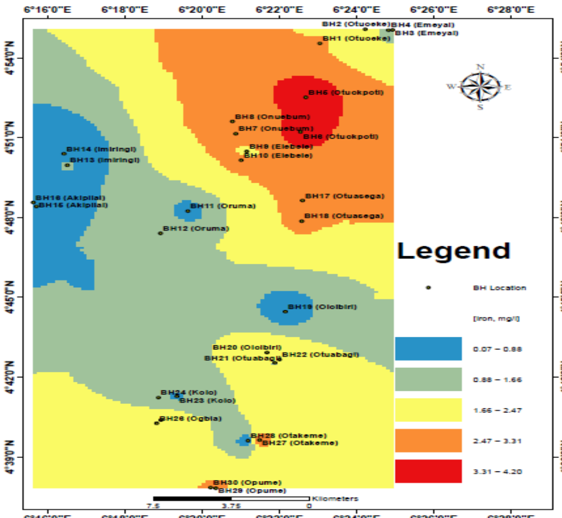


Fig. 13 Spatial distribution map of iron

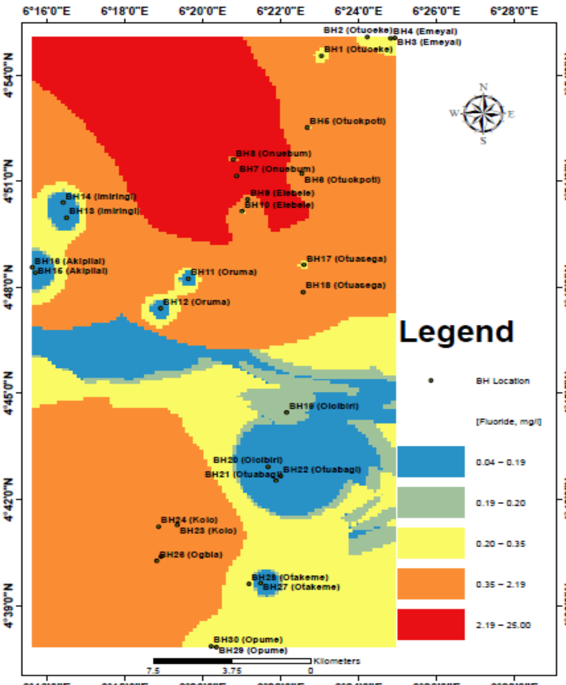


Fig. 14 Spatial distribution map of fluoride

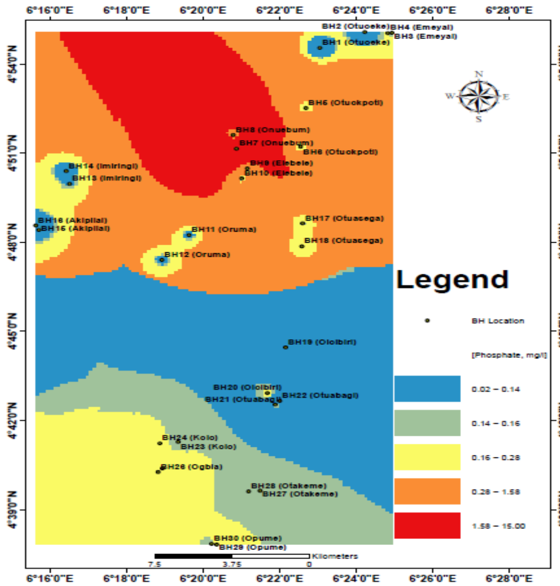


Fig. 15 Spatial distribution map of phosphate

The water quality index (WQI) values for the study area vary between 23.53 and 393.72 with a mean value of 108.69. Figure 16 shows the spatial distribution of groundwater quality status in terms of excellent water, good water, poor water, very poor water and unsuitable water respectively. The groundwater at BH14 (Imiringi), BH16 (Akipilai), and BH19 (Oloibiri) fall within class I (Table 3), classified as excellent water (Figure 16) for which the WQI <50 (WOI is less than 50) representing 7.89% of the distribution (Table 3) and suitable for drinking purposes. Boreholes like BH2 (Otuoeke), BH3 (Emeyal), BH4 (Emeyal), BH11 (Oruma), BH12 (Oruma), BH13 (Imiringi) BH21 (Otuabagi), BH22 (Otuabagi), BH23 (Kolo), BH24 (Kolo), and BH28 (Otakeme), the groundwater is delineated as good water (Figure 16) within the realm of class II (Table 3) representing 40% of the distribution for which the WQI varies between 50 and 100 (Table 3). The WQI (Table 3) for boreholes such as BH1 (Otuoeke), BH5 (Otuokpoti), BH6 (Otuokpoti), BH8 (Onuebum), BH9 (Elebele), BH10 (Elebele), BH17 (Otuasega), BH18 (Otuasega), BH20 (Oloibiri), BH25 (Ogbia), BH26 (Ogbia), BH27 (Otakeme), BH29 (Opume), and BH30 (Opume) is classified as poor water (Figure 16) and fall within class III representing 43.34% of the distribution for which the WQI value is between 100 and 200 (Table 3). While BH7 (Onuebum) is demarcated as very poor and unsuitable water (Figure 16) representing 5.44% and 3.33% distributions whereby their WQI values fall within classes IV and V respectively (Table 3). Therefore, groundwater with excellent and good quality status located at BH14 (Imiringi), BH16 (Akipilai), BH19 (Oloibiri), BH2 (Otuoeke), BH3 (Emeyal), BH4 (Emeyal), BH11 (Oruma), BH12 (Oruma), BH13 (Imiringi) BH21 (Otuabagi), BH22 (Otuabagi), BH23 (Kolo), BH24 (Kolo), and BH28 (Otakeme) are potable for consumption while poor, very poor and unsuitable groundwater categories located at BH1 (Otuoeke), BH5 (Otuokpoti), BH6 (Otuokpoti), BH8 (Onuebum), BH9 (Elebele), BH10 (Elebele), BH17 (Otuasega), BH18 (Otuasega), BH20 (Oloibiri), BH25 (Ogbia), BH26 (Ogbia), BH27 (Otakeme), BH29 (Opume), BH30 (Opume) and BH7 (Onuebum), are not fit for consumption. Groundwater of these categories should be avoided and attempt to use such will demand proper treatment for public health's sake (Ramakrishnaiah, 2009).

Table 2: Relative weight of groundwater physiochemical parameters

Sn	Chemical parameters	Desirable limit (WHO 2011)	Weight (wi)	Relative weight (Wi)
1	pH	7.5	4	0.07
2	EC	1000	4	0.07
3	Total dissolved solids	500	5	0.09
4	Total Hardness	100	4	0.07
5	Na^+	200	4	0.07
6	SO_4^{2-}	100	5	0.09
7	Ca^{2+}	70	3	0.05
8	Mg^{2+}	10	3	0.05
9	Cl^-	250	5	0.09
I0	Fe^{2+}	0.3	5	0.09
11	NO_3^-	10	5	0.09
I2	F^-	1.5	5	0.09
I3	PO_4^-	0.05	5	0.09
			Σwi=57	ΣWi = 1

Table 3: Water quality classification based on WQI

Water Quality Index (WQI) Value	Class	Groundwater Quality Status	Percentage Distribution
<50	I	Excellent Water	7.89%
50-I00	II	Good Water	40.00%
I00-200	III	Poor Water	43.34%
200-300	IV	Very Poor Water	5.44%
>300	V	Unsuitable Water	3.33%

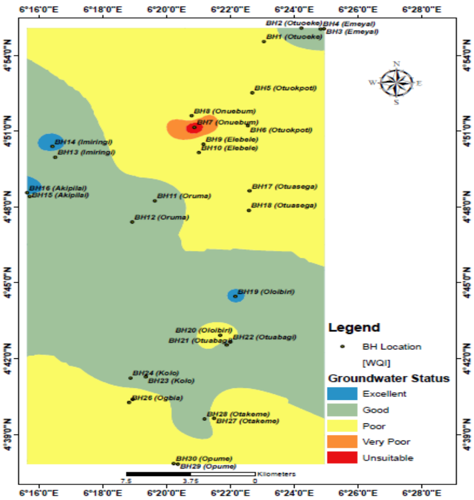


Fig. 16 Spatial distribution of water quality index (WQI) map

Irrigation Water Quality

In Ogbia LGA, the groundwater status of boreholes (BH1 – BH30) for irrigation purposes was categorized on the basis of class intervals of chloride (Cl^-) in meq/L, electrical conductivity (EC) in µS/cm, magnesium adsorption ratio (MAR) and sodium adsorption ratio (SAR) as shown in Table 4.

Table 4: Thresholds of some irrigation parameters for groundwater quality status of Ogbia LGA

Irrigation Parameter	Class Interval (Khattak et al. 2012)	Number of Boreholes	Percentage Distribution	Groundwater Status
(a) Cl^- (meq/l)	0-3.9	30	100	Suitable
	>3.9	None	0	Unsuitable
(b) Electrical Conductivity (µS/cm)	<1000	30	100	Suitable
	1001-1250	None	0	Marginally suitable
	>1250	None	0	Unsuitable
(c) Magnesium Adsorption Ratio (MAR) (meq/l)	< 50 %	14	46.67	Suitable
	>50%	16	53.33	Unsuitable
(d) Sodium Adsorption Ratio (SAR) (meq/l)	<6	13	43.33	Suitable
	6-10	17	56.67	Marginally suitable
	>10	None	0.00	Unsuitable

In this study, chloride values in meq/L range from 0.28 to 1.10 with mean value of 0.67 meq/L in relation to irrigation characteristics of the groundwater. As specified in Table 4(a), chloride between 0 and 3.9 meq/l is characterised suitable for irrigation while chloride greater than 3.9 meq/L (>3.9 meq/L) is considered unsuitable (Khattak et al., 2012). The spatial distribution of chloride is depicted in Figure 17(a). Figure 17(a) therefore shows that the boreholes (BH1 – BH30) fall within the suitable groundwater for arable crop production.

The EC values vary between 54 and 110 uS/cm with mean value of 78.7 uS/cm as presented in Table 1. EC indicates the level of salinity in groundwater application for irrigation farming. As stated in Table 4(b), EC less than 1000 uS/cm (EC<1000 uS/cm) is classified as suitable, for EC between 1001 and 1250 uS/cm is considered marginally suitable while EC >12550 is grouped as unsuitable (Khattak et al., 2012). The spatial distribution of EC (i.e., BH1 – BH30) is depicted by Figure 17(b). Hence, the EC for the study area is within the suitable range (<1000 uS/cm) that is desirable for good crop yield.

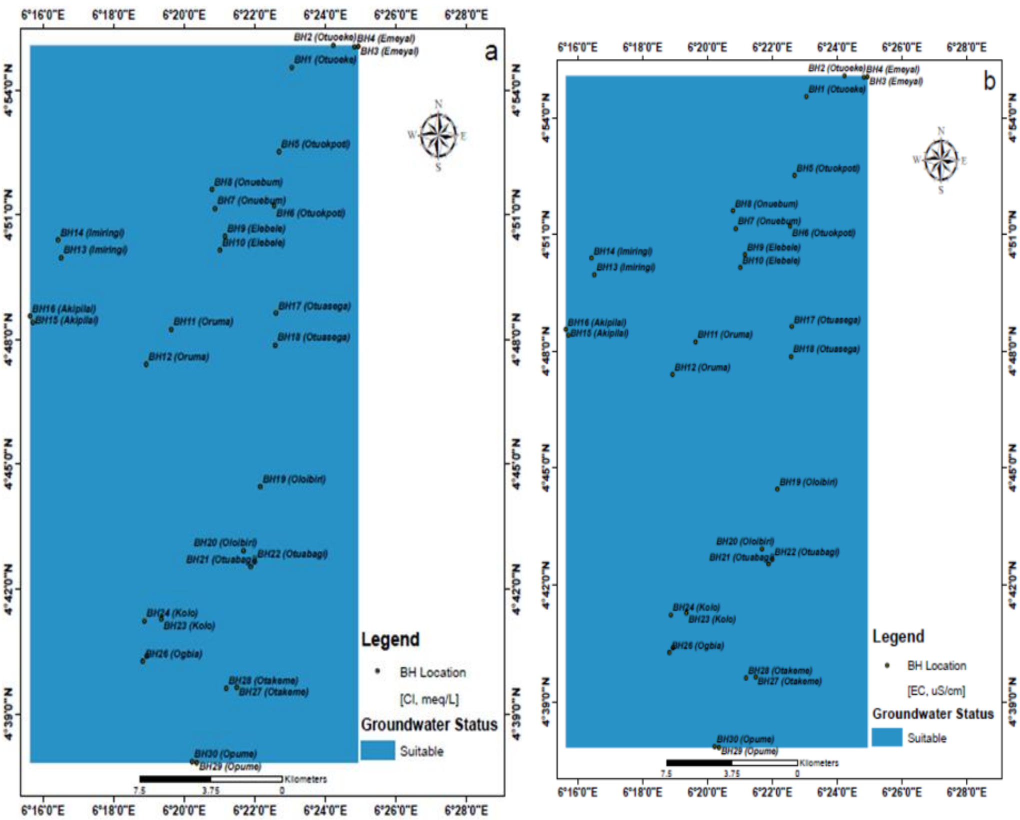
The values of MAR range from 32.86 to 64.64 meq/l having 50.38 meq/l as the mean value. The class intervals for classifying groundwater status comprise MAR <50% as suitable status for irrigation purposes and MAR >50% as unsuitable status as shown in Table 4(c) (Khattak et al., 2012). Figure 17(c) shows spatially the distribution of MAR whereby 47% (i.e., 14 out of the 30 boreholes) carries suitable status. This depicted no harmful consequence to soils in the area (Gupta and Gupta, 1987). The boreholes are BH6 (Otuokpoti), BH9 (Elebele), BH11 (Oruma), BH12 (Oruma), BH13 (Imiringi), BH14 (Imiringi), BH15 (Akipilai), BH16 (Akipilai), BH18 (Otuasega), BH19 (Oloibiri), BH20 (Oloibiri), BH23 (Kolo), BH24 (Kolo), and BH25 (Ogbia). While 53% falls within the unsuitable status for irrigation purposes. This unsuitable status will negatively impact soils (Gupta and Gupta, 1987). Also, the boreholes are BH1 (Otuoeke), BH2 (Otuoeke), BH3 (Emeyal), BH4 (Emeyal), BH5 (Otuokpoti), BH7 (Onuebum), BH8 (Onuebum), BH10 (Elebele), BH17 (Otuasega), BH21 (Otuabagi), BH22 (Otuabagi), BH26 (Ogbia), BH27 (Otakeme), BH28 (Otakeme), BH29 (Opume), and BH30 (Opume). Elevated magnesium concentration in water above calcium may affect crop performance and consequently yield. Crop will normally do well where the equilibrium between magnesium and calcium is maintained.

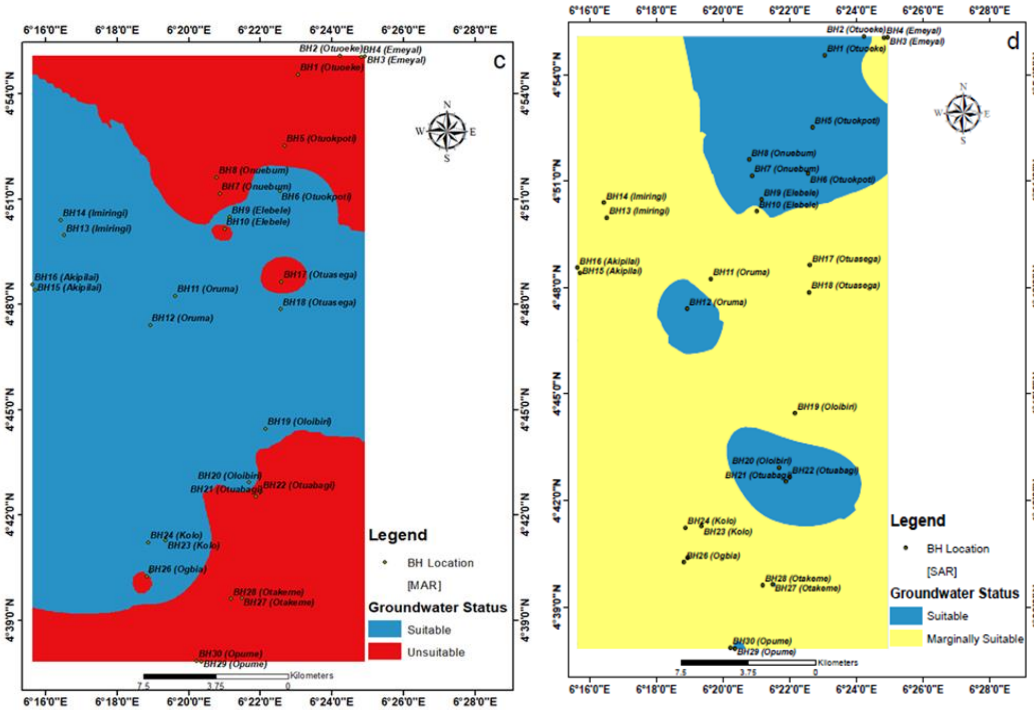
SAR is usually an expression of sodium hazard because it reveals the extent of sodium adsorption in soils. The SAR values vary from 0.81 to 8.39 meq/L with mean value of 5.46 (meq/L). The classification status of Ogbia groundwater using SAR for agricultural irrigation is stated in Table 4(d) (Khattak et al., 2012) such that SAR <6 meq/L is delineated as suitable, SAR between 6 and 10 meq/L is grouped as marginally suitable, and SAR >10 meq/L is classified as unsuitable water. The rating distribution status of SAR is shown spatially by Figure 17(d). Figure 17(d) falls within suitable and marginally suitable categories. In this study, boreholes BH1 (Otuoeke), BH2 (Otuoeke), BH5 (Otuokpoti), BH6 (Otuokpoti), BH7 (Onuebum), BH8 (Onuebum), BH9 (Oloibiri), BH12 (Oruma), BH20 (Oloibiri), BH21 (Otuabagi), BH22 (Otuabagi), BH27 (Otakeme), and BH29 (Opume) constitute 43.33% (i.e., 13 out of the 30 boreholes) of suitable groundwater for irrigation while boreholes BH3 (Emeyal), BH4 (Emeyal), BH10 (Elebele), BH11 (Oruma), BH13 (Imiringi), BH14 (Imiringi), BH15 (Akipilai), BH16 (Akipilai), BH17 (Otuasega) (Otuasega), BH18 (Otuasega), BH19 (Oloibiri), BH23 (Kolo), BH24 (Kolo), BH25 (Ogbia), BH26 (Ogbia), BH28 (Otakeme), and BH30 (Opume) constitute 56.67% (i.e., 17 out of the 30 borehole) of marginally suitable.

Increase in SAR up to the value of 30 lead to decrease in soil stability in term of aggregate (Barzegar et al., 1994). High SAR's value in water is associated with dispersion of colloids when applied to soil. High sodium in irrigation water sometimes replaces calcium and magnesium which causes disruption in soil structure and reduces the soil capacity to hold water and air.

Conclusion

The spatial analysis and interpretations of the groundwater quality of the study area successfully demonstrate that GIS and statistical approaches are reliable tools in evaluation and describing the spatial mapping and analysis of groundwater characteristics for potability and irrigation purposes. In this study, thirteen (13) water samples were collected from boreholes and analysed. The results of the physicochemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), major cations (i.e., magnesium, Mg^{2+}; calcium, Ca^{2+}; sodium, Na^{+}; and iron, Fe^{2+} and major anions (i.e., fluoride, F^{-}; chloride, Cl^{-}; sulphate, $SO4^{2-}$; nitrate, $NO3^{-}$; phosphate, PO_4^{-}) are within the acceptable standard provided by the WHO except for iron and fluoride. The spatial variation of the results of the physicochemical parameters were generated using IDW interpolation method to characterise the distribution of the parameters. Water quality index (WQI) was computed and classified the study area into excellent, good, poor, very poor and unsuitable water and their percentage distributions are 7.89% for excellent water, 40.00% for good water, 43.34% for poor water, 5.44% for very poor water and 3.33% for unsuitable water respectively. However, four irrigation indices were employed to assess the groundwater quality for irrigation purposes. The indices are chloride (Cl^-) in meq/L, electrical conductivity (EC) in µS/cm, magnesium adsorption ratio (MAR) and sodium adsorption ratio (SAR). The groundwater characteristics of chloride and EC indicated that the boreholes fall within the suitable status for arable crop production. MAR characterised the area into suitable and unsuitable representing 46.67% and 53.33% distribution respectively. While the SAR groundwater status for irrigation usage falls into suitable (43.33%) and marginally suitable (56.67%). Such that sodium adsorption ratio and magnesium hazard indicated potential threat to soil health if the water is administered without paying critical attention to them. On the basis of WQI and irrigation indices, the quality of groundwater for potability and irrigation varies. Therefore, groundwater campaign for safe water consumption is essential for public health interest and irrigation agriculture in the area will demand serious attention to avoid soil degradation and yield loss.





Spatial distribution maps of: Fig. 17(a) Chloride Index for Irrigation. Fig. 17(b) EC Index for Irrigation. Fig. 17(c) Magnesium Adsorption Ratio (MAR). Fig. 17(d) Sodium Adsorption Ratio (SAR) of the study area

Statements and Declarations

There are no competing interests to disclose that are relevant to the content of this article for any of the authors.

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