Hydrogeochemical characterization and Groundwater Quality Assessment in Ore, Southwestern, Nigeria

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Abstract

One of the objectives of the Millennium Development Goals is to have sustainable access to safe drinking water and basic sanitation. In line with this objective, an assessment of groundwater quality was carried out in Odigbo Local Government Area of Ondo State to assess the drinking, domestic and irrigation uses of the water. Samples from 30 randomly selected ground water sources; 16 shallow wells and 14 boreholes were analyzed using American Public Health Association method. Water quality index calculation, and diagrams such as Piper, Gibbs and Wilcox diagrams have been used to assess the groundwater in conjunction with irrigation indices such as % sodium, sodium absorption ratio, permeability index, and electrical conductivity. In addition statistical Principal component analysis were used to determine the homogeneity and source(s) influencing the chemistry of the groundwater. The results show that all the parameters are within the permissible limit of World Health Organization. The physicochemical analysis of samples indicates that the dominant major cations are in decreasing order of Na^+, Ca^{2+}, Mg^{2+}, K^+ and the dominant anions are HCO^{-3}, Cl^-, SO_4^{-2}, NO^{-3}. The values of water quality index variation (50-75) suggest a good water, accounts for 70% of the study area. The dominant groundwater facies revealed in this study are the non-carbonate alkali (primary salinity) exceeds 50% (zone 7); and transition zone with no one cation-anion pair exceeds 50% (zone 9), while evaporation; rock–water interaction, and precipitation; and silicate weathering process are the dominant processes in the hydrogeochemical evolution of the groundwater. The study indicates that water is within the permissible limits of irrigation indices adopted, and plot on excellent category on Wilcox plot. In conclusion, the water in the study area are good/suitable for drinking, domestic and irrigation purposes with low equivalent salinity concentrate and moderate electrical conductivity.

Keywords: Groundwater quality; water quality index; water-rock interaction; principal component analysis; hydrochemical facies

1. Introduction

Water is the most important resource for life survival. It is also an essential resource for drinking, irrigation, industrial, and economic development (Falowo et al., 2017). However its supply in sufficient quality and quantity is critical to all aspect of life. In recent years, effort has been made to meet these prerequisites, but have proved difficult even though water is the most abundant substance on the earth surface. Its unique properties make it the most important and abundant substance in the universe. Groundwater accounts for about 98% of the world fresh water and is distributed throughout the world (Tijani, 2016). Poor drinking water quality, high cost of water purification, human health problems, and loss of water supply are attributable to groundwater contamination. Access to quality groundwater has been a major concern for developing/under-developing countries especially in Nigeria as almost 75% of the entire population depends solely on groundwater for consumption (Abimbola et al., 2002). Most rural areas in Nigeria depend solemnly on rivers, streams and hand-dug wells for water supply while the urban settlements depend on treated pipe-borne water and boreholes for their water supply. This has consequently led to slow industrial, agricultural

growth in the rural areas (Adelana and Olasehinde, 2003; Adeyemi et al., 2003). The quality of groundwater for different purpose depend largely on its physical, chemical and bacteriological compositions and as a result of this, various concerned agencies have set out permissible standards for water usage. According to Davis and De-weist (1966), these standards are based on two main criteria, namely; the presence of objectionable tastes, odor and color and; the presence of substances with adverse physiological effects. However, mineral enrichment from underlying rocks can change the chemistry of the groundwater, making it unsuitable for the consumption (Ako et al., 1990).

Odigbo Local Government of Ondo State is becoming a cosmopolitan city in terms of infrastructural and urban utilities. It connects Ondo State with Lagos, and Benin, therefore there is influx of different ethnicity, nationals, and rural dwellers, seeking for greener pasture. This has brought about increase in population. This is seriously affecting the town leading to acute water supply over the last decade, while there is little or no provision for water supply expansion and quality control. Industrial discharges/effluents from petrochemical depots and companies is really contaminating the inadequate existing water sources (surface water and shallow wells) in the area. Assessing ground-water quality and developing strategies to protect aquifers from contamination are necessary aspects of water resource planning. Hence, the monitoring of the chemical, physical and biological conditions of groundwater is considered to be critical for the planning strategy for the protection of groundwater quality (Mogheir et al., 2006) and influence the utility of aquifer systems as sources of water (Paramaguru et al., 2016; Arko et al., 2019). The types and concentrations of dissolved constituents in the water of an aquifer system determine whether the resource, without prior treatment, is suitable for drinking-water supplies, industrial purposes, irrigation, livestock watering, or other uses, and if otherwise may alter the suitability of the aquifer system as a source of water (Dalila et al., 2017). Many researchers have conducted groundwater quality assessment using major ion chemistry analysis (Falowo et al., 2017; Paramaguru et al., 2016; Arko et al., 2019; Dalila et al., 2017; Haque et al., 2017; Ado et al., 2017). In this paper, hydrogeochemical characteristics and physicochemical parameters of groundwater (boreholes and dug wells) were assessed in Ore metropolis for groundwater environmental monitoring purpose. The data obtained from this study are valuable for understanding, identifying, and describing modifications in the condition of the groundwater quality.

2. Research Methods

2.1 Study Area

The study area is Odigbo Local Government of Ondo State. The area can access through Akure – Ore Lagos – Benin highways and is located within latitude 715000 – 75500mN and longitude 664750 – 725000mE (Fig. 1). Major part of the study area is devoted to agricultural and commercial activities. The study area tropical rainforest climate. The average temperature is 25°C. Relative humidity of the area differs within 70 % to 80 %. The average annual rainfall of the study area is about 1500 mm and 2500 mm. The geology of the area plays a significant role for assessing groundwater potential and quality of the region. The northern area falls within the geologic terrain, underlain by the Precambrian basement complex rocks of southwestern Nigeria, characterized by the migmatite-gneiss complex, older granites, charnockites, quartzite and minor intrusive lithologies (Obaje, 2009; Ogbe, 1972). The local geology consists of charnockite, fine grained biotite granite and gneiss in the north. Field observation shows that biotite granites in the area occur as large igneous bodies, and largely coarse grained. However the southern part of the study area is underlain by coastal plain sands of Benin formation; Ewekoro & Akinbo and Abeokuta formations (Fig. 2). The Abeokuta Formation in surface outcrops comprises mainly sand with sandstone, siltstone, silt, clay, mudstone and shale interbeds (Omosuyi, 2001; Nton and Elueze, 2006; Ogbe, 1972; Nton, 2001; Nton et al., 2009; Omatsola and Adegoke, 1981; Okosun, 1998). The area is well drained by rivers and streams that flow in the

same direction as the rock strike. These streams take their source from relatively high elevation about 200 m above the mean sea level and flow downhill along the strike into valleys. The topographical variation within the area is between 100 to 200 m above sea level.
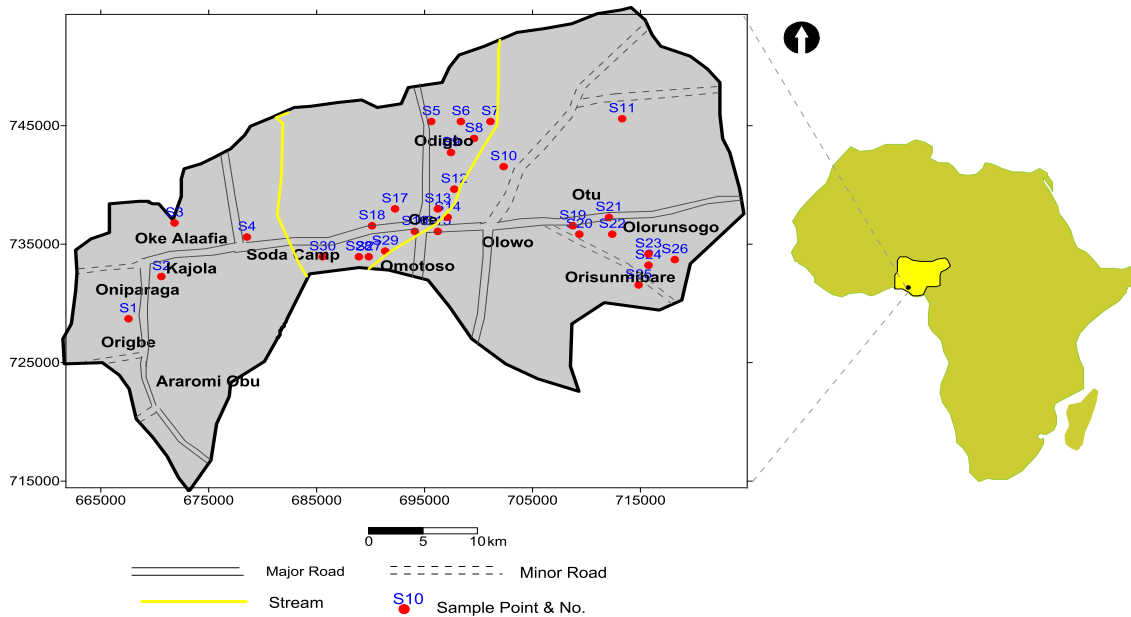

Fig. 1. Location map showing Odigbo Local Government Area and Sampling locations

2.2 Water Sampling

The study involved both field and laboratory activities. The field activity involved collection of water samples randomly (Jang et al., 2013; Junez-Ferreira and Herrera, 2013) from different boreholes and hand dug wells. A total of one-litre plastic 30 groundwater samples (Fig. 1) including 16 shallow dug wells (HDW) and 14 boreholes (BH) were taken randomly in the study between November 2018 - February 2019, before the onset of raining season to ensure the effluents from surface run off were mixed with the collected water samples. The water samples were collected into cleaned plastic bottles which were earlier rinsed with the particular water to be sampled. This was subsequently used in the laboratory for off-site analysis. The samples for bacteriological analysis were collected into 500 ml sterilized bottle and the cap covered with aluminum foil to avoid contamination during sampling in accordance to American Public Health Association method for the examination of water and wastewater (APHA, 2005). The samples were transported to the Federal Ministry of Water Resources laboratory in Akure, Ondo State for the physico-chemical and bacteriological analysis using American procedures. The bacteriological analyses were carried out immediately on arrival at the laboratory.
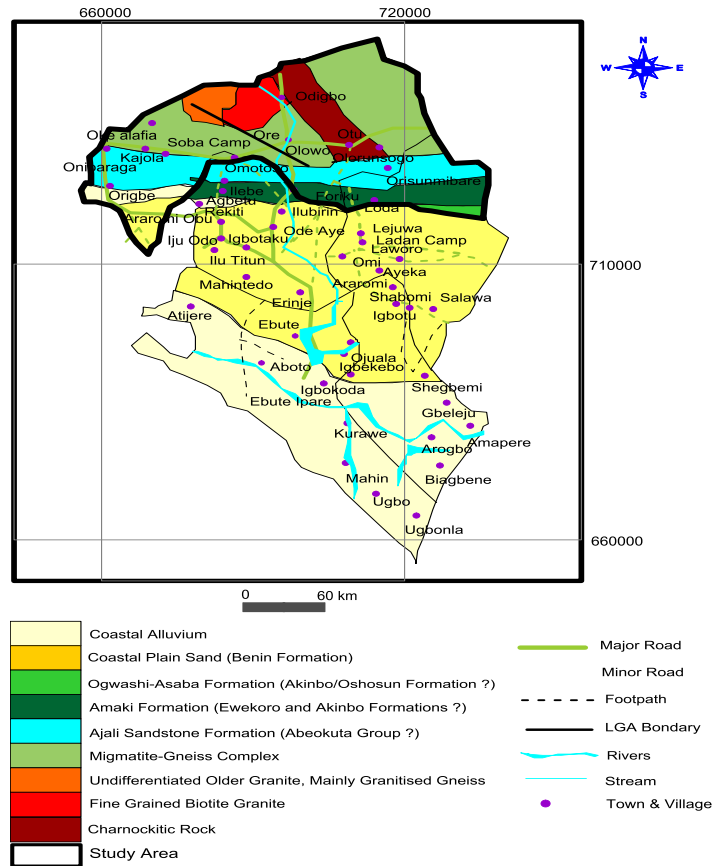
Fig. 2. Geological map of Southern part of Ondo State

2.3 Data Analysis

Statistical analysis was done using SPSS version 19.0 for windows and Microsoft Office Excel 2013. The method of principal components analysis (PCA) of factor analysis was used identify underlying dominant and causal variables among the parameters using varimax rotation method. The aim of PCA is construction of new variables called principal components out of a set of existing original variables. The new variables are a linear combination of the existing variables. The PCA is performed to reduce the large data set of variables into few factors called the principal components which can be interpreted to reveal underlying data structure.

The calculation of Water Quality Index was done in line with Horten (1965), Li et al. (2010), Sudhakar et al. (2014), Kalaivanan et al. (2017), and Srinivas and Nageswawararao (2013) using equations 1-3. Weights were allocated to each parameter measured in the water samples according to their relative importance in the overall quality of water for drinking purpose (Sakati and Sarma, 2007). In this study, a maximum weight of five (5) was assigned to NO_3^-, Fe^{2+}, Cl^-, TDS, and Fl^-; four (4) to pH, EC and Mn^+; three (3) was assigned to Ca^{2+}, Mg^{2+}, HCO_3^-; while Na^+ and Total Hardness (TH) assigned a weight of two (2).

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

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

$$q_i = \frac{C_i}{S_i} *100 \tag{2}$$

where, q_i is the quality rating, C_i is the concentration of each chemical parameter in each water sample in milligrams per litre, S_i is the WHO standard for each chemical parameter in milligrams per litre according to the guidelines of the World Health Organization Standard (WHO, 2011).

$$WQI = \sum_{i=1}^{n} SLi \tag{3}$$

Where SLi is the product of W_i and q_i.

For irrigation purpose, percentage sodium (%Na), Sodium Absorption Ratio (SAR), Residual sodium Carbonate (RSC), Permeability Index (PI), Equivalent salinity concentration (ESC), Kelly ratio (KR), and Magnesium ratio (MR) were determined and rated according to standard (Rao, 2006; Raju et al., 2011).

$$Na\% = \frac{(Na+K) \cdot 100}{(Ca+Mg+Na+K)} \tag{4}$$

$$SAR = \frac{Na}{\{(Ca + Mg)/2\}0.5} \tag{5}$$

$$RSC = (HCO_3 + CO_3) - (Ca + Mg) \tag{6}$$

$$PI = \frac{Na + (HCO_3)^2)}{Ca + Mg + Na} * 100 \tag{7}$$

$$ESC = 0.81Ca + 0.45SO_4 + (Na + Cl) \tag{8}$$

Chloro-alkaline indices (CA) is used in understanding the geochemistry of groundwater. Subba Rao et al. (2002) suggested two chloro-alkaline indices (CA1, CA2) for the interpretation of ion exchange between groundwater and host environment. A positive CA index indicates the exchange of Na^+ and K^+ from the water with Mg^{2+} and Ca^{2+} of the rocks, and is negative, when there is an exchange of Mg^{2+} and Ca^{2+} of the water with Na^+ and K^+ of the rocks. The CA indices are computed using equations 9 and 10.

$$CA1 = Cl^- - Na^+ + K^+ : Cl^- \tag{9}$$

$$CA2 = Cl^- - Na^+ + K^+ : Cl^- : SO_4^{2-} + HCO_3^- + NO_3^- \tag{10}$$

Kelly ratio (KR) is used to classify the irrigation water quality, which is the level of Na^+ measured against Ca^{2+} and Mg^{2+}, where the concentrations of ions are in meq/l. If KR < 1, it is suitable for irrigation, and if KR > 1, it is unsuitable. Magnesium ratio (MR) is the ratio of magnesium (Mg^{2+}) to alkaline earths ($Ca^{2+} + Mg^{2+}$) and expressed in percentage (%).

3. Results and Discussion

3.1 Physical and Chemical Parameters

The quality of ground water depends on various chemical constituents and their concentration, which are mostly derived from geology. Industrial and municipal solid wastes have emerged as one of the leading cause of pollution of surface and ground water. The statistical summary of the physical, chemical and bacteriological analyses on the groundwater samples is presented in Tables 1-3. The appearance of the studied water samples is clear, tasteless and odourless. These can affect positively its marketability for domestic, agriculture and industrial use. The temperature of groundwater governs to a large extent the biological species present and their rate of activity. The temperature of the water samples ranges from 25.1 to 27.6°C with an average of 25.5°C. The water turbidity ranges from 0.9 to 5.9 NTU and average of 3.3 indicating low silt/clay or colloidal content. The TDS ranges from 122 – 810 mg/l with a mean and standard deviation (stdev) of 377 and 189 respectively indicating a fresh water (Sudhakar et al., 2014; Subba Rao, 2002). The spatial distribution of Turbidity and TDS in Figure 4 shows relatively high TDS and turbidity in Ore, Soda camp and

Kajola. The electrical conductivity ranges from 120 to 674 µs/cm (av. 331.4 µs/cm). Chloride varies between 12.5 – 85.2 mg/l with an average of 35.17 and stdev of 21.75 indicating a brackish water type. The spatial distribution of chloride and EC in Figure 4 shows a generally low EC (less than 500 µs/cm) although higher in Ore environment, while chloride is high in Ore, Araromi Obu which is very close to the Atlantic Ocean.

Table 1. Result obtained from the Physical Parameters measured

Location	East	North	Well No.	Temp (°C)	EC (μS/cm)	Turbidity (NTU)	Colour	Odour	Taste	Appearance
ORE	667564	728709	1	25.2	260	3.9	Colourless	unobjectionable	Tasteless	Clear
KAJOLA	670613	732276	2	25.3	340	4.3	Colourless	unobjectionable	Tasteless	Clear
OKE ALAFIA	671833	736795	3	25.2	180	3.2	Colourless	unobjectionable	Tasteless	Clear
SODA CAMP	678541	735606	4	25.2	165	2.5	Colourless	unobjectionable	Tasteless	Clear
ODIGBO	695618	745357	5	25.3	260	2.9	Colourless	unobjectionable	Tasteless	Clear
	698363	745357	6	27.2	320	3.4	Colourless	unobjectionable	Tasteless	Clear
	701107	745357	7	27.6	420	1.5	Colourless	unobjectionable	Tasteless	Clear
	699582	743930	8	26.4	154	0.9	Colourless	unobjectionable	Tasteless	Clear
	697448	742741	9	25.1	210	1.2	Colourless	unobjectionable	Tasteless	Clear
	702327	741552	10	25.2	265	3.2	Colourless	unobjectionable	Tasteless	Clear
	713305	745595	11	25.2	247	2.4	Colourless	unobjectionable	Tasteless	Clear
ORE	697753	739649	12	25.5	541	5.8	Colourless	unobjectionable	Tasteless	Clear
	696228	737984	13	25.3	587	5.9	Colourless	unobjectionable	Tasteless	Clear
	697143	737271	14	25.2	623	5.2	Colourless	unobjectionable	Tasteless	Clear
	696228	736082	15	25.5	390	4.0	Colourless	unobjectionable	Tasteless	Clear
	694093	736082	16	25.2	674	5.4	Colourless	unobjectionable	Tasteless	Clear
	692264	737984	17	25.2	410	4.5	Colourless	unobjectionable	Tasteless	Clear
	690129	736557	18	25.2	420	2.5	Colourless	unobjectionable	Tasteless	Clear
OUT	708730	736557	19	25.2	258	3.4	Colourless	unobjectionable	Tasteless	Clear
	709340	735844	20	25.2	269	2.8	Colourless	unobjectionable	Tasteless	Clear
	712085	737271	21	25.3	452	4.4	Colourless	unobjectionable	Tasteless	Clear
	712390	735844	22	25.2	120	2.2	Colourless	unobjectionable	Tasteless	Clear
OLORUNSOGO	715744	734179	23	25.2	187	1.7	Colourless	unobjectionable	Tasteless	Clear
	715643	733228	24	25.3	125	1.6	Colourless	unobjectionable	Tasteless	Clear
	714829	731563	25	25.2	231	1.1	Colourless	unobjectionable	Tasteless	Clear
	718184	733701	26	25.2	230	2.1	Colourless	unobjectionable	Tasteless	Clear
OKITIPUPA RD	689824	733941	27	25.2	210	4.4	Colourless	unobjectionable	Tasteless	Clear
	688909	733941	28	25.2	350	3.9	Colourless	unobjectionable	Tasteless	Clear
	691349	734417	29	25.3	385	3.4	Colourless	unobjectionable	Tasteless	Clear
	685555	733941	30	25.2	527	5.2	Colourless	unobjectionable	Tasteless	Clear

However both EC and Chloride are within the WHO Standard of 500 µs/cm and 250 mg/l respectively. The pH of the water samples in the study area ranged from 6.4 to 8.2 and an average of 7.1, which indicates that the groundwater is slightly acidic to neutral water types. These values are within the permissible limits of 6.5 – 8.5 set by WHO (2011). The spatial distribution of pH of sampled water is shown in Figure 4. It is generally less than 7.0 indicating a slightly acidic water type, while Araromi Obu, Onigbe, Ore, Omotoso, Olowo are characterized by slightly alkalinity water type. Bicarbonates varies between 8 and 88 mg/L (av. of 36.13) with a wide stdev of 24.63. This obtained range of values is within the 120 mg/l recommended by WHO. However, values in the range of 5 – 55mg/l are the most preponderant, while sulphate values varies from 1.1 to 38.2 mg/l with an average of 9.0mg/l, and high at Soda camp. Consequently sulphate is within the WHO limit of 250 mg/L. Fluoride ranges between 0.01 to 0.87mg/l with an average concentration of 0.31 and low stdev of 0.22. Nitrate ranges from 1.23 – 15.21 mg/l with a mean of 7.11 and stdev of 4.19. The average value is within the acceptable limit of WHO of 50mg/l. Spatial distribution of nitrate in the study area in

Figure 5 shows closures of relatively high values in Ore and Orisunmibare (above 13.0mg/l). Sodium, Calcium, Magnesium, and Potasium vary from 3.5 – 55.5mg/l (av. 23.22mg/l), 2.36 – 36.8mg/l (av. 10.52mg/l), 1.24 – 33.5 (av. 9.87mg/l), and 1.42 – 14.25 mg/l (av. 5.77mg/l) respectively. Heavy metal concentrations of manganese and iron in the water range from 0.0 to 0.03mg/l (av. 0.01mg/l) and 0.0 to 0.03mg/l (0.01mg/l). These concentrations of the cations and heavy metals are very low and are within the standard of WHO. However spatial map of sodium/potassium shows corresponding trend of the ions enrichment in the study area (Fig. 5). The total hardness of the water varies between 40 – 119mg/l (av. 74.5mg/l) and stdev of 20.4. The hardness water in Ore is high (> 100mg/l) and account for just 10% of the area (Fig. 5). The physico-chemical analysis of groundwater samples indicates that the dominant major cations are in decreasing order; Na^+, Ca^{2+}, Mg^{2+}, K^+ and the dominant anions are HCO_3^-, Cl^-, SO_4^{-2}, NO_3^-.

3.2 Toxic metals/contaminant and Bacteriological parameters

Lead, arsenic, and mineral oil are the major toxic chemicals and contaminants observed in the samples water with concentrations ranging from 0.001 – 0.01mg/l. The concentrations of these contaminants are within the permissible of 0.01 specified by WHO (2011). This contaminants are noticeable around Ore, Kajola, and Odigbo town which have experienced influx of petrochemical companies and depots. The biological test recorded E-Coli of 0 Cfu/100 ml and total bacteria count ranging from 0 – 13 (av. 5.45). The values are less than 3 Cfu/100 ml and 10 Cfu/100 ml specified for total coliform and E-Coli respectively. However no trace of Enterococcus Faecalis was found in the samples. The values of water quality index varies from 37.06 to 140.20 (Fig. 5). Excellent water types (WQI of 0-50) account for 10% of the study area including Soda camp and Ore; Good water (WQI of 50-75) accounts for 70% of the study area; Fair water (WQI of 75-100) common in Ore, Olowo, Olorunsogo account for 12% of the area, while Bad water (WQI > 100) account 8% and covers Omotoso, Ore, and Orisunmibare.

3.3 Correlation Analyses and Principal Components

The result of correlation analysis using Pearson correlation in Table 4 shows strong positive correlation exists between some of the chemical parameters; pH and Cl (r = 0.80), pH and TDS (r = 0.53), EC and total hardness (r = 0.51), TDS and Nitrate (r = 0.57), HCO_3 and NO_3 (r = 0.64), Mg and NO_3 (r = 0.65), HCO_3 and TDS (r = 0.69), Mg and TDS (r = 0.55), Fe and TDS (r = 0.75), Fe and Na (r = 0.71) and Na and EC (r = 0.60). The strong positive correlation that existed among these chemical parameters is an indication of similar source. The weak positive correlation between nitrate and chloride (r = 0.21) is a clear indication of uncommon anthropogenic source (Raju, 2012). Principal component (PC) analysis is performed on groundwater data for better understanding of their interrelationships and probable source of major ions. The data set were subjected to five components analysis (Table 5). The principal component 1 (PC-1) has an eigen value of 2.866 which accounts for 20.5% of the total variance in the groundwater. This factor is strongly and positively loaded with parameters such as nitrate, manganese, TDS, bicarbonate, and magnesium. This association showed that all these variables have common source which accounts for their precipitation in the water samples. The processes assigned to this factor are organic matter degradation/anthropogenic pollution. The PC-2 has an eigen value of 2.704 which accounts for 19.3% of the total variance. This factor is strongly and positively loaded with the following parameters; TDS, calcium, iron, and sodium. This factor could be as a result of weathering and anthropogenic pollution. PC-3 has an eigen value of 1.955 which account for 13.947% of the total variance. This factor is strongly and positively loaded with pH and Cl, which be result of mixing of saline with fresh water and anthropogenic contamination. The PC-4 has an eigen value of 1.815 with total variance of 12.96%. Hardness and EC are the major parameters strongly and positively loaded with

this factor. PC-5 has an eigen value of 1.888 which accounts for 8.48% of the total variance. Only sulphate is strongly and positively associated with this factor. Therefore PC-4 and -5 share the same process of mineral dissolution or precipitation due to contributions from rock-water interactions.

3.4   Groundwater Classification

Piper (1953) trilinear plot was used in classifying the groundwater type (Fig. 6) by plotting the major cations and anions in a piper trilinear diagram. This diagram reveals similarities and difference among groundwater samples because those with similar qualities will tend to plot together as groups. The dominant groundwater facies revealed in this study are the non-carbonate alkali (primary salinity) exceeds 50% (zone 7); and transition zone with no one cation-anion pair exceeds 50% (zone 9). Zone 7 means primary salinity i.e combined concentrations of alkali metals, sulfate and chloride are greater than 50 percent of the total meq/L. Very concentrated waters of this hydrochemical facies are considered brackish or (in extreme cases) saline. Zone 9 implies that no specific cation-anion pair exceeds 50 percent of the total dissolved constituent load. Such waters could result   from multiple mineral dissolution or mixing of two chemically distinct ground-water bodies. Na, Ca, HCO_3, and Cl are the dominant cations and anion occurring in the waters. Hence, the area is dominated by alkali metal/alkaline earth-bicarbonate groundwater facies. This confirms that the groundwater contributions of alkaline earth metals (Ca + Mg) and alkali metals (Na + K) and more of weak acids (HCO_3) than strong ones (SO_4 + Cl). It has been revealed that the hydrogeochemistry of the groundwater systems is influenced by the hydrogeological setting, geology, chemical weathering, ionic exchange, and agricultural inputs. From the Gibbs [36] analysis/diagram (Fig. 7), evaporation, rock–water interaction, and precipitation are the dominant processes in the hydrogeochemical evolution of the groundwater samples (Fig. 7a&b). Since the study area is also dominated by silicate rocks and minerals, the silicate weathering process is more than carbonic weathering (Fig. 7c).

3.5   Groundwater Irrigation Assessment

Electrical Conductivity: The electrical conductivity of the water ranges from 120 to 674 μs/cm with an average of 331 μs/cm which corresponds to moderate (medium salinity). However, from the map, the water in the study area shows variation of low salinity to medium salinity. However the area is generally of low salinity (95% coverage) except small closure of high EC observed in Ore area.

Na Percentage (%): The structure of the soil is considerably affected by the presence of Sodium. Na concentration is important in classifying water for irrigation purposes. The % Na of the samples varies between 20.67 and 81.86 and an average of 46.10. This suggests suitable irrigation water since the mean value is less than 60%. Figure 8(a) shows that the area generally falls within "permissible irrigation rating" and occupies about 65%, while "Good" and "Doubtful" account for 20% and 15% respectively of the study area. Excess sodium concentration in groundwater produces the undesirable effects because sodium reacts with soil to reduce its permeability and support little or no plant growth. Higher Na% in Omotoso, Soda camp and parts of Ore may be dissolution of minerals from lithological composition, and the addition of chemical fertilizers by the irrigation waters (Egbueri, 2018).

Sodium Absorption Ratio (SAR): The important chemical parameter for estimating the degree of suitability of water for irrigation as sodium content or alkali hazard for crops, which is expressed in sodium adsorption ratio (SAR). SAR is calculated from the ratio of sodium to calcium and magnesium. Calcium and magnesium ions are important since they are tending to counter the effect of sodium. Higher concentration of SAR leads to breakdown in the physical structure of the soil. Sodium is adsorbed and become attached to soil particles.

Table 2. Summary of the Analyzed Chemical Parameters

Well No.	pH	Cl⁻ (mg/L)	Ca Hardness (mg/L)	Mg Hardness (mg/L)	Total Hardness (mg/L)	SO_4^{2-} (mg/L)	NO_3^- (mg/L)	Mn (mg/L)	TDS (mg/L)	HCO_3^- (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	Na^+ (mg/L)	Fe^{2+} (mg/L)	Fl⁻ (mg/L)	K (mg/L)
1	7.9	65.5	50	23	73	1.2	6.22	0.02	495	12	8.12	5.23	44.5	0.01	0.12	3.20
2	6.9	30.1	42	24	66	2.5	2.56	0.01	350	8	11.32	5.21	26.5	-	0.30	4.99
3	6.6	23.3	24	16	40	3.4	4.87	0.00	555	16	3.25	2.36	33.2	0.01	0.08	3.34
4	6.4	14.5	35	47	82	1.2	5.69	0.01	230	22	14.25	6.65	14.4	-	0.04	1.42
5	6.8	28.0	38	61	99	5.9	6.23	0.02	215	34	6.98	6.31	12.5	-	0.01	4.50
6	7.8	74.4	22	48	70	5.4	4.12	0.03	236	21	5.47	2.58	5.9	-	0.36	4.22
7	7.5	38.8	32	22	54	10.2	9.40	0.01	340	29	12.45	2.59	9.8	-	0.57	2.69.
8	7.0	25.3	27	55	82	9.5	7.44	0.01	350	33	5.66	7.54	6.5	0.01	0.25	2.87
9	6.5	22.1	31	36	67	18.5	6.33	0.01	258	44	8.87	7.25	12.3	-	0.12	2.86
10	6.9	18.6	36	18	54	2.6	1.23	0.01	210	20	7.58	6.36	10.4	-	0.08	5.10
11	7.1	46.7	18	65	83	9.4	8.36	0.00	260	70	2.36	9.87	14.8	-	0.22	4.10
12	7.2	85.1	22	75	97	3.5	3.44	0.02	444	74	2.22	15.25	3.5	-	0.87	3.66.
13	7.9	44.5	24	95	119	3.5	4.25	0.01	250	21	4.25	13.77	52.3	0.01	0.25	8.94
14	8.2	85.2	60	23	83	5.8	15.21	0.01	810	66	26.21	25.32	50.5	0.03	0.60	4.87
15	8.2	81.4	62	20	82	3.4	12.34	0.02	720	87	17.02	18.20	45.3	0.03	0.58	3.33
16	6.8	24.2	52	56	108	1.5	10.11	0.03	690	68	15.32	23.21	42.8	0.02	0.44	4.32
17	6.4	20.4	40	41	81	1.1	4.25	0.02	222	28	8.25	15.25	22.5	0.01	0.32	8.64
18	6.6	18.5	22	24	46	2.2	3.66	0.00	195	15	2.36	11.32	44.3	0.01	0.25	6.21
19	6.6	12.5	38	28	66	10.2	9.89	0.00	198	9	1.24	36.80	9.8	-	0.24	3.21
20	6.8	20.4	48	32	80	18.7	5.36	0.00	201	8	6.98	3.33	19.5	-	0.02	4.87
21	6.6	21.5	32	22	54	3.5	10.47	0.03	252	25	11.84	8.74	24.8	-	0.03	4.45
22	7.4	28.8	23	32	55	4.8	14.25	0.03	316	48	12.40	9.58	17.9	-	0.25	11.32
23	6.9	34.3	24	25	49	15.4	13.99	0.03	520	69	33.50	2.41	13.2	0.01	0.58	10.26
24	7.0	22.2	51	29	80	11.3	12.35	0.01	440	44	8.77	4.40	12.4	0.01	0.35	14.25
25	7.2	23.7	42	15	57	3.5	8.87	0.00	410	32	9.65	2.36	10.2	0.01	0.11	9.98
26	7.4	33.2	22	44	66	9.9	2.36	0.00	449	20	5.98	8.87	9.8	0.01	0.30	11.40
27	6.6	22.9	26	32	58	2.5	1.87	0.00	412	25	7.60	10.25	8.6	0.01	0.21	8.62
28	6.5	18.5	34	27	61	16.6	1.28	0.02	122	11	6.02	7.87	7.8	-	0.54	4.28
29	6.8	16.4	38	66	104	23.4	2.25	0.02	185	13	3.25	3.21	42.4	0.02	0.36	3.34
30	7.5	26.6	47	62	109	38.2	12.33	0.02	780	88	11.90	15.23	55.5	0.02	0.58	3.85
WHO	8.5	250	-	20	500	250	50	0.4	500	120	50	75	200	3	1.5	12
Min	6.4	12.5	18	15	40	1.1	1.23	0	122	8	1.24	2.36	3.5	0	0.01	1.42
Max	8.2	85.2	62	95	119	38.2	15.21	0.03	810	88	33.5	36.8	55.5	0.03	0.87	14.25
Mean	7.08	35.17	35.69	39.78	74.50	9.00	7.11	0.01	377	36.13	9.87	10.52	23.22	0.01	0.31	5.77
S.D.	0.53	21.75	12.09	20.11	20.40	8.27	4.19	0.01	189	24.63	6.97	7.89	16.41	0.01	0.22	3.01

Table 3. Summary of the Analyzed Toxic Chemicals and Contaminants

|	Toxic Chemicals							Contaminants					Microbiological analysis	
Well No.	Lead (mg/L)	Cyanide (mg/L)	Cadmium (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Mercury (mg/L)	Pesticide (mg/L)	Mineral oil (mg/L)	Ammonia (mg/L)	Phenol (mg/L)	Detergent (mg/L)	Radionuclides (Bq/L)	Total Bacteria count	E. Coli
1	0.008	ND	NL	0.004	ND	ND	NIL	0.001	ND	NIL	NIL	NIL	12	0
2	ND	ND	NL	0.010	ND	ND	NIL	0.001	ND	NIL	NIL	NIL	8	0
3	0.007	ND	NL	ND	ND	ND	NIL	0.001	ND	NIL	NIL	NIL	5	0
4	0.004	ND	NL	ND	ND	ND	NIL	NIL	ND	NIL	NIL	NIL	8	0
5	0.001	ND	NL	ND	ND	ND	NIL	NIL	ND	NIL	NIL	NIL	8	0
6	0.010	ND	NL	ND	ND	ND	NIL	NIL	ND	NIL	NIL	NIL	4	0
7	0.002	ND	NL	ND	ND	ND	NIL	NIL	ND	NIL	NIL	NIL	3	0
8	0.005	ND	NL	ND	ND	ND	NIL	NIL	ND	NIL	NIL	NIL	1	0
9	0.002	ND	NL	ND	ND	ND	NIL	0.001	ND	NIL	NIL	NIL	1	0
10	0.001	ND	NL	ND	ND	ND	NIL	NIL	ND	NIL	NIL	NIL	5	0
11	0.001	ND	NL	ND	ND	ND	NIL	0.003	ND	NIL	NIL	NIL	12	0
12	0.001	ND	NL	0.006	ND	ND	NIL	0.002	ND	NIL	NIL	NIL	13	0
13	ND	ND	NL	ND	ND	ND	NIL	0.001	ND	NIL	NIL	NIL	8	0
14	ND	ND	NL	0.001	ND	ND	NIL	0.001	ND	NIL	NIL	NIL	12	0
15	ND	ND	NL	0.003	ND	ND	NIL	NIL	ND	NIL	NIL	NIL	10	0
16	ND	ND	NL	0.001	ND	ND	NIL	0.001	ND	NIL	NIL	NIL	5	0
17	ND	ND	NL	0.003	ND	ND	NIL	NIL	ND	NIL	NIL	NIL	8	0
18	ND	ND	NL	ND	ND	ND	NIL	0.001	ND	NIL	NIL	NIL	1	0
19	ND	ND	NL	0.001	ND	ND	NIL	NIL	ND	NIL	NIL	NIL	0	0
20	ND	ND	NL	ND	ND	ND	NIL	NIL	ND	NIL	NIL	NIL	0	0
21	ND	ND	NL	0.001	ND	ND	NIL	NIL	ND	NIL	NIL	NIL	0	0
22	0.006	ND	NL	ND	ND	ND	NIL	NIL	ND	NIL	NIL	NIL	0	0
23	0.005	ND	NL	ND	ND	ND	NIL	NIL	ND	NIL	NIL	NIL	1	0
24	0.003	ND	NL	ND	ND	ND	NIL	NIL	ND	NIL	NIL	NIL	8	0
25	0.003	ND	NL	ND	ND	ND	NIL	0.002	ND	NIL	NIL	NIL	1	0
26	0.003	ND	NL	ND	ND	ND	NIL	0.001	ND	NIL	NIL	NIL	12	0
27	0.001	ND	NL	ND	ND	ND	NIL	0.002	ND	NIL	NIL	NIL	5	0
28	0.001	ND	NL	0.007	ND	ND	NIL	0.001	ND	NIL	NIL	NIL	1	0
29	0.009	ND	NL	0.007	ND	ND	NIL	0.005	ND	NIL	NIL	NIL	5	0
30	0.008	ND	NL	0.006	ND	ND	NIL	0.005	ND	NIL	NIL	NIL	12	0
WHO, Standard	0.01	0.01	0.003	0.01	0.05	0.00	0.005	0.01	0.05	0.001	0.01	0.1	0	0
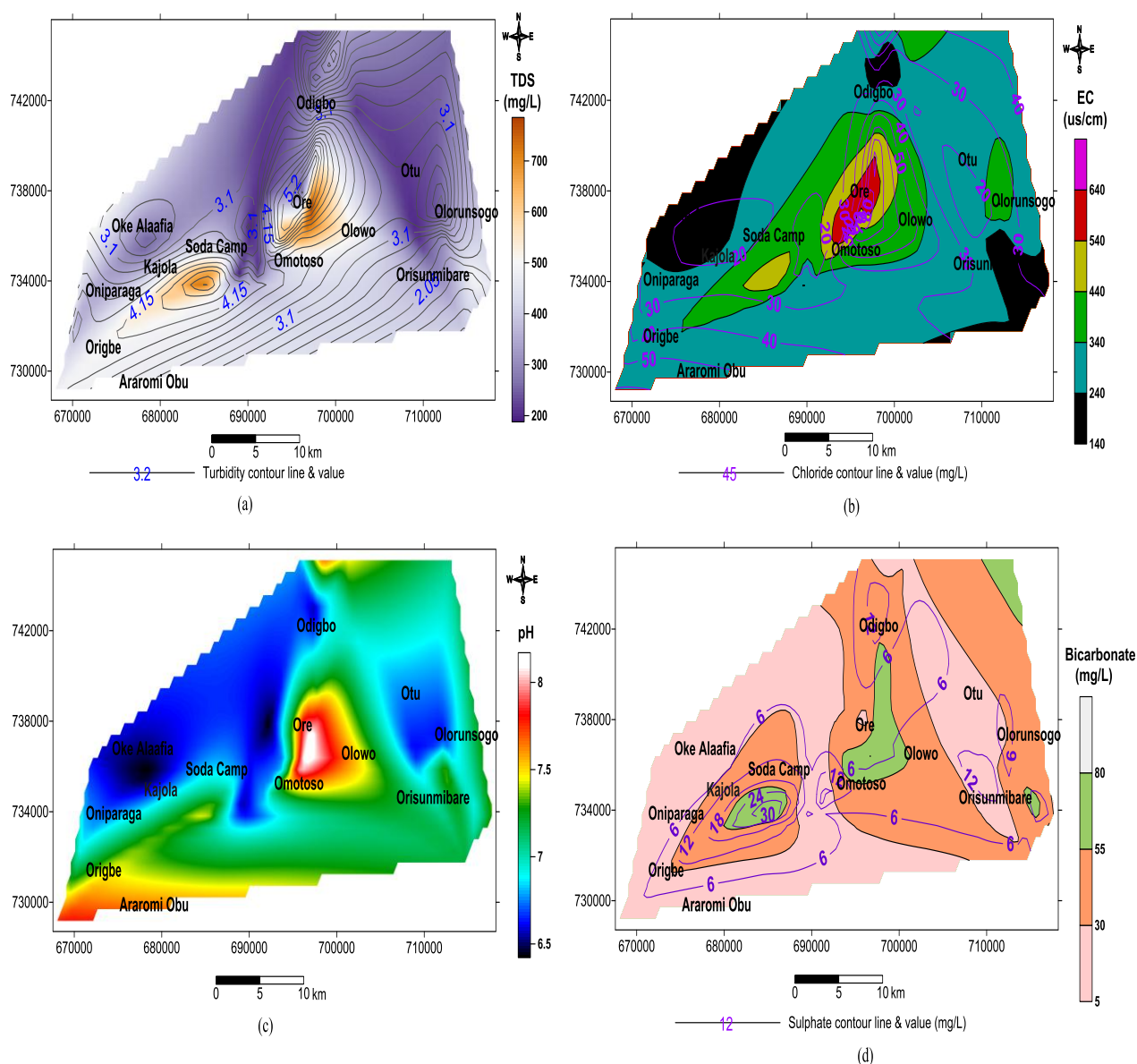
Fig. 4. Spatial Distribution of (a) TDS/Turbidity (b) EC/Chloride (c) pH (d) Bicarbonate/Sulphate

The soil then become hard and compact when dry and impervious to water penetration. Sodium replacing adsorb calcium and magnesium is a hazard as it causes damage to the soil structure. The degree to which irrigation water tends to enter into cation exchange reaction in soil can be indicated by the SAR. The SAR values of the studied water samples vary from 0.22 to 3.99 with a mean of 1.39 with relatively low SAR in the eastern flange of the study area (Fig. 8b). The values are within 0 - 10 specified by Singh (2015) as excellent water for irrigation purpose.
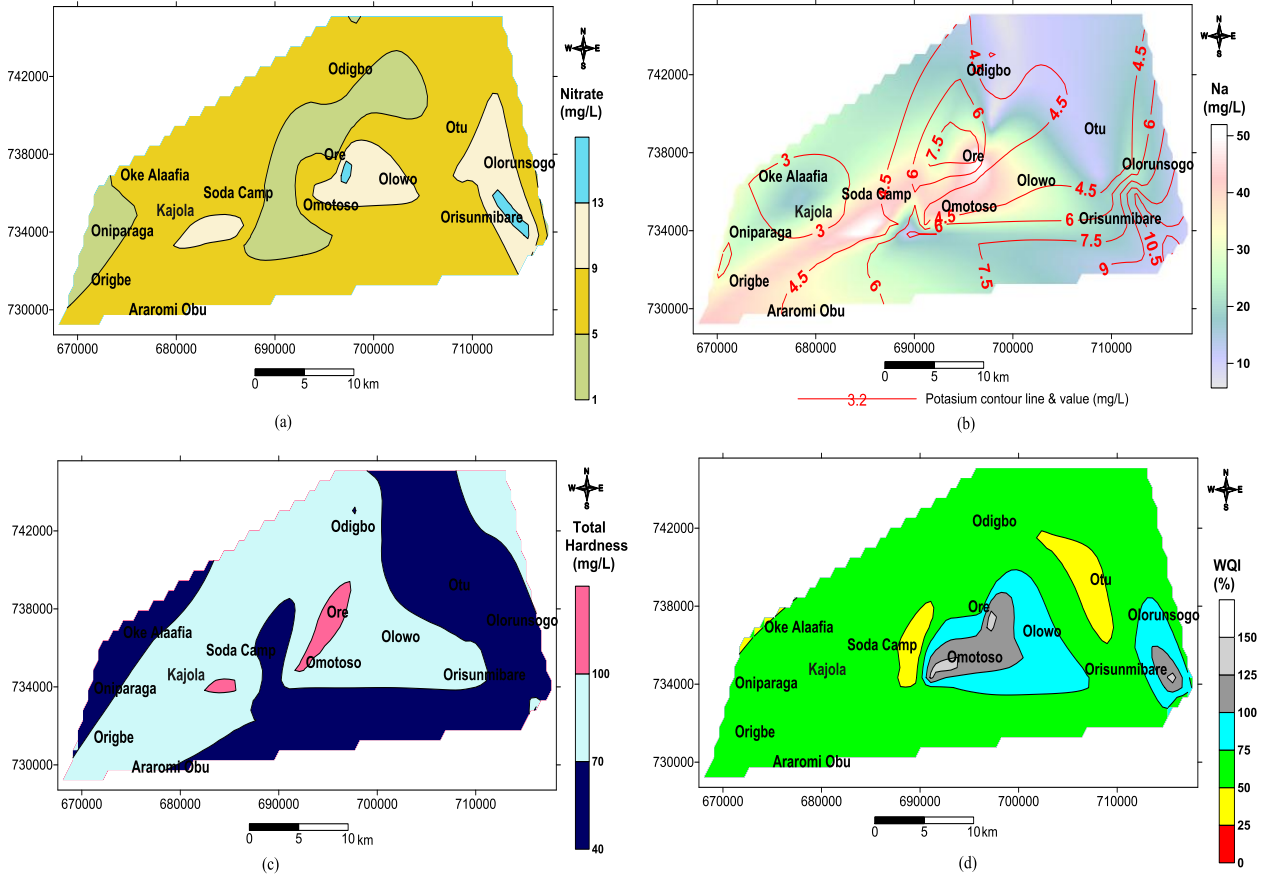
Fig. 5. Spatial Distribution of (a) Nitrate (b) Na/K (c) Total Hardness (d) Water Quality Index (WQI)

There is a close relationship between SAR values in irrigation water and the extent to which Na is absorbed by soils. If water used for irrigation is high in Na and low in Ca, the ion-exchange complex may become saturated with Na, which destroys soil structure, because of dispersion of clay particles. As a result, the soils tend to become deflocculated and relatively impermeable. Such soils can be very difficult to cultivate.

Permeability Index: Permeability index is a major function, which has influence over the utility of water for agriculture. Soil permeability is affected by long-term use of irrigation water with high salt content as influenced by Na^+, Ca^{2+}, Mg^{2+}, and HCO_3 contents of the soil. The PI values >75% comes under class I and indicates an excellent quality of water for irrigation. The PI value between 25% - 75% comes under class II indicates that the good quality of water for irrigation and the PI value less than 25% comes under class III indicates that the unsuitable nature of water for irrigation. The calculated PI value ranges from 34.27 to128.90 and an average of 79.56meq/l. According to Figure 8c, 68% of area falls within class I while 32% falls under class II category.

Equivalent Salinity Concentration: The equivalent salinity values range from minimum of 1.24 mg/l (Olorunsogo) to maximum of 5.68 mg/l (Ore) with a mean of 2.50mg/l. The ESC is generally low (less 5 mg/l) across the study area. The equivalent salinity map (Fig. 8d) shows that high values were obtained from Ore, Omotoso, Olowo, and extended to Kajola down to Onigbe.

Residual Sodium Carbonate (RSC): The Residual Sodium Carbonate (RSC) values ranges between − 2.34 and +0.46, with an average of -0.70 (Table 6) which agrees with less than 2.5 specified by Singh (2015) for the purpose of irrigation. The excess sum of carbonate and bicarbonate in groundwater over the sum of calcium and magnesium influences the suitability of groundwater for irrigation. When the excess carbonate concentration becomes too high, the carbonate combines with calcium and magnesium to form solid materials which settles out of the water. The relative abundance of sodium with respect to alkaline earths and the quantity of bicarbonates and carbonate in excess of alkaline earths also influence the suitability of water for irrigation.

Magnesium ratio and Kelly's ratio: Magnesium ratio (MR) is the ratio of magnesium (Mg^{2+}) to alkaline earths (Ca^{2+} + Mg^{2+}) and expressed in percentage (%). Magnesium damages soil structure, when water possesses more Na^+ and high salinity. In equilibrium more Mg^{2+} can affect soil quality by rendering it alkaline, thus it affects crop yields (Rao, 2006; Singh, 2015). The MR of the water samples varies from 5.26 to 77.94 and average of 46.90 (Table 6) suggesting a suitable water for irrigation. Kelly ratio (KR) is used to classify the irrigation water quality, which is the level of Na^+ measured against Ca^{2+} and Mg^{2+}, where the concentrations of ions are in meq/l.

Chloro-alkaline indices (CA): This helps in understanding the chemistry of groundwater along its flow path. Subba Rao et al. (2002) suggested two chloro-alkaline indices (CA1, CA2) for the interpretation of ion exchange between groundwater and host environment. A positive CA index indicates the exchange of Na^+ and K^+ from the water with Mg^{2+} and Ca^{2+} of the rocks, and is negative, when there is an exchange of Mg^{2+} and Ca^{2+} of the water with Na^+ and K^+ of the rocks. The groundwater samples shows CA1 and CA2 in the range of -1.38 to 1.08 (av. 0.35) and -0.94 to 2.38 (av. 0.40). If the KR is less than one, it is suitable for irrigation, and if it is more than one, it is unsuitable. The KR values calculated for the water samples is in between 0.16 and 3.31, with a mean of 0.94 and still within the suitable range of less than 1. Both indices have an average positive values, confirming predominant cation-anion exchange reaction (Table 6), in which ion exchange of Na^+ and K^+ from the water with Mg^{2+} and Ca^{2+} of the rocks. Wilcox's (1948) diagram is adopted for the classification of groundwater for irrigation, wherein the EC is plotted against % Na. Data of the groundwater samples of the area are plotted in the Wilcox's diagram in Figure 9, all the samples plotted within the "excellent. The agricultural yields are generally high in lands irrigated with waters belonging to excellent to good categories. This is probably due to the absence of excess sodium salts, which cause osmotic effects on soil-plant system. When the concentration of sodium is high in irrigation water, sodium ions tend to be adsorbed by clay particles, displacing Mg and Ca ions by base-exchange process. This exchange process of Na in water for Ca and Mg in soil reduces permeability and eventually results in soil with poor internal drainage (Collins and Jenkins, 1996).

4. Conclusion

From the results, it can be concluded that the different parameters analyzed were within the permissible limit recommended by World health organization. The WQI of water samples show a predominant Good water Type (WQI of 50-75) accounts for 70% of the study area. This implies that the water in the study area is good for drinking and other domestic uses. There strong positive correlation that existed among analyzed parameters, which is an indication of similar source. The chemical analysis of groundwater samples indicates that the dominant major cations are in decreasing order; Na+, Ca2+, Mg2+, K+ and the dominant anions are HCO3-, Cl-, SO4-2, NO3-. The PCA analysis was used to understand dominant processes affecting the water quality parameters. The processes inferred from the five factors are organic matter degradation, anthropogenic pollution, weathering, mixing of saline with fresh water, mineral dissolution and/or precipitation.

Table 4. Correlation Matrix of Chemical Parameters in Water Samples from the Study Area

Parameter	pH	Cl	Hardness	SO$_4$	NO$_3$	Mn	TDS	HCO$_3$	Mg	Ca	Fe	K	Na	EC
pH	1													
Cl	0.800	1												
Hardness	0.272	0.223	1											
SO$_4$	-0.033	-0.224	0.255	1										
NO$_3$	0.371	0.213	0.037	0.161	1									
Mn	0.168	0.246	0.224	0.046	0.300	1								
TDS	0.534	0.471	0.188	0.090	0.566	0.142	1							
HCO$_3$	0.385	0.465	0.351	0.218	0.642	0.344	0.687	1						
Mg	0.258	0.223	-0.093	0.038	0.645	0.409	0.552	0.489	1					
Ca	0.126	0.172	0.312	-0.074	0.309	-0.019	0.296	0.308	0.040	1				
Fe	0.462	0.318	0.344	0.123	0.370	0.084	0.749	0.467	0.400	0.339	1			
K	0.061	-0.147	-0.155	-0.094	0.166	-0.042	0.043	0.029	0.157	-0.142	0.068	1		
Na	0.398	0.199	0.402	0.113	0.231	0.129	0.492	0.216	0.187	0.291	0.707	-0.140	1	
EC	0.320	0.371	0.518	0.013	0.065	0.282	0.341	0.313	0.121	0.488	0.428	-0.248	0.595	1

Table 5. Varimax orthogonal rotated factor loadings from PCA of the Analyzed parameters

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
pH	0.198	0.332	0.843	0.000	0.005
Chloride	0.212	0.117	0.864	0.217	-0.223
Hardness	-0.007	0.387	0.169	0.608	0.342
Sulphate	0.136	0.149	-0.226	0.089	0.850
Nitrate	0.842	0.241	0.026	-0.125	-0.008
Manganese	0.592	-0.308	0.217	0.455	0.149
TDS	0.556	0.611	0.342	-0.088	0.005
Bicarbonate	0.731	0.282	0.233	0.170	0.117
Mg	0.827	0.089	0.119	-0.168	-0.012
Ca	0.221	0.549	-0.239	0.415	-0.474
Fe	0.299	0.816	0.242	-0.029	0.098
K	0.156	0.048	0.007	-0.655	0.009
Na	0.065	0.762	0.185	0.236	0.133
EC	0.105	0.493	0.191	0.666	-0.104
Eigen value	2.866	2.704	1.955	1.815	1.188
% Variance	20.475	19.313	13.964	12.965	8.484
Cumulative % variance	20.475	39.788	53.752	66.717	75.201
Interpretation of process	Organic matter degradation/ anthropogenic pollution	Weathering and anthropogenic pollution	Mixing of saline and fresh water and anthropogenic pollution	Mineral dissolution	Mineral precipitation
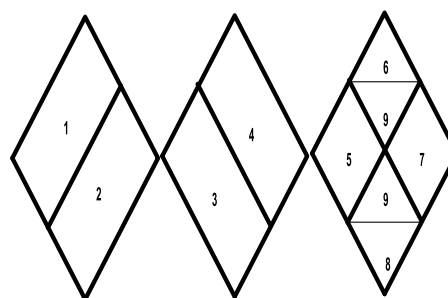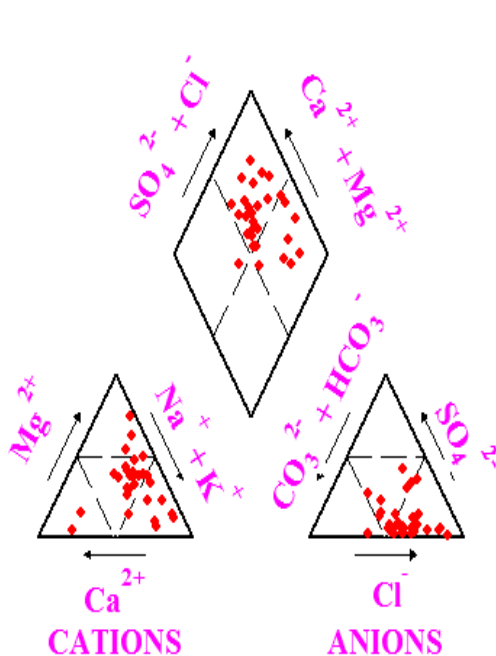
Fields — Characteristics of water

1. Alkaline earth (Ca + Mg) exceed alkalies (Na + K)
2. Alkalies exceed alkaline earth
3. Weak acids (CO + HCO) exceed strong acids (SO + Cl)
4. Strong acids exceed weak acid
5. Carbonate hardness (secondary alkalinity) exceeds 50%
6. Non-carbonate hardness (secondary alkalinity) exceeds 50%
7. Non-carbonate alkali (primary salinity) exceeds 50%
8. Carbonate alkali (primary alkalinity) exceeds 50%
9. No one cation-anion pair exceeds 50%

Fig. 6. Piper Trilinear diagram of groundwater in the study area with dominant zones of 7 and 9.
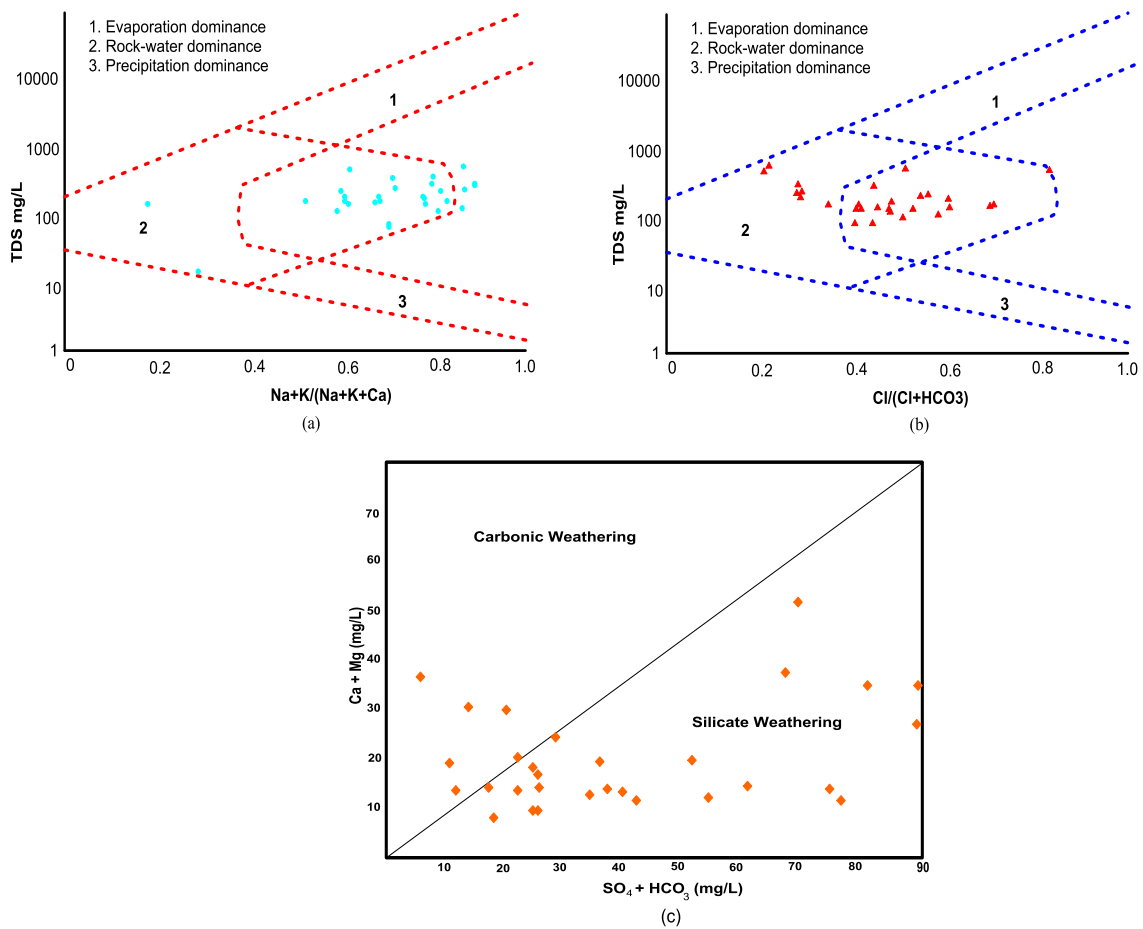
Fig. 7. (a) Gibbs diagram for cations (b) Gibbs diagram for anions (c) Scatter plot for carbonate weathering versus silicate weathering

The dominant groundwater facies revealed are the non-carbonate alkali (primary salinity) exceeds 50% (zone 7); and transition zone with no one cation-anion pair exceeds 50% (zone 9). From the Gibbs analysis, evaporation, rock–water interaction, and precipitation are the dominant processes in the hydrogeochemical evolution of the groundwater samples with the silicate weathering process more than carbonic weathering. Based on the classification of irrigation water according to %Na, SAR, PI, MR, and KR values, all the sample locations are good/suitable for irrigation purposes with low equivalent salinity concentrate and moderate electrical conductivity. Based on the Wilcox classification, all the water samples belong to excellent water category for irrigation use due to the absence or low of excess sodium salts that cause deflocculating and reduce the permeability of soil.
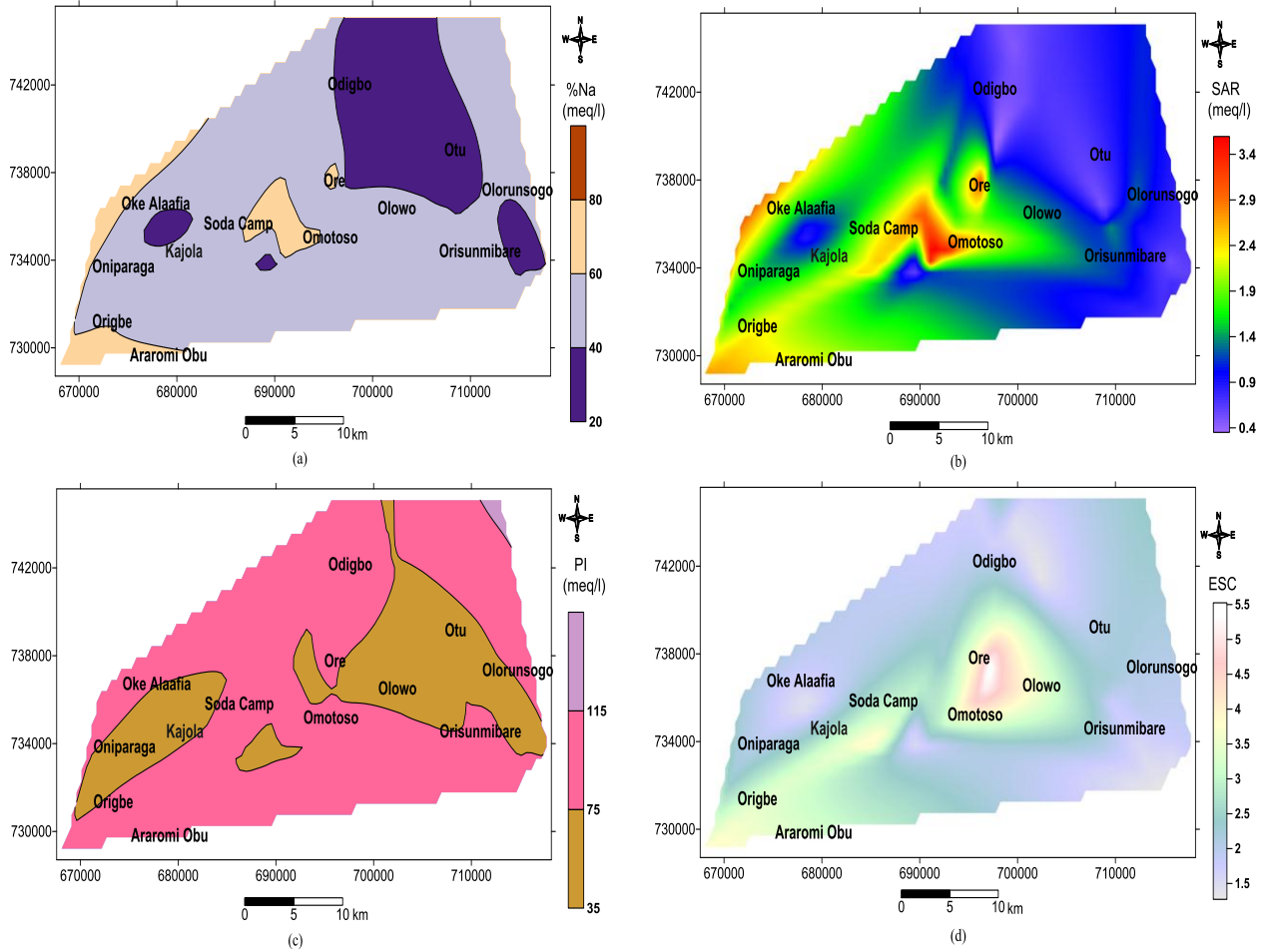
Fig. 8. Spatial Distribution of (a) %Na, (b) SAR, (c) PI, and (d) ESC

Table 6. Summary of Calculated Chloro-alkaline indices and irrigation indices

| Well No.	CA1	CA2	RSC	MR	KR
1	0.37	1.25	-0.73	61.91	1.08
2	0.29	0.66	-1.06	68.17	0.97
3	-0.28	-0.27	-0.12	69.42	2.75
4	0.10	0.05	-1.14	77.94	0.42
5	0.71	0.43	-0.33	54.58	0.61
6	0.98	2.38	-0.23	67.75	0.44
7	0.82	0.65	-0.68	35.79	0.37
8	0.86	0.43	-0.30	35.31	0.34
9	0.57	0.18	-0.37	46.85	0.49
10	0.72	0.56	-0.61	34.27	0.48
11	0.77	0.41	0.46	28.27	0.94
12	1.00	1.05	0.27	19.35	0.16
13	0.03	0.04	-0.69	33.72	2.19
14	0.46	0.45	-2.34	43.05	0.64
15	0.48	0.38	-0.88	40.65	0.85
16	-0.59	-0.18	-1.30	42.11	0.77
17	0.32	0.20	-0.98	37.14	0.68
18	-1.06	-0.94	-0.51	25.58	2.54
19	0.47	0.20	-1.79	5.26	0.22
20	0.28	0.18	-0.61	67.56	1.15
21	0.05	0.03	-1.00	59.07	0.77
22	0.77	0.33	-0.71	58.09	0.52
23	0.91	0.32	-1.75	65.82	0.2
24	1.08	0.36	-0.22	56.67	0.57
25	0.99	0.53	-0.39	57.08	0.49
26	1.05	1.08	-0.61	42.64	0.46
27	1.00	0.78	-0.73	45.11	0.33
28	0.81	0.52	-0.71	45.77	0.38
29	-1.38	-0.59	-0.21	52.53	3.31
30	-0.94	-0.18	-0.30	40.29	1.39
Min	-1.38	-0.94	-2.34	5.26	0.16
Max	1.08	2.38	0.46	77.94	3.31
Average	0.35	0.40	-0.70	46.90	0.94
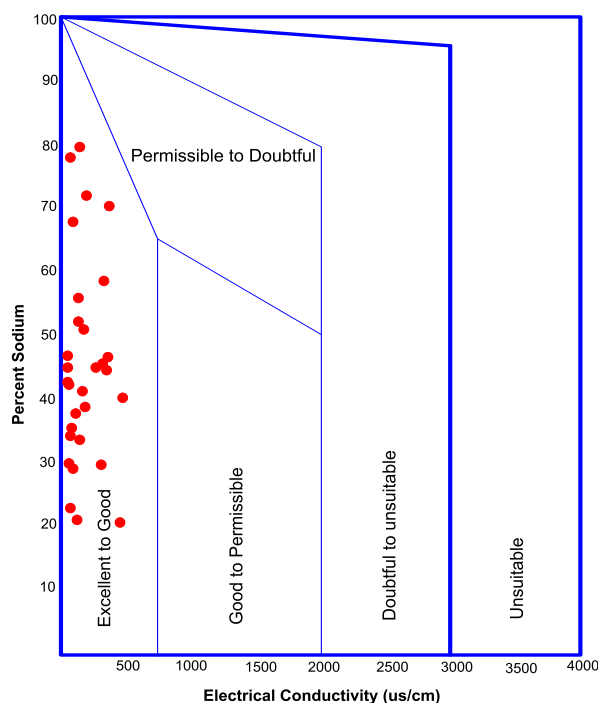
Fig. 9. Classification of the irrigation waters

References

Abimbola, A.F., Odukoya, A.M., Olatunji, A.S. 2002. Influence of Bedrock on the Hydrogeochemical Characteristics of Groundwater in Northern Part of Ibadan Metropolis. Journal of Nigerian Association of Hydrogeologists (NAH), Water Resources, Volume 13:1-6.

Adelana, S.M.A., Olasehinde, P.I. 2003. High Nitrate in Water Supply in Nigeria: Implications for Human Health Water Resources, Journal of Nigerian Association of Hydrogeologists (NAH), Water Resources Volume 14, pp. 1-11.

Adeyemi, G.O., Adesile, A.O., Obayomu, O.B. 2003. Chemical Characteristics of Some Well Waters in Ikire Southwestern Nigeria. Journal of Nigerian Association of Hydrogeologists (NAH), Water Resources Volume 14, pp. 12-18.

Ado, G.H., Habiba, H., Sallau, I.A., Jafaru, M. 2017. Analysis of Water Quality Using Physicochemical Parameters of Boreholes Water Taken From Areas around Dala Hills, Northwestern Nigeria. American Journal of Water Science and Engineering. Vol. 3, No. 6, Pp. 80-83. Doi: 10.11648/J.Ajwse.20170306.13

Ako, B.D., Adeniyi, F.I., Adepoju, J.F. 1990. Statistical Tests and Chemical Quality of Shallow Groundwater from a Metaphorphic Terrain, Ile-Ife/Modakeke, Southwestern Nigeria. Journal of African Earth Science 10(3); 602-613.

APHA, 2005. Standard Methods for the Examination of Water and Wastewater. 25th Edition, American Public Health Association, Washington DC.

Arko, W.E., Hodgson, I.O.A., Nyame, F.K. 2019. Assessment of Drinking Water Quality at Dodowa in the Dangbe West District of the Greater-Accra Region, Ghana. African Journal of Environmental Science and Technology, Vol. 13(5), pp. 181-190. Doi:10.5897/Ajest2019.2653

Collins, R., Jenkins, A. 1996. The Impact of Agricultural Land Use on Stream Chemistry in the Middle Hills of the Himalayas, Nepal. Journal of Hydrology, 185, 71-86. Http://Dx.Doi.Org/10.1016/0022-1694(95)03008-5

Dalila, Z., Boudoukha, A., Abderrahmane, B., Lahcen, B. 2017. Water Quality Assessment For Drinking And Irrigation Using Major Ions Chemistry In The Semiarid Region: Case Of Djacer Spring, Algeria, Asian Journal Of Earth Science, 10:9-21. Doi:10.3923/Ajes.2017.9.21

Egbueri, J.C. 2018. Assessment of the Quality of Groundwater Proximal To Dumpsites in Awka and Nnewi Metropolises: A Comparative Approach. Int J Energy Water Res. Https://Doi.Org/10.1007/S4210 8-018-0004-1

Davis, S.N., De-Wiest, R.M.J. 1966. Hydrogeology. John Wiley and Sons, New York. 463p

Falowo, O. O., Akindureni, Y., Ojo, O. 2017. Irrigation and Drinking Water Quality Index Determination for Groundwater Quality Evaluation in Akoko Northwest and Northeast Areas of Ondo State, Southwestern Nigeria. American Journal of Water Science and Engineering. Vol. 3, No. 5, Pp. 50-60. Doi: 10.11648/J.Ajwse.20170305.11.

Haque, S., Sadique, A. B M., Mazharul-Islam, M.D., Sultana, Z., Nargis, A., Hassan, M. 2017. Assessment of Irrigation Water Quality of Pabna District (North-Western Part) Of Bangladesh for Securing Risk-Free Agricultural Production. American Journal of Water Science and Engineering. Vol. 3, No. 6, Pp. 67-71. Doi: 10.11648/J.Ajwse.20170306.11

Horten, R.K. 1965. An Index Number for Rating Water Quality. J. Water Poll. Cont. Fed., 37(3):300-306.

Jang, C.S., Chen, S.K., Kuo, Y.M. 2013. Applying Indicator-Based Geostatistical Approaches to Determine Potential Zones of Groundwater Recharge Based on Borehole Data. Catena, 101, 178–187.

Júnez-Ferreira, H.E., Herrera, G.S.A. 2013. Geostatistical Methodology for the Optimal Design of Space-Time Hydraulic Head Monitoring Networks and Its Application to the Valle De Querétaro Aquifer. Environ. Monit. Assess, 185, 3527–3549.

Kalaivanan, K., Gurugnanam, B., Pourghasemi, H.R., Suresh, M., Kumaravel, S. 2017. Spatial Assessment of Groundwater Quality Using Water Quality Index and Hydrochemical Indices in the Kodavanar Sub-Basin, Tamil Nadu, India. Sustain Water Resour Manag. Https: //Doi.Org/10.1007/S4089 9-017-0148-X

Li, P., Qian, H., Wu, J. 2010. Groundwater Quality Assessment Based on Improved Water Quality Index In Pengyang County, Ningxia, Northwest China. E-Journal of Chemistry. 7(S1):S209-S216. Doi: 10.1155/2010/451304

Mogheir, Y., Singh, V.P., Lima, J.L.M. 2006. Spatial Assessment and Redesign of a Groundwater Quality Monitoring Network Using Entropy Theory, Gaza Strip, Palestine. Hydrogeol. J., 14, 700–712.

Nton, M.E. 2001. Sedimentary and Geochemical Studies of Rock Units in the Eastern Dahomey Basin, Southwestern Nigeria. Unpublished Ph.D. Thesis, University of Ibadan, 315p.

Nton, M.E., Elueze, A.A. 2006. Aspects of Source Rock Evaluation and Diagenetic. Association of Petroleum Geologist Bulletin, 19 (1), 35 - 49.

Nton, M.E., Ikhame, P.R., Tijani, M.N. 2009. Aspect of Rock-Eval Studies of the Maastritchian-Eocene Sediments from Subsurface, In the Eastern Dahomey Basin Southwestern Nigeria. European Journal of Scientific Research, 25 (3), 417 - 427.

Obaje, N.G. 2009. Geology and Mineral Resources of Nigeria. Published By Springer-Verlag Berlin Heidelberg. 221p.

Ogbe, F.G.A. 1972. Stratigraphy of Strata Exposed in the Ewekoro Quarry, Western Nigeria. In T.J.F. Dessauvagie and Whiteman (Eds) African Geology, University Press, Nigeria, pp. 305 - 322.

Okosun, E.A. (1998). Review of the Early Stratigraphy of Southwestern Nigeria, Journal of Mining and Geology, 34 (1), 1998, 27 - 35.

Omatsola, M.E., Adegoke, O.S. 1981. Tectonic Evolution and Cretaceous Stratigraphy of the Dahomey Basin, Journal of Mining Geology, No. 18 (1), 130-137.

Omosuyi, G.O. 2001. Geophysical and Hydrogeological Investigations of Groundwater Prospects in the Southern Part of Ondo State, Nigeria. Ph.D. Thesis, Department of Applied Geophysics, Federal University of Technology, Akure, Nigeria.195pp.

Paramaguru, P., Anandhan, P., Chidambaram, S., Ganesh, N., Nepolian, M., Devaraj, N., Vasudevan, U.A., Rakesh, R.G., Pradeep, K. 2016. Appraisal of Groundwater Quality in the Cuddalore District of Tn, India, International Research Journal of Earth Science, Vol. 4(6), 23-30.

Piper, A.M. 1953. A Graphic Procedure in the Chemical Interpretation of Water Analysis. Us Geological Survey Groundwater Note, 12.

Rao, N.S. 2006. Nitrate Pollution and Its Distribution in the Groundwater of Srikakulam District, Andhra Pradesh, India. Environ Geol, 2006, 51(4):631–645

Raju, N.J. 2012. Evaluation of Hydrogeochemical Processes in the Pleistocene Aquifers of Middle Ganga Plain, Uttar Pradesh, India. Environmental Earth Sciences, 65, 1291-1308. Http://Dx.Doi.Org/10.1007/S12665-011-1377-1

Raju, N.J., Shukla, U.K., Ram, P. 2011. Hydrogeochemistry for the Assessment of Groundwater Quality in Varanasi: A Fast-Urbanizing Center in Uttar Pradesh, India. Environmental Monitoring and Assessment, 173, 279-300. Http://Dx.Doi.Org/10.1007/S10661-010-1387-6

Singh, S., Raju, N.J., Ramakrishna, C. 2015. Evaluation of Groundwater Quality and Its Suitability for Domestic and Irrigation Use in Parts of the Chandauli-Varanasi Region, Uttar Pradesh, India. Journal of Water Resource and Protection, 7, 572-587. Http://Dx.Doi.Org/10.4236/Jwarp.2015.77046

Srinivas, G., Nageswararao, G. 2013. Assessment of Groundwater Quality Using Water Quality Index. Arch. Environ. Sci., 7:1-5.

Subba, N., Prakasa, J., Devadas, D., Srinivasa, K.V., Krishna, C., Nagamalleswara, B. 2002. Hydrochemistry and Groundwater Quality in a Developing Urban Environment of a Semi-Arid Region, Guntur, Andhra Pradesh, India. Journal of the Geological Society of India, 59, 159-166.

Sudhakar, G., Swarnalatha, G., Venkataratnamma, Z., Vishnuvardhan, 2014. Determination of Water Quality Index for Groundwater of Bapatla Mandal, Guntur District, Andhra Pradesh, India. International Journal of Engineering Research and Technology. 3(3):77-80.

Tijani, M.N. 2016. Groundwater: The Buried Vulnerable Treasure; an Inaugural Lectures of University Of Ibadan, 80pp.

Wilcox, L.V. 1948. Classification and Use of Irrigation Waters. U.S. Department Of Agriculture, Washington Dc, 962.

WHO, 2011. Guidelines for Drinking Water Quality, 3rd Ed. World Health Organization, Geneva, 2011.