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RESEARCH ARTICLE

GROUNDWATER QUALITY EVALUATION FOR DRINKING, DOMESTIC AND IRRIGATION USES IN PARTS OF ODE IRELE LOCAL GOVERNMENT AREA OF ONDO STATE, NIGERIA

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ABSTRACT

Groundwater assessment for drinking and irrigation purposes at Ode Irele local government area of Ondo State, southwestern Nigeria was carried out. Thirty-two water samples were obtained from boreholes. Atomic Absorption Spectroscopy, flame photometry, Turbidimetric, Argentometric and Titrimetric methods were used to analyze the samples according to American Public Health Association Standard method. Results show that all the measured parameters are within the recommended limits of the World Health Organization, with predominant slightly acidic water pH, soft (av. 46.79 mg/l), and fresh (av. 96.82). Piper trilinear diagram and Durov reveal three major water facies; (i) secondary hardness; combined concentrations of sulfate, chloride, magnesium and calcium exceed 50 percent of total mg/l; (ii) primary salinity; combined concentrations of alkali metals, sulfate and chloride are greater than 50 percent of the total mg/l, very concentrated waters of this hydrochemical facies are considered brackish or (in extreme cases) saline; and (iii) no specific cation-anion pair exceeds 50 percent of the total dissolved constituent load. Strong positive correlation exists between many of the chemical parameters, notable among them are: Cl and HCO₃ (0.754), Cl and Ca (0.750), SO₄ and HCO₃ (0.731) and Ca and Fe (0.721). These positive correlations is an indication of similar source hydrogeochemical processes and common anthropogenic source. The % Na of the samples (av. 44.07), SAR (0.44), RSC (av. -0.67), PI (av. 83.54), electrical conductivity (av. 150.9 µs/cm), KR (av. 0.44), and MR (av. 44.0) satisfied standard recommended values for suitable irrigation water.

KEYWORDS

Hydrogeochemistry, Durov diagram, Piper plot, Ode Irele, Water quality index, salinity hazard.

1. INTRODUCTION

Groundwater is one of the essential resources on earth for human survival and industrial development (Todd, 1980). Groundwater is very important in the sense of its practical utility for domestic, irrigation, drinking, and industrial purposes and plays significant role in the living organism that existing in the world. Consequently, assessment of groundwater for drinking and irrigation has become a necessary and important task for present and future groundwater quality management (Fetter, 1994; Fetter, 1990). Groundwater quality depends on the geology of the environment, quality of the recharged water, atmospheric precipitation, inland surface water and subsurface geochemical processes. The progress in water quality research had been enormous over the past years taken into account the physical, chemical, biological and microbiological aspects; water quality assessments heavy metals and synthetic organic compounds.

Human health is affected, in many world regions, by vector-transmitted diseases associated with vector organisms which breed in the aquatic environment. This problem is enormous since there are 200 million people suffering from one such disease alone, i.e. schistosomiasis (Anonymous, 1996). However, since the occurrence of such diseases, and their containment, is closely linked to water resource development projects, pollution sources and effects. Pathogenic agents causing water-

borne diseases include bacteria and viruses as well as protozoa and helminths. Although they interfere only marginally with aquatic life in general, they cause severe public health problems and are considered responsible for most of the infant mortality in developing countries (Egbueri et.al, 2019). Monitoring is usually done indirectly by identifying and quantifying indicators of faecal pollution such as the coliform groups (Kumar et.al, 2009).

Although the 2009 MDG Report mentions that the world is ahead of schedule in meeting the MDG 2015 target on drinking water, in 2008 some 13% of the world's population relied on unimproved water sources (surface water from lakes, rivers, dams, or unprotected dug wells or springs) for their drinking, cooking, bathing and other domestic activities. Of the 884 million people without access to safe drinking water, 84% live in rural areas (Anonymous, 1996). Disparities between rural and urban areas are most evident in the African region where, in 2008, only 48% of rural populations had access to an improved water source, compared to 84% of urban dwellers (Anonymous, 1996).

The study area is located within the coastal environment of Dahomey basin, where there is possibility of aquifer salinization like sea water intrusion, dissolution of salts, etc. In view of this groundwater quality, groundwater quality assessment was undertaken in Irele Local Government of Ondo State to determine the suitability of water for

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The mainland of the study area is incised by few motorable roads and several feeder roads and foot paths. These rivers and streams are being fed by several lagoons, ponds, canals, creeks and small streams scattered across the study area. The area is characterized by heavy annual rainfall averaging about 2,000 mm. Rainfall is distributed virtually over all the months of the year with the minima occurring between November and March (Iloeje, 1981). Plant type is generally mangrove in the coastal part of the study area, typical of swamp forest, while the mainland area is characterized by oil palm, rubber plantation and other broadleaved species, typical of rainforest vegetation. The different ethnic groups that live in the area are the Egbados, Ikales, Ilajes and Ijaws. They live in hamlets, villages and towns which are closely separated from each other although mostly connected by fairly-good to poor roads (Omosuyi, 2001).

occur (Nton, 2001). The age is Neocomian to Albian. Overlying the Ise Formation is the Afowo Formation, which composed of coarse to medium grained sandstones with variable but thick interbedded shales, siltstones and claystones. The sandy facies are tar-bearing while the shales are organic-rich (Enu, 1990). The lower part of this Formation is transitional with mixed brackish to marginal horizons that alternate with well sorted, sub-rounded sands indicating a littoral or estuarine near-shore environment of deposition. Using palynological assemblage, Billman assigned a Turonian age to the lower part of this Formation, while the upper part ranges into the Maastrichtian (Billman, 1992). Araromi Formation overlies the Afowo Formation (Figure 3) and has been described as the youngest cretaceous sediment in the eastern Dahomey basin (Omatsola et al., 1981). It is composed of fine to medium grained sandstone at the base, overlain by shales, siltstone with interbedded limestone, marl and lignite. This Formation is highly fossiliferous containing abundant planktonic foraminifera, Ostracods, pollen and spores. Omatsola and Adegoke assigned a maastrichtian to palaeocene age to this Formation based on faunal content (Omatsola et al., 1981).

The Ewekoro Formation overlies the Araromi Formation in the eastern Dahomey basin. It is an extensive limestone body, which is traceable over a distance of about 320 km from Ghana in the west, towards the eastern margin of the Dahomey basin in Nigeria (Jones et.al, 1964). Elueze and Nton has reported that the limestone is of shallow marine origin owing to abundance of coralline algae, gastropods, pelecypods, echinoid fragments and other skeletal debris (Elueze et.al., 2004). It is Palaeocene in age.

Overlying the Ewekoro Formation is the Akinbo Formation, which is made up of shale and clayey sequence (Ogbe, 1972). The claystones are concretionary and are predominantly Kaolinite (Elueze et.al., 2004). The base of the Formation is defined by the presence of glauconitic band with lenses of limestone (Nton, 2001; Enu, 1990; Billman, 1992; Omatsola et.al., 1981; Jones et.al., 1964; Elueze et.al., 2004; Ogbe, 1972). The Formation is Palaeocene to Eocene in age. The Oshosun Formation overlies the Akinbo Formation (Figure 3) and consists of greenish grey or beige clay and shale with interbeds of sandstones.

Table 1: Summary of the Geology of the Study Area (Obaje, 2009)

Group	Formation	Lithology	Age
	Benin	Poorly sorted sands with lenses of clay	Oligocene-recent
	Ilaro	Massive, yellowish poorly consolidated cross-bedded sandstones	Eocene
	Oshosun	Greenish or beige clay with interbeds of sandstones	Eocene
	Akinbo	Shale and clayey sequence	Paleocene-Eocene
	Ewekoro	Limestone with presence of coralline algae, gastropods, pelecypods, echinoids fossils	Paleocene
Abeokuta	Araromi	Shales, siltstone with interbedded limestone, marl and lignite	Maastrichtian Paleocene
		Medium-fine grained sandstone	
	Afowo	Coarse-medium grained sandstone; interbedding of shales, siltstones and claystones	Turonian Maastrichtian
	Ise	Coarse-medium grained sands	Neocomian-Albian
		Conglomerates and grits	
Basement Complex			Precambrian

The shale is thickly laminated and glauconitic. According to Okosun, the basal beds consist of any of the following facies; sandstones, mudstones, claystones, clay-shale or shale (Okosun, 1998). This Formation is phosphate-bearing (Nton, 2001; Enu, 1990; Billman, 1992; Omatsola et.al., 1981; Jones et.al., 1964). The Ilaro Formation overlies conformably the Oshosun Formation and consists of massive yellowish poorly consolidated, cross-bedded sand stones. The youngest stratigraphic sequence in the eastern Dahomey basin is the Benin Formation (Figure 3). It is also known as the coastal plain sands and consists of poorly sorted sands with lenses of clays (Jones et.al., 1964). The sands are in parts cross bedded and show transitional to continental characteristics. The age is from Oligocene to recent.

2. MATERIAL AND METHODS

In the present investigation one ground water samples each were collected from thirty two locations (Fig. 4) which are functional and continuously in use for drinking and domestic purposes, in the month of November (2018) - February (2019). Samples were collected in polythene bottles, pre-cleaned by washing with non-ionic detergents, rinsed with water, 1:1 hydrochloric acid and finally with de-ionized water. Before sampling, the bottles were rinsed three times with sample water. Tube wells were operated at least five minutes before collection of the water samples. The water quality parameter determination was done using standard methods and techniques according to APHA (APHA, 2005). Samples were brought to the laboratory for analysis of physico-chemical, toxic/heavy metals and bacteriological parameters. At the end of the sample collection, the water samples were placed in the refrigerator before being taken to Federal Ministry of Water Resources, Akure, Ondo State for chemical and bacteriological analysis, that is, for cations (Mg^{2+} , Ca^{2+} , Na^+ , K^+), anions (NO_3^- , SO_4^{2-} , Cl^- , HCO_3^-) and trace elements (Fe , Zn^{2+}). The temperatures of the samples were measured at the point of collection using mercury in glass thermometer and digital pH meter model-361 was used to determine the pH values. Electrical conductivity of the samples was determined using an EI digital conductometer model 611. Mg^{2+} and Ca^{2+} , and trace elements were analysed using Atomic Absorption Spectroscopy. Na^+ and K^+ were analysed using Flame photometry method

while NO_3^- , SO_4^{2-} , Cl^- , HCO_3^- were analyzed using Macro-Kjeldahl, Turbidimetric, Argentometric and Titrimetric methods respectively. Total Hardness was measured using EDTA (Ethylene Diamine Tetra Acetic Acid) as titrant with ammonium chloride and ammonium hydroxide buffer solution (PH-10) and Erichrome Black T as indicator. Total Dissolved Solid was determined by Gravimetry method.

Figure 4: Base map/Data acquisition map of the study Area

The bacteriological analysis was performed on each of the samples for two hours. The sample sprayed on a cellulose membrane with 0.45µm pores where the bacteria were collected on the filtration membrane surface, the membrane was transferred with sterile forceps and placed on TRIGETOL-7 AGAR, and incubated for 24 hours at 37°C. The method used to discover total coliform, faecal bacteria and Escherichia coli is colony form using TREGITOR-7 AGAR mediums, where usually in laboratories the type of colony is diagnosed on the light of shape characteristics without using any other means. Statistical analysis was done using SPSS version 19.0 for windows and Microsoft Office Excel 2013 on the analyzed parameters to understand the degree of association and interrelationship between them.

Water quality index (WQI) is a simple and concise method useful for indicating impairment of water quality. WQI helps for the better management of water quality issues and improve the effectiveness of protective measures. It is an important parameter to classify water quality for suitability of drinking purposes (Srinivasamoorthy et al., 2008). The standards for drinking purposes as recommended by WHO have been considered for the calculation of WQI (WHO, 2011). WQI calculation has been done by assigning weights (w_i) according to relative importance of each chemical parameter for drinking purposes. The parameters like chloride, nitrate, total dissolved solids, iron and sulfate has been assigned maximum weight 5 because of the major importance in water quality assessment (Vasanthavigar et.al., 2010). Bicarbonate is given the minimum weight of 1 as it plays an insignificant role in the water quality. Other parameters like calcium, magnesium, sodium, total hardness (TH), manganese, and potassium were assigned weight between 1 and 5 depending on their importance in water quality determination. The WQI is computed from the following equation:

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

where, W_i is the relative weight, w_i is the weight of each parameter and n is the number of parameters. The third step is the calculation of the quantity rating scale (q_i) for each parameter by applying the equation;

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

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

$$WQI = \sum_{i=1}^n S Li \dots\dots\dots 3$$

Where $S Li$ is the product of W_i and q_i . The WQI range and type of water can be classified as excellent water (<50); good water (50 -100); poor

water (100 - 200); very poor water (200 - 300); water unsuitable for drinking purposes (>300). 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 (Raju et.al. 2011; Raju, 2012).

$$\text{Na \%} = \frac{(\text{Na} + \text{K}) \times 100}{(\text{Ca} + \text{Mg} + \text{Na} + \text{K})} \dots\dots\dots 4$$

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

$$\text{RSC} = (\text{HCO}_3 + \text{CO}_3) - (\text{Ca} + \text{Mg}) \dots\dots\dots 6$$

$$\text{PI} = \frac{\text{Na} + (\text{HCO}_3)^2}{\text{Ca} + \text{Mg} + \text{Na} \times 100} \dots\dots\dots 7$$

$$\text{ESC} = 0.81\text{Ca} + 0.45\text{SO}_4 + (\text{Na} + \text{Cl}) \dots\dots\dots 8$$

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 the KR is less than one, it is suitable for irrigation, and if it is more than one, it is unsuitable. Magnesium ratio (MR) is the ratio of magnesium (Mg^{2+}) to alkaline earths ($\text{Ca}^{2+} + \text{Mg}^{2+}$) and expressed in percentage (%).

3. RESULTS AND DISCUSSION

The results of the physical, chemical, heavy metals/toxic contaminants, and bacteriological analysis are presented in Tables 1 – 4. The pH, or hydrogen ion activity, is expressed on a logarithmic scale and represents the negative base-10 log of the hydrogen ion concentration. Waters are considered acidic when the pH is less than 7.0 and basic when the pH exceeds 7.0. Water with a pH value equal to 7.0 is termed neutral and is not considered either acidic or basic. The pH of most groundwater generally ranges between 5.0 and 8.0. It indicates whether water is likely to be either corrosive or scale forming. The pH of the water samples ranges from 6.6 to 7.9 with an average (av.) of 7.1. From Fig. 5, the study is generally characterized by slightly acidic to neutral. However, basic pH is observed in the south eastern part.

Hardness is a term relating to the concentrations of certain metallic ions in water, particularly magnesium and calcium. In hard water, the metallic ions of concern may react with soap to produce an insoluble residue (Domenico et.al., 1990). These metallic ions may also react with negatively charged ions to produce a solid precipitate when hard water is heated (Freeze et.al., 1979). Hard waters can thus consume excessive quantities of soap, and cause damaging scale in water heaters, boilers, pipes, and turbines. Many of the problems associated with hard water, however, can be mitigated by using water-softening equipment. The total hardness recorded varies between 15 and 107mg/l (av. 46.79mg/l), which can

regarded as soft water (Davis et.al., 1970). However Ca-hardness is more in the sample (av. 32.18mg/l) than Mg-hardness (14.59mg/l). The spatial distribution of Ca-hardness and Mg-hardness are shown in Figures 5b and c, relatively high Ca-hardness is observed in Ode Irele, Ayeka, and Salawa camp. Mg-hardness is widespread around Orisunmibare and Salawa camp.

Chloride in groundwater may originate from various sources including: the dissolution of halite and related minerals, marine water entrapped in sediments, and anthropogenic sources. Chloride is the most prevalent anion in most water. It can be either as an anion (Cl^-) or in combination with some element such as NaCl, CaCl and MgCl. They are among the most suitable component in water. A high chloride content makes water salty to taste and unpleasant to use. Low concentration of this parameter is an indicative of absence of salt water contamination in ground water. The chloride varies from 5.6 – 48.8mg/l with an a mean of 21.48mg/l. The southern area is characterized by relatively high chloride values (Fig. 5d) which could be as a result of high anthropogenic activities (contamination from sewage, and other domestic wastes) and also closeness of the area to major rivers. Sodium does not appear in large quantity in ground water except ocean intrudes into aquifer. The recorded values of sodium ranges from 1.28 to 9.8mg/l (av. 4.74). Generally, the area contains low sodium concentrations (Fig. 6a). Although it's relatively higher in Araromi (western part). The potassium concentration is in between 3.25 – 28.9 mg/l, with a mean of 12.20mg/l. Orisunmibare and Ayeka are characterized by relatively high values greater ranging from 22 – 28mg/l (Fig. 6b) due intensive agricultural activities. High dosage of potassium chloride can interfere with nerve impulses, thereby affecting almost all body functions including the heart. Excess potassium in water may be removed by reverse osmosis. However the potassium concentration is generally low in the study area.

Sulphate, an anion formed by oxidation of the element sulfur, is commonly found in groundwater. Sulphate in water is likely from decaying organic matter, which means that sulphate is an indicator of organic pollution in water especially in hand dug well or surface water bodies such as along the stream channel. The concentration in the study area varies from 8.5 – 43.6 mg/l and a mean of 17.91mg/l (Fig. 7a). Generally the area has low concentration of sulphate, although noticeable relatively higher values are observed in Araromi and some areas in the southern part which could be as a result of mineral dissolution. Iron is the second most abundant metallic element in the earth's outer crust (Hem, 1985), iron in groundwater may originate from variety of mineral sources; and several sources of iron may present in a single aquifer system. Oxidation and reduction potentials, organic matter content, and the metabolic activity of bacteria can influence the concentration of iron in groundwater. The concentration of iron is very low in the area as it ranges from 0.01 and 0.59 mg/l (av. 0.26). Although the geochemistry of manganese is similar to that of iron, the manganese concentration in unpolluted waters is typically less than half the iron.

Table 2: Result obtained from the Physical Parameters measured/examined

Location	East	North	Well No.	EC ($\mu\text{S}/\text{cm}$)	Turbidity NTU	Colour	Odour	Taste	Appearance
Ladan Camp	724587	731801	1	115	0.032	Colourless	Odourless	Tasteless	Clear
	715744	725617	2	180	0.005	Colourless	Odourless	Tasteless	Clear
	717574	724428	3	156	0.030	Colourless	Odourless	Tasteless	Clear
	715744	723714	4	198	1.250	Colourless	Odourless	Tasteless	Clear
Loda Camp	719403	726568	5	105	1.500	Colourless	Odourless	Tasteless	Clear
	724892	727282	6	185	2.450	Colourless	Odourless	Tasteless	Clear
	724587	718006	7	140	0.007	Colourless	Odourless	Tasteless	Clear
	722148	718957	8	124	0.005	Colourless	Odourless	Tasteless	Clear
	712695	718719	9	114	1.100	Colourless	Odourless	Tasteless	Clear
	715439	717055	10	119	0.920	Colourless	Odourless	Tasteless	Clear
	718794	714201	11	205	2.120	Colourless	Odourless	Tasteless	Clear
	721538	714676	12	180	1.000	Colourless	Odourless	Tasteless	Clear
Ajagba	725197	715152	13	155	0.003	Colourless	Odourless	Tasteless	Clear
	724282	713963	14	142	0.007	Colourless	Odourless	Tasteless	Clear
	725807	713011	15	148	0.002	Colourless	Odourless	Tasteless	Clear
	733126	712536	16	120	0.012	Colourless	Odourless	Tasteless	Clear
Ayeka	720623	712060	17	114	0.054	Colourless	Odourless	Tasteless	Clear
	721843	712060	18	113	0.025	Colourless	Odourless	Tasteless	Clear
	718184	711584	19	121	1.180	Colourless	Odourless	Tasteless	Clear
	717269	712536	20	111	1.120	Colourless	Odourless	Tasteless	Clear
	714219	711346	21	142	0.030	Colourless	Odourless	Tasteless	Clear
	711170	709682	22	185	0.120	Colourless	Odourless	Tasteless	Clear
	709645	711584	23	190	1.450	Colourless	Odourless	Tasteless	Clear
	713000	713249	24	182	1.250	Colourless	Odourless	Tasteless	Clear

Salawa Camp	726722	706114	25	143	0.005	Colourless	Odourless	Tasteless	Clear
	726722	705400	26	212	5.042	Colourless	Odourless	Tasteless	Clear
	728247	705400	27	178	3.120	Colourless	Odourless	Tasteless	Clear
	730686	707303	28	181	3.850	Colourless	Odourless	Tasteless	Clear
	733126	709682	29	192	4.030	Colourless	Odourless	Tasteless	Clear
	723978	699930	30	202	2.500	Colourless	Odourless	Tasteless	Clear
Orisunmibare	724283	729423	31	98	1.5	Colourless	Odourless	Tasteless	Clear
	723978	734179	32	85	1.2	Colourless	Odourless	Tasteless	Clear

concentration (Davis et al., 1970). However no indication of trace of manganese in the groundwater samples. Nitrate is the most frequently detected drinking water contaminant, as well as the most common form of nitrogen in groundwater (Freeze et al., 1979). Madison and Brunett developed concentration criteria to qualitatively determine if nitrate levels (as an equivalent amount of nitrogen) in ground water may be by anthropogenic sources. Using these criteria, nitrate levels of less than 0.2 mg/l are considered to represent natural or background levels (Madison et al., 1984). Concentrations ranging from 0.21 to 3.0 mg/l are considered transitional, and may or may not represent human influences. Concentrations between 3.1 and 10 mg/l may represent elevated concentrations due to human activities. High concentrations of nitrate are undesirable in drinking waters because of possible health effects. In particular, excessive nitrate levels can cause methemoglobinemia primarily in infants (Anonymous, 1996). The maximum contaminant level,

for nitrate (measured as N) is 10 mg/l (Rao, 2006). The range of nitrate in the study area is in between 1.0 and 2.5mg/l. Figure 7b shows that nitrate are relatively higher along the southern and eastern boundaries which could be as a result of high anthropogenic discharge. The concentration of Calcium and bicarbonate varies from 2.1 – 49.4mg/l (av. 11.50mg/l) and 6.0 – 28.0 mg/l (av. 12.32mg/l) respectively. The obtained values are within the World Health Organization Standard of 75 and 120mg/l respectively for drinking water (WHO, 2011). In Figure 8b, relatively higher calcium concentration is predominant in the southern area, while higher bicarbonate values (20 – 24mg/l) are common in Ayeka and Salawa camp (Fig. 8a). Electrical conductivity (EC) of water measures the ability of water to conduct electric current, which is a function of ionic salt or impurity water contains. EC measured in the study area ranges from 85 to 212 $\mu\text{S}/\text{cm}$ (av. 212 $\mu\text{S}/\text{cm}$).

Table 3: Summary of the Analyzed Chemical Parameters

Well No.	pH	Cl ⁻	Ca H.	Mg H	T.H	SO ₄ ²⁻	NO ₃ ⁻	Mn	TDS	HCO ₃ ⁻	Mg ²⁺	Ca ²⁺	Zn ²⁺	Fe ²⁺	K	Na
1	6.6	7.4	22	12	34	18.2	2.3	ND	129.5	8	2.91	2.8	0.08	0.27	8.20	2.25
2	6.9	6.8	36	19	55	9.0	1.2	ND	62.5	6	4.50	4.5	0.09	0.27	4.90	1.28
3	7.2	9.5	20	10	30	8.5	1.5	ND	60.3	8	2.22	3.2	0.07	0.23	3.25	1.87
4	7.1	10.5	28	15	43	25.6	2.2	ND	69.7	10	2.00	2.5	0.08	0.43	4.58	2.25
5	7.4	11.8	25	8	33	12.2	2.0	ND	88.1	6	1.62	2.8	0.07	0.23	12.25	2.20
6	7.0	16.5	9	44	53	14.6	1.5	ND	80.4	8	1.44	4.0	0.07	0.32	14.25	5.57
7	6.9	10.3	5	10	15	8.8	1.9	ND	140.2	12	2.44	5.5	0.07	0.38	6.58	5.42
8	6.8	9.9	6	12	18	12.2	1.1	ND	133.8	10	2.08	6.5	0.09	0.34	8.87	6.22
9	7.1	15.4	8	8	16	10.2	1.0	ND	65.4	16	1.11	3.9	0.09	0.11	5.59	3.22
10	7.2	26.5	44	6	50	22.1	1.8	ND	85.5	12	1.90	4.5	0.08	0.09	11.25	9.80
11	6.6	18.8	52	10	62	19.5	2.2	ND	65.3	8	2.80	2.3	0.08	0.01	7.74	9.42
12	6.6	29.5	32	10	42	15.2	1.5	ND	88.4	8	1.65	5.9	0.08	0.08	8.54	2.58
13	7.0	23.3	48	12	60	9.8	1.2	ND	62.3	12	1.25	6.4	0.07	0.11	5.20	5.47
14	7.1	25.9	40	18	58	10.3	1.8	ND	64.7	10	1.22	4.4	0.09	0.18	6.87	3.54
15	7.9	10.5	56	9	65	10.5	1.8	ND	120.2	14	1.56	8.8	0.09	0.12	12.54	7.20
16	7.0	9.9	25	12	37	16.2	2.4	ND	111.1	8	6.81	4.2	NIL	0.14	19.34	3.12
17	7.1	8.8	36	11	47	9.5	1.8	ND	66.3	9	6.22	4.4	NIL	0.08	5.54	3.20
18	7.1	19.2	41	8	49	9.1	1.5	ND	55.5	6	1.25	4.5	NIL	0.08	4.58	5.80
19	6.7	10.5	18	6	24	12.3	1.5	ND	68.6	11	2.24	3.2	NIL	0.09	6.35	7.72
20	6.6	14.2	32	8	40	16.8	1.1	ND	141.1	8	2.29	3.5	0.07	0.11	9.88	3.33
21	6.6	5.6	26	14	40	8.8	2.3	ND	122.2	10	2.02	7.2	0.08	0.16	10.25	2.58
22	7.2	8.7	32	12	44	10.3	2.3	ND	88.4	10	4.58	7.4	0.08	0.25	12.25	2.41
23	7.1	11.6	11	10	21	14.5	2.1	ND	62.6	12	2.95	5.5	NIL	0.22	10.58	2.20
24	7.5	44.2	16	18	34	26.8	2.1	ND	140.2	18	2.32	6.5	NIL	0.42	8.89	8.64
25	6.9	42.3	18	6	24	23.3	2.5	ND	142.8	24	2.55	49.4	NIL	0.55	24.5	5.52
26	6.8	45.6	48	12	60	42.3	2.2	ND	65.4	20	5.55	42.5	NIL	0.59	26.3	8.66
27	6.6	40.2	65	14	79	43.6	1.8	ND	138.3	28	10.50	40.3	0.07	0.48	27.2	3.21
28	7.2	44.6	63	19	82	30.1	1.6	ND	145.9	14	10.20	40.5	0.07	0.45	28.9	2.28
29	7.7	48.8	56	32	88	23.6	1.8	ND	141.5	22	9.82	32.3	0.07	0.42	8.0	3.45
30	7.0	45.5	62	45	106	42.8	2.2	ND	153.3	20	8.88	15.5	0.09	0.35	15.1	2.21
31	7.3	23.2	23	7	30	9.1	1.1	ND	60.5	8	4.40	2.1	0.06	0.27	24.1	8.1
32	7.5	20.4	21	8	29	11.2	1.0	ND	63.2	9	3.95	2.5	0.06	0.27	20.20	9.4

The range of values obtained is far below the permissible limit of 1500 $\mu\text{S}/\text{cm}$ [20]. Figure 9 shows a uniform EC in the study area, except a portion of near Salawa camp and Ode Irele which are relatively higher, consequently high concentration of electrolytes in this area poses health risks to humans; hence not tolerable. Total Dissolved Solids (TDS) is a measure of salinity that has a great effect on the taste of drinking water. It indicate the total salt concentration of dissolved ions from soils and rocks in water. In other words, it is a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized or micro-granular suspended form. Maximum permissible limit of 500 mg/l is the recommended limit and maximum permissible limit of 1500 mg/l (WHO, 2011). Consequently the groundwater in the study area are within the permissible limit and can be regarded as fresh water

(Fetter, 1990). However, some area in the south show relatively higher values greater than 125mg/l (Fig. 10a). Magnesium concentration ranges from 1.11 – 10.50mg/l with a mean of 3.79, while Zinc varies from 0.06-0.09 mg/l (av. 0.08). Excessive concentrations of magnesium are undesirable in domestic water because of problem of scale formation and also because of its diuretic effects. Generally significant dissolved quantities of the metal zinc occur only in low pH or high temperature groundwater (Davis et al., 1970). However none of the samples analyzed contain magnesium and zinc concentration above the 50mg/l and 5mg/l respectively recommended (WHO, 20). The samples recorded no trace values of toxic/heavy metals except lead (0.0004mg/l). Also the bacteriological analysis recorded no value for coliform, E. Coli, Enterococcus faecalis, while aerobic mesophilic count varies from 0-

6cfu/ml which far less than 100cfu/ml maximum recommended. The values of water quality index varies from 23 to 86 (Fig. 10b). Excellent water types with WQI values less than 50 account for 80%, while good

water with WQI values in between 50 - 100 accounts for 20% of the study area.

Table 4: Summary of the Analyzed Toxic Chemicals and Contaminants

Well No.	Toxic Chemicals						Contaminants					
	Lead	Cyanide	Cadmium	Arsenic	Barium	Mercury	Pesticide	Mineral oil	Ammonia	Phenol	Detergent	Radionuclides (Bq/L)
1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
11	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
16	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
19	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
20	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
21	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
22	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
23	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
24	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
25	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
27	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
28	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
29	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
30	0.0004	ND	NL	NIL	ND	ND	ND	ND	ND	ND	ND	ND
31	0.0004	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
32	0.0004	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

The result of correlation analysis using Pearson correlation in Table 6 shows strong positive correlation exists between some of the chemical parameters, notable among them are: Cl and HCO_3 (0.754), Cl and Ca (0.750), SO_4 and HCO_3 (0.731) and Ca and Fe (0.721). The strong positive correlation that existed among these chemical parameters is an indication of similar source hydrogeochemical processes and clear indication of common anthropogenic source.

Trilinear plotting systems were used in the study of water chemistry and quality (Hem, 1985; Piper, 1944). It has been used extensively to delineate variability and trends in water quality. The technique of trilinear analysis has contributed extensively to the understanding of ground-water flow, and geochemistry (Dalton et al., 1978). Distinct zones within aquifers having defined water chemistry properties are referred to as hydrochemical facies (Freeze et al., 1979). Determining the nature and

distribution of hydrochemical facies can provide insights into how ground-water quality changes within and between aquifers. The plotted groundwater chemical parameters (Fig. 11a) fall within secondary hardness; combined concentrations of sulfate, chloride, magnesium and calcium exceed 50 percent of total mg/l; primary salinity; combined concentrations of alkali metals, sulfate and chloride are greater than 50 percent of the total mg/l, very concentrated waters of this hydrochemical facies are considered brackish or (in extreme cases) saline; and 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. This facies are also confirmed by the Durov diagram (Fig. 11b). The Gibbs analysis/diagram (Fig. 12), shows no dominant evaporation, rock-water interaction, or precipitation. In addition, the study area is dominated by silicate weathering process (Gibbs, 1970).

Table 5: Summary of the Microbiological Analysis

Well No.	Presumptive coliform	Enterococcus faecalis	E. Coli	Aerobic Mesophilic count
1	00	00	00	06
2	00	00	00	06
3	00	00	00	06
4	00	00	00	06
5	00	00	00	06
6	00	00	00	05
7	00	00	00	06
8	00	00	00	06
9	00	00	00	06
10	00	00	00	06
11	00	00	00	06
12	00	00	00	06
13	00	00	00	06

14	00	00	00	06
15	00	00	00	00
16	00	00	00	00
17	00	00	00	00
18	00	00	00	00
19	00	00	00	00
20	00	00	00	00
21	00	00	00	05
22	00	00	00	00
23	00	00	00	00
24	00	00	00	00
25	00	00	00	00
26	00	00	00	00
27	00	00	00	00
28	00	00	00	06
29	00	00	00	05
30	00	00	00	06
31	00	00	00	00
32	00	00	00	00

However for purpose of irrigation, the water samples are evaluated by % Na, Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC), Permeability Index, and electrical conductivity, Kelly ratio, magnesium ratio, and equivalent salinity concentration were determined, as shown in Table 7. The % Na of the samples varies between 12.78 and 67.48 (av. 44.07) which fall within the moderate/permisible irrigation class. High percentage sodium in water for irrigation purpose may stunt the plant growth and also reduces soil permeability. The sodium adsorption ratio gives a clear idea about the adsorption of sodium by soil. SAR of the studied water samples varies from 0.08 to 0.99 with a mean of 0.44. The values are within 0 - 10 specified by as excellent water for irrigation purpose. RSC values varies from -2.63 to -0.02 (av. -0.67). This values are in agreement with which recommended maximum of 2.5 for irrigation water (Singh et.al., 2015). The values of PI of the water is in between 19.54 - 153.09 with a mean of 83.54, which generally fall within the class II or moderate irrigation as specified by Subba Rao (Srinivasamoorthy et.al., 2008). The electrical conductivity of the water ranges from 85 to 212 $\mu\text{S}/\text{cm}$ with an average of 150.9 $\mu\text{S}/\text{cm}$ which corresponds to low salinity hazard (Singh et.al., 2015). The ESC values also confirmed low salinity with values ranging from 0.51 - 3.78 (av. 1.44). Also the KR and MR values range from 0.03 - 1.19 (0.44) and 7.84 - 77.55 (av. 44.0) respectively. More magnesium in water will adversely affect crop yields as the soil becomes more saline. The obtained mean values are within good (KR less than 1) and suitable (MR less than 50) respectively recommended for suitable irrigation water.

Figure 5: Spatial Distribution for (a) pH (b) Ca Hardness (c) Mg Hardness (d) Chloride

Figure 6: Areal Distribution for (a) Na (b) Potassium

Figure 7: Distribution of: (a) Sulphate and (b) Nitrate

Figure 8: Spatial Distribution for (a) Bicarbonate (b) Calcium

Figure 9: Spatial Distribution for Electrical Conductivity

Figure 10: Areal Distribution of (a) TDS (b) Water Quality indices

4. CONCLUSION

The study has provided critical information about the state of the groundwater quality in Ode Irele local government area of Ondo State,

southwestern Nigeria. As at February 2019, when the water samples were collected and analyzed, all the measured parameters are within the recommended limits of the World Health Organization, with TDS values suggesting a fresh water with low electrical conductivity. The values of water quality index indicated an excellent water types with WQI values less than 50 and account for 80% of the study area. The strong positive correlation that existed among these chemical parameters is an indication of similar source hydrogeochemical processes and clear indication of common anthropogenic source. The study also shows no dominant process of evaporation or rock-water interaction or precipitation. All the irrigation indices used to assess the groundwater satisfactorily confirmed the usefulness of the water for irrigation/agriculture. However the southern area shows relatively higher values in all the parameters measured, which implies that the area could be susceptible to anthropogenic activities. Therefore in order to keep the groundwater in the south within the safe limits for consumption and irrigation purposes, adequate measures must be taken to significantly reduce anthropogenic activities.

Table 6: Correlation Matrix of Chemical Parameters in Water Samples from the Study Area

Parameter	EC	pH	Cl	Hardness	SO ₄	NO ₃	TDS	HCO ₃	Mg	Ca	Zn	Fe	K	Na
EC	1													
pH	-.082	1												
Cl	.426	.144	1											
Hardness	.543	.124	.571	1										
SO ₄	.554	-.147	.757	.595	1									
NO ₃	.402	-.086	.142	.157	.389	1								
TDS	.112	-.049	.381	.255	.441	.305	1							
HCO ₃	.392	.075	.754	.394	.731	.277	.507	1						
Mg	.329	.065	.534	.643	.626	.176	.412	.521	1					
Ca	.393	-.850	.750	.429	.690	.285	.451	.805	.606	1				
Zn	.078	-.003	-.152	.258	-.099	-.273	.132	-.142	-.060	-.211	1			
Fe	.415	.082	.570	.178	.631	.279	.441	.634	.456	.721	-.110	1		
K	.073	.022	.536	.249	.560	.159	.307	.473	.558	.685	-.187	.557	1	
Na	-.168	.168	.206	-.126	.044	-.142	-.162	.083	-.237	-.018	-.243	-.043	.188	1

Table 7: Results Summary of the calculated irrigation indices

Well No.	RSC	%Na	PI	SAR	KR	MR	ESC
1	-0.25	44.79	96.44	0.22	0.26	63.14	0.59
2	-0.50	23.33	56.78	0.10	0.09	62.24	0.51
3	-0.21	32.45	104.68	0.20	0.24	53.35	0.56
4	-0.13	42.63	129.85	0.26	0.34	56.87	0.73
5	-0.17	59.97	111.02	0.26	0.35	48.82	0.66
6	-0.19	65.61	107.86	0.61	0.76	37.24	1.01
7	-0.28	45.95	95.54	0.48	0.50	42.24	0.83
8	-0.33	50.10	88.17	0.54	0.55	34.53	0.93
9	-0.02	49.74	153.09	0.37	0.49	31.94	0.83
10	-0.18	65.21	107.76	0.98	1.12	41.04	1.56
11	-0.21	63.78	102.25	0.99	1.19	66.74	1.22
12	-0.30	43.46	87.46	0.24	0.26	31.55	1.33
13	-0.23	46.77	103.23	0.52	0.56	24.36	1.25
14	-0.16	50.75	117.92	0.39	0.48	31.37	1.16
15	-0.34	52.76	89.96	0.59	0.55	22.61	1.06
16	-0.64	45.22	54.98	0.22	0.18	72.77	0.74
17	-0.58	27.75	60.12	0.23	0.19	69.97	0.65
18	-0.23	53.02	97.62	0.62	0.77	31.41	1.06
19	-0.16	59.16	111.87	0.81	0.98	53.57	0.88
20	-0.23	52.27	99.82	0.34	0.40	51.89	0.84
21	-0.36	41.60	81.09	0.22	0.21	31.62	0.64
22	-0.58	35.91	59.90	0.17	0.14	50.50	0.75
23	-0.32	41.46	87.98	0.19	0.19	46.93	0.78
24	-0.22	53.93	103.14	0.74	0.73	37.04	2.14
25	-2.28	24.47	29.75	0.21	0.09	7.84	3.65
26	-2.25	28.93	32.13	0.33	0.15	17.71	3.78
27	-2.42	22.51	27.11	0.12	0.05	30.05	3.31
28	-2.63	22.66	19.54	0.08	0.03	29.34	3.28
29	-2.06	12.78	29.21	0.14	0.06	33.39	3.05
30	-1.18	24.28	41.79	0.11	0.06	48.57	2.41
31	-0.34	67.48	87.23	0.73	0.75	77.55	1.18
32	-0.30	67.30	92.36	0.86	0.91	72.26	1.19

Figure 11: (a) Trilinear Diagram of the water samples (b) Durov diagram confirming the geochemical trends of the water samples

Figure 12: (a) Gibbs diagram for cations (b) Gibbs diagram for anions (c) Scatter plot for carbonate weathering versus silicate weathering

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