Groundwater for Sustainable Development 9 (2019) 100226

Contents lists available at ScienceDirect

Groundwater for Sustainable Development

journal homepage: www.elsevier.com/locate/gsd

Groundwater quality assessment of shallow aquifer hand dug wells in rural localities of Ilorin northcentral Nigeria: Implications for domestic and irrigation uses

Kehinde Olojoku Ibrahim[a,b,*], Modreck Gomo[a], Saheed Adeyinka Oke[c]

[a] Institute for Groundwater Studies, University of the Free State, POBox 339, Bloemfontein, 9300, South Africa
[b] Department of Geology and Mineral Sciences, Faculty of Physical Sciences, University of Ilorin, P.M.B.1515, Ilorin, Nigeria
[c] Unit for Sustainable Water and Environment, Civil Engineering Department, Central University of Technology, Private Bag X20539, Bloemfontein, 9300, South Africa

ARTICLE INFO

Keywords:
Groundwater quality
Shallow hand dug wells
Water table aquifer
Rock mineral
Rural localities

ABSTRACT

The suitability of water for any use depends on its level of quality which can be influenced by several factors. This research determined the quality of shallow hand dug wells for domestic and irrigation uses in the rural localities of Ilorin, Northcentral Nigeria. Twenty (20) water samples were collected from shallow hand dug wells in the study area during wet and dry seasons. The water samples were assessed for physical and chemical qualities. Results indicates that pH of water samples is acidic to alkaline which ranges between 6.7 and 7.6 in dry season and ranges from 6.6 to 7.2 for wet season. The pH values fall within the permissible limits of World Health Organization (WHO) standards and Nigerian Drinking Water Quality Standards (NDWQS). Quality standards of chemical parameters analysed in the water samples falls within the permissible limits. $MgHCO_3$ is considered as the most dominant water type in both seasons. Magnesium occurrence was traced to the disintegration of rock minerals while dominance of bicarbonates in the water contributed mostly by carbon dioxide charged recharge water during precipitation. Irrigation parameters tested includes Soluble Sodium Percentage (SSP), Residual Sodium Bicarbonate (RSBC), Sodium Absorption Ratio (SAR) and Magnesium Adsorption Ratio (MAR) which all indicates that the water samples are also suitable for irrigation.

1. Introduction

Quality assessment of groundwater is of great concern for mankind because it has a direct influence on human life. The quality of groundwater resource is of great important whether for industrial, domestic or for agricultural uses. Presently, reliability on groundwater for drinking is used by more than fifty percent of the world's population including those who live in the rural areas of developing world (Tatawat and Chandel, 2008). One of the largest uses of groundwater is also in the area of crop irrigations in the rural farming system where some water resource sources such as dam, canal, or river are not available; therefore, the quality of groundwater is very important in such area. (see Tables 9–12)

Current analysis has proved that groundwater getspolluted drastically by various factors which include anthropogenic sources such as improper disposes of sewage, waste, garbage which have caused a lot of water borne diseases (cholera, typhoid, diarrhoea, viral haemorrhagic fever). Agricultural wastes from the use of pesticides, insecticides and fertilizers which often dispersed over large area could infiltrates and causes threat to the fresh groundwater ecosystem (Rao and Prasanthi, 2012). Pollution of groundwater can also occur through natural sources such as soil that possess some high level of heavy metals which could leached into the groundwater and also has been established that geology play an important role in the chemistry of groundwater as the hosting lithologies contribute most of the cations and anions observed in the groundwater (Abimbola et al., 2002). Groundwater pollution also results from industrial effluent discharges.

Remediation of groundwater contamination is thus very difficult except in some defined small area but most emphasis on the groundwater contamination remediation is placed on prevention before contamination occurs.

The study intends to highlig highlight quality status in the shallow aquifer hand dug wells of the study area with their hydrochemical dynamics as well as those factors influence its quality. In this study, shallow aquifer hand dug wells were assessed for their concentrations of inorganic substances. Shallow hand dug wells are targeted in this

* Corresponding author. Institute for Groundwater Studies, University of the Free State, POBox 339, Bloemfontein 9300, South Africa.
E-mail address: ibrakeo@yahoo.com (K.O. Ibrahim).

https://doi.org/10.1016/j.gsd.2019.100226
Received 12 January 2018; Received in revised form 12 July 2018; Accepted 8 May 2019
Available online 12 May 2019
2352-801X/

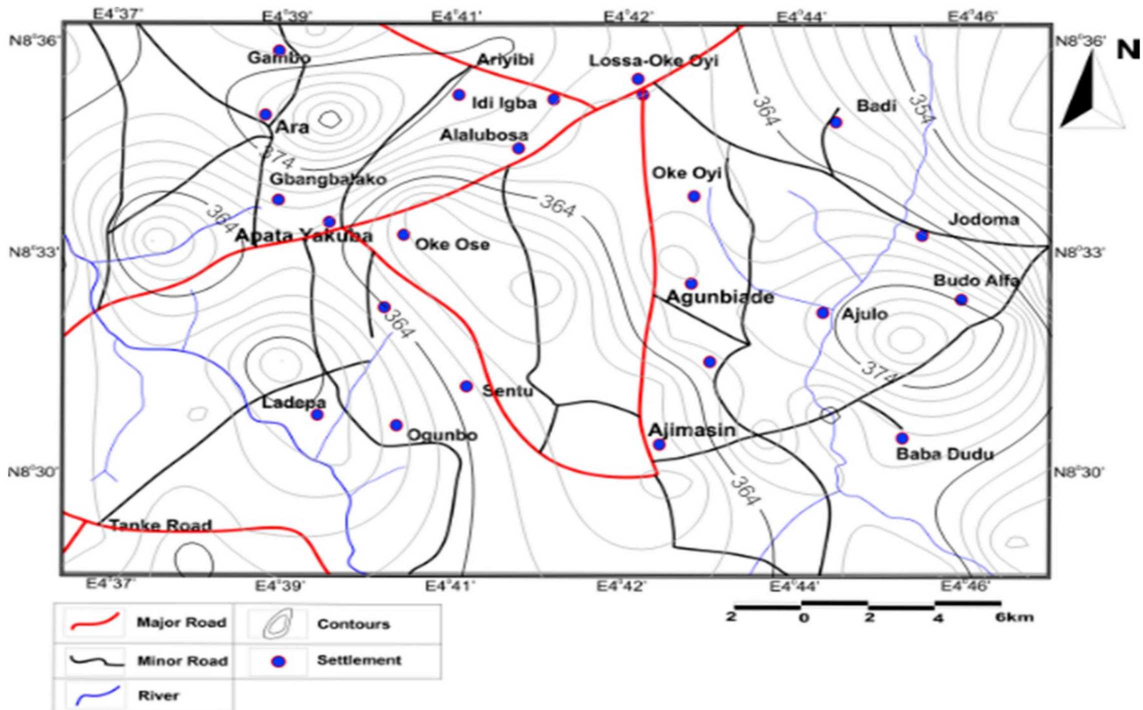


Fig. 1. Location map of study area.

research because it is the main source of water supply in this study area and also it is generally believed that shallow permeable water table aquifers are the most susceptible to contamination.

2. Study area

The study area is a rural community situated in Ilorin area of Kwara State in the Northcentral part of Nigeria. It is bounded by latitude 8° 32′ and 8° 36′ and longitude 4° 39′ and 4° 43′which falls within the basement complex of Nigeria (Fig. 1). People in the study area rely on a shallow hand dug wells as their primary source of water for domestic and irrigations uses. The geology of the area is underlain by crystalline rocks of basement complex. Different types of crystalline rocks are found in various parts of the study area among which are migmatite - gneiss, banded gneiss, granite gneiss, augen gneiss, quartzites, older granites and also observed are the intrusions of pegmatitic rocks. The crystalline rocks possess porosities of less than 3% (Bouwer, 1978). Rocks of basement complex, when not weathered are not permeable and produce no storage capacity.

3. Materials and methods

Twenty (20) groundwater samples were randomly collected from shallow hand dug wells in the study area (Fig. 2). These water samples were taken from different places in the study area purposely to have a wide coverage of the sampling. Sampling exercise was carried out for both wet and dry seasons. The first water sampling was carried out in the middle of March representing the peak of dry season while the second water sampling was conducted in late September that represent maximum period of rain season because sampling involving two seasons will allow groundwater elemental concentration monitoring. It is observed that the quality status of water sampled for a particular season of a given well may or may not actually represent the same quality status when later sampled for the same well in another season period.

4. Results and discussions

4.1. Domestic use

Water samples collected from the wells were analysed for their major cation and anion concentrations. The physical analysis of the water samples was taken directly on the field while chemical analysis was conducted in the chemistry department, University of Ilorin, Ilorin, Nigeria. Anions were analysed by means of convectional titration methods while cations were determined using standard methods of Atomic Absorption Spectrophotometry. A statistical summary for the physico-chemical analyses of the sampled wells in the study area is presented in Table 1. The interpretation of physical and chemical parameters for domestic use was based on World Health Organization Standards (WHO, 2011) for potable water.

According to Satpathy et al. (1987); Westbrook et al. (2005); Frohlich et al. (2008); Kim et al. (2009) and Vengosh (2013) described different processes and factors that could aid hydrochemical characteristics of groundwater to include anthropogenic contamination, ion exchange, dissolution and dilution, water rock interaction and interaction of seawater especially through the precipitation and salinisation.

The pH values for the analysed water samples found between 6.7 and 7.6 for the dry season having a mean of 7.1 while ranges from 6.6 to 7.2 in wet season with a mean of 6.9. The pH for the both seasons is within the acceptable permissible limits by (W.H.O, 2011) standard of 6.5–8.5, therefore, the pH in the study area is acidic to alkaline in nature. Electrical conductivity of the water samples tested in the area ranges between 106 and 318 μS/cm and a mean of 209.2 μS/cm for dry season while for the wet season ranges between 119 and 379 μS/cm and a mean of 226.6 μS/cm. The EC for the two seasons falls within the World Health Organization (W.H.O., 2011) permissible standards for drinking water which is 1000 μS/cm.

However, some traces of high amount of EC in sampled water could be attributed to the presence of some metallic ore in the basement rocks within the area. Total Dissolve Solids (TDS) in the water samples for dry season found between 96 and 176 mg/l with a mean of 126.6 and 107–176 mg/l of a mean 132.2 mg/l for the wet season. For the two

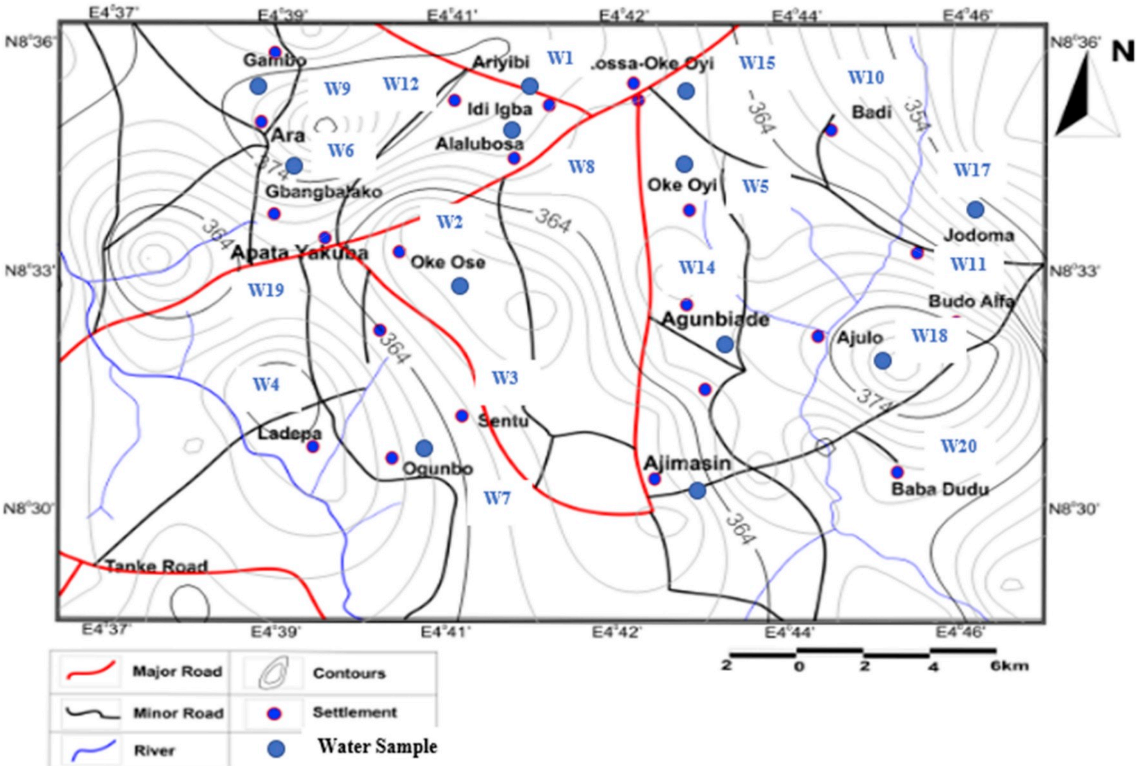


Fig. 2. Location map showing water sample points.

Table 1
Physical parameter of the water samples from the study area (Dry Season).

Sample Location	Depth (m)	pH	EC (µS/cm)	Temp. (°C)	TDS (mg/l)	TH (mg/l)	Turbidity
W7	8.7	7.0	253	24.1	102	8.1	2.1
W3	8.2	7.6	164	23.6	121	12.3	2.4
W20	8.9	7.4	318	24.2	98	11.2	2.3
W1	7.6	6.8	224	25.1	176	13.3	2.9
W11	8.1	6.8	106	28.6	142	9.2	2.1
W14	7.4	7.1	132	23.2	152	14.3	2.4
W6	9.2	6.9	124	25.3	148	12.3	2.2
W17	8.3	7.4	118	24.0	106	8.4	2.3
W5	8.7	6.7	163	27.2	132	15.2	3.0
W2	7.5	7.0	224	26.4	138	16.4	2.4
W16	10.2	7.0	298	25.1	96	9.6	2.3
W8	8.6	7.2	314	25.0	114	12.5	2.1
W10	7.6	6.7	231	25.3	168	18.6	2.2
W13	7.8	7.1	254	26.9	123	8.4	2.0
W15	9.6	7.0	217	27.1	115	9.1	2.5
W9	8.4	7.3	208	24.3	109	8.7	2.0
iW12	6.8	7.2	193	25.6	128	7.2	2.0
W19	8.6	7.0	218	24.3	136	10.1	2.3
W4	8.9	6.9	151	26.0	106	8.4	2.1
W18	7.8	7.2	273	27.0	121	8.9	2.3

Table 2
Physical parameter of the water samples from the study area (Wet Season).

Sample Location	Depth (m)	pH	EC (µS/cm)	Temp (°C)	TDS (mg/l)	TH (mg/l)	Turbidity
W7	8.7	6.8	272	24.3	116	10.2	2.4
W3	8.2	7.2	182	24.1	132	16.0	2.6
W20	8.9	7.0	379	23.7	114	14.0	2.7
W1	7.6	6.7	236	26.0	169	18.4	3.1
W11	8.1	6.6	119	27.8	112	11.5	2.3
W14	7.4	7.2	154	24.7	176	15.6	2.6
W6	9.2	6.7	132	24.0	133	13.6	2.5
W17	8.3	7.2	130	24.3	118	9.0	2.4
W5	8.7	7.0	175	26.1	156	18.1	3.2
W2	7.5	6.8	239	25.2	145	17.0	2.8
W16	10.2	6.6	314	26.0	107	10.0	2.6
W8	8.6	7.0	327	26.3	124	14.1	2.1
W10	7.6	6.6	246	24.6	186	22.4	2.6
W13	7.8	6.9	273	24.4	117	9.2	2.1
W15	9.6	6.6	236	26.4	129	11,2	2.8
W9	8.4	7.1	220	25.1	121	10.9	2.2
W12	6.8	7.0	206	24.2	111	8.4	2.0
W19	8.6	6.7	232	26.2	125	10.3	2.4
W4	8.9	6.8	162	24.1	122	10.1	2.4
W18	7.8	7.0	298	25.3	132	11.4	2.5

seasons, TDS is within the acceptable limits of 1000 mg/l (W.H.O, 2011), therefore with TDS, water in the area is suitable for drinking. One of the strong effects of having high percentage value of TDS in water is gastro-intestinal irritation and can also causes stains of fabric (Olusiji and Adeyinka, 2010).

Total Hardness in the sampled water for the dry season ranges between 7.2 and 18.6 mg/l with a mean of 11.6 mg/l and 8.4–22.4 of a mean 13.1 for the wet season. Based on the standard permissible limit of (W.H.O., 2011) which is 500 mg/l, the water for both seasons is soft and considered to be fit for human consumption. Most of the occurrence of hardness in water associated with the presence of high amount in magnesium and calcium ions (Mg^{+} and Ca^{2+}). Turbidity of 5.0 (NTU) usually recommended for portable water but for the sampled water in dry season ranges between 2.0 and 3.0 with a mean of 2.3 while between 2.0 and 3.2 of a mean of 2.5 for wet season and this shows that turbidity for those considered seasons are falls within the maximum acceptable standards of WHO.

Calcium values in the analysed water is between 1.0 and 5.4 mg/l with a mean of 2.9 mg/l for the dry season while ranges between 2.2 and 10.8 mg/l of a mean 5.6 mg/l. Based on the (W.H.O, 2011) standard for calcium in drinking water, there is no specific limitations but on the Side of Nigerian Standards Drinking Water Quality (NSDWQ,

Table 3
Chemical parameters of the water sample (mg/L) from the study area (Dry Season).

Sample location	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl-	HCO_3^-	SO_4^{2-}	NO_3^-	Fe^{2+}
W7	5.4	6.3	8.4	7.3	13.8	34.6	14.3	2.8	0.3
W3	2.6	1.6	6.7	8.8	6.6	28.2	18.4	1.8	0.5
W20	3.4	3.6	5.4	6.2	10.4	27.6	24.6	2.9	0.6
W1	1.5	2.4	2.4	6.9	11.4	13.7	12.4	1.5	0.2
W11	1.0	2.1	3.2	6.1	9.2	26.6	28.3	2.2	0.2
W14	2.2	2.2	3.6	6.8	8.3	18.4	15.2	3.1	0.4
W6	2.0	1.9	4.9	7.4	8.4	32.1	16.4	2.9	0.3
W17	1.8	2.1	2.8	6.7	8.1	13.2	23.6	2.2	0.1
W5	2.1	2.8	3.4	6.6	8.5	80.7	24.1	2.8	0.2
W2	2.4	2.9	3.6	5.9	10.2	42.6	26.6	2.1	0.1
W16	3.3	4.5	6.1	9.3	11.4	12.5	22.7	3.3	0.3
W8	2.1	3.2	3.8	9.6	10.4	27.3	24.8	2.2	0.1
W10	3.6	4.7	3.1	10.4	9.4	44.2	23.3	3.4	0.8
W13	4.3	3.2	6.3	10.6	11.2	84.9	26.1	2.7	0.4
W15	3.4	4.8	6.9	9.6	13.4	37.5	15.4	4.1	0.1
W9	3.8	2.6	2.8	10.8	12.3	26.3	23.8	3.4	0.3
W12	3.6	5.1	3.9	6.2	11.6	42.6	21.4	3.1	0.3
W19	4.1	3.3	3.6	10.6	12.8	54.2	22.9	3.4	0.8
W4	2.1	1.6	3.3	9.4	8.2	17.4	26.4	2.6	0.5
W18	3.6	3.4	6.4	10.8	8.8	33.7	25.3	2.8	0.4

2007), the allowable permissible limit for calcium should not exceed 75 mg/l. Water samples in the area for the both seasons falls within the acceptable level of NSDWQ. Calcium (Ca) and Magnesium (Mg) are found in large quantities in some brine. In some cases, high amount of calcium within the earth crust could responsible for its presence in the groundwater. Also, almost all-natural waters, including seawater, contain either or both calcium carbonate and calcium sulphate. Calcium occurs in many other silicate minerals that are present in the rocks such as garnet, epidote, titanite, and wollastonite.

Magnesium contents in the samples for the dry season is between 1.6 and 6.3 mg/l with a mean of 3.2 mg/l while ranges between 2.2 and 9.4 mg/l with a mean of 4.7 mg/l. When compared with a standard given by WHO of 20 mg/l, magnesium in the analysed water for the two seasons found to be suitable for any domestic purpose. High presence of magnesium in water results from leaching of ferromagnesian minerals like biotite, olivine that present in the rocks. Magnesium also forms in groundwater when there is a contact between some certain rocks and groundwater especially carbonate minerals as they do occur in natural water.

Sodium values in the water for the dry season ranges from 2.4 to 8.4 mg/l with a mean of 4.5 mg/l and for the wet season ranges between 4.4 and 6.5 mg/l having a mean of 3.9 mg/l. The (W.H.O., 2011) recommended limits for sodium is 200 mg/l, therefore, all the water samples in both the seasons are found with the acceptable standard limits making the water in the area to be suitable and fit for human consumption. Potassium permissible limit in the drinking water was not specified by (W.H.O., 2011) but consideration was based on the Nigerian Drinking Water Quality Standards (NDWQS, 2007) limit of 10 mg/l. For the dry season, the potassium concentration in the water ranges from 5.9 to 10.8 mg/l with a mean of 8.3 mg/l and for the wet season found between 5.6 and 10.6 mg/l of a mean 8.1 mg/l. It was observed that in some locations like 13, 14, 16 and 20 in the two seasons there was high level in potassium concentrations and these were attributed to the abundance of potassium in some mineral vein intrusions that are present in the most basement rocks in the area like pegmatite intrusions in migmatite outcrops of the area.

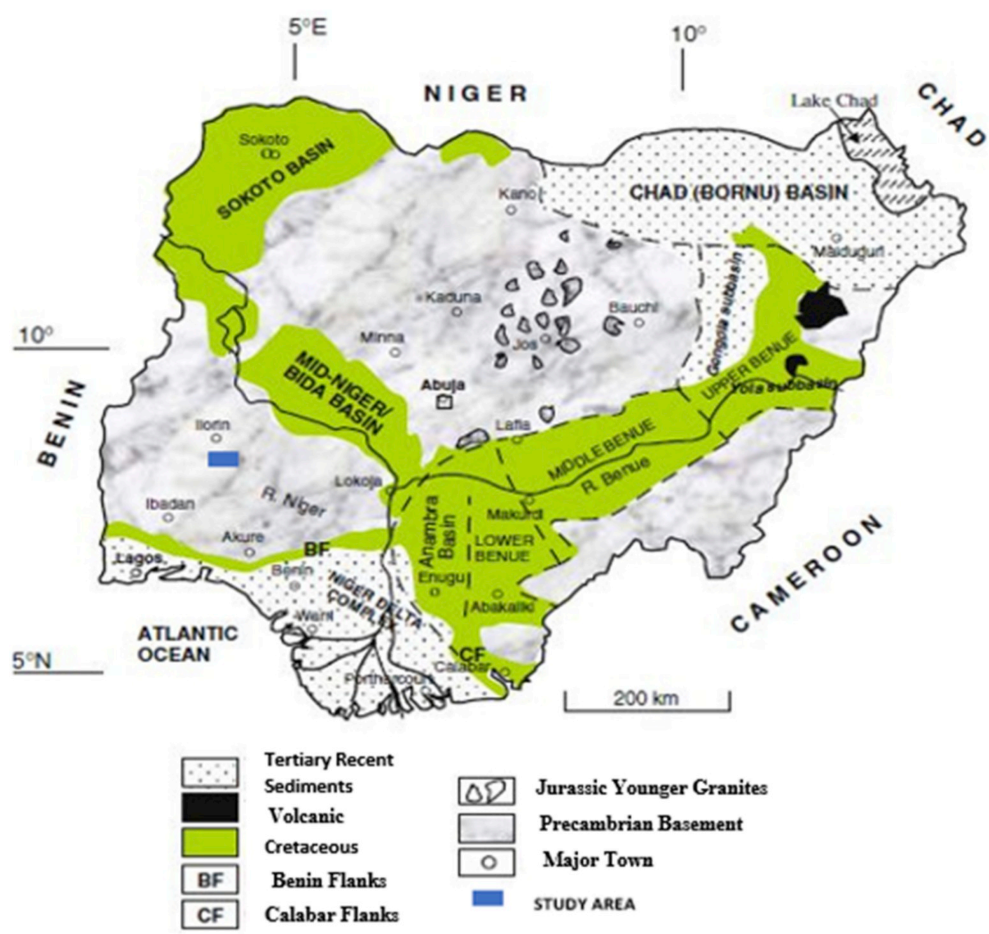


Fig. 3. Geological map of Nigeria showing study area (after Obaje and Abba,1996).

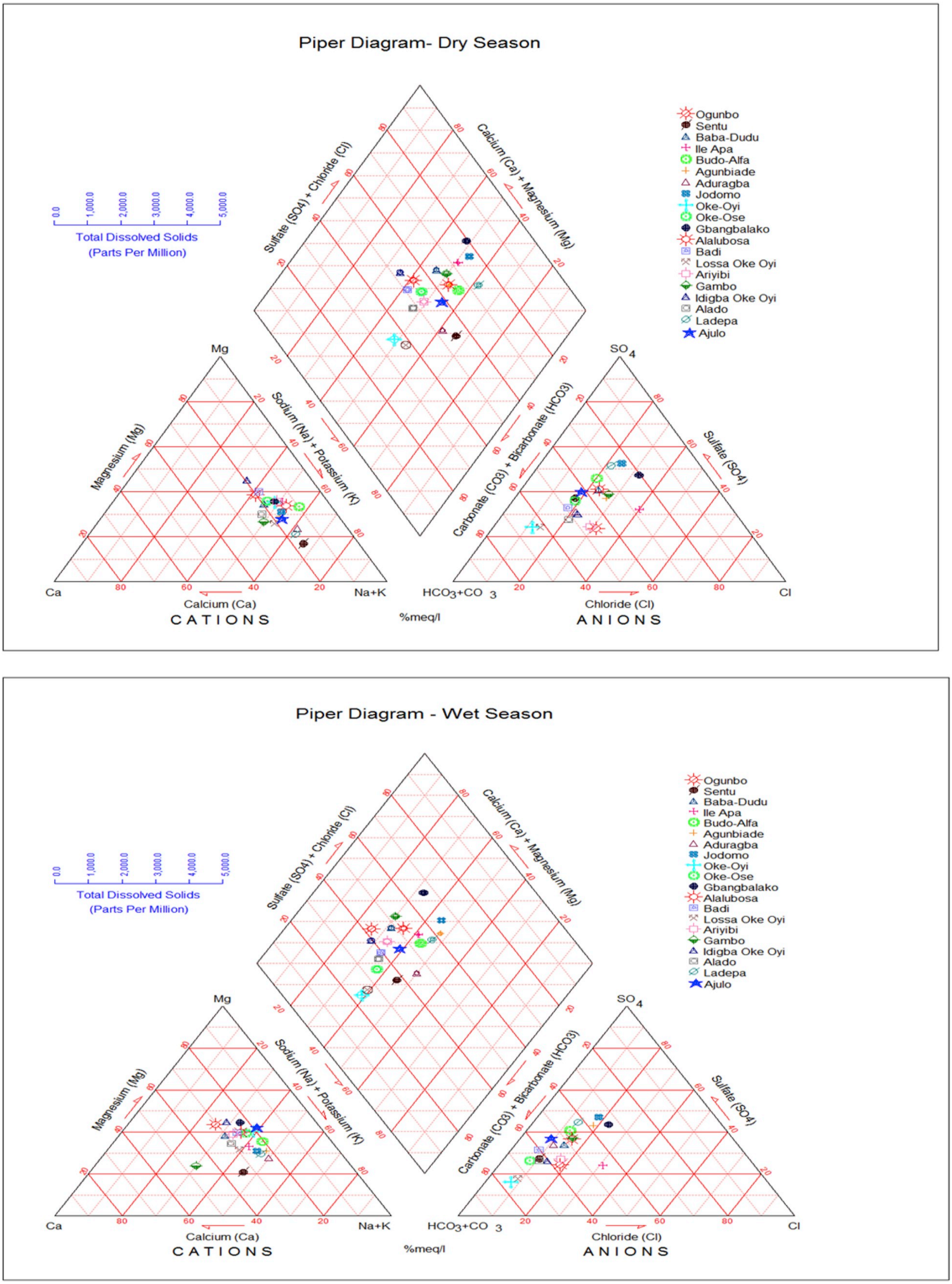


Fig. 4. Piper Trilinear Diagram showing chemical characters of groundwater in the study Area.

Table 4
Chemical parameter of the water sample (mg/L) from the study area (Wet Season).

Sample Location	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl-	HCO_3^-	SO_4^{2-}	NO_3^-	Fe^{2+}
W7	10.8	9.4	6.5	6.9	9.8	54.0	18.1	1.6	0.2
W3	5.8	2.2	4.3	8.1	4.2	43.2	14.9	0.8	0.1
W20	7.9	6.1	5.1	7.4	6.4	39.3	20.5	1.7	0.3
W1	3.6	2.8	2.6	6.8	7.2	18.1	7.6	0.4	0.3
W11	2.2	2.3	2.1	5.6	5.2	32.4	22.4	1.3	0.1
W14	3.0	2.6	3.2	7.4	6.3	22.3	19.8	2.1	0.3
W6	3.2	2.4	4.1	6.9	4.6	38.0	18.6	1.8	0.1
W17	3.5	2.7	3.6	6.4	5.1	16.8	17.9	1.7	0.1
W5	2.8	3.3	2.3	6.3	6.2	108.2	18.2	2.3	0.3
W2	4.0	4.1	3.3	6.8	4.3	60.0	19.0	0.9	0.1
W16	6.9	8.2	5.2	10.6	7.3	18.4	18.8	2.4	0.2
W8	5.2	5.1	3.1	9.2	6.2	33.2	20.0	1.8	0.1
W10	6.8	6.3	4.4	10.1	4.3	54.6	22.4	2.6	0.3
W13	7.5	4.9	5.4	10.4	7.1	101.3	19.3	2.4	0.1
W15	8.4	7.2	6.2	9.4	8.1	46.5	17.8	2.9	0.1
W9	9.5	3.0	2.1	8.5	6.2	33.1	20.4	2.7	0.2
W12	6.9	7.1	4.3	7.2	6.5	51.7	17.8	2.6	0.1
W19	6.8	4.7	3.4	9.6	6.2	61.4	20.4	2.8	0.2
W4	3.2	2.4	2.2	8.4	4.3	23.6	19.7	2.0	0.2
W18	4.8	6.4	5.1	10.6	4.2	42.3	22.6	2.2	0.2

Concentrations of chloride in the sampled water for the dry season are between 6.6 and 13.8 mg/l with a mean of 10.2 mg/l while for the wet season ranges from 4.2 to 9.8 mg/l with a mean of 6.0 mg/l. However, WHO maximum permissible limits for the chloride is 250 mg/l. Water samples in the two considered seasons are found with the standard acceptable limits. Some of the sources of chloride presence in water include human wastes, fertilizers and dissolution of magmatic rocks (Freeze and Cherry, 1979). Also, some other source of chloride in the water involves recharge from meteoric water, weathering from underlying basement rocks (Olusiji and Adeyinka, 2010).

Bicarbonates values ranges from 12.5 to 84.9 mg/l with a mean of 34.9 mg/l for the dry season and ranges from 16.8 to 108.2 mg/l with a mean of 44.0 mg/l. There is no specific limit provided by the (W.H.O., 2011) for bicarbonates in water but it was observed that most of the bicarbonate ion occurrence in the water results from the dissolution of carbonate rocks, carbon dioxide from the atmosphere or from respiration of aquatic organisms.

Sulphate concentration values in the dry season of analysed water samples is between 12.4 and 28.3 mg/l with a mean of 21.8 mg/l and for the wet season ranges from 7.6 to 22.6 mg/l having a mean of 19.0 mg/l. The standard limit by the (W.H.O., 2011) for sulphate in water is 250 mg/l. Those values for the water sample within the seasons considered falls in the standard limits. Some trace of sulphate in the water sampled in the area might have resulted from some improper disposing of solid and liquid wastes in the area and also by unlawful use of chemical like fertilizers by the farmers in the area. Though, sulphates also occur in natural water. Nitrate concentration ranges between 1.5 and 4.1 mg/l with a mean of 2.8 mg/l for dry season while ranges from 0.4 to 2.9 mg/l of a mean 2.0 mg/l for the wet season. WHO acceptable standard for nitrate in water is 50 mg/l, therefore all the water samples in the area for the two concerned seasons are within the acceptable limit. Minor traces of nitrates in water of the study area implies that there is just little impact from agricultural practices in the area and small effects of sewage dispose in the area. Nitrates could also occur in the soil naturally through degradation of microbes in nitrogenous organic material like protein.

Iron levels in the dry season of sampled water is found between 0.1 and 0.8 mg/l with a mean of 0.4 mg/l while for the wet season is from 0.1 −0.0.3 mg/l with a mean of 0.08 mg/l. Standard recommended level by the (W.H.O., 2011) for iron is 3.0 mg/l, therefore, water samples in the area for both seasons are within the acceptable limits which signifies that the water in the area is good for human health. Some traces of few occurrence of iron in water of the area probably due to the weathering of iron mineral rocks like garnets, magnetite, amphibolite that are present in the area.

Main water types in the area were determined based on the percentage of each cation and anion present in the water in milliequivalent per litre as shown in Table 2 and Table 3 which later presented on the Piper Diagram (Piper, 1944) as shwon in Fig. 3. $MgHCO_3$ is considered as the most dominant water type in the area for both two seasons. The most possibly factor that responsible for the geochemical processes in the water type in this area is the dissolution of minerals in the various rock types that are found in the area. Further evidence in supporting water rock interaction as the main factor for the geochemical processes of groundwater chemistry in the area is shown in the plotted Gibbs (1970) diagram in Fig. 4.

Occurrence of magnesium (Mg^{2+}) also results from the breakdown of some mineralogical components that are present in the rocks which includes minerals like biotite, hornblende, pyroxene and olivine. Dominance of bicarbonates in the water contributed mostly by the carbon dioxide charged recharge water during precipitation. Mg^{2+}, Ca^{2+} and $HC0_3$ play roles in the chemistry of groundwater through the dissolution of carbonate rocks while silicate weathering regarded as the process behind some amount of Na^+ and K^+ that present in the water. Other prominent water type in the area is $MgS0_4$ and presence of sulphates in this water attributed to the use of some harmful farm chemicals like fertilizers, pesticides by the farmers in the area. Though, sulphates also occur in natural water.

Table 5
Summary of physico-chemical parameters of water samples for dry and wet seasons.

Parameters	Season 1 (Dry Season)				Season 2 (Wet Season)				
	Min Values	Max Values	Mean Value	SD	Min Values	Max Values	Mean Value	SD	W.H.O. (2011)
Ph	6.7	7.6	7.1	0.2	6.6	7.2	6.9	0.2	6.5–8.5
EC (μS/cm)	106	318	209.2	64.8	119	379	226.6	70.9	1200
Temp. (^{0}C)	23.2	28.6	25.4	1.4	23.7	27.8	25.1	1.1	28
TDS (mg/l)	96	176	126.6	22.5	107	176	132.3	22.7	1500
TH (mg/l)	7.2	18.6	11.1	3.2	8.4	22.4	13.1	3.8	500
Turbidity	2.0	3.0	2.3	0.3	2.0	3.2	2.5	0.3	5.0
Ca^{2+} (mg/l)	1.0	5.4	2.9	1.1	2.2	10.8	5.6	2.5	–
Mg^{2+}(mg/l)	1.6	6.3	3.2	1.3	2.2	9.4	4.7	2.2	20
Na^+ (mg/l)	2.4	8.4	4.5	1.7	4.4	6.5	3.9	1.4	200
K^+ (mg/l)	5.9	10.8	8.3	1.8	5.6	10.6	8.1	1.6	–
Cl^- (mg/l)	6.6	13.8	10.2	2.0	4.2	9.8	6.0	1.5	250
$HC0_3$(mg/l)	12.5	84.9	34.9	19.9	16.8	108.2	44.0	25.0	–
$S0_4^-$ (mg/l)	12.4	28.3	21.8	4.7	7.6	22.6	19.0	3.2	250
$N0_3$ (mg/l)	1.5	4.1	2.8	0.6	0.4	2.9	2.0	0.7	50
Fe^{2+} (mg/l)	0.1	0.8	0.4	0.2	0.1	0.3	0.2	0.08	3.0

Table 6
Saturation indices for water samples (Wet Season).

Sample No.	SI (Anhydrite) ($CaS0_4$)	SI (Aragonite) ($CaC0_3$)	SI (Calcite) ($CaCO_3$)	SI (Dolomite) ($CaMg(CO_3)_2$)	SI (Gypsum) ($CaSO_4$:$2H_2O$)	SI (Halite) (NaCl)
W7	- 0.57	0.99	1.14	2.33	- 0.27	- 5.99
.W3	- 0.78	0.68	0.82	1.32	−0.47	−6.51
W20	−0.60	0.73	0.87	1.73	−0.29	−6.27
W1	−1.10	0.24	0.38	0.76	−0.79	−6.46
W11	−1.05	0.08	0.22	0.55	−0.75	−6.74
.W14	−0.93	0.09	0.23	0.49	−0.63	−6.46
W6	−0.95	0.03	0.48	0.93	−0.63	−6.50
W17	−0.87	0.06	0.21	0.39	−0.57	−6.50
W5	−1.15	0.63	0.78	1.74	−0.85	−6.66
.W2	−0.91	0.59	0.74	1.59	−0.61	−6.64
W16	−0.65	0.39	0.54	1.25	−0.35	−6.19
W8	−0.74	0.49	0.63	1.35	−0.44	−6.49
W10	−0.66	0.77	0.91	1.89	−0.36	−6.52
W13	−0.73	1.03	1.18	2.28	−0.43	−6.23
W15	−0.64	0.84	0.98	2.00	−0.34	−6.08
W9	−0.49	0.74	0.89	1.37	−0.19	−6.66
W12	−0.72	0.79	0.93	1.99	−0.42	−6.34
W19	−0.68	0.82	0.97	1.88	−0.38	−6.47
W4	−0.90	0.14	0.28	0.54	−0.60	−6.79
.W18	−0.77	0.52	0.67	1.56	−0.47	−6.46

Table 7
Saturation indices for water samples (Dry Season).

Sample No.	SI (Anhydrite) ($CaS0_4$)	SI (Aragonite) ($CaC0_3$)	SI (Calcite) ($CaCO_3$)	SI (Dolomite) ($CaMg(CO_3)_2$)	SI (Gypsum) ($CaSO_4$:$2H_2O$)	SI (Halite) (NaCl)
W7	−0.85	0.56	0.71	1.59	−0.55	- 5.71
W3	−1.02	0.13	0.27	0.43	−0.71	−6.12
W20	−0.86	0.19	0.33	0.77	−0.56	−6.04
W1	−1.30	−0.33	−0.18	−0.06	−1.00	−6.30
W11	−1.34	−0.40	−0.25	−0.10	−1.04	−6.33
W14	−1.11	−0.08	0.07	0.23	−0.80	−6.28
W6	−1.16	0.08	0.23	0 .53	−0.86	−6.15
W17	−1.09	−0.39	−0.24	−0.33	−0.79	−6.42
W5	−1.15	0.37	0.53	1.26	−0.85	−6.35
W2	−1.01	0.18	0.33	0.83	−0.71	−6.23
W16	−0.87	−0.13	0.01	0.25	−0.56	−5.93
W8	−1.06	−0.03	0.11	0.49	−0.75	−6.19
W10	−0.88	0.40	0.55	1.31	−0.58	−6.33
W13	−0.85	0.69	0.83	1.64	−0.55	−5.97
W15	−1.01	0.38	0.53	1.31	−0.70	−5.81
W9	−0.81	0.22	0.36	0.65	−0.51	−6.25
W12	−0.90	0.40	0.55	1.35	−0.60	−6.13
W19	−0.85	0.53	0.68	1.36	−0.54	−6.13
.W4	−1.01	−0.23	−0.09	−0.21	−0.71	−6.35
W18	−0.84	0.28	0.43	0.92	−0.54	−6.04

4.2. Saturation Indices

The major elements and trace metals are transported in the chemical elements through groundwater. Both anion and cation concentrations that are present in groundwater form complex association, therefore aqueous complexes formations are very necessary in describing aquifer characteristics because both toxicity and bioavailability of metals that are usually occur in water are based on the aqueous speciation or complexation of the metal (Langmuir, 1997).

Saturation Indices (SI) is useful to determine possible chemical reaction and to measure some level of chemical departures from the thermodynamic equilibrium between the aquifer and minerals present.

Saturation index (SI) of water samples was calculated using below equation:

$$SI = \log_{10} (IAP / Ksp) \quad (1)$$

Where IAP refers to as the ion activity product and K_{sp} is the solubility product at a given temperature. However, the saturation index (SI) in a particular mineral indicates whether the groundwater is undersaturated with respect to the mineral in question when the value of SI is below 0, it is at the equilibrium with the mineral when calculated value of SI is 0 or regarded to be supersaturated aqueous solution with respect to the mineral in question when it is greater than 0. Consecutively, if the groundwater is considered to be undersaturated with respect to the mineral, as been showed with a negative SI, this means that the groundwater would theoretically dissolve that particular mineral concerned. But if the groundwater is supersaturated with respect to a particular mineral, this implies that the mineral would precipitate from the groundwater. Though there are still some uncertainties which are associated with the range values of SI that indicates equilibrium phases due to some anomalies from the field-measured of pH values, laboratory analysed concentration of ions, ionic strength and equilibrium constants that are involved during calculations of SI parameters (Langmuir, 1997). In this research, a geochemical program called PHREEQC developed by (Parkhurst and Appelo, 1999) was applied in calculating SI values for twenty (20) hand dug well samples collected from the study area in both wet and dry seasons (Table 4 and Table 5).

Results from SI calculated values shows water in the study area for two considered seasons (wet and dry seasons) are greatly undersaturated with respect to anhydrite ($CaS0_4$), gypsum ($CaSO_4$:$2H_2O$), and halite (NaCl), which means that these minerals will continue to dissolve in the water. The water is supersaturated with respect to the

Table 8
Values for irrigation parameters indices (dry season).

Sample No.	SAR	SSP (%)	MAR (%)	TDS (mg/l)	RSBC (meq/l)	EC (µS/cm)
W7	3.47	26.9	53.8	102	0.30	253
W3	4.62	45.0	38.1	121	0.33	164
W20	2.89	62.4	51.4	98	0.28	318
W1	1.23	52.5	61.5	176	0.14	224
W11	2.58	75.0	67.7	142	0.39	106
W14	2.43	70.3	50.0	152	0.19	132
W6	3.50	75.9	48.7	148	0.43	124
W17	2.00	70.9	53.9	106	0.13	118
W5	2.17	67.1	57.1	132	1.21	163
W2	2.21	64.2	54.7	138	0.58	224
W16	3.10	66.4	57.7	96	0.03	298
W8	2.33	71.7	60.8	114	0.34	314
W10	1.52	61.9	56.6	168	0.54	231
W13	3.25	69.3	42.3	123	1.17	254
W15	3.42	66.8	58.5	115	0.44	217
W9	1.56	68.0	40.6	109	0.24	208
W12	1.87	53.7	58.6	128	0.52	193
W19	1.88	65.7	44.6	136	0.68	218
W4	2.43	77.4	43.2	106	0.18	151
W18	3.42	71.1	48.5	121	0.37	273

Table 9
Values for irrigation parameters indices (wet season).

Sample No.	SAR	SSP (%)	MAR (%)	TDS (mg/l)	RSBC (meq/l)	EC (µS/cm)
W7	2.04	39.9	46.5	116	0.35	272
W3	2.15	60.8	27.5	132	0.42	182
W20	1.92	47.2	43.6	114	0.24	379
W1	1.23	52.5	61.5	169	0.14	236
W11	2.58	75.0	67.7	112	0.39	119
W14	2.43	70.3	50.0	176	0.19	154
W6	3.50	75.9	48.7	133	0.43	132
W17	2.00	70.9	53.9	118	0.13	130
W5	2.17	67.1	57.1	156	1.21	175
W2	2.21	64.2	54.7	145	0.58	239
W16	3.10	66.4	57.7	107	0.03	314
W8	2.33	71.7	60.8	124	0.34	327
W10	1.52	61.9	56.6	186	0.54	246
W13	3.25	69.3	42.3	117	1.17	273
W15	3.42	66.8	58.5	129	0.44	236
W9	1.56	68.0	40.6	121	0.24	220
W12	1.87	53.7	58.6	111	0.52	206
W19	1.88	65.7	44.6	125	0.68	232
W4	2.43	77.4	43.2	122	0.18	162
W18	3.42	71.1	48.5	132	0.37	298

calcite, aragonite and dolomite. The over saturation of these minerals most especially dolomite results from presence of calcium and magnesium in the water. Calcium (Ca) and Magnesium (Mg) are found in large quantities in some brine. In some cases, high amount of calcium within the earth crust could responsible for its presence in the groundwater. Also, almost all-natural waters, including seawater, contain either or both calcium carbonate and calcium sulphate. Calcium also forms in many silicate minerals that present in the rocks like garnet, epidote, titanite and wollastonite. Magnesium occurrence in the water is possibly results from the dissolution of mineral rocks (ferromagnesian minerals such as biotite and olivine) in the area as it been observed from a high concentration of magnesium in the water samples and magnesium-rich groundwater containing a significant amount of salt is also thought to be essential for dolomite formation.

Table 11
Water quality parameters for irrigation (Ayers and Westcot, 1985; Eaton, 1950; Wilcox, 1948).

Class	EC (µS/cm)	RSC (mg/l)	SAR	SSP (%)	Use as irrigation
1	< 117.51	< 1.25	< 10	< 20	Excellent
2	117.51–508.61	1.25–2.5	10–18	20–40	Good
3	> 503.61	> 2.5	18–26	40–80	Fair
4	–	–	> 26	> 80	Poor

Table 12
TDS classification for Irrigation Use (Robinove et al., 1958).

Classification	TDS (mg/l)
Non saline	< 1000
Slightly saline	1000–3000
Moderately saline	3000–10,000
Very saline	> 10,000

4.3. Irrigation use

The parameters used in the characterization of shallow wells for irrigation in this work are Soluble Sodium Percentage (SSP), Residual Sodium Bicarbonate (RSBC) which were calculated based on approach given by Todd (1980) and Gupta (1987), Sodium Absorption Ratio (SAR) was calculated using Richards (1954), Magnesium Adsorption Ratio (MAR) calculated based on Raghunath (1987) as well as Total Dissolved Solids, TDS (Richards, 1954) as shown in Table 6 and Table 7based on the following equations:

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

$$SSP = \frac{Na^{+} \ + \ K^{+}}{Ca^{2+} \ + \ Mg^{2+} + Na^{+}\ K^{+}} * 100 \tag{3}$$

$$\mathrm{RSBC} = \mathrm{HC0_3}^{2-} \text{ - } \mathrm{Ca}^{2+} \tag{4}$$

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} * 100 \tag{5}$$

Joshi et al. (2009) explained that high concentration of electrical conductance (EC) causes reduction in the amount of water going to the plants. EC provide status of salinity hazard in water and its effects on the productivity of crops. The EC values obtained in this work ranges between 106 and 318 µS/cm with a mean of 209.2 µS/cm for the dry season while for the wet season ranges between 119 and 379 µS/cm with a mean of 226.6 µS/c and all these values are within the acceptable limits of 1000 µS/cm (W.H.O., 2011). Based on the description by Richard (1954) who described that water can only be used for irrigation

Table 10
Classification of Water for Irrigation based on EC values (Richard, 1954).

S/No.	Electrical Conductivity (µS/cm)	Water Type	Use for irrigation
1	< 250	Low saline water	Entirely safe
2	250–750	Moderate saline	Safe under most condition
3	750–2250	Medium to High saline	Safe only with permeable soil and moderate leaching
4	2250–4000	High salinity	Unfair for irrigation
5	4000–6000	Very high salinity	
6	> 6000	Excessive salinity	

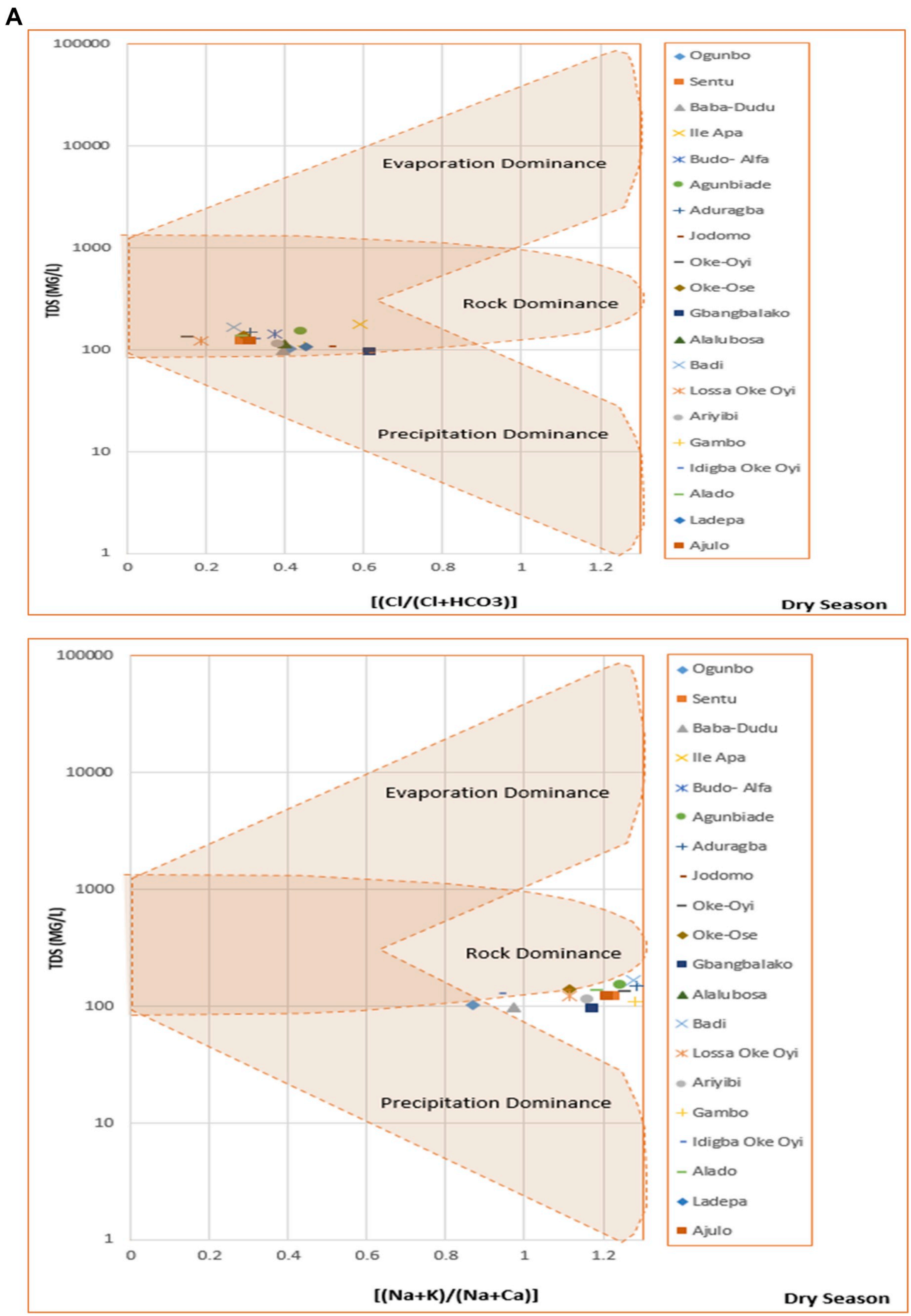
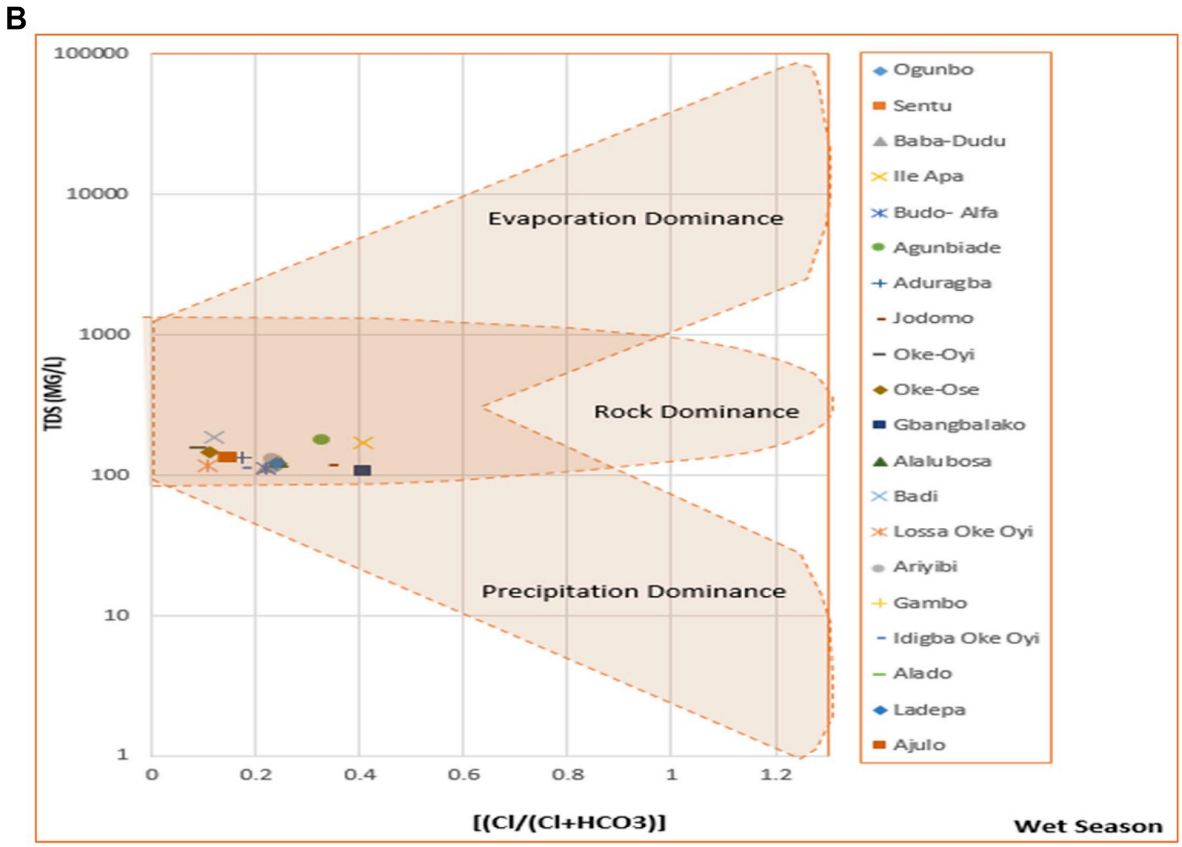


Fig. 5. a: Gibbs' plots of water samples in the stuay area (Dry Season).
b: Gibbs' plots of water samples in the stuay area (Wet Season).



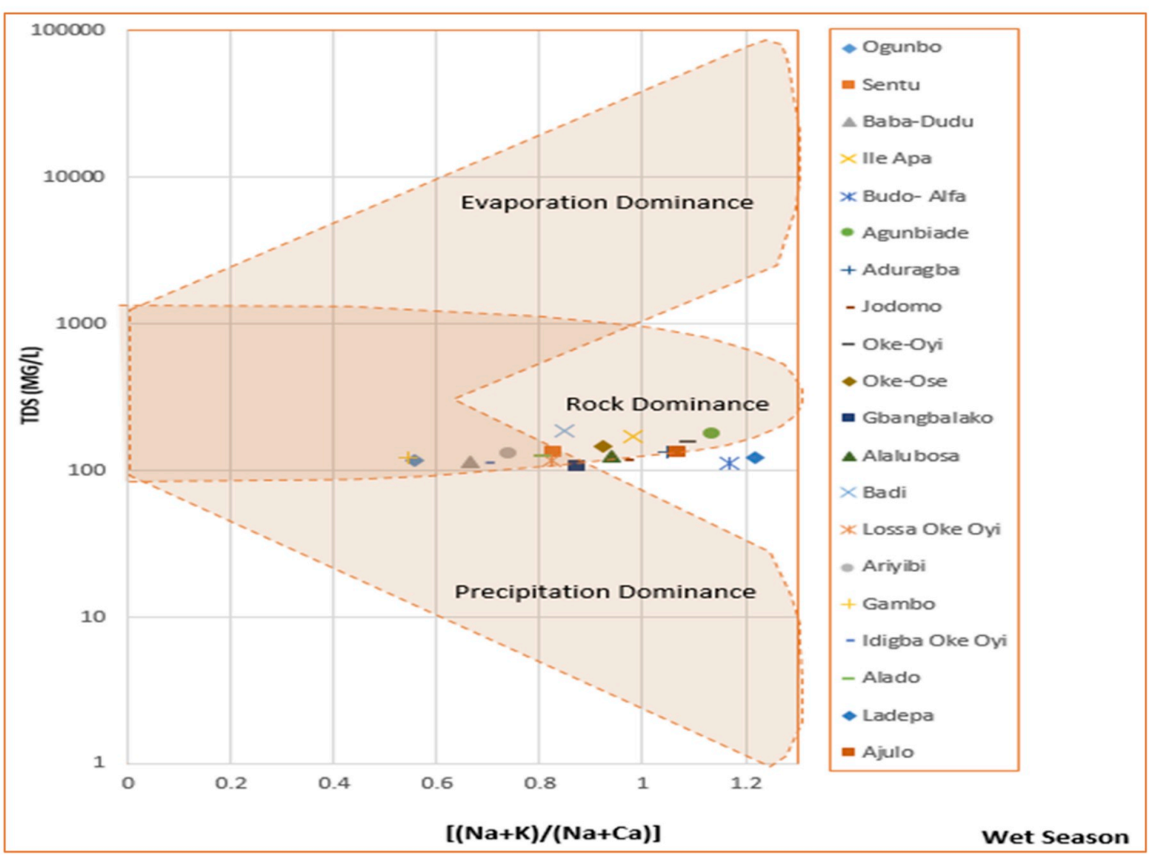


Fig. 5. (*continued*)

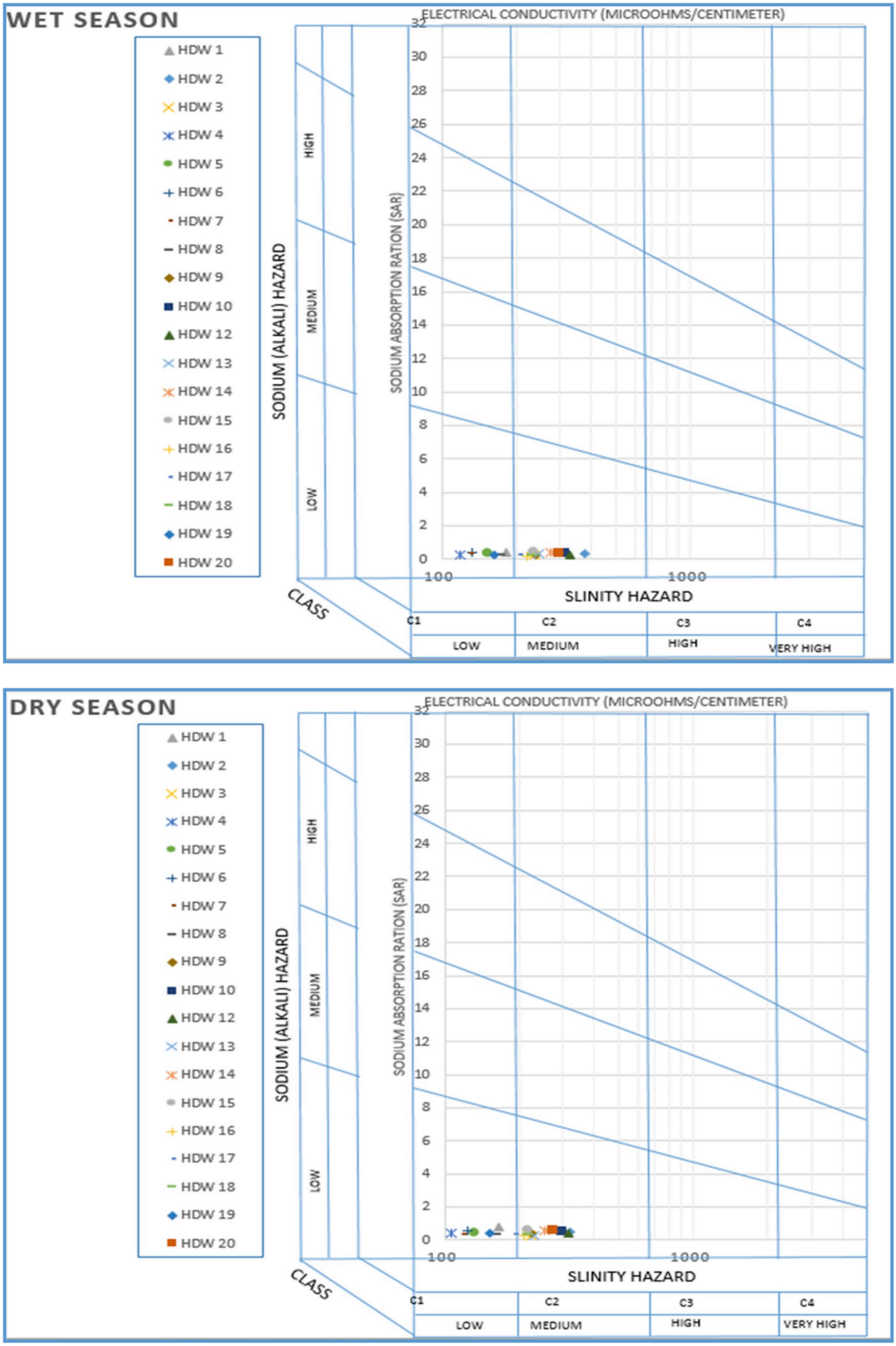


Fig. 6. Classification of Water based on EC and SAR values.

only when its possess low to moderate saline water (Fig. 5). Total Dissolved Solids (TDS) obtained from the water samples for dry season is between 96 and 176 mg/l with a mean of 126.6 and 107–176 mg/l of a mean 132.2 mg/l for the wet season. For the two seasons, TDS is within the acceptable limits of 1000 mg/l, therefore with TDS, water in the area is suitable for irrigation. Also, based on the classification of Robinove et al. (1958), this water is regarded as non-saline and considered to be excellent for irrigation (see Fig. 6).

Sodium Absorption Ratio (SAR) value for each of analysed water samples was determined based on the Richard (1954) as described above. However, sodium hazard is generally expressed as the sodium adsorption ratio (SAR). The SAR shows specific amount of sodium, calcium and magnesium ions that are present in the water. For this work, the SAR ranges from 1.2 to 3.5 for the dry season while for the wet season is between 0.84 and 2.17. According to Todd (1980) described irrigation water having SAR values below 10 to be excellent for irrigation uses. The amount of magnesium in the water is regarded as another most very useful index in classifying the quality of water for irrigation. It is generally observed that magnesium and calcium in most of the cases, maintain a state of equilibrium in the water but when there is an increase in the level of salinity of the water, it then causes a decline in the crop productivity (Joshi et al., 2009). The values of MAR obtained for dry season in this work is between 38.1 and 67.7 while for the wet season ranges between 24.0 and 57.1 though there are high values for MAR in some water samples which above recommended limits of 50% by Ayers and Westcott (1985).

Soluble Sodium Percentage (SSP) give an estimate on the amount of sodium ions available in the water which shows an indication of possible hazard that might results from the accumulation of sodium ions. The SSP also serves as important indices in classifying suitability of water for irrigation. Joshi et al. (2009) explained that large amount of sodium in the water for irrigation will give a plant a stunt growth and also reduce permeability in the soil. Values obtained for SSP ranges from 26.9 to 75.9 for dry season while ranges from 39.9 to 66.3 for the wet season and based on the value given by Wilcox (1948) recommended limit of 80% and those values obtained in this work are less than 80% therefore they are good for irrigation.

High percentage value of Residual Sodium Bicarbonate (RSBC) increases or causes high rate in the pH values and any kind of soil irrigated with this kind of water will results to the infertility due to the presence of sodium bicarbonates (Eaton, 1950). However, those values obtained for RSBC in this work is between 0.03 – 1–21 for dry season while from −0.05 – 1.66 for the wet season and these values considered to be good for irrigation based on the standard limits of 2.5 meg/l.

5. Conclusion and recommendation

This work has provided information on the physico-chemical characteristics of shallow aquifer wells in the rural area of Ilorin, Northcentral Nigeria. From the analysis of water samples, the pH values indicated that water in the area is acidic to alkaline type and all the pH values falls within the acceptable and recommended limits for domestic uses. Also, concluded that all other parameters tested both physical and chemical parameters are within the permissible limits therefore making the water to be suitable for any kind of domestic use. Although, it is observed from the studies, that most of these chemical constituents present in the water sampled have been influenced by the geological formation of parent rocks in the area but all the studied wells in the area still makes positive compliance, and suitable for domestic uses.

Results obtained for irrigation parameters indicates that the water samples in the area are suitable for irrigation, though expected that there would be some anthropogenic influences but those expected influences are not apparent and have no much effects in the water analysed.

This work recommended that those existing shallow hand dug wells in the study area should have continuous monitoring against environmental influence especially by reconstructing some of the wells' aprons for proper well covering. It is also recommended that both the government and private individual should assist in constructing and develop good borehole wells in the study area as shallow hand dug wells do not meet the demand of water by villagers for domestic and irrigation purposes.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gsd.2019.100226.

References

Abimbola, A.F., Odukoya, A.M., Adesanya, O.K., 2002. The environmental impact assessment of waste disposal site on groundwater in oke - ado and lagos, south-western Nigeria. In: Proceedings, 15th Annual Conference of Nigerian Association of Hydrogeologists, Kaduna, Nigeria, pp. 42.

Ayers, R.S., Westcot, D.W., 1985. Water quality for agriculture (FAO). Irrigation and drain. Paper 29 (1), 1–109.

Bouwer, H., 1978. Ground Water Hydrology. McGraw – Hill, New York, pp. pp210.

Eaton, F.M., 1950. Significance of Carbonate in irrigation water. Soil Sci. 67 (3), 128–133.

Freeze, R.A., Cherry, J.A.C., 1979. Groundwater Prentice Hall, Engle Wood Cliff's. pp. 604.

Frohlich, R.K., Barosh, P.J., Boving, T., 2008. Investigating changes of electrical characteristics of the saturated zone affected by hazardous organic waste. J. Appl. Geophys. 64, 25–36.

Gibbs, R.J., 1970. Mechanisms controlling world water. Chem. Sci. 170, 795–840.

Gupta, S.K., Gupta, I.C., 1987. Management of Saline Soils and Water. Oxford and IBH publication Coy, New Delhi, India, pp. 399.

Joshi, D.M., Kumar, A., Agrawal, N., 2009. Assessment of the irrigation quality of river ganga in haridwar district, India. J. Chem. 2 (2), 285–292.

Kim, K.Y., Park, Y.S., Kim, G.P., Park, K.H., 2009. Dynamic freshwater – saline water interaction in the coastal zone of jeju island, South Korea. Hydrogeol. J. 17, 617–629.

Langmuir, D., 1997. Aqueous Environmental Geochemistry. Prentice Hall, Upper Saddle River, N.J., pp. 600.

Nigeria Standard Drinking Water Quality (NSDWQ), 2007. Nigeria Standard for Drinking Water Quality. pp. 15–17.

Obaje, N.G., Abaa, S.I., 1996. Potential for coal derived gaseous hydrocarbon in middle benue Trough of Nigeria. J. Petrol. Geol. 19, 77–94.

Olusiji, S.A., Adeyinka, O.A., 2010. Portability status of some hand dug wells in Ekiti State, Southwestern Nigeria. Int. J. Sci. Technol. 1 (2), 102–109.

Parkhurst, D.L., Appelo, C.A.J., 1999. User's guide to PHREEQ C (version 2) - A Computer Program for Speciation, Batch - Reactions, One - Dimensional Transport, and Inverse Geochemical Calculations: U.S. Geological Survey Water - Resources Investigation Report, 99-4259. pp. 312.

Piper, A.M., 1944. A graphic procedure in geochemical interpretation of water analysis. Trans. A.M. Geophysics Union 25, 914–923.

Raghunath, I.M., 1987. Groundwater, second ed. Wiley Eastern Ltd, New Delhi, India.

Rao, V.S., Prasanthi, S., Shanmukha, J.V., Prasad, K.R.S., 2012. Physicochemical analysis of water samples of nujendla area in guntur district, Andhra Pradesh, India. Int. 4 (2), 691–699.

Richard, L.A., 1954. Diagnosis and Improvement of Saline and Alkali Soils. Agric., Washington, D.C, pp. 160.

Robinove, C.C., Langford, R.H., Brookhart, W., 1958. Saline Water Resources of North Dakota. US Geological Survey Water Supply Paper 1428.

Satpathy, C.C., Mathur, P.K., Nair, K.V.K., 1987. Contribution of edayur- sadras estuarine system to the hydrographic characteristics of kalpakkam coastal waters. JMBA (J. Mar. Biol. Assoc.) 29 (1 -2), 344–350.

Tatawat, R.K., Chandel, C.P.S., 2008. Quality of groundwater in Jaipur City, Rajasthan (India) and its suitability for domestic and irrigation purpose. Appl. Ecol. Environ. Res. 6 (2), 79–88.

Todd, D.K., 1980. Groundwater Hydrology. John Willey and Sons Publisher, New York.

Vengosh, A., 2013. Salinization and saline environments. Treatise on geochemistry 9, 333–365 Elsevier.

Westbrook, S.J., Rayner, J.L., Davis, G.B., Clement, T.P., Bjerg, P.L., Fisher, S.J., 2005. Interaction between shallow groundwater, saline surface water and contaminant discharge at a seasonally and tidally forced estuarine boundary. J. Hydrol. 302 (1 -4), 255–269.

Wilcox, L.V., 1948. The Quality of Water for Irrigation Purpose U.S. Department of Agriculture. Technical Bulletin of 1962, Washington, D.C., U.S.A.

World Health Organization (WHO), 2011. Guidelines for Drinking Water Quality. Final Task Group Meeting, Geneva.