Evaluation and characterization of groundwater of the Maastrichtian Lafia formation, Central Benue trough, Nigeria

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MS received 30 January 2018; revised 25 October 2018; accepted 16 April 2019; published online 17 June 2019

Hydrochemical assessment of groundwater in the Lafia formation, Central Benue trough, Nigeria was carried out with the aim of determining its quality for domestic and irrigation purposes. Thirty groundwater samples from boreholes and hand-dug wells were analyzed using atomic spectrometry and titrimetric methods. The water quality index (WQI) was evaluated from physicochemical parameters and used in assessing the groundwater quality for drinking, while the electrical conductivity (EC), percentage sodium (%Na), sodium absorption ratio (SAR) and magnesium hardness (MH) were evaluated to assess its suitability for irrigation. The physico-chemical parameters in order of dominance are $\text{HCO}_3^- > \text{NO}_3^- > \text{Cl}^- > \text{PO}_4^{3-} > \text{SO}_4^{2-}$ for the anions and $\text{Fe}^{3+} > \text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{Pb}^{2+} > \text{K}^+$ for the cations. The pH indicates acidic to weakly alkaline water (5.1–7.3); EC ranges from 110 to 1396 $\mu\text{S}/\text{cm}$, while the total dissolved solids range between 136.9 and 3.4 mg/l, based on which it is classified as freshwater. WQI showed that only 40% of the groundwater samples are suitable while 60% are unsuitable for drinking and will therefore require treatment. Three water facies: $\text{Ca}^{2+} + \text{Mg}^{2+}$, $\text{Ca}^{2+} + \text{Na}^+ + \text{K}^+$ and HCO_3^- characterized the area indicating the groundwater-quality situation. Based on EC classification, 33.33% of the water samples are considered excellent, 60% as good, 6.67% as permissible while on the basis of %Na, only 13.34% are unsuitable for irrigation. SAR of 96.67 and 3.33% of the groundwater samples indicate excellent and doubtful waters, respectively. 93.4% of groundwater samples has $\text{MH} < 50$ and are considered suitable for irrigation.

Keywords. Lafia; groundwater; geologic formation; water quality index; water facies; irrigation.

1. Introduction

Groundwater is an essential element for human existence on earth. The hydrochemistry of groundwater is very important with regard to drinking, irrigation and industrial water supplies, as the presence of certain chemical constituents makes the groundwater unfit for industrial and agricultural use (Michael 1990). Around the world, the availability of high-quality groundwater for human

consumption is on the decline (Bouderbala *et al.* 2016). The quality of groundwater can significantly be impacted by land usage, geology and anthropogenic activities (Bocanegra *et al.* 2013).

Groundwater chemistry generally shows a direct relationship with its quality and determines its suitability or unsuitability for domestic, industrial and agricultural purposes. For many years, due to the inadequate supply of water from the municipal water supply, hand-dug wells and boreholes

have been the major sources of water supply in Lafia and environs. However, information about the physico-chemical characteristics of the groundwater with respect to drinking and agricultural purposes has not been prioritized, as water from these boreholes is put to use without a quality test. The determination of groundwater quality for human consumption is important for the well-being of the increasing population (Ishaku 2011). It is therefore pertinent to establish those quality criteria for healthy living and improved food production, considering the growing population and increased agricultural activities in the study area. These qualities are dependent on the quality of recharged water, atmospheric precipitation, inland surface water and subsurface geochemical processes (Vasanthavigar *et al.* 2010).

Various researchers (Offodile 1976a, 1983, 2002; Aku 1983; Achohwora 1986) who have worked on the study area focused on its geology, hydrogeology, groundwater occurrence and aquifer's yield, while little is known about its hydrochemistry and suitability for drinking and irrigation. Kumar (2013) studied groundwater chemistry and identified natural processes as controlling factors of the hydrochemistry, while Ishaku *et al.* (2012) identified anthropogenic contaminations, natural mineralisation and cation exchange as factors controlling the hydrochemistry. Groundwater quality for drinking and agricultural or other purposes has been studied (Onwuka *et al.* 2004, 2013; Ehirim *et al.* 2009; Prasanna *et al.* 2011; Ishaku *et al.* 2012; Rao *et al.* 2013; Omonona *et al.* 2014; Das and Nag 2015; Akpah *et al.* 2017).

Water quality index (WQI) is an important technique for demarcating groundwater quality and its suitability for drinking (Tiwari and Mishra 1985). Ishaku *et al.* (2012) and Omonona *et al.* (2014) used the WQI to classify groundwater for drinking. Das and Nag (2015) calculated water indices such as the sodium absorption ratio (SAR), permeability index (PI), residual sodium carbonate (RSC) and Kelley ratio (KR) to identify the irrigational suitability of groundwater.

The present investigation focuses on the evaluation and characterization of groundwater chemistry, its quality for drinking and agricultural purposes. Water supply for drinking and irrigation in this region is sourced through groundwater as the annual average rainfall range is between 1000 and 1500 mm (Binbol 2006). There are no major polluting industries in the study area.

WQI, Piper trilinear diagram and total hardness were used to classify water for drinking while electrical conductivity (EC), percentage sodium (%Na) according to Raghunath (1987), Sadashivaiah *et al.* (2008) and Hagrais (2013), SAR according to Richard (1954) and Todd and Mays (2005) and magnesium hardness (MH) according to Szabolcs and Darab (1964) was evaluated to classify water for irrigation.

1.1 Study area description

Lafia, the capital of the Nasarawa state in north central Nigeria, and its environs lie between latitude 8°18'–8°42'N and longitude 8°18'–8°48'E (figure 1). Two major distinct seasons (wet and dry) characterise the area; the wet season lasts from March to October, while the dry season lasts from November to February. Rainfall between January and February is a rare occurrence. The annual average rainfall ranges between 1000 and 1500 mm while the mean annual humidity is 70% and the relative humidity is 60–80% (Binbol 2006). The annual average temperature is 28.5°C with an annual average sunshine hour of 6.7 per day. A high temperature of 33–36°C is experienced in the area during the dry season.

The study area is drained majorly by River Amba and is characterized by the Guinean savannah vegetation.

The original vegetation has been tampered with due to human activities such as farming, bush burning and grazing, which has given rise to a secondary forest (Achohwora 1986).

1.2 Geology of the study area

The study area is underlain by the Lafia formation also called the 'Lafia sandstone' by Cratchley and Jones (1965). It is the youngest formation in the Central Benue trough, Nigeria (Zaborski 1998). It was deposited under continental (fluvial) condition in the Maastrichtian and lies unconformably on the Awgu formation which was deposited during the Late Turonian transgression, early Coniacian and terminated in the early Santonian. This deposition marks the end of marine sedimentation in this part of the Benue trough. It consists of bluish-grey to dark black carbonaceous shales, calcareous shale, shaley limestone, limestone, sandstones, siltstones and coal seams. The Lafia formation is lithologically characterised by ferruginised sandstones, red loose sands, flaggy mudstones, clays

Figure 1. Map of Nigeria showing the location of the study area.

and claystones. The type locality is in and around Lafia town (Offodile 1976b) and outcrops along the banks of River Amba on the Lafia-Doma road. The formation is fine to coarse grained, friable and feldspathic. It ranges in thickness from about 10 to 150 m in the Lafia area and much thicker towards the south-west of the town. The formation thins out to the north, around Shabu (figure 2).

1.3 Hydrogeology of the study area

The study of the hydrogeology of the Lafia formation was to a very good extent pioneered by Offodile (1976a) who made a brief survey of the water resources of the area in light of its importance to the development of the region. A highlight of some hydrogeological characteristics of the aquifers of Lafia formation using drilled logs and water analyses of some selected wells in the area was made.

The Lafia formation comprises mainly fine to coarse grained sandstones, which are highly porous and permeable. The formation is highly permeable and gives rise to several springs (or marshy areas) called *fadama* at its contact with the less permeable underlying Awgu formation (Musa 2015).

2. Materials and methods

Thirty groundwater samples were collected from the discharge points of daily abstracted hand-dug

wells and boreholes in the month of April 2017. Sampling was done early in the morning before water abstraction commenced by the residents covering areas such as Gandu, Doma, Yelwa Doma, Major Musa, Shabu, Mada and Assakio (figure 3), to characterise and evaluate its quality for drinking and agricultural purposes. The study area was gridded into four quadrants to have an even distribution of samples. Seven samples were collected from each quadrant while two samples were collected from the municipal centre at an arbitrary distance due to its high human activities. At every sample location, two water samples were collected for the detection of anions and cations. The samples were filtered in situ through a $0.45\ \mu\text{m}$ membrane filter, collected in labelled 125 ml bottles and kept under cold condition. Samples for cation analytes were acidified to a pH less than 2 with nitric acid in water solution at 0.15% concentration by weight. EC, temperature (T°) and hydrogen ion concentration (pH) were measured in situ. A SOLINT temperature, level and conductivity (TLC) metre was used in measuring EC and T° by lowering it into a well. At the point of contact with water, the temperature and EC of the water is displayed and read from the digital screen of the metre. The pH metre was used in measuring pH while the evaporation technique using gravimetric analysis was used to determine total dissolved solids (TDS) (figure 4).

Atomic absorption spectrometry was used for the determination of Ca^{2+} , Fe^{2+} and Pb^{2+} concentrations while a UV spectrophotometer was used in determining the concentration of NO_3^- . The concentrations of Na^+ and K^+ were determined using flame analysis while titrimetric and colorimetric methods were used in determining the concentrations of Cl^- and HCO_3^- and SO_4^{2-} , respectively. The results of anion and cation analytes were evaluated to calculate the WQI, hence the quality of the water for drinking was deduced. WQI was calculated according to Ramakrishnaiah *et al.* (2009), Reza and Singh (2010), Gebrehiwot *et al.* (2011) and Ishaku *et al.* (2012).

Based on the WQI value, groundwater are classified as excellent water, good water, permissible water, poor water, very poor water or water unsuitable for drinking purposes. Piper (1944) trilinear diagrams and Stiff pattern diagrams were used to characterize groundwater into different facies or types. The hardness of the water was evaluated in accordance with Todd and Mays (2005), to determine the potability of the water.

Figure 2. Topographic map of the study area.

Figure 3. Geological map of the study area.

Figure 4. Graphical representation of WQI.

Table 1. Summary of physio-chemical parameters.

Sample	pH	EC ($\mu\text{S}/\text{cm}$)	TDS	% NO_3^-	PO_3	K^+	SO_4^{2-}	HCO_3^-	Cl^-	Ca^{2+}	Mg^{2+}	Fe^{2+}	Pb^{2+}	Na^+
1	6.6	759	86.2	2.49	0.17	0.2	0	85.4	0.2	0.221	0.063	1.538	0.088	0.119
2	5.8	275	98.4	1.25	0.24	0.14	0	97.6	0.3	0.251	0.066	1.682	0.068	0.043
3	5.6	479	111.5	4.37	0.28	0.24	0.26	109.8	0.2	0.331	0.082	1.953	0.074	0.621
4	5.3	376	49.6	5.21	0.56	0.11	0	48.8	0.4	0.178	0.053	2.999	0.057	0.046
5	5.1	320	136.9	2.18	0.57	0.09	0	134.2	0	0.114	0.033	2.502	0.092	2.511
6	5.5	571	37.1	1.64	0.28	0.08	0	36.6	0.1	0.222	0.055	2.434	0.497	0.067
7	5.4	110	85.9	1.23	0.19	0.1	0	85.4	0.19	0.116	0.032	2.825	0.015	0.023
8	5.5	675	46.6	5.41	0.19	0.15	0.12	36.6	0.1	0.325	0.081	2.262	0.074	9.23
9	6.3	167	98.2	2.49	0.1	0.08	0	97.6	0.2	0.266	0.066	1.942	0	0.014
10	5.4	438	86.5	3.48	0.23	0.07	0	85.4	0.1	0.222	0.076	2.921	0.123	0.651
11	5.8	244	134.8	1.76	0.28	0.1	0	134.2	0.09	0.267	0.089	2.363	0.086	0.004
12	5.6	230	98.9	1.67	0.18	0.21	0.14	97.6	0	0.716	0.225	1.958	0.051	0.003
13	5.4	149	73.8	2.49	0.27	0.02	0	73.2	0.29	0.216	0.072	2.081	0.26	0.014
14	6.3	1396	50.5	2.18	0.48	0.15	0	48.8	0.79	0.21	0.076	2.194	0.09	0.462
15	6.1	780	67.1	5.21	0.2	0.1	0	61	0.19	0.42	0.236	2.555	0.081	5.14
16	5.9	435	49.6	4.62	0.23	0.13	0.01	48.8	0.1	0.116	0.053	2.527	0	0.341
17	7.3	615	3.4	4.96	0.19	0.25	0.18	0	0	0.303	0.156	1.942	0	2.56
18	5.7	248	122.7	3.98	0.54	0.1	0	122	0.1	0.31	0.134	1.779	0.076	0.094
19	5.9	134	73.7	3.26	0.48	0.08	0	73.2	0.19	0.148	0.032	2.062	0.077	0
20	5.8	264	62	4.46	0.12	0.09	0	61	0	0.239	0.043	2.925	0.076	0.624
21	5.5	566	37.9	4.3	0.19	0.42	0.54	36.6	0.1	0.218	0.028	1.336	0.092	0
22	5.5	211	49.3	2.7	0.44	0.11	0	48.8	0.11	0.113	0.041	1.313	0.077	0.084
23	5.4	665	62	1.69	0.1	0.24	0.18	61	0.1	0.336	0.064	2.961	0.222	0.046
24	6.3	198	98.7	3.23	0.19	0.04	0	97.6	0	0.406	0.624	2.74	0.1	0
25	5.4	452	25.6	3.23	0.17	0.13	0.07	24.4	0	0.403	0.599	1.794	0.287	0
26	5.3	249	74.2	5.01	0.27	0.1	0.02	73.2	0.1	0.301	0.021	1.844	0.103	0.481
27	6.3	1396	37.7	4.33	0.18	0.08	0.01	36.6	0.11	0.361	0.364	1.873	0.156	0.214
28	6.1	780	86.4	2.06	0.25	0.1	0.07	85.4	0.11	0.618	0.082	1.057	0.174	0
29	5.8	432	74.6	2.75	0.47	0.43	0.54	73.2	0.09	0.229	0.077	2.048	0.039	0
30	7.1	616	98.9	0.97	0.13	0.1	0.02	97.6	0.79	0.264	0.034		0.024	0.14

Secondary parameters such as the percentage of sodium ($\text{Na}\%$), SAR and MH were computed using mathematical equations (1)–(3) according

to Richard (1954), Szabolcs and Darab (1964), Raghunath (1987), Todd and Mays (2005), Sadashivaiah *et al.* (2008) and Hagraas (2013),

respectively. These secondary parameters and the waters EC were used in evaluating the groundwater of the study area for irrigation purposes:

$$\text{Na}\% = \frac{(\text{Na}^+ + \text{K}) \times 100}{\text{Ca} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+}, \quad (1)$$

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

$$\text{MH} = \frac{\text{Mg}^{2+} \times 100}{\text{Ca}^{2+} + \text{Mg}^{2+}}. \quad (3)$$

3. Results and discussions

3.1 Hydrochemistry

From the physiochemical analysis of the groundwater samples, the order of dominance of the anions is $\text{HCO}_3^- > \text{NO}_3^- > \text{Cl}^- > \text{PO}_3^- > \text{SO}_4^{2-}$ and $\text{Fe}^{2+} > \text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{Pb}^{2+} > \text{K}^+$ for the cations (table 1). Bicarbonate (HCO_3^-)

Table 2. Summary of the statistical analysis of the physiochemical parameters.

Parameters	Mean	Max	Min	WHO (2011) standard
pH	5.85625	7.3	5.1	6.2–8.5
EC	491.75	1396	110	500
TDS	73.71875	136.9	3.4	600
NO_3^-	3.155938	5.41	0.97	200
PO_3^-	0.27625	0.57	0.1	200
K^+	0.146563	0.43	0.02	75
SO_4^{2-}	0.084375	0.54	0.01	50
HCO_3^-	72.05625	134.2	24.4	0.01
Cl^-	0.1825	0.79	0.1	250
Ca^{2+}	0.289656	0.716	0.113	250
Mg^{2+}	0.134438	0.624	0.021	50
Fe^{2+}	3.20271	16.336	1.538	0.1
Pb^{2+}	0.11425	0.497	0.1	10
Na^+	1.023813	9.23	0.1	500

Table 3. Classification of water type (Vasanthavigar et al. 2010).

Range	Water type
<50	Excellent water
50–100.1	Good water
100–200.1	Poor water
200–300.1	Very poor water
>300	Water unsuitable for drinking purposes

is the most dominant anion having a concentration range of 36.6–134.2 mg/l and an average value of 72.06 mg/l. Sewage effluents emanating from pit latrines are the major source of bicarbonate, especially around Assakio, Doma, Gandu and Yelwa Doma areas and the dissolution of carbonate rocks such as limestone. Sulphate has the least concentration ranging between 0.01 and 0.54 mg/l with a mean value of 0.084 mg/l and it is associated with the dissolution of gypsum and anthropogenic activities. The Fe^{3+} has the highest concentration and ranges from 1.54 to 16.33 mg/l, with an average of 3.20 mg/l, which is above the WHO recommended limit (0.1 mg/l) for drinking water. The high concentration of Fe^{3+} in the groundwater of the study area is attributable to the geological formation (ferruginised sandstones and lateritic soil) which are rich in Fe^{3+} as revealed by Musa

Table 4. Water quality classification.

Samples	WQI	Description
1	112.4502	Poor water
2	88.47689	Good water
3	100.4163	Good water
4	93.48218	Good water
5	118.334	Poor water
6	456.546	Water unsuitable for drinking purposes
7	52.64959	Good water
8	105.1239	Poor water
9	33.48885	Excellent water
10	149.5036	Poor water
11	111.2053	Poor water
12	76.30788	Good water
13	249.5194	Very poor water
14	130.2028	Poor water
15	116.9684	Poor water
16	42.57073	Excellent water
17	39.79386	Excellent water
18	96.83334	Good water
19	97.36963	Good water
20	107.3812	Poor water
21	264.4366	Very poor water
22	110.4159	Poor water
23	235.1214	Very poor water
24	125.7777	Poor water
25	272.77	Very poor water
26	118.2779	poor water
27	181.7663	Poor water
28	199.6623	Poor water
29	70.37273	Good water
30	21.4125	Excellent water

(2015). The high concentration of Na^+ compared to Ca^{2+} (mean values of 1.02 and 0.28 mg/l, respectively) denotes the effect of ion exchange between them (Kumar 2013). Leaching of clay minerals is one the major sources of the cations.

3.2 Water quality for drinking purposes

Results of the physiochemical parameters are summarized in table 1 and were correlated with the WHO (2011) standards to evaluate and characterise groundwater for drinking. The pH of the groundwater (table 2) ranges from 5.1 to 7.3 with a mean value of 5.86 (weakly acidic to slightly alkaline). Low pH is caused by the precipitation of iron in stored water sampled before testing, while high pH results from the presence of bicarbonates, carbonates and hydroxides of calcium. The EC has an average of 491.75 $\mu\text{S}/\text{cm}$ with 36.67% of the water samples having an EC range of 566–1396 $\mu\text{S}/\text{cm}$ above the WHO (2011) limit, while 63.33% of the samples with an EC range of 110–479 $\mu\text{S}/\text{cm}$ are within the WHO (2011) limit. TDS is the measure of the inorganic pollution load of a water system which shows that the groundwater in the study area can be classified as freshwater according to Carroll (1962) classification. It has a peak and the lowest values

of 136.9 and 3.4 mg/l, respectively, with a mean value of 73.72 mg/l. High TDS may cause a laxative or constipation effect (APHA 1995). The pH values are within the range reported by Musa (2015) while the EC and TDS values contradict those reported by the author for Lafia (who limits his studies to only hand-dug wells; table 3). The ground WQI ranges from 21.41 to 456.55 with a mean value of 139.27 (table 4). About 13.33% of the water samples are classified as excellent water with a WQI range of 21.41–42.57; 26.67% as good water (WQI range 52–100); 43.34% as poor water (WQI range 105–199); 13.33% as very poor water (WQI range 235–272) and 3.33% (sample 6) as water unsuitable for drinking purposes. The southern part of the study area (Yelwa Doma, Major Musa and Adobi) is dominated by good water. Poor water and very poor water are concentrated in the central part (Lafia and Doma) areas, even though some locations within the central parts such as Gandu and Agode contained excellent and good water. The poor to very poor water in the central part can be attributed to industrial waste such as e-waste, indiscriminate refuse dumps, to sewage effluent from pit latrines brought about by the dense population compared to the southern or northern parts with less population.

Figure 5. Piper trilinear diagram of the study area.

3.3 Water type

Groundwater in the study area was characterized using Piper trilinear and Stiff diagrams (figures 5 and 6, respectively). Three water types were deduced: the $\text{Ca}^{2+} + \text{Mg}^{2+}$ water type known for temporary hardness; the $\text{Ca}^{2+} + \text{Na}^{+} + \text{K}^{+}$ water type and the $\text{HCO}_3^{-} + \text{CO}_3^{-}$ water type. The $\text{Ca}^{2+} + \text{Mg}^{2+}$ and $\text{Ca}^{2+} + \text{Na}^{+} + \text{K}^{+}$ water types are the dominant types. The trend of the $\text{Ca}^{2+} + \text{Mg}^{2+}$ water type in a straight line on the Piper

diagram (figure 6) is an indication of a solution or precipitation. The source of the $\text{HCO}_3^{-} + \text{CO}_3^{-}$ water type is rainfall mixed with atmospheric carbon dioxide, usually low in calcium and magnesium and is said to be juvenile water (Akpah *et al.* 2017).

The Stiff pattern diagrams showed similar patterns for all samples with the exception of samples 8, 15 and 17. Water with similar qualities tends to plot together as a group while the size of the pattern is approximately equal to the ionic content. The similarity in pattern is an indication

Figure 6. (a–c) Stiff (1951) patterns of the study area.

Figure 6. continued

that the waters are of the same source with little variation in TDS due to the differences in temperatures which causes dissolution, ion exchange capacity and adsorption (Ngabirano *et al.* 2016).

3.4 Hardness

The total hardness (H_T) of the water samples was calculated according to Todd and Mays (2005), using the cations Ca^{2+} and Mg^{2+} which controls groundwater hardness. The H_T , ranges from 0.42 to 3.57, with a mean value of 1.25. Groundwater in the study area is classified as very soft water (Linsley *et al.* 1992) and hence poses no health risk that may arise from the excessive consumption of calcium or magnesium.

3.5 Water quality for irrigation

Chemical composition and usage conditions are the determinants of water quality for irrigation (Hussein *et al.* 2010). In this research, the EC, %Na, the SAR and MH were used to evaluate groundwater in the study area for irrigation. The EC ranges from 110 to 1396, having a mean value of 491. Based on the EC classification of water for irrigation, 33.33% of the water samples are considered excellent, 60% as good while 6.67% are permissible. %Na in water samples varied between 3.738 and 95.851, with an average value of 48.31 (table 5). It showed that

23.33% of water samples are good, permissible and doubtful, respectively, while 16.67% are excellent and 13.34% are unsuitable for irrigation. Low Na^+ water can be used for irrigation on all soils with minimal danger of harmful exchangeable Na^+ developing (Singh *et al.* 2009), while on the other hand, high sodium water in most soils will require special soil management, such as good drainage, high leaching and organic matter as it produces harmful exchangeable sodium (Akpah *et al.* 2017). High Na% in water will result in the replacement of Mg^{2+} and Ca^{2+} by Na^+ which impedes soil permeability, reduces soil drainage, affects soil structure and aeration and therefore, affects plant growth (Singh *et al.* 2008, 2009; Akpah *et al.* 2017). SAR ranges between 0.004 and 20.47 with a mean value of 1.87. Based on SAR, 96.67% and 3.33% of the groundwater are classified as excellent and doubtful waters, respectively. The low SAR of the water samples implies that the water will make the soil soft, loose and pervious with little sodium accumulation in the soil, as high SAR is responsible for compact, hard and impervious soils (George 1983; Akpah *et al.* 2017). Plants in the study area will have low susceptibility to sodium hazard or sodicity (Uzoije *et al.* 2015) as the soil's physical conditions will be suitable for good plant germination. The proportion of sodium to other cations is one of the most useful criteria for determining the quality of water for irrigation. The MH of

Table 5. Description of groundwater for irrigation purposes based on EC and %Na (after Raghunath 1987; Sadashiviah *et al.* 2008; Hargras 2013) and SAR (after Richard 1954; Todd and Mays 2005).

Description	EC	% of sample	Na%	% of sample	SAR	% of sample
Excellent	<250	33.33	<20	16.67	<10	96.67
Good	250–750	60	20–40	23.33	10–18	–
Permissible	750–2000	6.67	40–60	23.33	–	–
Doubtful	2000–3000	–	60–80	23.33	18–26	3.33
Unsuitable	>3000	–	>8–0	13.34	>26	–

groundwater ranges from 6.52% to 60.58%, with an average value of 25.83%. MH >50 is considered unsuitable or harmful for irrigation (Szabolcs and Darab 1964; Singh *et al.* 2009; Brindha *et al.* 2014; Akpah *et al.* 2017). Only 6.6% of the water samples fall within this category, while 93.4% with MH <50 are considered suitable for irrigation (Al-Tabbal and Al-Zboon 2012).

4. Conclusion

Groundwater assessment in Lafia and environs was carried out to determine its suitability for various purposes. The hydrochemistry revealed the anions and cations in order of dominance as $\text{HCO}_3^- > \text{NO}_3^- > \text{Cl}^- > \text{PO}_3^- > \text{SO}_4^{2-}$ and $\text{Fe}^{3+} > \text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{Pb}^{2+} > \text{K}^+$, respectively. All parameters fall below the WHO recommended limit for drinking water except for Fe^{3+} , which was as high as 16.53 mg/l. The high concentration of Fe^{3+} in the groundwater of the study area can be attributed to the oxidation of Fe^{2+} present in feruginised sandstones and lateritic soil.

WQI showed that 13.33% of groundwater in the study area can be classified as excellent water, 30% as good water, 40% as poor water, 13.33% as very poor water and 3.33% as water unsuitable for drinking purposes. Groundwater in the study area was characterised into three types using Piper's (1944) trilinear diagram, with type I as the $\text{Ca}^{2+} + \text{Mg}^{2+}$ water type, Type II as the $\text{Ca}^{2+} + \text{Na}^+ + \text{K}^+$ water type and Type III as the $\text{HCO}_3^- + \text{CO}_3^{2-}$ water type. The Types I and II are the dominant water types. Type I water is known for temporary hardness, while rainfall mixed with atmospheric carbon dioxide is believed to be the source of the $\text{HCO}_3^- + \text{CO}_3^{2-}$ type. The Stiff pattern showed similar patterns for all samples with the exception of samples 8, 15 and 17, which is an indication that the water are of the same source, with little difference in the TDS in the groundwater of the study area.

Based on the EC, %Na, SAR and the MH evaluated, the groundwater in the study area generally ranges from permissible to excellent water for irrigation.

Acknowledgements

The first author is grateful to the Petroleum Technology Development Fund (PTDF) for the offer of scholarship to pursue a doctoral degree in hydrogeology.

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Corresponding editor: ABHIJIT MUKHERJEE