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Investigating the Quality of Groundwater from Hand-dug Wells in Lapai, Niger State using Physico-chemical and Bacteriological Parameters

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Abstract

Access to potable water is one of the important ingredients for sustainable development of any community. The quality status of groundwater from shallow hand dug well in Lapai area of Niger State, North-central Nigeria was investigated in the present study using physico-chemical and bacteriological indices. A total of 35 groundwater samples were collected from hand-dug wells and analysed for their chemical and bacteriological parameters. Prior to the analysis, the physical parameters were determined insitu using standard equipment in accordance with American Public Health Association Standard for water and waste-water sampling. The geological mapping of the area revealed granite-gneiss as the dominant rock type. The structural analysis of the study area revealed the principal joint direction as NE-SW. The result of the laboratory analyses of the groundwater samples showed that the mean concentrations of the major cations and anions are below the permissible limit recommended by the Nigerian Standard for Drinking Water Quality. However, the mean concentration of iron, copper and zinc in locations along transition zone were found to be slightly higher than their respective recommended maximum permissible limit. Their presence in the groundwater may be attributed to rock-water interaction leading to bedrock dissolution, chemical weathering and dilution effect of the overlapping ferruginous sandstone from the nearby Bida Basin as well as possible leachate from decomposing metallic objects at dumpsites. The groundwater is extremely poor bacteriologically owing to the proximity of hand dug well to unlined soakaways and pit-latrine. The mean concentration of total coliform (150.30 cfu/100ml), E.coli (65.50 cfu/100ml) and faecal strepp (85.40 cfu/100ml) in the hand dug wells from the area implies faecal contamination, an indication that the water is in contact with human or animal faeces and it may be responsible for the occurrence of foodborne and waterborne diseases in the area. Physical parameters such as turbidity, conductivity and total dissolved solid show wide range and deviation which is attributable to the presence of the metals and bacteria in the groundwater. Boiling of water before use for domestic purposes is recommended as most bacteria do not withstand elevated temperature. Sensitization of the people on the importance of good hygiene should be carried out in the area.

Keywords: Evaluation, Groundwater Quality, Hand-dug wells, Lapai, Niger State

Introduction

Access to potable water is one of the important ingredients for sustainable development of any community. According to the World Health Organization, about 1.1 billion people globally do not have access to potable water supply while 2.4 billion people do not have access to good sanitation. Water is an essential resource for life and good health. It is so vital that it improves many health conditions such as chronic exhaustion, dehydration, toxin removal, poor blood circulation, waste removal and good kidney function. There is an increasing awareness that water will be one of the most critical natural resources in future due to the fact that about 2 million children less than 5 five years die annually in developing countries as a result of diarrhea diseases (WHO, 2008). According to WaterAid (2016) report, lack of potable water killed more people in Nigeria (about 73, 000) than Boko Haram (slightly above 4,000). This shocking revelation places importance on the need to regularly monitor the quality and source of our daily water supply. Water is an essential requirement of human and industrial development and the most delicate part of the environment and hence, monitoring of its quality is essential to guarantee a safe environment and healthy people. Water is a universal solvent and has the ability to dissolve and interact with organic and inorganic components of the aquifer material through which it migrates. These materials constitute the amount of total dissolved solids present in the groundwater which enhances its conductivity. This implies that groundwater chemistry is a function of the mineral composition and the formation as it moves from recharge to discharge areas which varies spatially and temporally depending of on the chemical nature of the water, mineralogy of the geological formations and residence time of the groundwater (Amadi, 2014).

For instance, research carried out by Etu-Efeotor (1998) on the hydrochemical analysis of surface and groundwater at Gwagwalada area of central Nigeria revealed that the surface has high concentration of nitrates, phosphates and sulphates in surface water are believed to have resulted from the human and agricultural activities in the area. Adakole *et al.* (2010) studied the quality characteristics of water in Samaru area showed that all the physical parameters considered conformed with the (WHO, 2008) standards, while some of the chemical parameters like total hardness, nitrate, chloride and sulphate of the samples do not conform to the standard. Aremu *et al.* (2011) evaluated the physiochemical properties of groundwater from hand-dug wells, boreholes and stream water in Bwari and its environs. The result showed that the water are slightly acidic, soft, fresh, have low to moderate chemical ions values and are classified as Ca-Na-HCO_3, Ca-K-HCO_3, Mg-Ca-HCO_3, and Na-K- HCO_3 water types.

Muhammed (2012) reported that over 90% of the water samples analysed from parts of Kaduna Metropolis is in conformity with the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) standard in term of physico-chemical quality. However, over 65% of the samples were contaminated by coliform. This confirms anthropogenic contamination of some of the groundwater in the study area. It also indicated that the borehole water is more potable than the shallow hand dug wells. Nur and Ayuni (2004) investigated on the water quality characteristics of groundwater in Jalingo metropolisshowed that some of the water samples do not conform to WHO (2006) permissible standard in terms of pH, iron, magnesium and coliform count. It further stated that the water samples have generally low concentration of anions and cations and classified the dominant water type in the area as $Na^{+}K^{-}Cl^{-}SO_4$ water type.

Adesida and Omosuyi (2005) analysed groundwater chemistry of weathered zone aquifers of an area underlain by basement complex rocks, Akure, Nigeria. The results show that there is a human activity imprint on the groundwater chemistry, which overshadows the normal expected influence of weathering and bedrock geology. Ako (1996) carried out the chemical quality of shallow groundwater from a metamorphic terrain of part of Southwest Nigeria. The study concluded that the pattern of nutrient concentration between surface and groundwater investigated show that the chemistry of the groundwater is dependent to a large extent on the host bedrock. Adekunle *et al.* (2007) evaluated the physico-chemical and biological quality of water sources in Southwestern Nigeria. They attributed the contamination/pollution of some of the water analysed to both geogenic and anthropogenic factors.

Ofodile (2002) determined the impact of human activities on groundwater quality of shallow aquifers in Jimeta-Yola. The study revealed elevated concentration for contamination/pollution tracers (NO_3^-, Cl^-, SO_4^{2-}) and electrical conductivity. They suggested that the contamination/ pollution is due to human activities. Olobaniyi and Owoyemi (2004) determined the groundwater quality in the deltaic plain sand aquifer of Warri area. They reported saltwater contamination in some of the samples based on high chloride content, low Ca/Mg and Na/Cl ratio. They stated that the water is suitable for domestic and industrial purposes in terms of its physico-chemical attributes. However, the presence of heterotrophic and coliform bacteria compromises this quality. Edet and Okereke (1997) assessed the contamination risk of coastal plain aquifers in Calabar by some potentially toxic elements. They concluded that the small scale mining activities, low concentration of elements, immobility of mineral species under the prevailing Eh-pH conditions, dilution and precipitation of mineral phases make contamination risk of the coastal plain sand very low.

Furthermore, the quality of surface and groundwater in Agaie, Bida, Minna, Suleja, Rafi and Zungeru areas of Niger State has been studied by many workers (Olasehinde and Amadi, 2009; Yisa and Jimoh, 2013; Olasehinde *et al.*, 2015; Amadi *et al.*, 2016). Such studies have not been carried out in Lapai Local Government Area of Niger State, North-central Nigeria. The need to ascertain the quality status of groundwater from shallow aquifers in the area was necessitated by the incidence of waterborne diseases such as cholera, typhoid and diarrhea among children in the area.

Materials and Methods

Study Area

Lapai is one of the local government areas of Niger State (Figures 1 and 2) and hosts the prestigious IBB University Lapai. It is accessible through Paiko-Lapai road and Bida-Agaie-Lambata road. The study area is characterised by two seasons: wet and dry seasons. The area records its highest temperature of about 35^{0}C during the dry season (November to March) while during the rainy season (April to October), the temperature drops to about 24°C (Annor *et al.*, 1990). The vegetation type is Guinea Savannah and the area is mostly dominated by shrubs and grasses sandwiched by tall trees (Dada, 2008).

Geologically, Lapai lies within a transition (contact) zone. The Pan African basement complex rocks of Minna overlap with the Cretaceous sediments from the Bida Basin (Ajibade, 1976; Obaje, 2009). The structural element displayed in the basement rocks (schist, granite and gneiss) as obtained through geological mapping indicates a NE-SW trend, which also correspond to the regional fracture pattern (Figure 3).

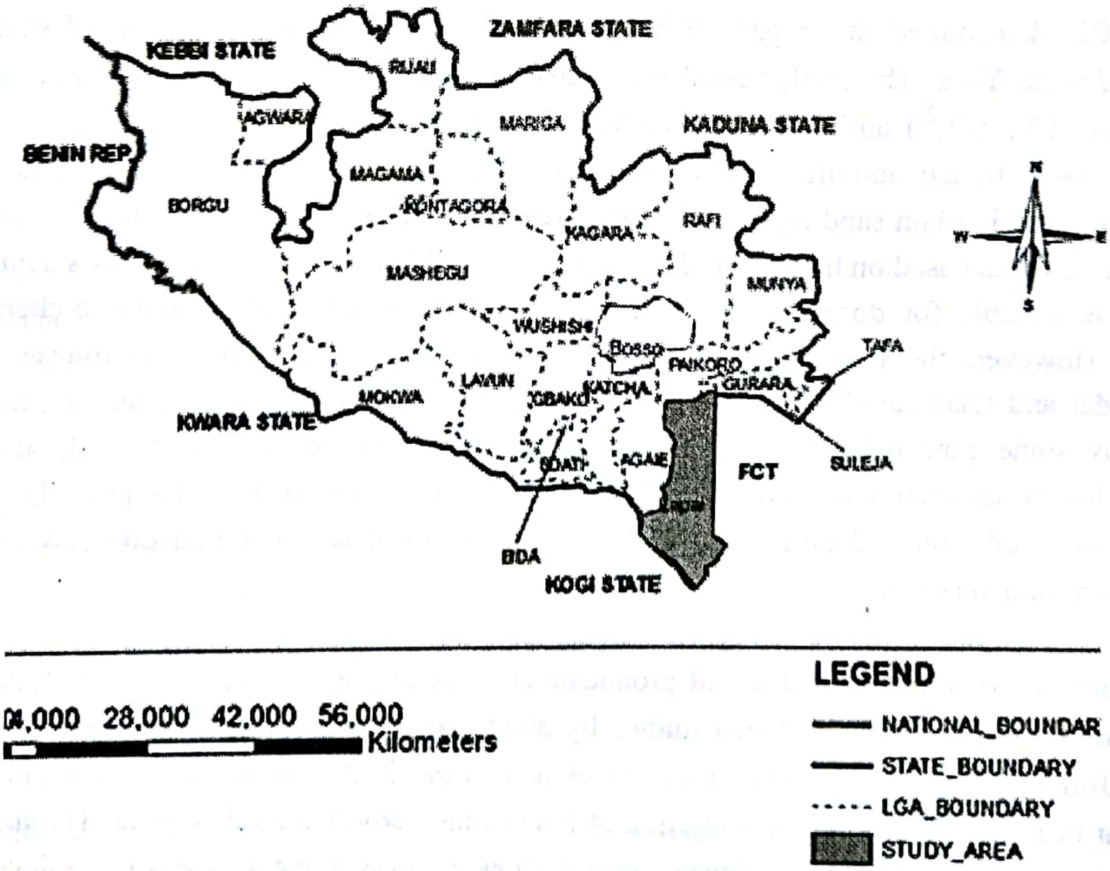

Figure 1: Map of Niger State showing Lapai Local Government Area.

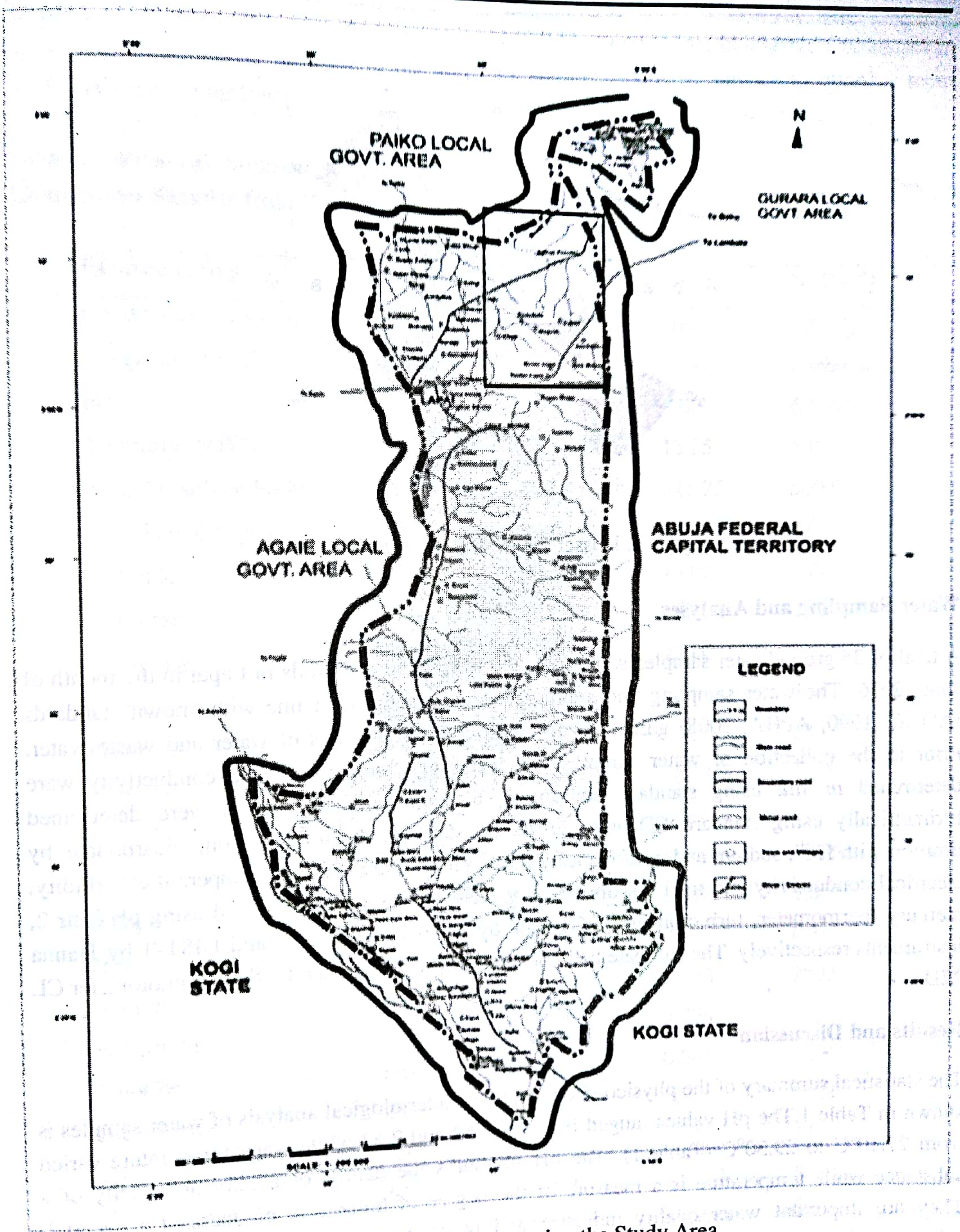

Figure 2: Map of Lapai Local Government Area showing the Study Area.

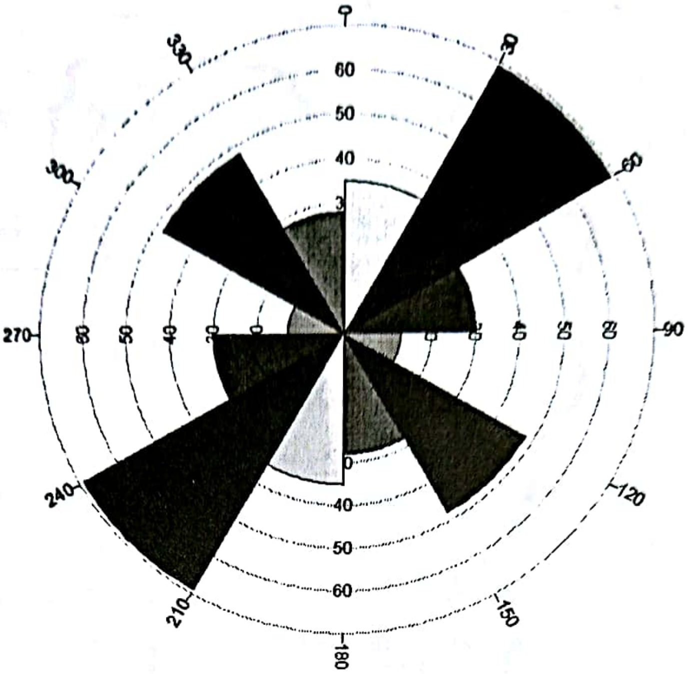

Figure 3: Rosset diagram for the study area.

Water Sampling and Analyses

A total of 35 groundwater samples were collected from hand-dug wells in Lapai in the month of June, 2016. The water sampling and analyses were carried out in line with known standards (AOAC, 1990; APHA, 2008) guidelines for sampling and analysis of water and waste water. Prior to the collection of water samples, the water pH, temperature and conductivity were determined *in situ* using standard equipment. Calcium and magnesium were determined titrimetrically using standard EDTA, chloride by standard $AgNO_3$ titration, bicarbonate by titration with HCl, sodium and potassium by flame photometry. The pH, temperature, turbidity, electrical conductivity and total dissolved solids were determined in the field using pHTestr 2, mercury thermometer, turbidiometer, ECTestr+ by Eutech Instruments and DIST-3 by Hanna instruments respectively. The sulphate and phosphate were determined by Spectrophotometer CL 22D.

Results and Discussion

The statistical summary of the physico-chemical and bacteriological analysis of water samples is shown in Table 1.The pH values ranged between 6.52 and 7.37 while water temperature varied from 27.10°C to 29.30°C (Table 1). The pH measures the degree of acidity or basicity of a substance while temperature is a measure of the degree of hotness or coldness of a material. They are important water quality indicator and plays important role in the dissolution of substances in water. The pH falls within the acceptable range of 6.50-8.50 recommended by

Nigerian Standard for Drinking Water Quality (NSDWQ, 2007). Many biochemical processes in water are influenced by changes in pH and temperature. Chemical substances dissolve more readily in water under low pH and high temperature conditions (Amadi *et al.*, 2013).

Table 1: Statistical summary of results of Physico-chemical and Bacteriological Analyses of Groundwater Samples from Hand-dug Wells in Lapai Area of Niger State

Parameters (mg/L)	Minimum	Maximum	Mean	NSDWQ
Conductivity (µs/cm)	176.00	1193.00	464.12	1000.0
Temperature (°C)	27.10	29.30	28.48	Ambient
pH	6.52	7.37	7.02	6.5-8.5
Turbidity (NTU)	0.00	52.00	13.25	5.0
Total Dissolved Solid	118.00	800.00	311.25	500.0
Dissolved Oxygen	4.40	7.36	6.08	8.0
Chloride	12.10	95.60	14.06	200.0
Hardness	66.00	261.00	167.00	150.0
Alkalinity	19.00	74.00	42.00	-
Nitrate	0.47	30.50	22.01	50.0
Calcium	18.30	59.40	29.20	200.0
Magnesium	2.44	32.60	18.71	20.0
Phosphate	0.11	1.41	0.66	-
Sulphate	18.00	88.00	40.50	100.0
Copper	0.12	1.48	0.77	1.0
Iron	0.07	0.65	0.19	0.3
Sodium	13.00	58.00	28.63	250.0
Potassium	3.00	13.00	7.375	-
Fluoride	0.00	1.28	0.541	1.5
Bicarbonate	0.00	5.00	0.85	100.0
Zinc	0.77	3.47	1.17	3.0
T.Coliforms (cfu/100ml)	10.00	445.00	150.30	10.0
E-coli (cfc/100ml)	5.00	225.00	65.50	0.0
Feacal Strepp (cfc/100ml)	8.00	305.00	85.40	0.0

Total dissolved solids (TDS) indicate the amount of substances dissolved in water. Its concentration ranged between 118.00 mg/L to 800.00 mg/L and a mean concentration of 311.25 mg/L while the concentration of electrical conductivity (EC) varied from 176.00 mg/L to 1193.00 mg/L with an average value of 464.12 mg/L (Table 1) as against their respective maximum permissible limit of 500.00 mg/L for TDS and 1000.00 mg/L for conductivity (NSDWQ, 2007). The EC and TDS are pollution tracers and important water quality indicators.It is an indication that certain materials or ionsare partially or completely dissolved in water. The water sample locations with elevated values correspond to hand-dug wells characterized by poor on-site-sanitation. The wide range observed in EC and TDS are proofs that the water in the area has deteriorated either anthropogenically or geogenically (Amadi, 2014). The turbidity value ranged from 0.00-52.00 NTU with a mean value of 13.25 NTU as against the allowable limit of 5.0 NTU. It was observed that the hand-dug wells with high turbidity value were not covered and possibility of unwanted material entering into these wells especially during rainfall cannot be overemphasised. The presence of suspended materials in water makes it turbid and this affect the colour and transparency of the water. Runoff also enhances the turbidity of these uncovered wells without build-up base. The total hardness ranged between 66.0-261.0 mg/L with a mean value of 167.00 mg/L while alkalinity content varied between 19.0-74.0 mg/L with an average value of 42.0 mg/L. The presence of calcium and magnesium ions is believe to be responsible for the hardness of water.

The dissolved oxygen (DO) is a measure of the amount of oxygen required to oxidize organic matter by bacterial action, it gives an idea of the oxidizable matter actually present in a water sample and allows pollution load evaluation to be established. The concentration of DO ranged between 4.40 mg/L to 7.36 mg/L with a mean value of 6.08 mg/L while (Table 1). These values are within the recommended limit of water for domestic use (WHO, 2008). The concentrations of the major anions (chloride, sulphate, bicarbonate, nitrate, phosphate) were observed to be far lower than their respective maximum acceptable limit (NSDWQ, 2007; Table 1) thereby indicating no pollution. High concentration of these anions (chloride, sulphate, nitrate and phosphate) in water especially in non-coastal areas may be attributed to urban/semi-urban pollution due to poor sanitation, leachate from dumpsites, industrial effluent and fertilizer application or geogenically induced via chemical weathering and bedrock dissolution (Dan-Hassan *et al.*, 2012; Amadi and Nwankwoala, 2013; Unuevho *et al.*, 2016; Akpah and Ezeigbo, 2010; Isiaku and Ezeigbo, 2010; Nwankwor and Etche, 1990).

Similarly, the concentration of the major cations (sodium, calcium, magnesium and potassium) was below their respective recommended permissible limit (NSDWQ, 2007; Table 1). The concentration of fluoride ranged from 0.00-1.28 mg/L and a mean value of 0.54 mg/L and these values are below the permissible limit of 1.5 mg/L (NSDWQ, 2007). High fluoride content in water causes dental and skeletal fluorosis in animals (Aminu and Amadi, 2014; Maspalma *et al.*, 2016; Okunlola *et al.*, 2016). The concentration of iron in the water ranged from 0.07 to 0.65 mg/L with a mean value of 0.19 mg/L while the concentration of zinc varied between 0.77 mg/L and 3.47 mg/L with an average value of 1.17 mg/L (Table 1) as against the maximum recommended value of 0.30 mg/l and 3.0 mg/l respectively (NSDWQ, 2007). Iron is an essential nutrient that is vital to the processes by which cells generate energy. High iron content in water does not constitute any health problem; rather it affects the colour and taste of the water. The high iron content in the groundwater from the shallow aquifer may be attributed to rock-water interaction especially at the contact zone where the basement rocks overlap the iron-rich (ferruginous) sandstone from the Bida Basin. The concentration of copper ranged between 0.12 to 1.48 mg/L with an average concentration of 0.77 mg/L and these values are slightly above the maximum permissible limit recommended value of 1.00 mg/l in few locations and may be attributed to decomposition and subsequent leachate of abandoned metallic objects, chemical weathering of rock and urban surface run-off (Ranjana, 2009; Amadi *et al.*, 2014; Olasehinde *et al.*, 2015).

The concentration of *Escherichia coli (E.coli)* ranged between 5.00-225.00 cfu/100mL with an average value of 65.50 cfu/100mL while *total coliform (TC)* varied from 10.00-445.00 cfu/mL and a mean value of 150.30 cfu/mL (Table 1). The concentration of *faecal strepp* is in the order of 8.00 cfu/mL to 305.00 cfu/mL with a mean value of 85.40 cfu/mL. The Escherichia coli and *coliform bacteria* cause foodborne and waterborne illness. They are commonly found in the intestines of animals and humans and their presence in water is a strong indication of recent sewage or animal/human waste contamination. During rainfalls *E.coli* from animal and human wastes especially via open defecation are transported into the open hand-dug wells and get them contaminated. The practice of open defecation or defecating along stream channels as currently practiced in the area reveals poor sanitation in the area and these platform favours bacteria contamination of water. Furthermore, siting of shallow hand dug wells near sewage track, unlined pit-latrine and soakaway exposes the shallow groundwater system in the area to faecal contamination and these explains the prevalence of waterborne diseases such as cholera, typhoidand diarrhea among children in the area. The upsurge in the population of Lapai due to students and staff of IBB University has exerted pressure on the shallow groundwater system and the associated impact on the water quality cannot be ignored completely. This is a true scenario of urbanization colliding with government failure to provide basic amenities thereby resulting in deterioration of the water regime. A correlation of the highest concentration of *total coliform*, *Escherichia coli* and *faecal strepp* in the groundwater samples and their corresponding maximum permissible values (Figure 3) further confirmed the fact that the groundwater from the hand-dug wells are poor in terms of microbial quality.

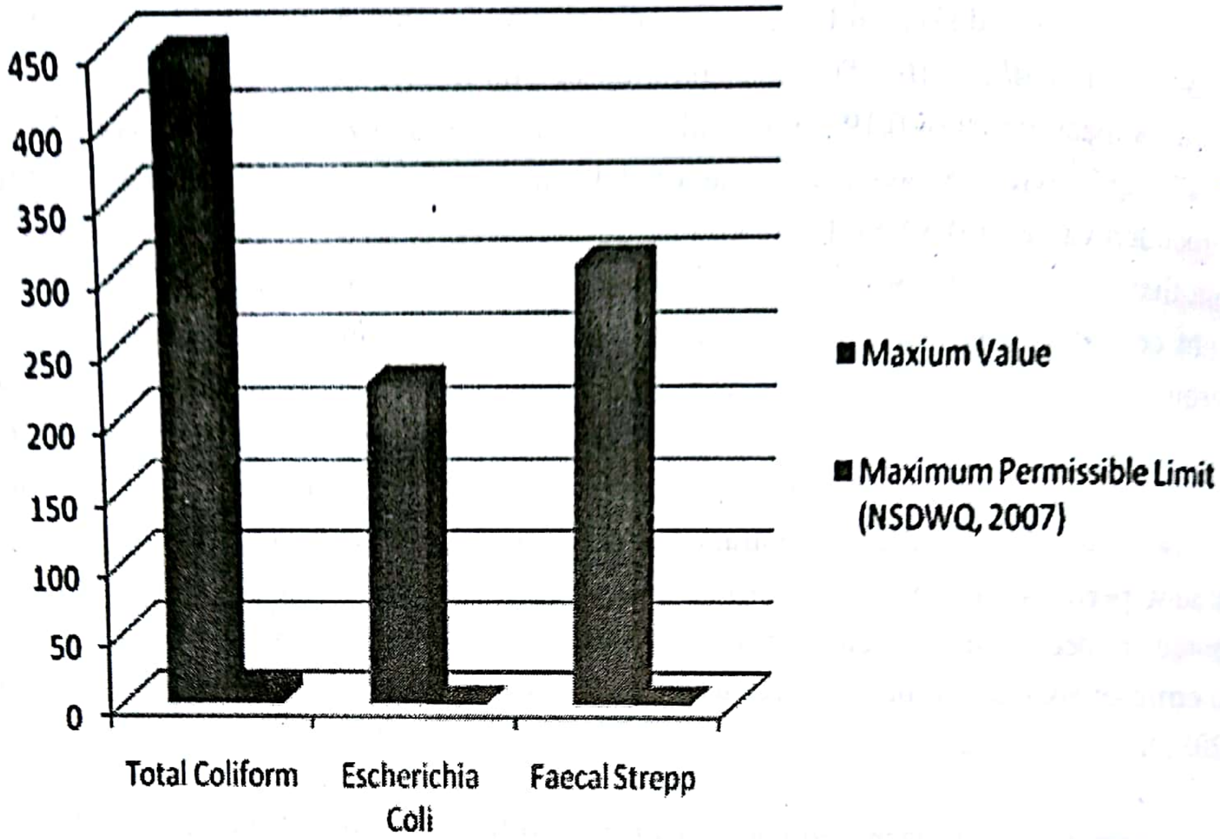

Figure 3: Bar chart of maximum concentration versus the maximum permissible limit of the analyzed bacteriological paramters.

Piper Diagram

This method was devised by Piper in 1944 to outline certain fundamental principles in a graphic procedure which appears to be an effective tool in separating analytical data for critical study with respect to sources of the dissolved constituents in water. Piper diagram consists of three parts: two trilinear diagrams along the bottom and one diamond-shaped diagram in the middle. The trilinear diagram illustrates the relative concentration of cations (left diagram) and anions (right diagram) in each sample. The concentration of 8 major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, CO_3^{2-}, HCO_3^- and SO_4^{2-}) are represented on a trilinear diagram by grouping the K^+ with Na^+ and the $CO_3^{2-}$with HCO_3^-, thus reducing the number of parameters for plotting to 6. On the Piper diagram, the relative concentration of the cations and anions are plotted in the lower triangles, and the resulting two points are extended into the central field to represent the total ion concentrations. The degree of mixing between freshwater and saltwater can also be shown on the Piper diagram. The Piper diagram (Figure 4) can also be used to classify the hydrochemical facies of the groundwater samples according to their dominant ions. The water type in the area is Ca-SO_4 water type, an indication of fresh shallow water from a basement terrain.

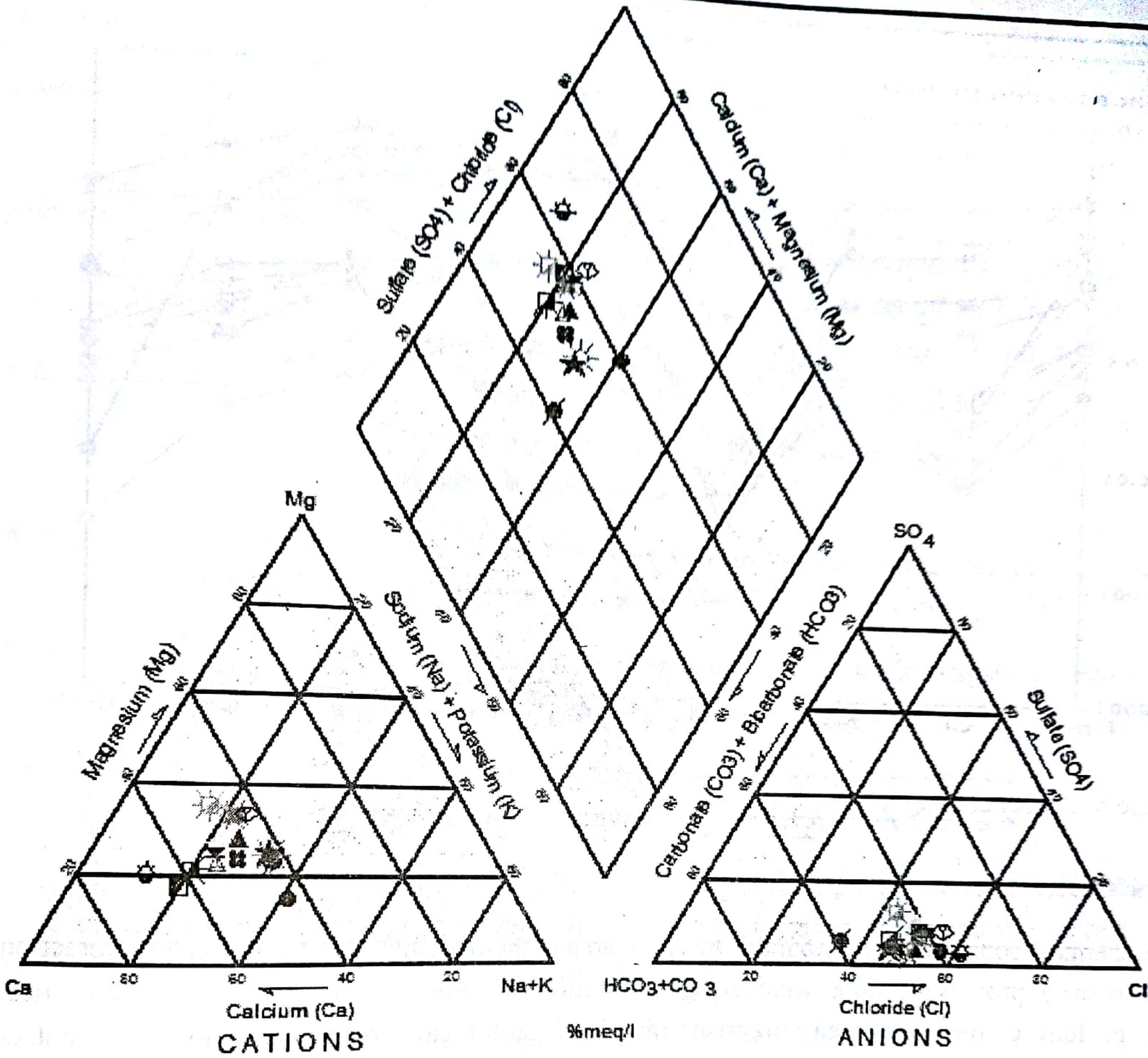

Figure 4: Piper Diagram

Schoeller-Plots

These semi-logarithmic diagrams were developed to represent major ion analyses in meq/l and to demonstrate different hydrochemical water types on the same diagram (Figure 5). This type of graphical representation has the advantage that, unlike the Piper diagram, the actual concentration of individual parameters are displayed and compared accordingly.

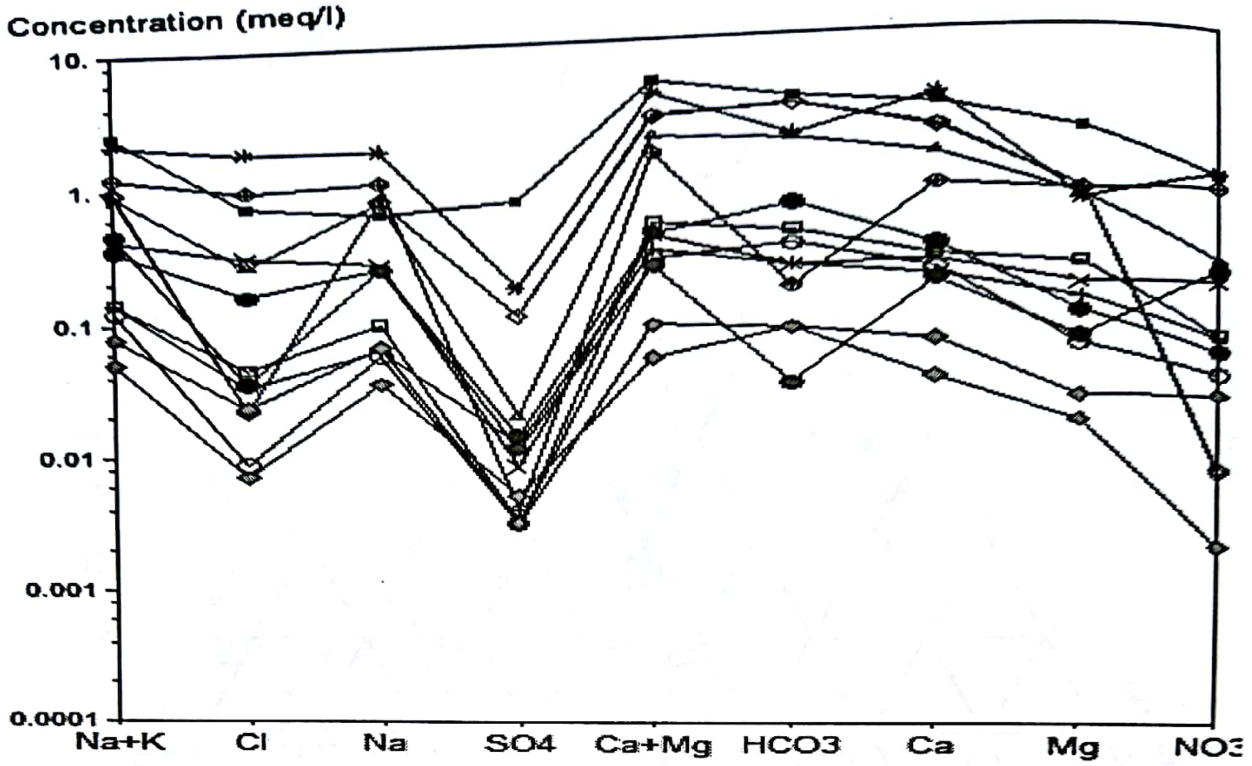

Figure 5: Schoeller Diagram.

Conclusions

The chemical composition of groundwater in an area is the imprints of the rock-water interaction and chemical processes such as weathering, dissolution and ionic exchange and human activities. The geology of the study area comprises of mixed geological terrain (transitional or contact zone). The principal joint trends in SE-NW direction, conforming with the regional trend. The results of the laboratory analysis indicate the concentration of the major cations and anions are within the permissible limit recommended by Nigerian Standard for Drinking Water Quality. The hydrochemical facies analysis revealed that water type in the area is Ca/Mg-HCO_3 water type, indicating fresh shallow water from Basement terrain. However, the water in the area is poor bacteriologically due to faecal contamination of the water in the area by human and animal faeces. These are responsible for water-borne diseases.

Recommendation

Due to the poor bacteriological conditions of the groundwater, boiling of water before drinking is advocated as most bacteria cannot withstand high temperature. The need to sensitize the people on the importance of personal hygiene and good sanitation is recommended. Grouting of the base and proper covering of hand-dug wells in the area to avoid entering of materials into the wells is suggested.

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