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Adebayo Olatunbosun Sojobi

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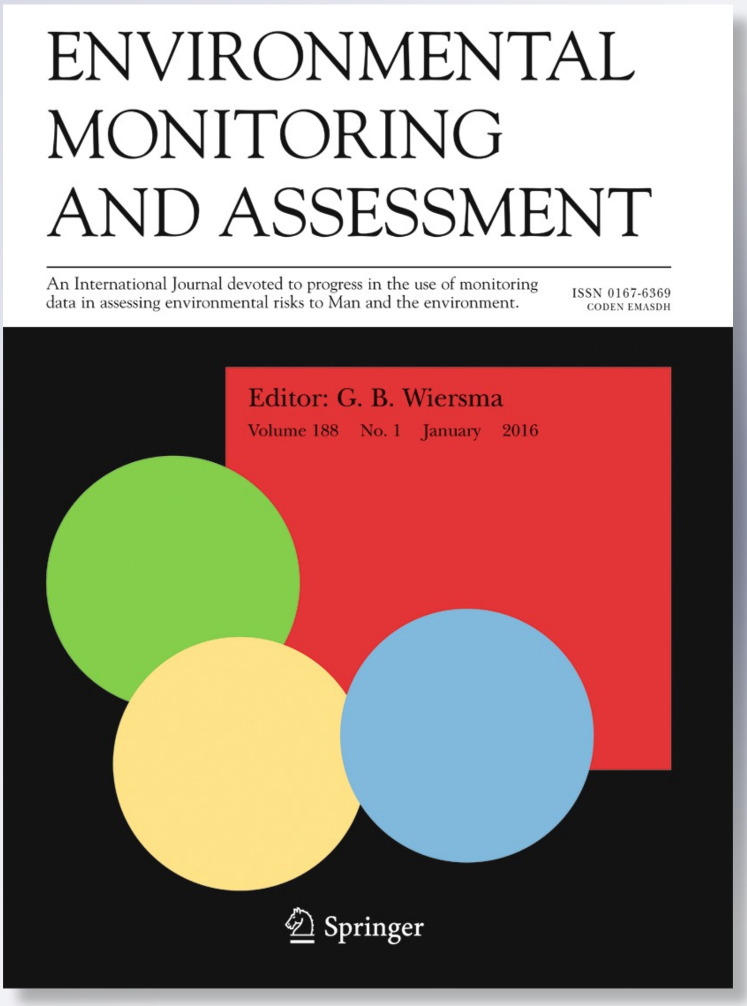

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Abstract Evaluation of water quality of nine boreholes and three open hand-dug wells in a rural community in North Central Nigeria revealed relative abundance of cations Na > k > Ca > Mg > Zn > Pb and anions $Cl^- > PO_4^{2-} > SO_4^{2-} > NO_3^-$ in the boreholes and cations Ca > Na > K > Mg > Pb and anions $NO_3^- > PO_4^{2-} > SO_4^{2-} > Cl^-$ in the wells. The major contaminants exceeding SON and WHO permissible limits were NO_3^-, Mg, TH, pH and Mg, Pb, TH, pH and DO in the wells and boreholes, respectively. They are attributable to anthropogenic sources such as domestic waste water and poor waste disposal and natural sources such as mineral dissolution from clayey aquifer which made the acidic groundwater unsuitable for consumption unless they are appropriately treated. Correlation studies revealed existence of three major mineral groups in the aquifer Ca-Fe group, Na-Mg group, Zn-K group, as well as a minor group Pb-group, and they determine the chemical composition of the groundwater and the ionic exchange between the groundwater and mineral-bearing clayey aquifer. In order to curb microbial contamination by *Enterobacter aerogenes* and *Escherichia coli*, it is recommended that proper latrines and drainages be provided while domesticated animals should be restricted from boreholes and well. Further, treatment with water guard and pur purifier is recommended.

A. O. Sojobi (✉)
Department of Civil Engineering, Landmark University, PMB 1001, Omu Aran, Kwara State, Nigeria
e-mail: adebayosojobi@gmail.com

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Introduction

Water is essential for supporting livelihoods, safeguarding public health, providing food security, ensuring environmental sustainability, promoting industrial and economic development, improving living standards, and achieving sustainable development (Dinka et al., 2015; Falkenmark, 2015; Gwenzi et al., 2015; Huang et al., 2014; Kumar et al., 2015; Mayzelle et al., 2015; Sobowale et al., 2015). It is estimated that about 3.4 billion people in developing countries are highly vulnerable to water insecurity which developed countries have overcomed through massive technological, management investments as reported by Vorosmarty et al. (2010) as well as infrastructural investments.

According to Estache (2008) and Tortajada (2002), efficient delivery of improved water services depends not only on the provision of infrastructure but also on well-planned, properly maintained and operated infrastructure, effective regulations, responsive and flexible institutions, efficient public and private operators, increased accountability, appropriate governance structures, sustainable financing, and effective public participation.

The inability of governments at federal, state, and local government levels to meet the basic water needs of their populations have resulted in economic, social, environmental, and health costs. The attendant results

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are poor water access in urban, peri-urban, and rural areas, high rate of premature mortality and morbidity, environmental pollution, consumption of contaminated, over-exploited and polluted groundwater, and surface water resources and decreased household income and productivity (Sojobi et al., 2014; Tortajada, 2002). Oyegoke et al. (2012) attributed the water demand-supply gap in Nigeria to the use of ad hoc isolated prescription, unsustainable initiatives, paucity of innovative solutions in planning and development, population explosion, faulty and poor maintenance culture, frequent power outage, poor planning, and lack of political will.

In order to close the infrastructural deficit gap, Sub-Sahara Africa (SSA) needs approximately \$93 billion (World Bank, 2011). Developing countries such as Nigeria would need to invest \$1.2–1.5 billion every year to provide necessary services such as safe drinking water, electricity, and good roads (Fay et al., 2010) while Estache (2008) recommended that not less than 8 % of their annual GDP must be expended on infrastructure.

It has been found that the problem of water quality in developing countries, Nigeria inclusive, is also a problem of water crises. Water crises in many parts of the world are caused by deficient water governance characterized by mismanagement, corruption, lack of appropriate institutions, bureaucracy, and lack of investment (Biswas and Tortajada, 2010; Gutierrez et al., 2013; UNESCO, 2009). These crises can be categorized as economic water crises, political water crises, institutional water crises, technological, operational, and water quality crises.

In order to address these crises, multi-focussed solutions embedding innovative financing, sustainable (community) water governance, citizen participation, post-construction guidance and support, institutional reforms, transparency and accountability, and poverty alleviation are required (Baguma et al., 2012; Biswas and Tortajada, 2010; Gutierrez et al., 2013; Sato, 2014; Taher et al., 2012; Tortajada, 2002; Tortajada, 2010; Wiek and Larson, 2012). In addition, it is high time water professionals realized that the heterogeneous nature of water problems which varies locally, regionally, seasonally, and yearly cannot be solved by them alone since they are interlinked with other development and social sectors (Biswas, 2008).

For rural people, the major sources of drinking water are groundwater from boreholes, shallow wells, and springs (Dwairo et al., 2006; NBS, 2010) and are often consumed without treatment which poses a threat to their health (Abatneh et al., 2014). Groundwater alone serves 25 % of human population in arid and semi-arid regions (Jackson et al., 2001; Oki and Kanae, 2006).

Groundwater quality is affected and determined by anthropogenic and natural processes which include hydrogeological condition of the aquifer, geochemical reactions, lithology, soil-rock water interactions, saline water intrusion, tidal fluctuation, agricultural activities, unplanned rural and urban development, industrialization, land use changes, improper solid and liquid waste disposal and management, groundwater pumping, proximity to and leaching from potential sinks such as poorly designed landfills, septic tanks, and drainage system, and quality of wells and boreholes (Akhtar et al., 2014; Al-ahmadi and El-Fiky, 2009; Huang et al., 2014; Kumar et al., 2015; Oni and Hassan, 2013; Oyelami et al., 2013; Porowska, 2014; Rao, 2014; Srinivas et al., 2013; Vasanthaviger et al., 2013; Wanke et al., 2015). Contaminants in groundwater vary from one location to another and include different kinds of microbes, organic and inorganic substances, anions, cations, heavy metals, and minerals as shown in Table 1. Water-related diseases associated with poor quality and contaminated water are listed in Table 2.

Materials and methods

The study area is Omu Aran located in Irepodun Local Government Area of Kwara State in the North Central region of Nigeria. Omu Aran is located on latitude 8.9^0 N and longitude 5.60 E while Kwara State is located on latitude 8^0 $30^/$N and longitude 5^0 $0^/$E (Sojobi et al., 2014). The vegetation is predominantly guinea savannah as shown in Fig. 1 while the climate is tropical maritime monsoon with about 8 months of heavy rainfall. The average annual rainfall, average annual maximum temperature, and annual mean relative humidity are 1262.8 mm, 35.8 °C, and 82.2 %, respectively (KWADP 2012).

Basic amenities such as piped-borne water and hospitals are grossly inadequate. Based on statistics provided by National Bureau of Statistics (NBS), 88.68 % of the population in Kwara State are poor, which is one of the highest in Nigeria and indicates extreme level of poverty as reported in a joint-report by NBS/UNICEF/UNFPA Joint (2011). Furthermore, 41.2 % of the households in Irepodun LGA shown in Fig. 2 rely on borehole

Table 1 Summary of groundwater results for some locations

Researcher(s)	Study area	Location	Contaminants	Remark	No of groundwater sources/samples
Wanke et al. (2015)	SW Omusati/Oshana, Okongo/Ohangwena, Omatjete/Omaruno, Okanguati/Kunene	Namibia	F, NO_3, SO_4, TDS, E-coli	Treatment before drinking and regular monitoring	44 shallow wells (1–3 m) 15 deep wells (up to 30 m)
Srinivas et al. (2013)	Tuticorin	India	EC, pH, TDS, Ca, Mg, Na, K, TH, Cl	Groundwater is unfit for irrigation	21 wells (10-m depth)
Vasanthaviger et al. (2013)	Thirumanimuthar	India	TDS, EC, Na^+, Cl^-, HCO_3^-, PO_4, K^+, F^-, pH, SO_4^{2-}, $H_4S_20_4^-$, Br^-	Spatial groundwater characterized by hydrogeochemical regimes	194 samples
Rao (2014)	Andhra Pradesh	India	EC, Na^+, Cl-, SO42-, Mg2+, $Ca2^+$	Remediation required	30 samples
Oyelami et al. (2013)	Ido Osun (Osun State)	Nigeria	Cl-, Na, Mn	Regular assessment and monitoring & improved waste management required	20 wells
Porowska (2014)	Otwock	Poland	HCO_3^-, Cl^-, Ca^{2+}, Mg^{2+}, Na, K, Fe, DOC	Landfill must be engineered to control leachate impact on groundwater quality	32 samples (1–2.7 m)
Oni & Hassan (2013)	Aba-Eku (Ibadan)	Nigeria	Pb, Cd, Fe	Remediation of landfill and surrounding groundwater required	2 wells
Akhtar et al. (2014)	Lahore	Pakistan	TDS, Turbidity	Monitor and protect aquifer against continuous contamination	340 wells
Akinyemi & Souley (2014)	Abeokuta North, Ifo, Obafemi, Obafemi Owode, Odeda	Nigeria	pH, Mg	Treat groundwater before drinking and irrigation	1 spring, 1 well, 1 borehole
Al-ahmadi & El-Fiky (2009)	Wadi Marwani	Saudi Arabia	pH, TDS, Mg, Na, SO4, Cl, NO3	Groundwater safe for drinking	16 wells (5–15.3 m)
Bacquart et al. (2015)	Myingyan and Tha Pyay Thar	S. & SE Asia	As, Mn, U, F, Fe	Regular drinking water testing	20 wells

Table 2 Water-related diseases caused by some contaminants in water

Parameters	Causes	Diseases	Source
Ph		Gastrointestinal irritation	Khan et al. (2013)
SO_4	Fertilizer contamination	Laxative action	WHO (1996)
NO_3 and NO_2	Over-application of fertilizer, sewage disposal, manure application, wastewater, leakage, landfill leachate, municipal runoff	Methemoglobinemia in infants	Khan et al. (2013), Saeedi et al. (2012)
Pb		Subencephalopathic, neurological, and behavioral effects	WHO (1993)
	Acute toxicity	Tiredness, lassitude, abdominal discomfort, irritability, anemia and behavioral changes	Gerlach et al. (2002)
	High levels of Pb in children	Convulsion, neurological damage, organ failure, coma, and death	Khan et al. (2013)
	Moderate levels of Pb	Hearing loss, inhibit growth, learning disabilities	Khan et al. (2013)
	Accumulative toxicity	Lead poisoning, harm stomach, intestine, and stomach	Shu et al. (2011)
Cd	High toxicity	Kidney disease, anaemia, chronic poisoning leading to albuminuria, and osteomalacia	Shu et al. (2011)
Hg	Accumulative toxicity	Harm nervous system, heart, kidney, intestines, and stomach	Shu et al. (2011)
Cu		Harm liver, cardiovascular disease and coronary heart disease	Shu et al. (2011)
Mn		Cartilage growth disturbances when deficit, arthroncus and soft bone, Mn-poisoning, manganese-related madness, and pneumosclerosis	Shu et al. (2011)
Zn		Retard intelligence development and cardiosvascular, sickness, vomiting	Shu et al. (2011)
Cr^{6+}		Contact dermatitis and respiratory cancer	Shu et al. (2011)
As	High concentration	Sickness, stomach ache, diarrhea, inflammatory bowel disease, edema or even death, hernolytic anemia, jaundice, red blood cell disruption	Shu et al. (2011)
Ca	Deficiency	Osteoporosis and hypertension	Yang and Chiu (1999)
Mg	Deficiency	Vasocontrictions, hypertension, cardiac arrhythmia, atherosclerotic vascular disease, acute myocardial infarction, preeclampsia in pregnant women, diabetes miletus, osteoporosis,	Melles and Kiss (1992); Yang et al. (2002)
	Water low in Mg	Increased morbidity and mortality, cardiovascular disease, higher risk for motor neuronal disease, pregnancy disorders, preeclampsia, fracture in children, neurodegenerative disease, preterm birth, low weight birth, cancer	Verd et al. (1992)

while 31.2 % rely on wells as their major sources of water for drinking and cooking (NBS, 2010).

Water samples for this study were collected between August 4 and September 11, 2014 from nine (9) boreholes (wells with electric pump) and three (3) hand-dug wells (artificial pumpless wells). Samples were collected at each site weekly with the aid of new high-density PET screw-capped containers of 1.5-L capacity. Water from the boreholes was allowed to run for 5 min, immediately followed by reduction in the water flow in order to avoid splashing during filling of bottles. Gases were removed from the bottles by filling and emptying the bottles before the collection of actual water samples. For hand-dug wells, the water was given a little disturbance with a drawing bucket for about five consecutive times to allow for proper mixing of the well water before

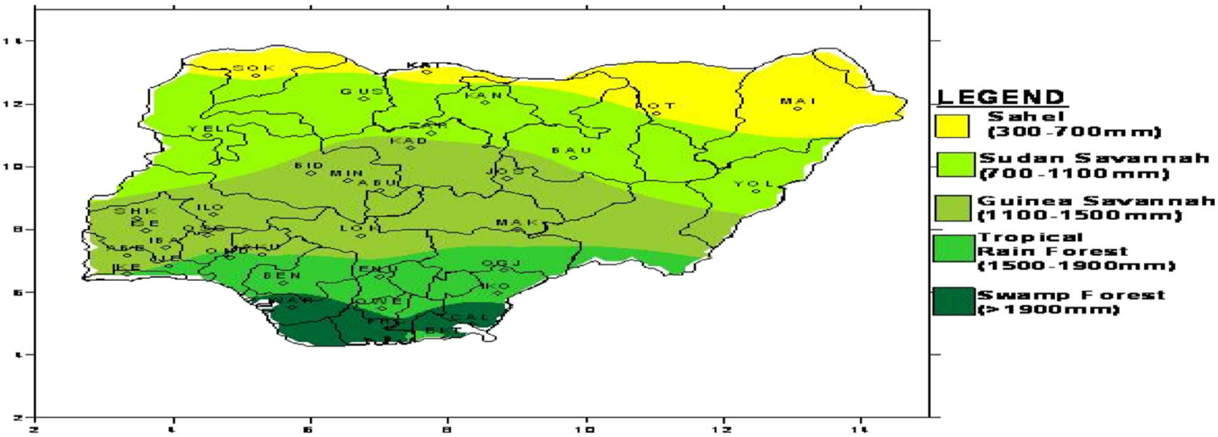

Fig. 1 Map of Nigeria showing the vegetation zones

the actual samples were drawn out. In each case, the PET bottles and stoppers were thoroughly washed with distilled water for three times and thrice with the water to be sampled before actual sample collection (Dahunsi et al., 2014).

At each site, one bottle was filled with water, having no added acid while the other bottle was filled with the water from the same point and acidified by adding a few drops of 5 % HNO_3 to stop microbial proliferation. At the same time, samples for microbial analysis were collected using autoclave-sterilized sample bottles from the same locations (Dahunsi et al., 2014). The water samples were preserved in a refrigerator at 40° C to keep the water content intact before they were transported within 3 hours in an ice cooler at 4 °C to Central Research Laboratory of the Federal University of Technology, Akure, in Ondo State, Nigeria, for physical, chemical, and microbiological analyses.

Physical parameters including pH (HI 9024-C, Hanna Instruments, Smithfield, RI, USA), temperature (HI 98517, Hanna Instr.), salinity (HI 19311, Hanna Instr.), electrical conductivity (HI 2315, Hanna Instr.), and total dissolved solids (TDS) (VSI 22, VSI Electronics Private Limited, Punjab, India) were analyzed in situ using the aforementioned hand digital meters. Dissolved oxygen was analyzed using the azide modification of Winkler's method as described in APHA (1992). Chloride content was determined by titration according to the method described in (Dahunsi et al., 2014). Determination of the major anions was carried out using ultraviolet (UV) spectrophotometer screening method (APHA, 2012) using a UV spectrophotometer (DR 2800, HACH, Washington, USA) (Dahunsi et al., 2014; Khan et al., 2013; Ayandiran et al., 2014). To maintain reliability and reproducibility in the analyses, the blank, standard, and pre-analyzed were done after every 10 samples

Fig. 2 Showing location of Irepodun LGA in Kwara State and the surrounding States

(Dahunsi et al., 2014). Standard methods were used to determine the total viable and coliform bacteria counts as the most probable number (MPN) in water samples as described in APHA (2012). Metal analyses were done with the aid of atomic absorption spectrophotometer (AAS) (Sens AA 3000, GBC, Australia) using the method in APHA (2012). For each water parameter, the average values obtained in the baseline for boreholes and well water samples were recorded.

Results and discussion

Physico-chemical properties

The results displayed in Table 3 showed that the relative abundance of the major cations and anions in the boreholes were Na > k > Ca > Mg > Zn > Pb and $Cl^- > PO_4^{2-} > SO_4^{2-} > NO_3^-$, respectively. For the wells, the relative abundance of the major cations and anions were Ca > Na > K > Mg > Pb and $NO_3^- > PO_4^{2-} > SO_4^{2-} > Cl^-$, respectively. Our findings were different from the relative cations and anions obtained by Devic et al. (2014) which were Ca > Mg > Na > K and HCO_3^-, $SO_4^{2-} > Cl^- > NO_3^-$, respectively.

Based on Freeze and Cherry (1979) classification, the groundwater in the study area can be described as freshwater (TDS < 1gL^{-1}) since both the boreholes and wells have mean TDS values of 0.23 and 0.42 mg/l values. The freshwater nature of the groundwater was also corroborated by their mean EC values of 300 and 530 ms/cm, respectively, which was < 1500 μs/cm for freshwater according to Mondal et al. (2008). These results also indicate that borehole water was clearer than well water and contained less dissolved substances even though they have the same mean turbidity value of 0.01 NTU. Their apparent low turbidity (<0.01), which is very good (Akhtar et al., 2014), could be very deceptive as a clean source of drinking water that does not require treatment. However, their pH (<6.5) revealed that they were acidic according to Akhtar et al. (2014) which could lead to gastrointestinal irritation (Khan et al., 2013) and require alkaline treatment in order to improve their pH to the acceptable range of 6.5–8.5 as shown in Table 4 (SON, 2007; WHO, 2006). Sojobi et al. (2014) attributed their acidic nature to the geological formation of the area, and their average TDS was below the SON and WHO permissible limits of 500 mg/l. Similarly, Akinyemi and Souley (2014) found pH to a problem in groundwater resources in Ogun State and recommended treatment before drinking.

Further, the boreholes and wells with mean total hardness (TH) values of 178.67 and 210 mg/l could be classified as moderately hard (150–200 mg/l) and hard (200–300 mg/l), respectively, based on classification of Abd El Salam and Abu-Zuid (2015) and were higher than the SON permissible limit of 150 mg/l required for drinking water. Nonetheless, the TH of the boreholes was highly variable with a higher standard deviation (SD) of 122.85 compared to that of wells of 4.08. Hard water promotes deposition of metals in water pipelines, precipitation of the metals during treatments which has the potential to reduce the efficiency of water treatment. In addition, hard water causes more expense of soap when used for laundry purposes owing to its low-foaming ability. Results of correlation studies revealed that the major ions contributing to the hardness were Na, Ni, K, and Mg.

The mean value of DO (6.5 mg/l) for well was within the SON permissible limit of 7.5 mg/l while that of borehole (7.91 mg/l) exceeded it, even though both of them were above WHO permissible limit of 4 mg/l. The level of their DO could be traced to their BOD_5. Borehole had higher mean BOD_5 of 3.4 mg/l compared to well with mean value of 2.60 mg/l. Their low BOD_5 which was below SON permissible limit of 6 mg/l indicated low organic pollution, with boreholes having a higher organic pollution. The higher organic pollution of the borehole could be linked to poor construction of the boreholes and their location to possible sources of pollution such as domestic wastewater effluents and sewage tanks. This was also buttressed by the fact that borehole had higher mean *Escherichia coli* level of 658.33 cfu/ml compared to well with mean value of 570 cfu/ml.

Besides, the boreholes were also found to have mean yeast concentration of 403.67 cfu/ml which was also higher than 160 cfu/ml obtained for well. In contrast, well had total coliform (TC) of 1100 which was greater compared to the mean concentration of 803.33 obtained for the boreholes.

The mean sodium (Na) concentrations of the boreholes (8.67 mg/l) and wells (12.8 mg/l) were below the SON and WHO permissible limit of 200 mg/l but were lower compared to their corresponding mean chloride concentrations of 69.42 and 4.5 mg/l. This suggests preponderance of halite sources as a major source of chloride ion for the boreholes. Similarly, the chloride

Table 3 Statistics of physico-chemical analyses of the groundwater resources of the study area

Parameters	Borehole					Wells				
	No. data	Max	Min	Avg	SD	No. data	Max	Min	Avg	SD
Turb (NTU)	54	0.01	0.001	0.01	0.00	18	0.03	0.01	0.01	0.01
EC (ms/cm) x 10^2	54	3.4	2.75	3.00	0.23	18	5.35	5.25	5.30	4.08
pH	54	5.75	5.68	5.72	0.00	18	5.37	5.35	5.36	0.03
TS (mg/l)	54	0.73	0.16	0.37	0.24	18	0.47	0.45	0.46	0.01
TDS (mg/l)	54	0.34	0.15	0.23	0.07	18	0.43	0.41	0.42	0.01
TH (mg/l)	54	354	80	178.67	122.85	18	215	205	210	4.08
DO (mg/l)	54	8.10	7.95	7.91	0.11	18	6.52	6.48	6.5	0.02
BOD_5 (mg/l)	54	3.60	3.10	3.40	0.16	18	2.65	2.55	2.60	0.04
Cl (mg/l)	54	123.50	41.00	69.42	72.06	18	4.60	3.50	4.5	0.08
$N0_3$ (mg/l)	54	4.30	3.40	3.77	1.86	18	96.30	96.20	96.25	0.04
SO_4 (mg/l)	54	6.10	5.20	5.60	0.31	18	5.55	5.45	5.5	0.04
PO_4 (mg/l)	54	15.60	12.20	14.27	1.41	18	15.65	15.55	15.6	0.04
Cd (mg/l)	54	ND	ND	ND	ND	18	ND	ND	ND	ND
Pb (mg/l)	54	0.04	0.00	0.03	0.00	18	0.05	0.03	0.04	0.01
Cr (mg/l)	54	ND	ND	ND	ND	18	ND	ND	ND	ND
Ni (mg/l)	54	0.01	0.00	0.00	0.01	18	ND	ND	ND	ND
Zn (mg/l)	54	0.29	0.02	0.11	0.11	18	ND	ND	ND	ND
Fe (mg/l)	54	ND	ND	ND	ND	18	0.01	0.01	0.01	0.00
Na (mg/l)	54	12.95	6.45	8.67	2.99	18	12.85	12.75	12.8	0.04
K (mg/l)	54	12.95	2.25	7.24	4.36	18	5.10	4.90	5	0.08
Ca (mg/l)	54	7.05	1.90	3.67	2.36	18	22	20	21.00	0.82
Mg (mg/l)	54	0.94	0.75	0.84	0.07	18	0.92	0.90	0.91	0.01

Turb turbidity, *EC* electrical conductivity, *Max* maximum, *Min* minimum, *Avg* average, *SD* standard deviation

concentrations were below SON permissible limit of 250 mg/l. The high SD (±72.06 mg/l) of the chloride concentrations portrays the high variability of this halite sources within the area while the variability for the well is insignificant with SD value of 0.08. Na causes scale formation and corrosion in boilers as mentioned by Todd (1980). Also, high Na suggests strong water-aquifer interaction related to either cation exchange or anthropogenic pollution from wastewater and septic tanks according to Wayland et al. (2003).

The mean concentrations of magnesium (Mg) in both the boreholes (0.75 mg/l) and wells (0.91) were found to exceed SON permissible limit of 0.2 mg/l as depicted in Fig. 3(a). Mg is attributed to Mg-rich carbonates in the aquifer of both the boreholes and wells such as basalts, kaolinite, and hematite according to Trostle et al. (2014). Likewise, Nwankwoala et al. (2014) found Mg range of 0.52–1.23 mg/l with mean values of 0.89 mg/l for boreholes in Yenagoa which was attributed to Mg dissolution from minerals such as feldspar and mica while a range of 68–173 mg/l was obtained for groundwater in Manali region of India by Antony et al. (2008). Also, Devic et al. (2014) linked Mg in groundwater of Serbia to domestic effluents, minerals, and application of chemical fertilizers. Nonetheless, for adults, hard water rich in magnesium was associated with decrease in cardiovascular diseases as mentioned by Anne (2011).

The mean nitrate (NO_3) concentration in well (96.25 mg/l) exceeded the SON permissible limit of 50 mg/l as depicted in Fig. 3(b) while surprisingly, the mean nitrate concentration of boreholes (3.77 mg/l) was below the limit. High nitrate range of 0.02–42.45 mg/l was also reported by Devic et al. (2014) and was linked to anthropogenic sources. High nitrate concentration causes methemoglobinemia in infants (Khan et al., 2013; Saeedi et al., 2012) and some cancers according to Ward et al. (2005). Therefore, it is imperative to

Table 4 Comparison of well and borehole sample parameters with drinking water guidelines by WHO (2006) and SON (2007)

Parameter	WHO	SON	Samples which exceed WHO and SON permissible limits
Cadmium, Cd (mgL^{-1})	0.003	0.003	ND
Chloride, Cl (mgL^{-1})	–	250	None
Chromium, Cr (mgL^{-1})	0.050	0.050	ND
Copper, Cu (mgL^{-1})	2.000	1.000	–
Iron, Fe (mgL^{-1})	–	0.300	None
Lead, Pb (mgL^{-1})	0.001	0.010	All
Zinc, Zn (mgL^{-1})	–	3.000	None
Nickel, Ni (mgL^{-1})	0.020	0.020	None
Nitrate, NO_3^- (mgL^{-1})	–	50.000	Well 1, Well 2, Well 3
pH	–	6.5-8.5	All (Acidic)
Sulfate, SO_4^{2-} (mgL^{-1})	500	100	None
Total coliform cfu/mL	0×10^2	10	All
E. coli count cfu/mL	0×10^2	–	All
Electrical conductivity ($mScm^{-1}$)	1000	1000	None
Total suspended solids (mgL^{-1})	–	–	
Total solids (mgL^{-1})	–	–	
Total dissolved solids (mgL^{-1})	500	500	None
Total hardness (mg/l)		150	BH7,BH8, BH9, Well 1, Well 2, Well 3
Salinity (%)	–	–	
Turbidity (NTU)	1	5	None
Magnesium (Mg) (mgL^{-1})	200	0.2	All
Calcium (Ca) (mgL^{-1})	200		None
Sodium (Na) (mgL^{-1})	200	200	None
Dissolved Oxygen (mgL^{-1})	4	7.5	All
BOD_5 (mgL^{-1})		6	None

WHO World Health Organization, *SON* Standards Organization of Nigeria

ensure infants are given alternative potable water or ensure that groundwater sourced especially from boreholes only is given to infants and that they are treated before consumption. High nitrate concentration

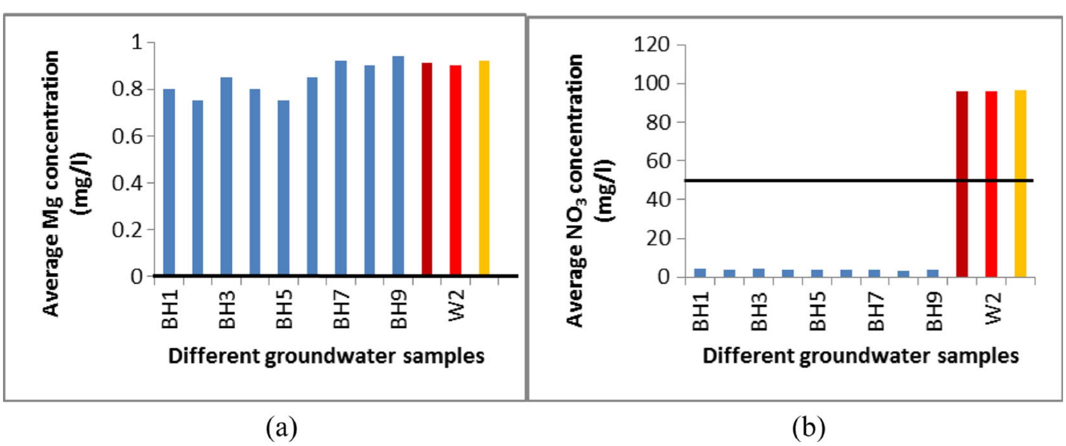

Fig. 3 **a** and **b** showing average concentrations of Mg and NO_3 in boreholes and wells

> 3 mg/l is usually associated with anthropogenic pollution sources such as poor septic systems and poor disposal of domestic wastewaters as mentioned by Kim et al. (2014) which is prevalent in the study area. Besides, most of the wells are open and poorly maintained which increases their susceptibility to anthropogenic pollutants. Nitrate, which is a key index of anthropogenic pollution according to Han et al. (2014), can be removed from groundwater by Pur Purifier which achieved 92.3 % removal efficiency according to Sojobi et al. (2015), through the use of nano-sized magnetite which achieved nitrate removal efficiency range of 67.3–79.1 % as mentioned by Cho et al. (2015) and combination of nano-filtration and reverse osmosis as described by Epsztein et al. (2015).

The presence of lead (Pb) in both the borehole and well water samples is of health significance. The mean Pb values of 0.03 and 0.04 exceeded the SON and WHO recommended limits of 0.01 and 0.001 mg/l as depicted in Fig. 4(a). Pb was also reported by Oni and Hassan (2013) for a site close to a landfill. Hence, the source of Pb could be attributed to disposal of domestic waste materials containing Pb close to the wells and boreholes owing to the poor waste disposal practices, absence of centralized disposal system in the study area, and absence of industrial activities in the area. Pb could cause subencelophalopathic and neurological disorders as reported by WHO (1993). Moderate levels of Pb could lead to hearing loss, inhibit growth, and learning disabilities while high levels of Pb could cause convulsion, organ failure, coma, and death (Khan et al., 2013) as well as tiredness, abdominal discomfort, and anemia as reported by Gerlach et al. (2002). Accumulative toxicity of Pb could lead to Pb poisoning which harms the stomach (Shu et al., 2011). Exposure to high dose of Pb could also lead to miscarriage in pregnant women and could damage male organ of reproduction as reported by Sojobi et al. (2014).

The mean phosphate concentration obtained for borehole of 14.27 mg/l was lower than 15.6 mg/l obtained for well water although both were less than the phosphate concentration in public tap of 27.5 ± 0.9 mg/l reported by Sojobi et al. (2014) but higher than the range of 6.9–19.9 mg/l reported by Ishaku et al. (2011) for boreholes in Mararaba-mubi, Northeast of Nigeria, who attributed the sources to organic decomposition, domestic effluent, and sewage and fertilizer. The mean sulfate concentrations in both boreholes and wells were 5.6 and 5.5 mg/l, respectively, and were within the SON permissible limits of 100 mg/l. Also, they were found to be lower compared to the range of 12–36.3 mg/l with mean of 20.4 obtained for groundwater located in Mararaba-mubi, Northeast of Nigeria (Ishaku et al., 2011). Correlation studies revealed a high positive correlation ($R^2 = 0.82$) between sulfate and Pb. It could portray that they have similar anthropogenic origin. This suggests that domestic wastewater from the area contains both ions. Therefore, residents should endeavor to dispose wastewaters in the provided drainage and far away from boreholes and wells where there is no provision of drainage.

The mean Ca concentrations of 3.67 and 21 mg/l of both the boreholes and wells were lower compared to 49.3 mg/l reported by (Viswanath et al., 2015) but were higher when compared to 2.97 mg/l for Yenagoa (Nwankwoala et al., 2014) which is a riverine area. This could suggest that Ca concentration decreases towards the coast. The mean Ca concentration was within the SON permissible limit of 200 mg/l. Nwankwoala et al. (2014) attributed the Ca concentration to dissolution of feldspars and micas while (Kim et al., 2014) attributed Ca to precipitation of carbonate minerals during silicate dissolution. Similarly, the mean Potassium (K) concentration in the boreholes and wells were 7.2 and 5 mg/l, respectively, and were higher than the mean of 4.9 and 0.91 mg/l obtained by Ishaku et al. (2011) and Trostle et al. (2014)], respectively. The high correlation between Ni ($R^2 = 0.92$) and Zn ($R^2 = 0.89$) suggests similar source of origin which could be from the aquifer rocks and minerals.

Trace elements such as Cr and Cd were not detected in both the boreholes and wells while Ni, Zn, and Fe were of insignificant concentrations in the groundwater of the study area. Though Cd was not detected in all the water samples, exposure to lower Cd for a long time could cause kidney diseases while exposure at high dosage level could lead to vomiting, albuminuria, and osteomalacia (Sojobi et al., 2014; Skrzypek et al., 2013).

Correlation analyses

For our study, the following classifications were used: perfectly correlated ($R^2 = 1$), very strongly correlated ($\pm 0.9 \le R^2 \le 1$), strongly correlated ($\pm 0.7 \le R^2 < \pm 0.9$), moderately correlated ($\pm 0.5 \le R^2 < \pm 0.9$), and poorly correlated ($R^2 < \pm 0.5$). Correlation values for all the parameters were shown in Table 4. The correlation studies revealed that the major cations contributing to

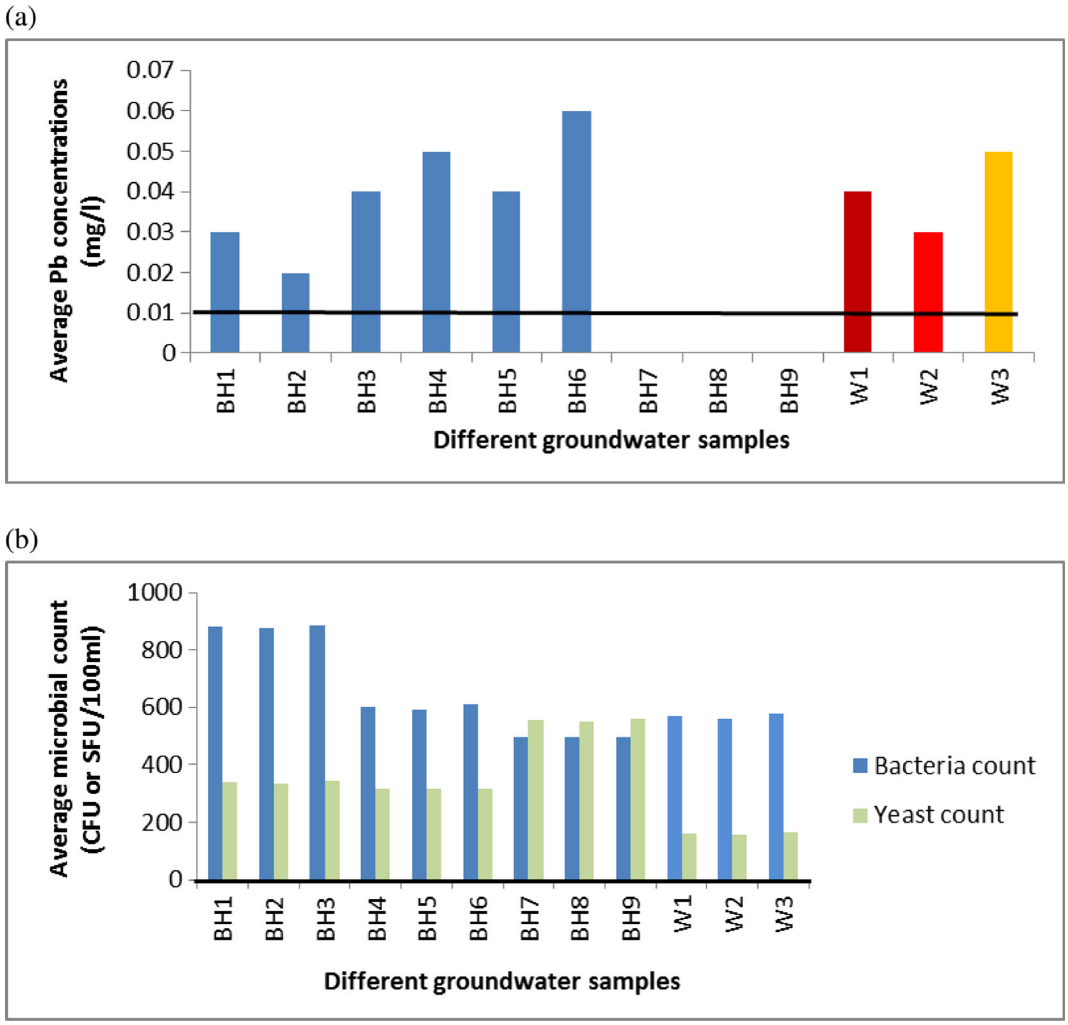

Fig. 4 **a** Average Pb concentration in boreholes and wells. **b** Average microbial count in boreholes and wells

TS which are very strongly and strongly correlated to TS are Na (0.91), K (0.86), and Mg (−0.84) while in terms of TDS, the major contributing cations which have strong and very strong correlations with TDS are Ca (0.92), Na (0.90), Mg (0.87), and Fe (0.80), as well as the anions NO_3 (0.80) and DO (0.84). This finding corroborates the results obtained by Viswanath et al. (2015) that Ca is the most significant parameter for predicting TDS. Our results also showed that the second and third most important parameter for predicting TDS were Na and (0.90) and Mg (0.87) for our study area. Of all the cations, Na with correlation value of 0.89 is the major contributor to total hardness alongside Ni, K, and Mg with correlation values of 0.89, 0.88, and 0.81, respectively, and the anion, PO_4 with negative correlation value of −0.82. The correlation results revealed that the three major mineral groups responsible for TH, TS, and TDS in the groundwater are Ca-Fe group (0.96), Na-Mg group (0.89), and Zn-K group (0.89), which seem to control the chemical composition of the groundwater. The fourth mineral group is the Pb group.

While chloride ion (Cl^-) is associated with the Zn-K group with strong/very strong correlations (0.97/0.84), NO_3 is linked with Ca-Fe group with perfect/very strong correlations (1.00/0.96). Mg and Ca did not show any correlation with any of the anions studied. It is likely the Mg^{2+} and Ca^{2+} are associated with bicarbonate minerals (HCO_3^-) as mentioned by Skrzypek et al. (2013). The major anions associated with Pb are SO_4^{2-} and PO_4^{2-}. Pb and Ni had strong negative correlation value of −0.87 which suggests a high dependency on each other and possible similar anthropogenic source (Devic et al., 2014), and they both have low concentration level in the groundwater. In like manner, Pb and SO_4^{2-} are strongly correlated (0.82) and suggest originating from similar anthropogenic sources such as domestic wastewaters and effluents. PO_4^{2-} is very strongly correlated with Ni and Zn with the same correlation value of −0.98 and strongly correlated with Pb (0.82) which seems to portray similar anthropogenic origin considering similar low concentration levels of the trace metals.

Likewise, the correlation results revealed the prevalent ionic exchange and affinity occurring in the groundwater aquifer system (Kim et al., 2014; Skrzypek et al., 2013). It was observed that Cl has strong preferential affinity for Zn > Ni > K in and while NO_3 has perfect affinity for Fe (1) and very strong affinity for Ca (0.96) while SO_4^{2-} and PO_4^{2-} prefer Pb. In addition, the Mg-rich aquifer encourages the dissolution of Mg into the aquifer. Even though it is dissolved, it is not a preferred cation by the major anions in the aquifer minerals. This scenario is responsible for the high level of Mg in both the groundwater and well. This finding corroborated results obtained by Akri (2015) that groundwater chemistry is mainly influenced by dissolution of halite, reverse ion exchange, and anthropogenic sources. The low ionic Na/Cl ratio of 0.12 suggests prevalence of halite sources in the boreholes while the high Na/Cl ratio of 2.84 for wells suggests Na-rich carbonate sources according to Hillel et al. (2015). Furthermore, low ionic ratio of Mg/Ca of 0.2 and 0.04 for the boreholes and wells which is < 0.5 indicated dissolution of limestone or gypsum in the aquifer as mentioned by Vengosh and Rosenthal (1994).

The turbidity of the groundwater was found to be strongly dependent on the Cl^-, NO_3^-, and Fe concentrations as well as the pH and electrical conductivity (EC) of the groundwater. The EC was found to be very strongly correlated with DO (0.99), NO_3^- (−0.99), Fe (−0.99), Ca (−0.96), pH (0.97), and BOD_5 (0.94). This shows that DO, NO_3^-, Fe, Ca, pH, and BOD5 can be used as a predictor for EC while NO_3^-, Fe, DO, Ca, and BOD_5 can be used to predict pH.

Microbiological parameters

Statistics of microbiological analyses of the groundwater samples of the study area is shown in Table 4. Isolated microorganisms from the borehole and well water samples were *Enterobacter aerogenes* and *E. coli*. *E. coli* and *E. aerogenes* are characteristics of the intestinal tract of man and animals (Thakur et al., 2012). *E. aerogenes* occurs mostly on grains and plant surfaces but may also inhabit the feces of man and animals. Their presence in borehole water is an indicator that the borehole water was contaminated with feces of man or animals or both as mentioned by Mackie, et al. (Mackie et al., 2006). *E. aerogenes* was also found in borehole water samples in Ilorin metropolis especially in surroundings that were littered with animal and fowl droppings as observed by Agbabiaka and Sule (2010). This situation is also typical of the borehole and well surroundings in Omu Aran where droppings from domesticated goats and sheep litter the surroundings of domestic homes, close proximity of poorly designed septic tanks coupled with widespread practice of open defecation owing to absence of good latrines in most homes.

E. aerogenes was also reported by Okiki and Ivbijaro (2013) and Thakur et al. (2012) in boreholes and wells in Imota, Lagos State, and water sources in Sloan City, Pradesh, respectively, while *E. coli* and *E. aerogenes* were reported by Jacinta and Adebayo (2015) in well and borehole water in Gwagwalada in Abuja, Nigeria. *E. aerogenes* alongside other microbes could cause illnesses such as fever, chills, headache, weakness, skin rash, sneezing and coughing, diarrhea, and abdominal pain (Okiki and Ivbijaro, 2013).

Contrary to the view of Mackie et al. (2006) that *E. aerogenes* is non-pathogenic in healthy individuals, Adejuwon et al. (2011) and Dauda (2010) found that they pose health risks to humans since they were found resistant to common antibiotics such as streptomycin, tetracycline, and ampicillin alongside *E. coli*. In addition, Olufemi and Oluwole (2012) alleged that *E. coli* and *E. aerogenes* were part of the leading fecal coliforms responsible for cholera outbreak in Ibadan.

For all the wells and most of the boreholes, the *E. coli* (bacteria) counts were greater than the yeast counts as depicted in Fig. 4(b). The average total coliform (TC) count in well water of 1100 MPN/100 ml was higher than that of borehole with 803.33 MPN/100 ml. This revealed that TC was highly attenuated in the boreholes more than the wells according to Donohue et al. (2015). The mean *E. coli* count in borehole of 658.33 CFU/100 ml was greater than that of well of 570 CFU/100 ml. Also, the yeast count of 403.67 CFU/100 ml in borehole was greater than 160 CFU/100 ml obtained in well water samples. Furthermore, fungi was not detected in both well and borehole water samples. In addition, spore-

Table 5 Correlation coefficients among the physico-chemical parameters ($n = 72$)

	NTU	EC	pH	TS	TDS	TH	DO	BOD5	Cl	NO3	SO4	PO4	Pb	Ni	Zn	Fe	Na	K	Ca	Mg
NTU	1	*0.74*	*−0.70*	−0.32	*−0.63*	−0.36	*−0.65*	−0.48	*−0.82*	*0.72*	0.24	−0.47	*0.69*	*−0.68*	*−0.74*	*0.72*	0.03	*−0.59*	*0.59*	0.01
EC		1	*0.97*	−0.22	*−0.83*	−0.18	*0.99*	*0.94*	*0.61*	*−0.99*	0.29	−0.4	−0.19	0.29	0.42	*−0.99*	*−0.60*	0.15	*−0.96*	−0.48
pH			1	−0.15	*−0.76*	−0.10	*0.98*	*0.92*	*0.66*	*−0.99*	0.09	−0.42	−0.32	0.34	0.46	*−0.99*	*−0.55*	0.30	*−0.95*	−0.43
TS				1	*0.70*	1.0	*−0.27*	−0.47	*0.63*	0.17	*−0.73*	*−0.79*	*−0.76*	*0.87*	*0.79*	0.17	*0.91*	*0.86*	0.43	*0.84*
TDS					1	*0.65*	*−0.84*	*−0.88*	−0.11	*0.80*	*−0.54*	−0.12	−0.21	0.25	0.13	*0.80*	*0.90*	0.34	*0.92*	*0.87*
TH						1	−0.23	−0.44	*0.67*	0.12	*−0.73*	*−0.82*	*−0.79*	*0.89*	*0.82*	0.13	*0.89*	*0.88*	0.38	*0.81*
DO							1	*0.96*	*0.57*	*−0.99*	0.30	−0.33	−0.16	0.23	0.37	*−0.99*	*−0.65*	0.13	*−0.98*	*−0.50*
BOD_5								1	0.36	*−0.92*	0.43	−0.09	0.06	0.00	0.15	*−0.92*	*−0.79*	−0.06	*−0.97*	*−0.59*
Cl									1	*−0.66*	−0.42	*−0.95*	*−0.81*	*0.93*	*0.97*	*−0.65*	0.25	*0.84*	−0.43	0.27
NO_3										1	−0.16	0.43	0.29	−0.34	−0.46	*1.00*	0.56	−0.25	*0.96*	0.46
SO_4											1	0.47	*0.82*	*−0.59*	−0.49	−0.16	*−0.64*	−0.82	−0.33	−0.47
PO_4												1	*0.82*	*−0.98*	*−0.98*	0.43	−0.49	*−0.85*	0.18	−0.45
Pb													1	*−0.87*	*−0.83*	0.29	*−0.50*	*−0.93*	0.08	−0.34
Ni														1	*0.99*	−0.33	*0.59*	*0.92*	−0.07	*0.55*
Zn															1	−0.45	0.47	*0.89*	−0.20	0.49
Fe																1	*0.57*	−0.25	*0.96*	0.47
Na																	1	*0.59*	*0.76*	*0.89*
K																		1	−0.01	*0.56*
Ca																			1	*0.65*
Mg																				1

NB Correlation values are given above. Values ≥ ±0.5 are in italics

Table 6 Statistics of microbiological analyses of the groundwater resources of the study area

Parameters	Borehole					Wells				
	No. of Data	Max	Min	Avg	SD	No. of Data	Max	Min	Avg	SD
TC (MPM/100 ml)	54	1110	1090	803.33	778.65	18	1105	1095	1100	4.08
E-Coli (CFU/100 ml)	54	885	494	658.33	561.58	18	580	560	570	8.16
Yeast (SFU/100 ml)	54	560	315	403.67	346.68	18	165	155	160	4.08
Fungi (SFU/100 ml)	54	ND	ND	ND	ND	18	ND	ND	ND	ND

TC total coliform, *Max* maximum, *Min* minimum, *Avg* average, *SD* standard deviation

forming yeasts were found in all the borehole and well water samples. Yeast contamination was also found in groundwater resources in Umudike in Abia State, Benin City, Calabar, and Jos (Ayanbimpe et al., 2012; Erah]et al., 2002; Obi and George, 2011; Okpako et al., 2009). The isolated species were *Mucor racemosus*, *Aspergillus niger*, *Rhizopus*, *Fusarium*, *Penicillium*, *Candida tropicalis*, *Candida lipolytica*, and *Rhodotorula* sp. (Ayanbimpe et al., 2012; Obi and George, 2011; Okpako et al., 2009).

Therefore, in order to avert outbreak of water-borne diseases in the study area, it is imperative that the community dwellers always treat their drinking water by use of water guard which was found effective in removing bacterial contamination in the various water sources in the study area as recommended by Sojobi et al. (2014).

For the physico-chemical parameters of well water samples, ANOVA test indicated that there was no significant difference since the F-statistic value of 0.00089 obtained was < the critical value of 3.52. Likewise, the ANOVA test also showed that there was no significant difference in the physico-chemical parameters of the borehole samples since the F-test statistic of 0.358 obtained was < 2.64 critical value. Comparison of the mean values of the well and borehole samples using the *t* test indicated that there was no sufficient evidence to show significant difference in their physico-chemical parameters since the *t* test value of 0.05693 obtained lies within the critical values of +2.080 and −2.080 for a two-tailed test at 0.05 significance level (Table 5).

Furthermore, ANOVA test for the microbiological parameters of the well samples indicated that there was no significant difference since the F-statistic value of 5.03 was < 5.14 critical value. The *p* value obtained for the F-statistic value was 0.053 and was > 0.053. The ANOVA test carried out for the microbiological parameters of borehole samples showed that there was significant difference since the F-statistic value of 8.55 was > 2.51 critical value obtained at 0.05 significance level. Therefore, we reject the null hypotheses and accept the alternative hypothesis that there was significant difference in the microbiological parameters of the borehole samples as recommended by Bluman (2013). Comparison of the mean values of the well and borehole samples using the *t* test showed that there was no significant difference in their microbiological parameters since the *t* test value of −0.07 lies within the critical values of +4.303 and −4.303 obtained at 0.05 significance level (Table 6).

Therefore, it can be deduced that the geological formation in the study area seems to be similar but the microbiological characteristics of the aquifer where each borehole and well were located tend to be different subject to ease of contamination. This implies that owners of wells and boreholes should ensure they are located professionally constructed and located in an environment that offers maximum protection form exogenous, anthropogenic potential sources of contamination.

Conclusion

The need for regular monitoring and protection of groundwater sources has been pointed out by several studies (Bacquart et al., 2015; Oyelami et al., 2013; Porowska, 2014; Rao, 2014; Vasanthaviger et al., 2013; Wanke et al., 2015), and it is re-emphasized in this study. Oftentimes, the necessity for treatment and the type of treatment required is only brought to the fore through such regular exercise which is often oblivious to the consumers and industrial users. Awareness of the type and potential sources of contaminants guides selection of appropriate and cost-effective treatment methods and safeguards consumers from potential health risks associated with contaminants from untreated groundwater sources and likewise guide the location and construction of boreholes and wells for domestic and industrial uses.

In developing countries where regular monitoring of groundwater resources is grossly lacking or inadequate, consumers, homeowners, and industrial users of groundwater should take it in their strides to carry out such exercise periodically. Also, domestic wastewaters and effluents should be appropriately disposed away from boreholes and wells to guard against leaching of heavy metals and other potential contaminants into the aquifer. Such boreholes and wells should be covered always while periodic maintenance and treatment should be carried out to keep them in good potable condition. Movements of domesticated animals such as goats and sheep should be restrained from locations of boreholes and wells to eliminate or reduce the risk of microbiological contamination.

Government should also endeavor to provide effective drainage system and appropriate solid waste disposal systems in rural areas. Such investment will go a long way to preserve the integrity and potability of the groundwater resources in such communities. In addition, government should set up monitoring network to periodically assess the groundwater in the state so as to identify potential sources of pollution before it reaches alarming levels. Local governments should also set up task force to ensure every residential house in the rural and peri-urban areas has appropriate sewage disposal systems and septic tanks to reduce microbial contamination of the groundwater resources in such areas.

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