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Abstract

Groundwater forms a very important part of the water supply chain and its quality can be affected by improperly constructed septic tanks used by homeowners in peri-urban locations such as Abeokuta in recent times. Sixty groundwater samples collected from hand-dug wells ≤15m from septic tanks were analysed for physicochemical and bacteriological parameters using standard procedures. Results were integrated with multivariate and hydrogeochemical analyses to assess the effect improperly built septic tanks have on groundwater quality around the Federal University of Agriculture, Abeokuta. The range of values for the measured parameters include: pH (6.26 – 8.66), EC (83 – 1035 µS cm^{-1}), TDS (42 – 621 mg L^{-1}), Mg^{2+} (2 – 60 mg L^{-1}), NO_3^- (5.09 – 17 mg L^{-1}), Fe (-.04 – 5.32 mg L^{-1}), BOD (0.1 – 13.2) and *E. Coli* (ND – 41×10 cfu mL^{-1}). The abundance of major ions are in the order Ca^{2+}>Mg^{2+}>K^+> Na^+ and Cl^- >SO_4^{2-} >HCO_3^- >NO_3^- >PO_4^{2-}. The piper trilinear plot shows that the dominant hydrochemical facies in the study area is the Ca^{2+}– Cl^- type. A correlation analysis and a principal component analysis both reflect intrusions from biological wastes such as surrounding septic tanks or municipal waste disposals as well as dissolutions from basal rocks. The possibility of infiltration from sewage into groundwater is confirmed by the number of samples with high BOD, NO_3^-, and *E. coli* concentrations. Contamination of groundwater with sewage exposes the populace to acute excreta-related illness. This therefore calls for stringent monitoring and management measures to be put in place by relevant regulatory authorities to safeguard the human health and environment within the study area.

Keywords: Abeokuta; Septic tank; Groundwater; Quality; Geogenic processes

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Introduction

Water is life and access to clean water, fit for purpose is a daily challenge in developing countries such as Nigeria [1]. Out of the various water sources available, ground water remains the largest available source of fresh water, thus forming a very important part of the water supply chain in both rural and urban areas of Nigeria due to its perceived less susceptibility to pollution compared to surface waters [2]. In addition, some surface waters such as streams usually dry up in dry season and as such, majority of the population rely basically on hand-dug wells for potable water supply.

Despite its location below the ground surface, groundwater quality depends on a variety of factors such as the quality of recharge water, atmospheric precipitation, municipal dumpsites and landfills and most importantly the type of sewerage systems employed by the population [3]. Unfortunately, sewage and waste water management in Nigeria do not involve central wastewater treatment systems and all home-owners have to install septic tanks in order to dispose domestic wastewater.

In a desperate effort to reduce construction cost, coupled with the poor regulation of construction activities by urban and town planning authorities in Nigeria, recent years have witnessed homeowners constructing septic tank units which do not meet specifications as opposed to an ideal septic tank which is a sedimentation tank consisting of a minimum of two chambers with dimensions about 1.5 m wide x 2.5 m long x 1.8 m tall [4]. These modified septic tanks consist of a circular pit or concrete ring above or below the ground with a diameter and depth both approximately a meter (in most cases) (Figure1). The walls are lightly lined with concrete and the floor is left unlined to allow for easy percolation [5]. These septic tanks units are not fit for sewage management in terms of volume, depth, required safeguards and distance from ground water sources especially when the surrounding soil is highly porous. Unfortunately, once groundwater is polluted, it is usually very difficult and costly to remediate [6]. Waste in septic tanks contains germs and pathogens which pose real threat of contamination to underground water and can serve as a vehicle for the spread of water borne diseases such as cholera, dysentery, schistosomiasis, lymphaticfilariosis, parasitic and viral infections [7].

Emenike et al. [8] assessed the geospatial and hydrochemical interactions of groundwater quality parameters within Abeokuta and revealed that all water quality parameters were within the World Health Organization's (WHO) guidelines for drinking water with the exception of EC, DO and coliform bacteria counts. Several other authors have also conducted studies on groundwater quality within Abeokuta primarily to have baseline information and trend on groundwater quality and also to assess effect of dumpsites and landfills on groundwater quality [9–12]. The results from these studies consistently show that groundwater from hand-dug wells are more polluted by anthropogenic activities than by geogenic processes. However, few studies have investigated and documented the effects sewerage systems employed by Nigerian communities have on groundwater quality.

Figure 1 Examples of modified septic tank units within study area.

An assessment of the impact of onsite sanitary sewage system and agricultural wastes on groundwater quality in Ikem and its environs, south-eastern Nigeria revealed fecal contamination and a high electrical conductivity and total dissolved solids above that set by WHO [13]. Similarly, an assessment of the effects of septic tank on the quality of groundwater from hand-dug wells in Effurun, Delta State, Nigeria concluded that there was possible contamination from septic tank due the proximity to the hand dug wells, as the distances between wells and the septic tanks failed short of the minimum recommended distance of 50 ft [14]. More importantly, the use of these improperly built septic sewerage tank units which do not meet regulatory standards in southwest Nigeria is a recent trend and there is no known documented information on the extent of its use and potential environmental impact. Therefore, a detailed study on groundwater quality in relation to the use of these modified septic tanks units is necessary to determine the potential effects of this recent trend on ground water quality and the possible health risk the consuming population may be exposed to.

Settlements around the Federal University of Agriculture Abeokuta like most peri-urban towns in Nigeria are increasingly becoming heavily populated due to influx of students and businesses as well as its closeness to Lagos, a major trading town. Septic tank sewerage system and open defecation are the major sewage systems within the study area and little or no attempt is made by residents to ascertain the depth to water table and direction of groundwater flow before sitting these septic tank units. Depth of groundwater within the study area is shallow and hand-dug wells are also designed and located without prior investigation to ascertain nearness to pollution sources making them prone to contamination. This rise in population, unchecked physical development coupled with observed sanitary issues via the use of improperly built septic tanks sewerage systems makes this study important to identify potential pollution sources, protect freshwater reserves and ensure sustainability. This investigation was aimed at assessing groundwater quality around improperly built septic tank sewerage units by integrating physicochemical and bacterial analysis, selected heavy metal analysis and multivariate analyses.

Materials and methods

1) Study area

The Federal University of Agriculture, Abeokuta is located along Alabata road, Odeda local government area, Abeokuta, southwest Nigeria. The major communities around the university from which groundwater were collected for this study include Alabata Village (AV), Funaab Gate (FG), Isolu (IS) and Camp (CA). These communities are peri-urban with residential buildings continuously being built in poorly structured settings. Unfortunately, poor regulation of construction activities by urban and town planning authorities and a desperate bid to reduce construction cost by homeowners have led to an increase in the use septic tank units which do not meet specifications (Figure 1). Majority of residents around the study area depend on groundwater for water supply while a few depend on streams. Figure 2 shows a map of the study area with sampling locations.

2) Geology and drainage

The study area is underlain by the sedimentary rocks of the eastern Dahomey Basin. Some parts are covered by the Ise Formation of the Abeokuta Group which consists of conglomerates and grits at base and in turn overlain by coarse to medium grained loose sands [15]. The basement rock of the area is unconformable, overlain by organically rich friable reddish sand consisting of ancient gneisss-migmatite suite (Complex) which has been distinguished into three major divisions due to the penetration of Pan-African bodies of granodiorites, Porphyritic granites, quartz diorites and pegmatites [16]. The major division include; biotite granite gneiss, porphyroblastic gneiss, porphyritic biotite granite, biotite schist and migmatite (Figure 3).

Groundwater occurrence within the study area is contained within fractured and in-situ weathered portions of rocks which are usually exploited through hand-dug wells or boreholes. Groundwater recharge is mainly by percolating rainwater and in some places, by seepage from adjacent surface water. Recharge areas consist of decomposed and fractured rocks in which pressure heads quickly spread through local water-bearing fissures and interconnected voids, thereby leading to abrupt rise in discharges in response to precipitation. The major river within the study area is the Tigba River which flows south-eastwards where it joins the Ogun River (Figure 4). Spring discharges in the study area are very common in the rainy season but cease completely during the dry season. The study area underlain by sedimentary formations is regarded as having good potential for groundwater due to the presence of aquiferous sandy layer [15]. Water levels in hand-dug wells within the study area occur at a depth of 4 – 14 m and some wells dry up during the dry season.

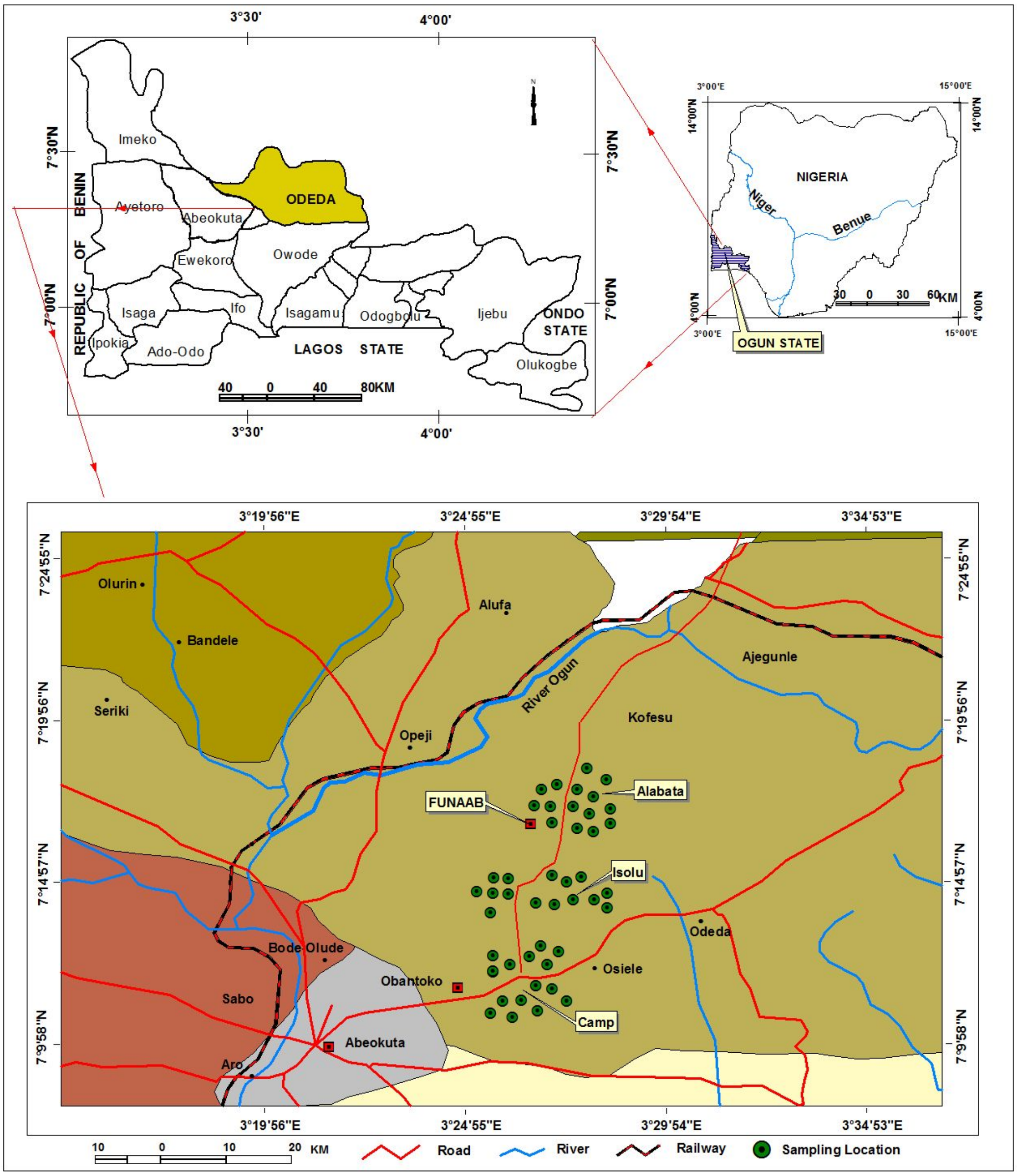

Figure 2 Map of study area.

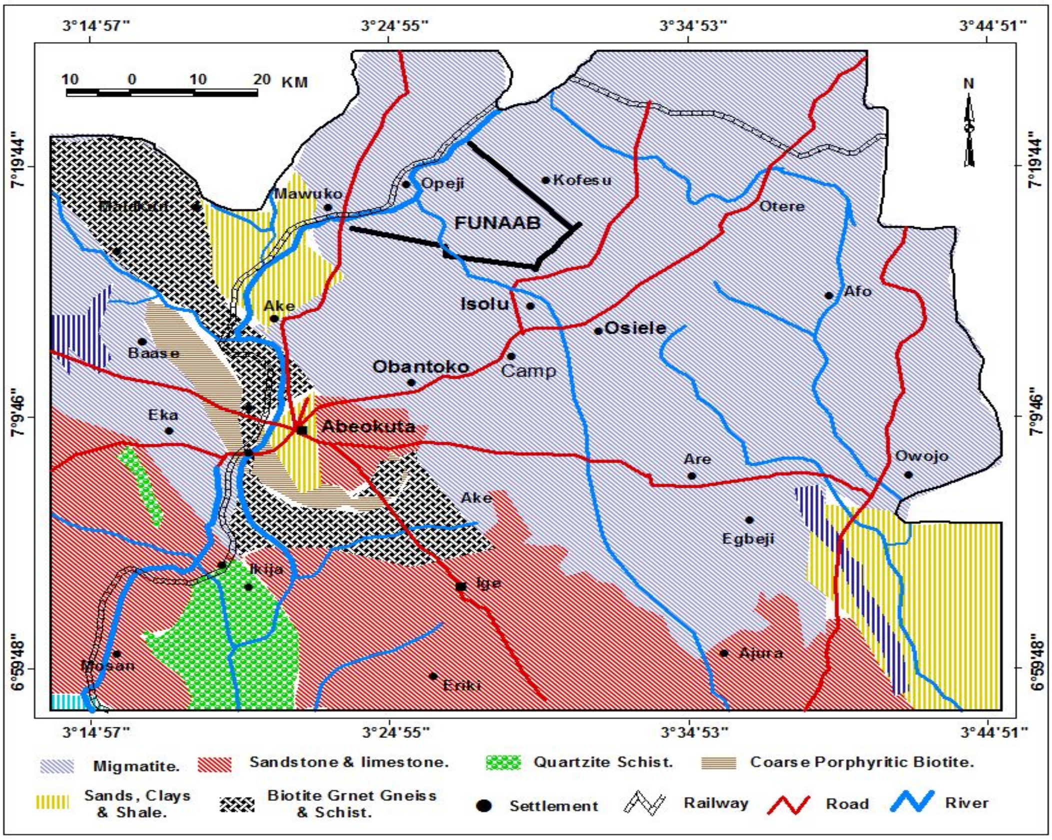

Figure 3 Geologic map of the study area.

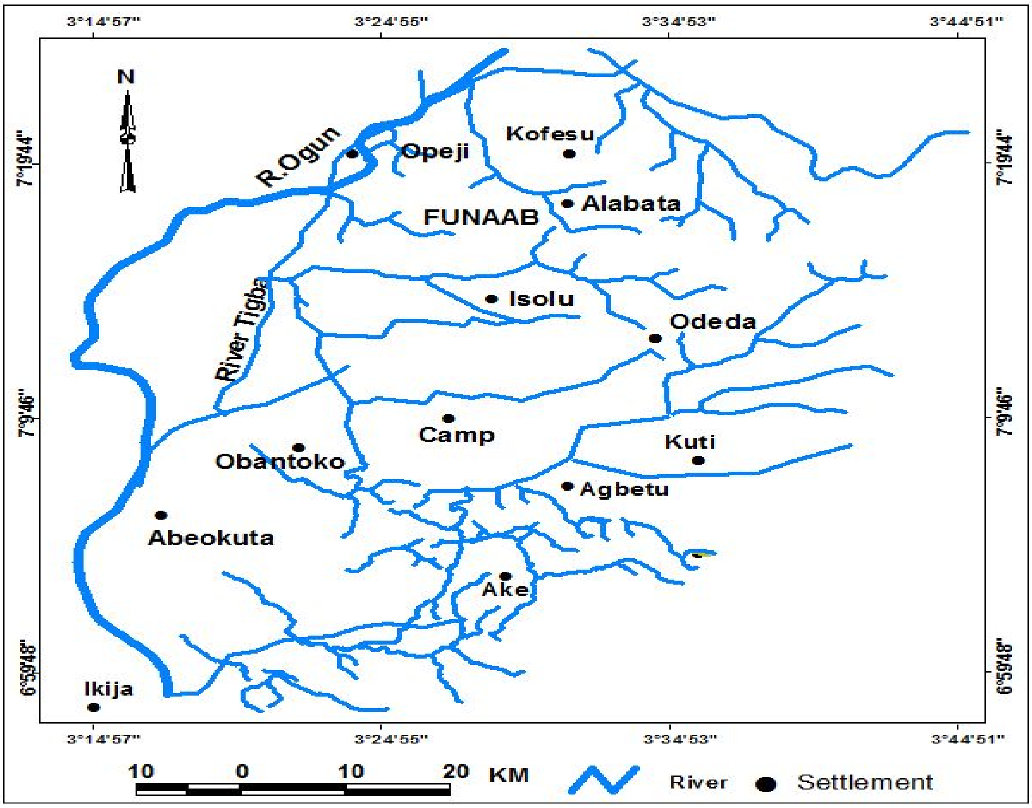

Figure 4 Drainage map of study area.

3) Sample collection

Sixty (60) sampling locations (fifteen from each community) which had hand-dug wells ≤15m from modified septic tank units were randomly selected for sampling. Water samples were collected in the February, 2019. Quality control procedures were ensured to avoid contamination during sampling and laboratory analysis. These included the collection of water samples in acid washed PET bottles and the inclusion of analytical blanks during analysis. All chemicals used were of analytical grade.

Groundwater samples from selected wells were carefully stored in lightproof insulated boxes containing ice-packs to ensure cooling before transport to the laboratory for analysis. Separate bottles were used to collect samples for the metals analysis and were fixed in-situ with 2 mL of concentrated HNO_3. Samples for microbial analysis were also collected in separate containers which had been sterilized at 121ºC for 15 min in an autoclave and sealed for sample collection.

4) Characterization of water quality parameters

The water quality parameters measured include; pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), chloride (Cl^-), nitrates (NO_3^{2-}), sulphates (SO_4^{2-}), phosphates (PO_4^{3-}), biocarbonates (HCO_3^-), biochemical oxygen demand (BOD) and essential heavy metals such as zinc and iron. pH, temperature, total dissolved solids (TDS) and electrical conductivity were determined in-situ with conventional instrumental procedures using an HI98129 electrode which had been calibrated with buffers pH 4.0 and 9.0 prior to measurement. Cations and anions were determined by standard titrimetric and spectrophotometric procedures using standard methods[17].Ca^{2+}, Mg^{2+}, Na^+ and K^+ were determined using the PerkinElmer PinAAcle 500 FAA spectrometer, while SO_4^{2-}, PO_4^{3-}, NO_3^- and Fe^{2+} were determined by Hach DR/2000 spectrophotometer. Zinc concentration in digested water samples were analyzed using a Buck 2015 AA atomic absorption spectrophotometer while total coliform counts (TCC) and *Escherichia Coli* were determined by using the Millipore filtration method.

The detection limit for Zn was below 0.005 mg L^{-1}. Method blanks were also included in all analytical procedures for quality control to correct for baseline. The results of the various water quality parameters were later compared with the related past studies, the Nigerian Standard for Drinking Water (NSDWQ) and WHO drinking water quality guidelines.

5) Multivariate statistical analysis

The data obtained from laboratory investigations were analysed using SPSS 23.0 (SPSS Inc., USA) software. Data were subjected to descriptive statistics and multivariate analysis. A correlation analysis was used to evaluate the relationships between water quality parameters and a principal component analysis (PCA) was conducted to investigate the possible sources of contamination. PCA has been considered to be efficient for the identification of contaminant sources. This technique groups variables such that variables belonging to one group are highly associated with one another [18]. The Piper trilinear diagram, an hydrogeological plot was also drawn to identify relevant dominant water types within the study area.

Results and discussion

1) Temperature, pH, electrical conductivity and total dissolved solids

The results of physical parameters, major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}), anions (Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, HCO_3^-) and heavy metals in groundwater for the different communities are presented in Table 1. Results from each sampling location are presented in the supplementary materials (SM) 1–4. The temperature of water samples were generally ambient ranging between 25.90°C and

27.40°C with a mean of 26.72°C. A high water temperature negatively impacts water quality by enhancing the growth of microorganism which may increase taste, odour, colour and corrosion problems [19]. Hydrogen ion concentration (pH) values of groundwater from all wells sampled fell within WHO [20] and NSDWQ [21] acceptable pH range of 6.5 – 8.5, with the exception of two wells (CA8 and CA9) within Camp community with pH less than 6.5. The slightly acidic nature of these two samples can be attributed to the influence of anthropogenic activities and/or oxidation of sulphide minerals contained in the host rocks [22]. Average pH of all groundwater samples within this study was found to be 6.77. pH, a measure of acidity or alkalinity of water is one of the most important water quality parameters when determining the potability of water. Alkaline waters cause corrosion of metal pipes and plumping systems while waters with pH less than 6.5 are more likely to contain microbial contaminants that can pose negative effects on the gastrointestinal tracts when consumed, thereby, resulting in diarrhea [23]. Groundwater samples from CA community were found to have significantly ($p=0.035$) lower pH values compared to IS, FG and AV communities (SM 5a).

Electrical conductivity (EC), the potential of water to transmit an electric current is dependent upon the presence of free ions such as calcium, magnesium and chloride, which carries electric current through water. The EC of the totality of groundwater samples analysed ranged between 83 $\mu S\ cm^{-1}$ to 1035 $\mu S\ cm^{-1}$ with an average of 404.4 $\mu S\ cm^{-1}$. Only one well (AV10) fell outside the acceptable limit of 1000 $\mu S\ cm^{-1}$ (SM 1). The variation in EC can be attributed to different degrees of enrichment in the deposition environment during accumulation and/or anthropogenic activities. A high water EC is not known to have a direct negative impact on human health. It can however cause an unwelcome mineral taste in water and as well as increase production costs in the industrial sectors due to corrosion on boiler systems. Waters with EC greater than 700 $\mu S\ cm^{-1}$ are considered inappropriate for irrigation purposes due to the development of alkaline soils [24]. EC of groundwaters differ depending on soil composition through which it flows. Groundwater samples from FG and AV communities have higher EC than groundwater samples from IS and CA communities. However, the differences were not statistically significant ($p=0.069$).

The TDS values for all groundwater samples analysed ranged between 42 $mg\ L^{-1}$ and 621 $mg\ L^{-1}$ at locations AV6 and AV10 respectively, and with an average of 201.58 $mg\ L^{-1}$. Only one of the samples (AV10) fell outside the WHO and NSDWQ maximum acceptable limit of 500 $mg\ L^{-1}$. 16.7% of the total water samples had TDS content above 300 $mg\ L^{-1}$ (SM 5b), the ideal TDS limit for drinking water according to the Bureau of Indian standard [25]. TDS of water samples across the four communities within the study area did not differ significantly ($p=0.068$).

2) Biological oxygen demand and groundwater potability

The biological oxygen demand (BOD) is one of the most important parameters used by regulatory agencies to monitor water quality. It is a measure of the microbial facilitated decomposition of all organic materials in water over a five-day period. Waters with BOD between 1 and 2 $mg\ L^{-1}$ indicate clean water, a 3 – 5 $mg\ L^{-1}$ BOD indicates water with doubtful quality and a BOD >5 $mg\ L^{-1}$ indicates nearby organic pollution source [25]. The BOD of water samples within this study ranged between 0.1 $mg\ L^{-1}$ to 13.2 $mg\ L^{-1}$ at locations CA10 and CA4 respectively, with an average of 4.9 $mg\ L^{-1}$. A high proportion (66.7%) of groundwater samples within this study had BOD content greater than 3 $mg\ L^{-1}$ while almost half (46.7%) had BOD contents greater than 5 $mg\ L^{-1}$ indicating the presence of organic pollution (SM 6), possibly infiltration of partially treated sewage from the improperly constructed septic tanks close to the wells. BOD contents of groundwater from wells across the four communities studied were significantly different (p=0.001) with wells in IS having a higher BOD compared to others (SM 7).

Table 1 Physical parameters for groundwater samples

Area		pH	Temp (°C)	EC (µS cm^{-1})	TDS (mg L^{-1})	Na^+ (mg L^{-1})	K^+ (mg L^{-1})	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})
FG	Min	6.51	26.8	285	142	11.00	2.00	50.00	14.00
	Max	7.95	27.1	915	458	27.00	31.00	211.00	60.00
	Mean	7.10	26.91	530.26	265.13	20.53	6.47	116.13	30.53
AV	Min	6.51	26.7	83	42	7.00	1.00	28.00	2.00
	Max	7.9	27.2	1035	621	44.00	34.00	122.00	46.00
	Mean	7.29	27.01	381.27	197.73	17.53	6.53	76.40	21.67
IS	Min	6.58	26.6	139	68	11.00	1.00	16.00	11.00
	Max	8.39	27.4	627	313	38.00	16.00	146.00	41.00
	Mean	7.27	26.9	353.6	176.8	18.80	5.53	86.80	22.47
CA	Min	6.26	25.9	140	219	9.00	1.00	30.00	12.00
	Max	7.4	26.1	788	188	50.00	16.00	170.00	44.00
	Mean	6.77	26.03	345.8	166.67	20.40	4.47	89.47	24.47
Area		**Cl^- (mg L^{-1})**	**NO_3^- (mg L^{-1})**	**SO_4^{2-} (mg L^{-1})**	**PO_4^{3-} (mg L^{-1})**	**HCO_3^- (mg L^{-1})**	**Fe (mg L^{-1})**	**Zn (mg L^{-1})**	
FG	Min	68.00	6.52	15.70	0.30	17.10	0.02	0.02	
	Max	190.00	12.85	50.38	0.84	44.17	0.13	0.47	
	Mean	112.53	10.17	31.63	0.59	28.65	0.06	0.07	
AV	Min	25.00	5.09	19.30	0.14	19.30	0.01	0.01	
	Max	107.00	15.49	56.11	0.70	37.22	0.08	0.18	
	Mean	65.27	9.71	38.60	0.45	28.44	0.04	0.05	
IS	Min	25.00	5.70	13.90	0.15	17.40	0.01	0.03	
	Max	210.00	17.00	52.81	0.78	48.32	0.09	0.51	
	Mean	79.53	9.42	31.69	0.51	28.20	0.06	0.11	
CA	Min	25.00	5.70	18.40	0.13	22.80	0.03	0.01	
	Max	130.00	16.33	44.30	0.81	46.19	0.08	0.09	
	Mean	51.20	8.58	31.98	0.52	29.47	0.05	0.04	

3) Hydrogeochemical analysis

The abundance of cations is in the order $Ca^{2+}>Mg^{2+}>K^+>Na^+$. The calcium concentrations in groundwater samples range from 16 mg L^{-1} to 211 mg L^{-1} at locations IS2 and FG12 respectively with an average of 92.2 mg L^{-1} for the study area. Magnesium ion ranged from 2 mg L^{-1} at location CA5 to 60 mg L^{-1} at locations FG15 and FG6 respectively with an average of 24.78 mg L^{-1} for the study area (SM 2 and 3). More than half (62%) of groundwater samples within this study had Ca^{2+} greater than 75 mg L^{-1} recommended by the WHO and NSDWQ for drinking water. Similarly, 52% of groundwater samples within this study had Mg^{2+} greater than 20 mg L^{-1} recommended by the WHO and NSDWQ for drinking water. Calcium and magnesium in water samples can be derived from the dissolution of basal rocks such as limestone and shale and are responsible for total hardness in water [26], a parameter that measures the capacity of water to react with soap to produce lather. Both calcium and magnesium are essential minerals and inadequate intake can result in adverse health effects. Hard water due to high concentrations of Ca^{2+} and Mg^{2+} in water is not a health risk except for those who are marginal for calcium and magnesium intake [27]. They may however constitute nuisance due to build-up of mineral on water pipes and the need for increased soap use during washing.

The concentration of sodium varied from 7 mg L^{-1} to 50 mg L^{-1} at locations AV6 and CA7 respectively. All the samples have sodium concentrations within the permissible limit of 200 mg L^{-1} stipulated by the WHO and NSDWQ. The concentration of K^+ in the groundwater varied from 1 mg L^{-1} at locations AV1 and C9 to 34 mg L^{-1} at location AV2. Sodium in the water samples is attributed to host rock dissolution, while potassium is thought to be from host rock dissolution and/or leaching of agricultural waste [24].

Chloride and sulphates are the dominant anions in groundwater in the study area. The order of abundance of anion is $Cl^->SO_4^{2-}>HCO_3^->NO_3^->PO_4^{3-}$ (Table 1). Chloride is a very important parameter which is often included in assessments as an indicator of dispersion of sewage into water bodies as high concentrations occur near sewage and other waste outlets or irrigation drains [25]. Chloride concentrations are usually lower than 10 mg L^{-1} in freshwaters, however, a maximum limit of 250 mg L^{-1} is recommended in drinking water. Chloride in groundwater in this study has an average of 77.13 mg L^{-1} and ranges from 25 mg L^{-1} at locations AV6 and IS5 to 210 mg L^{-1} at IS12. Cl^- concentrations in all water samples are within the permissible limit of 250 mg L^{-1}set for drinking water. The concentration of SO_4^{2-} in groundwater samples has an average of 33.48 mg L^{-1} and ranges from 13.9 mg L^{-1} to 56.11 mg L^{-1} at IS1 and AV10, respectively (SM 2 and 3). All the samples are within the maximum allowable limit of 100 mg L^{-1} stipulated by the WHO and NSDWQ. In this work, nitrates in groundwater samples has an average of 9.47 mg L^{-1} and ranges from 5.09 mg L^{-1} at AV10 to 17 mg L^{-1} at IS5. 38.3% of groundwater samples within the study area contained nitrates above the 10 mg L^{-1} allowable limit for drinking water. Nitrates are contaminants of natural waters and its presence in groundwater can be attributed to infiltration from leachates of sewage tanks, crop farms and animal waste dumps. Consuming too much nitrates in water can affect how blood carries oxygen and can cause methemoglobinemia (blue-baby syndrome) in infants less than 6 months [26]. Phosphates in groundwater in this study have an average of 0.52 mg L^{-1} and ranges from 0.13 mg L^{-1} at CA15 to 0.84 mg L^{-1} at FG2. Phosphates in groundwater can also be attributed to infiltration from onsite septic tank sewerage systems and/or leaching from agricultural waste disposal sites. The distribution of bicarbonates in groundwater samples within the study area has an average of 28.69 mg L^{-1} and ranges from 17.1 mg L^{-1} to 48.31 mg L^{-1} at FG6 and IS2 respectively. Bicarbonates are natural constituents of mineral waters derived from limestone. They play an important role in buffering acids and ensuring that water tastes pleasantly clean and refreshing.

Zinc is more abundant than iron in groundwater samples within the study area. Zn has an average of 0.07 mg L^{-1} and ranges from 0.1 mg L^{-1} to 0.51 mg L^{-1} (SM 4). Iron has an average of 0.05 mg L^{-1} and ranges from 0.1 mg L^{-1} to 0.13 mg L^{-1}. The highest concentration of Zn was found at location IS15 while the highest concentration of Fe was found at locations FG3 and FG14. Both Zn and Fe in groundwater samples within this study were below the acceptable limits for drinking water as stipulated by the WHO and NSDWQ with the exception sample FG3 and FG14 which had Fe concentrations greater than the acceptable limit of 0.1 mg L^{-1}. The concentrations of the heavy metals can be attributed to geogenic heavy metal concentrations and do not reflect contamination from anthropogenic activities.

4) Water type and hydrochemical facies

The result of hydrochemical analysis of groundwater samples from the study area is plotted on a piper trilinear diagram for visual comparison and delineation of hydrochemical facies. The piper trilinear diagram is an effective graphic procedure which helps to understand the sources of the dissolved constituents in water. According to the location of the sample in the plots, the hydrochemical facies can be identified. The piper trilinear plot is premised on the assumption that the most abundant ions in waters are Ca^{2+}, Mg^{2+}, Na^{+}, HCO_3^{-}, SO_4^{2-} and Cl^{-} [28]. The diagram consist of a diamond and two triangles. Waters plotted at the corner of the diamond is primarily com-posed of Ca^{2+}–Mg^{2+} and Cl–SO_4^{2-}, and can be classified as calcium/ magnesium and chloride/ sulfide type. Waters at the right corner of the diamond depicts Na^{+}–K^{+} and SO_4^{2-}–Cl^{-} which can be classified as sodium/potassium and sulfate/ chloride type [13]. The cations plot of the piper trilinear plot shows that about 80% of the water samples fall within Ca^{2+} water type, about 4% of the water samples fall within the Mg^{2+} water type while approximately 16% do not present a dominant cation type (Figure 5). Almost all water samples fall within the chloride section of the anions plot. This shows that the dominant water type in the study area is the Ca^{2+}–Cl^{-}type.

5) Bacteriological analysis

Groundwater should contain no microorga-nism unless contaminated which can arise from rapid percolation and intrusion of leachates through soils. Coliforms in water indicates that such waters have come in contact with human waste or animal intestine tract and its presence in the groundwater is strongly indicative of sewage contamination [29]. Therefore, microbial examination of water samples was carried out. More importantly, the counts of Escherichia coli, an intestinal bacterial pathogen, an indicator of faecal contamination was also assessed. The result of bacteriological analysis of ground-water samples shows significant concentration of bacteria coliforms (Table 2). Concentrations ranged from 0 to 102×10 cfu mL^{-1} and 0 to 41×10 cfu mL^{-1} for total coliform counts (TCC) and *E. Coli* respectively which is above the WHO and NSDWQ standards for drinking water. 76.7% of groundwater samples within this study con-tained bacterial coliforms with a maximum of 102×10 cfu mL^{-1} found at location CA7 (Table 2). 35% of the groundwater sampled within this study contained *E. Coli* coliforms (SM 8). This result confirms that groundwater within the study area is exposed to intrusion from sewage. Contaminated water can serve as a vehicle for the spread of water borne diseases such as cholera, dysentery, schistosomiasis, lymphatic filariosis, parasitic and viral infections [30].

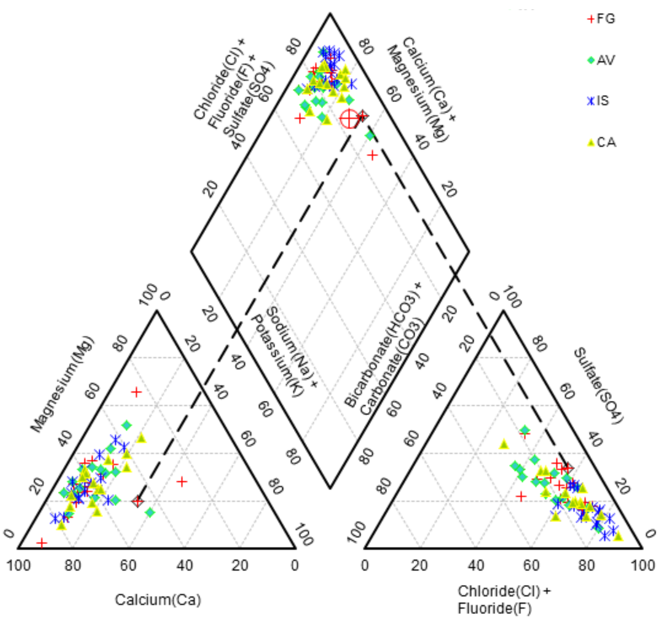

Figure 5 Piper trilinear diagram of the hydrogeochemical parameters of groundwater in the study area.

Table 2 Bacteriological analysis (× 10 cfu mL^{-1}) of groundwater in study area

Sample	Depth (m)	*E. Coli*	TCC	Remarks on well environment
FG1	7.2	0	10	Neat, lined, covered
FG2	5	5	14	Neat, lined, covered
FG3	8.3	3	10	Neat, lined, covered
FG4	6.5	0	0	Neat, lined, covered
FG5	6.2	0	16	Neat, lined, covered
FG6	8.3	10	28	Neat, lined, covered
FG7	5.4	0	12	Neat, lined, covered
FG8	6.8	0	9	Neat, lined, covered
FG9	7.3	0	0	Neat, lined, covered
FG10	4.8	0	18	Neat, lined, covered
FG11	4.3	9	27	Lined, not covered
FG12	7.1	0	0	Neat, lined, covered
FG13	4.5	0	18	Neat, lined, covered
FG14	4.7	0	12	Neat, lined, covered
FG15	5.3	0	8	Neat, lined, covered
AV1	4.3	7	19	Not lined, covered, neat environment
AV2	5.7	0	10	Neat, lined, covered
AV3	5	0	12	Neat, lined, covered
AV4	5.8	0	18	Neat, lined, covered
AV5	5.3	0	16	Neat, lined, covered
AV6	4.1	8	21	Neat, lined, covered
AV7	4.8	0	5	Neat, lined, covered
AV8	4.6	0	9	Neat, lined, covered
AV9	5.3	4	12	Neat, lined, covered
A10	6.1	12	20	Lined, covered, contained algae
AV11	3	3	11	Neat, lined, covered
AV12	4.7	0	1	Neat, lined, covered
AV13	6	11	27	Lined, not covered
AV14	4.8	0	13	Neat, lined, covered
AV15	5.4	0	12	Neat, lined, covered
IS1	6.3	0	9	Neat, lined, covered
IS2	5.7	0	0	Neat, lined, covered
IS3	8.9	1	17	Neat, lined, covered
IS4	10.8	27	70	Lined, covered, dirty environment
IS5	7.5	0	0	Neat, lined, covered
IS6	7.8	1	9	Neat, lined, covered
IS7	7.1	3	19	Neat, lined, covered
IS8	9.4	0	0	Neat, lined, covered
IS9	6.8	7	22	Neat, lined, covered, close to a poultry waste dump
IS10	7.4	0	0	Neat, lined, covered
IS11	8.3	0	0	Neat, lined, covered
IS12	5.9	0	2	Neat, lined, covered
IS13	6.5	2	3	Neat, lined, covered
IS1	6.9	9	15	Lined, covered, dirty environment
IS15	8	0	0	Neat, lined, covered
CA1	5.8	29	81	Lined, covered, dirty environment
CA2	9	4	6	Neat, lined, covered
CA3	7.5	0	0	Neat, lined, covered
CA4	8.3	0	0	Neat, lined, covered
CA5	6.8	5	14	Neat, lined, covered
CA6	5.4	0	0	Neat, lined, covered
CA7	3.5	41	102	Neat, lined, covered
CA8	7	0	0	Neat, lined, covered
CA9	14	0	0	Neat, lined, covered
CA10	5.8	14	21	Neat, lined, covered
CA11	6.4	0	4	Neat, lined, covered
CA12	4.1	0	31	Neat, lined, covered
CA13	6.9	0	5	Neat, lined, covered
CA14	4.3	0	8	Neat, lined, covered
CA15	7.4	0	3	Neat, lined, covered

Table 2 Bacteriological analysis (× 10 cfu mL^{-1}) of groundwater in study area *(Continued)*

Sample	Depth (m)	*E. Coli*	TCC	Remarks on well environment
Min	3.00	0	0	
Max	14.00	41	102	
Mean	6.37	3.59	13.82	

6) Multivariate analysis

6.1) Correlation analysis

A correlation analysis was conducted to investigate the relationships between groundwater quality parameters. This helps to understand how one parameter predicts the other [13]. The result reveals that Na^+, K^+ and Cl^- are significantly (p= 0.01, 0.01, 0.01 respectively) correlated with TDS (SM 9) and therefore appear to be major contributors to TDS content of groundwater samples within the study area. Similarly, Ca^{2+}, Na^+, K^+ and Cl^-were found to be major contributors to electrical conductivity. The ion pairs Ca^{2+}/Mg^{2+}, Ca^{2+}/Zn^{2+}, K^+/Cl^- and K^+/NO_3^- are also strongly correlated indicating that ions in each group could have originated from the same source [17]. The correlation analysis also reveals strong positive correlations between groundwater nitrate concentrations and total coliform counts. Environments associated with sewage contamination can be sources of nitrates in groundwater and have also been identified as breeding grounds for bacterial activities. This can be used to identify sewage pollution by testing for fecal coliforms [31].

6.2) PCA analysis

The principal component analysis (PCA) groups variables such that variables belonging to one group are highly associated with one another and it has been considered to be efficient for the identification of contaminant sources [18]. In this study, 14 variables from 60 ground-water samples were used for the PCA. This resulted in a reduction of the initial dimension of the dataset, with the first four components explaining 77.40% of the total sample variance. The first Principal component (PC1) accounts for 30.72% of the total variance and has strong loadings for Na^+, K^+, Fe, EC and TDS (Table 3). Sodium, potassium and iron are associated with biological wastes and can be contributions from leachates arising from surrounding septic tanks or municipal waste disposals. The second principal component (PC2) which accounts for 22.68% of the total variance has strong loadings for Ca^{2+}, Mg^{2+} Fe, Cl^-, SO_4^{2-} and HCO_3^-. Calcium, magnesium, bicarbonates and sulphates are abundant in groundwater originating mainly from dissolutions basal rocks such as shale and limestone. The third principal component PC3 accounts for 13.07% of the total variance and has strong loadings for Cl^-, PO_4^{3-} and NO_3^-. These are thought to be released from sewage most likely seepages from surrounding improperly built septic tanks. PC4 accounts for 10.91% of the total variance and has strong loadings for NO_3^-, BOD and Zn. A high BOD in water samples indicates microbial activity and is most commonly used as an indicator of pollution from sewage.

The scores plot illustrated in Figure 6, shows the pattern and relationships between groundwater quality parameters. PC2 and PC3 reflect possible contamination from unsanitary anthropogenic sources as NO_3^-, Cl^- and PO_4^{3-} are usually consistent with contamination arising from sewage [32].

7) Comparison of present study with the previous research and regulatory standards

The mean and range of values for water quality parameters for all sixty groundwater samples collected from the study area are presented and compared with acceptable limits stipulated by the WHO and the NSDWQ (Table 4). The results obtained within this study are also compared with results obtained in similar studies that have investigated groundwater quality in relation to improperly treated sewage. The result of the various studies is unanimous in the potential effect of improperly treated sewage on groundwater quality. The water parameters most affected by intrusion of leachates into underground aquifers include sodium, potassium, chlorides, nitrates, TDS, BOD and coliform bacteria

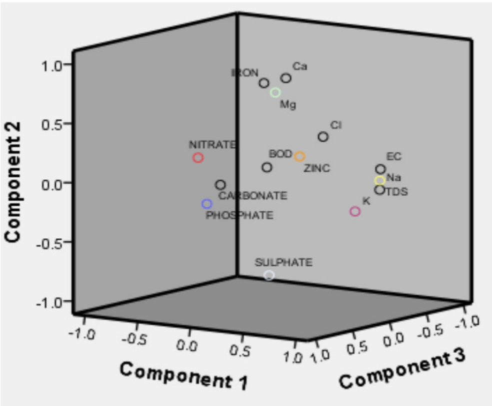

Figure 6 Component plot in rotated space of groundwater quality parameters in study area.

Table 3 Rotated component matrix of PCA of groundwater quality parameters

Parameter	PC1	PC2	PC3	PC4
TDS	**0.976**			
EC	**0.968**			
Na+	**0.964**			
K^+	**0.806**			0.308
Ca^{2+}		**0.797**		
Mg^{2+}		**0.689**	0.399	0.323
Cl^-		**0.571**	**0.618**	
NO_3^-			**0.701**	**0.551**
SO_4^{2-}		**- 0.775**	0.405	
PO_4^{3-}			**0.782**	
HCO_3^-	- 0.403	**0.495**		
BOD				**- 0.843**
Zn			-0.390	**0.630**
Fe	**0.564**	**0.790**	- 0.308	
Eigen values	**3.996**	**2.949**	**1.699**	**1.148**
% of variance	**30.742**	**22.681**	**13.070**	**10.910**
Cumulative %	**30.742**	**53.423**	**66.493**	**77.403**

Remark: Moderate to strong loadings are in bold.

Table 4 Comparison of present study with previous works and regulatory standards

Parameter	**This study**			**Previous works**	**Regulatory standards [14–15]**
	Min	**Max**	**Mean**		
Temperature (°C)	25.90	27.40	26.72	5.70 [13]	Ambient
pH	6.26	8.66	7.11	6.8 – 8.6 [33] 7.2 – 7.5 [34] 6.79 – 7.99 [35]	6.5 – 8.5
E.C. (µS cm^{-1})	83.00	1035.00	404.40	0.08 – 1.96 [13] 112 – 3387 [33] 189.43 [34] 530 – 564 [35] 12.49 – 66.3 [36]	1000
TDS (mg L^{-1})	42.00	621.00	201.58	210 [13] 70 – 2030 [33] 98.54 – 540.02 [34] 200 – 240 [35] 12222 – 40799 [36]	500
Total hardness (mg L^{-1} $CaCO_3$)	73.00	300.00	170.45		150
BOD_5 (mg L^{-1})	0.10	13.20	4.90	11 – 28 [35]	< 3
Ca^{2+} (mg L^{-1})	16.00	211.00	92.20	10 – 195 [13] 15.81 – 23.64 [35] 561.1 – 3767.6 [36]	75
Mg^{2+} (mg L^{-1})	2.00	60.00	24.78	1.65 – 33.78 [13] 0.29 – 0.72 [35] 0.48 – 972.8 [36]	20
Na^+ (mg L^{-1})	7.00	50.00	19.32	0.19 – 113 [13] 3000 – 12220 [36]	200

Table 4 Comparison of present study with previous works and regulatory standards (*continued*)

Parameter	This study			Previous works	Regulatory standards [14–15]
	Min	Max	Mean		
K^+ (mg L^{-1})	0.16	34.00	5.75	6.1 – 320 [36]	
Fe^{2+} (mg L^{-1})	0.04	5.32	0.05	0.11 – 0.21 [13] 0.02 – 0.03 [37]	0.1
Zn^{2+} (mg L^{-1})	0.02	0.51	0.07	0.1 – 0.2 [13] 0.3 – 0.7 [37] 1.12 – 2.7 [35]	3
Cl^- (mg L^{-1})	25.00	210.00	77.13	143.17 [13] 61 – 79 [37] 36 – 720 [33] 12.42 – 143.92 [34] 23.37 – 38 [35] 3195 – 29820 [36]	250
NO_3^- (mg L^{-1})	5.09	17.00	9.47	0.09 [13] 45 – 47 [37] 1.4 – 73.6 [33] 2.43 – 38.03 [34] 9.86 – 2.86 [35]	10
SO_4^{2-} (mg L^{-1})	10.10	56.11	33.48	0.64 – 11.92 [13] 724.2 – 8645.5 [36] 9.14 – 16 [35]	100
PO_4^{3-} (mg L^{-1})	0.10	0.84	0.52	7.75 – 30 [13]	
HCO_3^- (mg L^{-1})	17.10	48.32	28.69	0.16 – 10 [13] 24.4 – 1040.6 [36]	100
TCC (×10 cfu mL^{-1})	ND	102.00	13.82	3.69 – 8.92 [34] 176 – 264 [35]	0
E. Coli (×10 cfu mL^{-1})	ND	41.00	3.59		0

Remark: ND = Not Detected

Conclusion

In a peri-urban setting such as communities around the Federal University of Agriculture, Abeokuta where this study was carried out, groundwater remains the largest available source of freshwater. Thus, monitoring for groundwater quality within this area becomes an essential part of environmental safety. Results within this study reveal that majority of the water quality parameters fell under study fell within regulatory limits. However, the BOD and results of microbiological analysis, two important water quality parameters for assessing organic pollution in waters indicate that majority of the water samples are contaminated with sewage. Similarly, approximately 38% of samples contained nitrates above the recommended limits. The dominant hydrochemical facies in the study area is the Ca^{2+}– Cl^- type. From the correlation analysis, Na^+, K^+ shows strong correlations with Cl^- and NO_3^-, indicating that the ions could have originated from the same source. PCA reflect possible contamination from unsanitary anthropogenic sources such as surrounding improperly built septic tanks. The authors recommend a continuous monitoring of groundwater quality within the study area for a much longer period of time taking into consideration seasons. This will provide data on how dry or rainy conditions can contribute to how these improperly built septic tank units contaminate groundwater sources.

Declaration of interests

The authors hereby declare that we have no competing financial or personal interests or personal relationships that could have influence on the work reported in this paper.

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