



Assessment of seasonal variation of Nsukka phreatic aquifer groundwater quality

Chidozie Charles Nnaji✉, Kenneth Onuigbo, John Precious Nnam

The high dependence on groundwater supply by the residents of developing countries and low-income cities expose them to various diseases as a result of the toxic substances in the water they drink. Groundwater contamination quality depends on recharge water quality, atmospheric precipitation, inland surface water and sub-surface geochemical processes. This study was aimed at determining the physicochemical quality of phreatic groundwater in Nsukka, Nigeria and to investigate seasonal variation on groundwater quality as well as the various sources of contamination. A total of 8 wells were selected for quality monitoring. Water samples for water quality were collected in May, July, September and December and analyzed for physicochemical parameters following APHA standard methods. The water samples were generally acidic with pH values of 5.52 ± 0.63 , 4.56 ± 0.65 , 5.20 ± 0.59 and 6.1 ± 0.54 in May, July, September and December respectively. Iron cadmium, lead and zinc violated recommended values. All the samples collected in May, July and September exceeded guideline values for cadmium while all samples collected in May, September and December exceeded guideline values for lead. Results of analyses clearly show that water quality parameters vary widely across the four sampling seasons. There was a very high correlation between Cl^- and the alkali and earth alkali metals at 95% confidence level as follows: Cl^- and K^+ ($r = 0.90$), Cl^- and Ca^{2+} ($r = 0.881$), Cl^- and Na^+ ($r = 0.844$), Cl^- and Mg^{2+} ($r = 0.664$). The drinking water quality indices results obtained ranged from 43% - 48% for NIS, 40% - 46% for WHO and 46% - 52% for EPA which shows that the water is not fit for consumption without treatment. However, irrigation water quality indices show that the water can be used for irrigation without treatment. The average values of SAR are 1.25, 0.67, 1.37 and 0.78 for May, July, September and December which indicate suitability for irrigation. Results of principal component analyses linked groundwater contamination in the area to PC1 (anthropogenic activities), PC2 (leaching of iron from lateritic soil formation), PC3 (interaction between rainwater and atmospheric gases), PC4 & PC5 (impact of industrialization). Piper's trilinear plots show that the $\text{Na}^+ - \text{Cl}^-$ type is the most dominant irrespective of season. Alkali metals exceeded alkali earth metals in 71% of the samples while strong acids exceeded weak acids in 80.6% of the samples.

INTRODUCTION

Majority of the population in developing countries are not connected to the municipal water supply network and are thus compelled to get water from other sources such as water vendors, surface water, shallow wells and boreholes that may be unsafe for drinking and other domestic purposes due to high possibilities of contamination (WHO 2006, 2011; Frederick Bloetscher et al. 2016). With the shrinking of surface water resources as a result of climate change and gross pollution of water bodies as a result of industrial activities, many urban and rural dwellers resort to groundwater for domestic water supply (David Chikodzi and Linda Yeukai Mapfaka, 2018; Magreth S Bushesha, 2018). The use of shallow groundwater sources in particular for drinking and other domestic purposes is a common feature of many low-income urban communities in developing countries (Graham and Polizzotto, 2013). However, shallow and permeable aquifers are most susceptible to contamination as a result of their proximity to the ground surface (Adejuwon and Mbuk, 2011). Generally, the quality of groundwater depends on the quality of the recharge water, atmospheric precipitation, inland surface water and subsurface geochemical processes. Shallow

wells draw from the groundwater nearest the land surface, which may be directly affected by anthropogenic activities. Hence, sufficient separation is required between the water table and the ground surface to ensure that percolating water is purified to an acceptable level before joining groundwater.

The physicochemical and biological quality of water is usually altered by a complex system of interactions between water and soil/aquifer which include: filtration, sedimentation, precipitation, oxidation-reduction, sorption-desorption, ion-exchange and biodegradation (Balke and Zhu, 2008). Though the soil provides a substantial level of purification of percolating water, the upper unconsolidated portion of the soil contributes to water pollution, especially if it contains humic substances. Besides, point sources such as pit latrine, solid waste dump, septic tank and agricultural chemicals from farmlands have been identified as major sources of groundwater contamination. There are concerns that discharges of chemical and microbial contaminants from sewage disposal facilities to groundwater may negatively affect human health (Graham and Polizzotto, 2013). Several studies have confirmed the role of onsite sewage disposal systems in groundwater pollution (Kiptum, Ndamnuki, 2016; Vilane and Dlamini, 2016; Bonda et al., 2014). Hence, deep wells are usually more reliable both in terms of yield and water quality, especially where

University of Nigeria, Nsukka, Nigeria;

✉Corresponding author: Chidozie Charles Nnaji; University of Nigeria, Nsukka, Nigeria; Email: Chidozie.nnaji@unn.edu.ng; phone +234-803-894-8808

Table 1 Details of Determination of Physicochemical Parameters of Well Water

Parameter	Consideration	Principle	Standard Method	Equipment
pH	Health (indirect) Interferes with treatment	Electrometry	APHA 4500H ⁺ B	HANNA pH meter
Turbidity	Health (indirect)	Turbidimetry	APHA 2130 B	HANNA Turbidity meter
Conductivity	None	Electrometry	APHA 2510 B	Conductivity meter
Calcium		EDTA Titrimetry	APHA 3500-Ca B	Titration
Potassium		Photometry	APHA 3500-K B	Flame photometer
Magnesium		EDTA Titrimetry	APHA 3500-Mg B	Titration
Sodium		Photometry	APHA 3500-Na B	Flame photometer
Chloride	None	Argentometry	APHA 4500Cl ⁻	Titration
Sulphate	Health	Turbidimetry	APHA 4500 SO ₄ ²⁻ E	UV-Visible Spectrophotometer
Total hardness	Acceptability	EDTA Titrimetry	APHA 2340 B	Titration
Alkalinity		Potentiometric titration	APHA 2320 B	Titration/pH meter
Iron	Aesthetics	Phenanthroline colorimetry	APHA 3500-Fe A	HACH DR 890 Colorimeter
Cadmium	Health	Atomic absorption spectrophotometry	APHA3500 – Cd	Varian AA240 AAS
Manganese	Health	Atomic absorption spectrophotometry	APHA 3500-Fe A	Varian AA240 AAS
Lead	Health	Atomic absorption spectrophotometry	APHA 3500-Pb A	Varian AA240 AAS
Arsenic	Health	Atomic absorption spectrophotometry	APHA 3500-As A	Varian AA240 AAS
Chromium	Health	Atomic absorption spectrophotometry	APHA 3500-Cr A	Varian AA240 AAS

seawater intrusion is unlikely. However, deep groundwater quality can be altered by the chemical composition of the aquifer, length of storage and the chemical composition of recharge water. The inherent chemical constituents of permeable rocks can limit the quality of the water as they may have dissolved impurities from rock and sand strata (Umo and Okoye, 2006). Groundwater moving through sedimentary rocks and soils may pick up a wide range of compounds such as magnesium, calcium, and chlorides (Lenntech 1998). While gypsum, limestone and halite dissolve readily in water, thereby increasing total dissolved solids and water hardness, hard rocks such as granite and sandstone yield water of higher quality because of their resistance to dissolution.

This study was necessitated by the current status of water supply in the study area. Groundwater is the main source of water supply because of the complete collapse of the municipal water supply system. The few who can afford it drill deep wells for commercial supply via water tankers while others resort to shallow wells which are more affordable but yields water of questionable quality. Besides, these shallow wells dry up in dry season thereby subjecting those who depend on them to some degree of water stress. Hence, the aim of this study was to investigate the seasonal variation of shallow well water quality, to ascertain its suitability for various purposes and to identify the sources of pollution.

METHODOLOGY

The study area is Nsukka, Enugu State, Nigeria located on latitude 6° 51' 28 19" N and longitude 7° 23' 44.77" E in the South Eastern part of Nigeria. It is in the humid tropical climatic region and is characterized by distinct wet and dry seasons. According to Iloeje (1995), the dry season generally begins about the middle of October and ends around March, while the rainy season sets in April and ends in early October. However, in recent times, the rainy season begins with a prolonged onset spanning from March to May, reaching a peak in September and

finally receding in November. The area was predominantly rural but has been slowly and gradually urbanized as a result of the establishment of the first full-fledged Nigerian university in 1955. The inhabitants of the area are mainly farmers, artisans, petty traders, middle and low-income civil servants and university lecturers. There are numerous small and medium scale business outfits and industries such as paint manufacturing, cassava processing, automobile repairs, bakeries, vegetable oil processing, poultry, piggery, etc. The city is characterized by poor planning, resulting in poor housing and sanitation arrangements. Waste management basically involves collection of waste from the numerous open dumps scattered across the city and carting them away to the final disposal point. Unfortunately, collection rate seriously lags behind the rate of waste generation, resulting in accumulation of waste at these dumps. In addition, most streets and roads do not have drainage channels for safe and proper conveyance of stormwater. This usually results in inundation of the soil by runoff and in the process leaching contaminants from solid waste dumps and other premises.

A total of 15 wells located within a radius of 6 km were pre-selected for reconnaissance out of which 8 were finally selected for water quality monitoring. Physical observation of the wells was conducted and the depth and diameter of each well was recorded. The eight wells were monitored for a period of one year and samples for water quality analyses were collected in viz: May, July, September and December. These months represents different seasons of the year namely: rainfall inception, rainy season, peak of rainy season and dry season respectively. Samples were taken in clean 1.5 L plastic containers which were rinsed thrice with well water before sample collection. The samples were analyzed following APHA standard methods as shown in Table 1.

RESULTS AND DISCUSSION

The immediate surroundings of some of the wells were paved to about 1metre square while others were situated amidst vegetation. Five of the

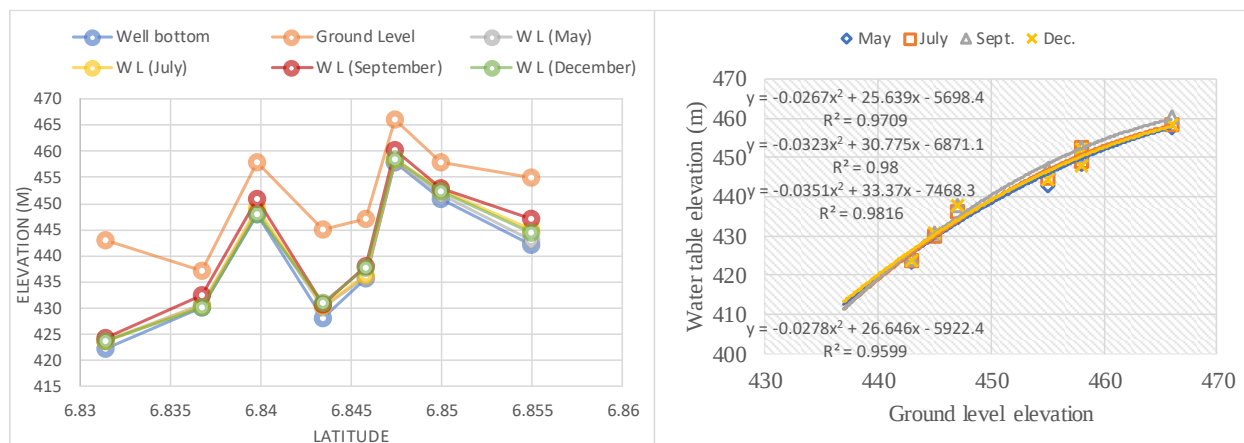


Figure 1 Seasonal water level variation in wells

Table 2 Descriptive statistics of the water quality parameter results

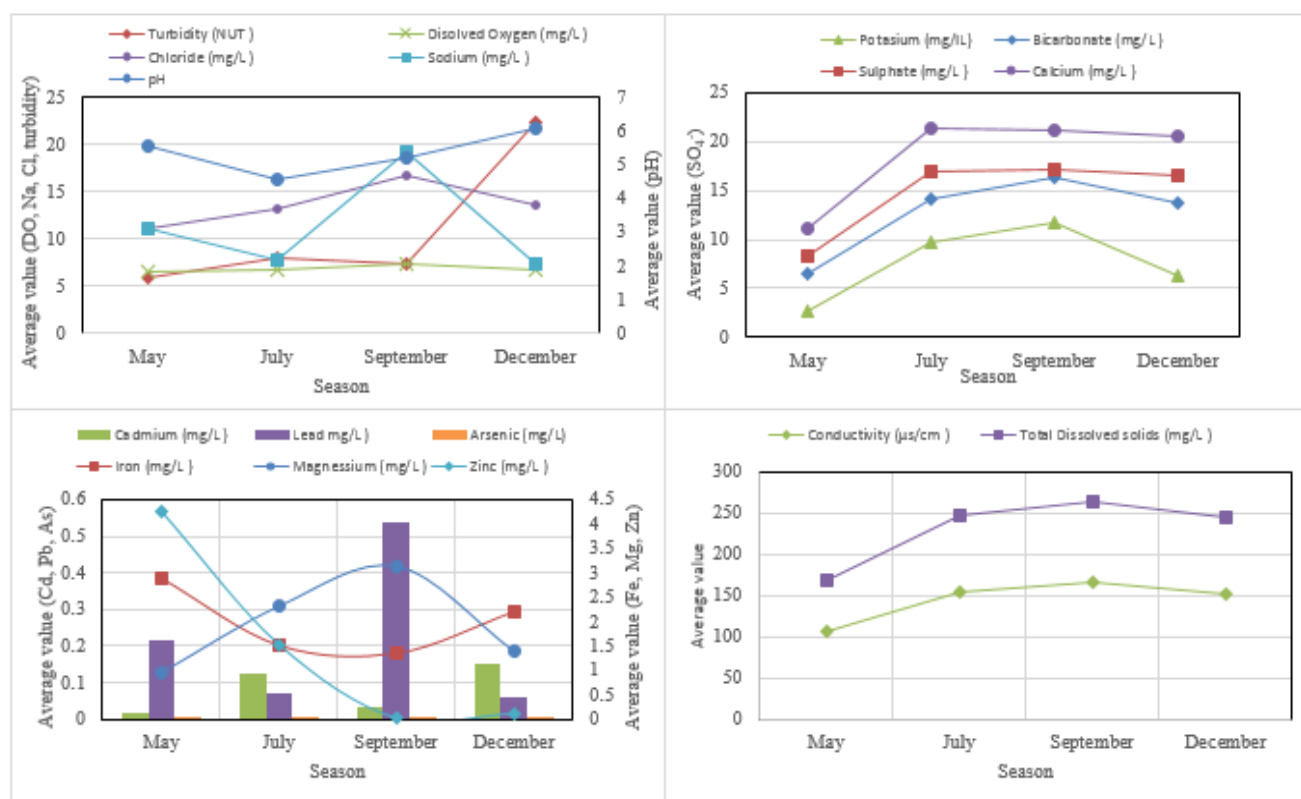
Parameters	May	July	Sept.	Dec.	NIS	WHO 2011	EPA
Temperature (°C)	29.8 ± 0.08	27.2 ± 0.08	27.1 ± 0.09	29.4 ± 0.14	Ambient	-	-
pH	5.52 ± 0.63	4.56 ± 0.65	5.2 ± 0.59	6.1 ± 0.54	6.5 – 8.5	6.5 – 8.5	6.5 – 8.5
Conductivity (µs/cm)	105.73 ± 107.46	154.1 ± 150.80	164.6 ± 152.15	152.6 ± 131.07	1000	250	-
Total Dissolved solids (mg/L)	63.36 ± 64.33	92.5 ± 90.53	98.6 ± 91.10	91.6 ± 78.71	500	-	500
Hardness (mg/l)	10.95 ± 11.43	20.82 ± 18.63	23.44 ± 27.13	15.92 ± 13.31	150	-	-
Turbidity (NTU)	5.9 ± 6.82	7.96 ± 8.05	7.34 ± 9.17	22.3 ± 44.78	5	5	-
Dissolved Oxygen (mg/L)	6.5 ± 0.38	6.65 ± 0.59	7.4 ± 0.3	6.8 ± 0.5	-	-	-
Total Alkalinity (mg CaCO ₃ /L)	3.75 ± 0.75	4.9 ± 6.45	4.79 ± 9.02	7.5 ± 4.11	-	-	-
Bicarbonate (mg CaCO ₃ /L)	3.75 ± 0.75	4.61 ± 6.51	4.6 ± 9.12	7.5 ± 4.11	-	-	-
Carbonate (mg CaCO ₃)	ND	ND	ND	ND	-	-	-
Sulphate (mg/L)	1.96 ± 1.32	2.74 ± 1.69	0.8 ± 1.35	2.84 ± 5.00	100	500	250
Chloride (mg/L)	11.07 ± 10.92	13.29 ± 17.44	16.75 ± 14.82	13.5 ± 12.72	250	250	250
Sodium (mg/L)	11.07 ± 13.66	7.69 ± 8.45	19.13 ± 17.76	7.44 ± 8.05	200	200	-
Potassium	2.66 ± 2.87	9.68 ± 12.58	11.63 ± 13.44	6.3 ± 8.05	-	-	-
Calcium (mg/L)	2.78 ± 4.03	4.5 ± 5.12	4.12 ± 3.88	4.1 ± 4.53	-	-	-
Magnesium (mg/L)	0.97 ± 1.01	2.3 ± 1.67	3.20 ± 4.75	1.38 ± 0.74	0.2	-	-
Chromium (mg/L)	ND	ND	ND	ND	0.05	0.05	0.1
Iron (mg/L)	0.38 ± 0.29	0.20 ± 0.07	0.18 ± 0.10	0.29 ± 0.57	0.3	0.3	0.3
Cadmium (mg/L)	0.018 ± 0.012	0.124 ± 0.23	0.036 ± 0.018	0.15 ± 0.30	0.003	0.003	0.005
Lead (mg/L)	0.214 ± 0.049	0.07 ± 0.16	0.536 ± 0.41	0.06 ± 0.03	0.01	0.01	0.015
Zinc (mg/L)	4.24 ± 2.64	1.52 ± 3.70	0.024 ± 0.029	0.124 ± 0.26	3	3	5
Arsenic (mg/L)	0.007 ± 0.004	0.008 ± 0.01	0.0041 ± 0.0036	0.0041 ± 0.037	0.01	0.01	0.01

wells had their walls lined to a depth of about 1.0 m while the others were not lined at all. All the wells were covered with either circular or square metal plates. The wells investigated had diameters ranging from 0.7 to 1.2m and depths ranging from 7.05 to 2.09m. The average water level was 0.92, 1.45, 2.79 and 1.4m in May, July, September and December respectively. This shows that the groundwater is quite shallow given that Nsukka is not a coastal area. The water level in the wells was generally higher in the rainy season month of September than all the other months. This can be attributed to the rise in water table due to intense rainfall occurring almost on a daily basis. September has the highest rainfall of about 222.5mm and a 77% chance of daily rainfall. The lowest water level was observed in the month of May. This is because rainfall was just setting in and the ground was still dry which implies that any storm event would merely serve to wet the soil and therefore will not contribute significantly to the water table. One of the wells sampled had no water in May partially due to the reason already adduced and partly due to the fact that this particular well was the

shallowest (0.7m) and the well bottom was on an elevation of 466m which is higher than the other wells (Table 2). The dynamic response of the water table to seasonal variation in rainfall suggests that the main source of groundwater recharge is rainfall (Sarun and Sheela, 2018; Manti Patil et al. 2019). The soil is highly permeable with 13.182% of rainfall reaching the water table by infiltration and the geologic formation provides perched aquifer units trapped by basal shale units on the flanks of its outliers (Uzoije et al. 2014). The long rainy season lasting for about eight months leaving behind an average of 1579 mm of precipitation in its wake ensures abundant yield of the wells during the rainy season. Groundwater is the major source of water supply in the area because there are no surface water bodies and given the high cost of boreholes, many house owners resort to hand dug wells which are usually more affordable. Figure 1 shows that the ground surface elevation in the study area tends to follow the latitude. The water table elevation is also a function of the ground level elevation.

Table 3 Percentage violation of Standards

Parameters	May	July	Sept.	Dec.	May	July	Sept.	Dec.
	NIS				EPA			
pH	100.0	100.0	100.0	100.0	100.0	100.0	100.0	75.0
Turbidity	37.5	62.5	50.0	62.5	37.5	62.5	50.0	62.5
Iron	50.0	12.5	12.5	12.5	50.0	12.5	12.5	12.5
Cadmium	100.0	100.0	100.0	75.0	100.0	100.0	100.0	75.0
Lead	100.0	37.5	100.0	100.0	100.0	37.5	100.0	100.0
Zinc	50.0	12.5	0.0	0.0	50.0	12.5	0.0	0.0
Arsenic	0.0	25.0	0.0	0.0	0.0	25.0	0.0	0.0
Mean	72.9	50.0	72.5	70.0	72.9	50.0	72.5	65.0

**Figure 2** Seasonal Variation of water quality parameters

The physicochemical parameters of the water samples are presented in Table 2. The water samples were generally acidic with pH values of 5.52 ± 0.63 , 4.56 ± 0.65 , 5.20 ± 0.59 and 6.1 ± 0.54 in May, July, September and December respectively. Table 3 shows that all the water samples were in violation of stipulated pH range of 6.5 – 8.5. These were however generally higher than those (2.6 – 4.5) reported by Appleyard et al. (2015) which was partly attributed to decline in rainfall. Other possible causes of low groundwater pH include dissolution of atmospheric acids in rainwater and decaying organic matter. Elevated concentrations of acidic gases have been linked to increase in anthropogenic activities. Takem et al. (2015) observed that the use of fossil fuel and high traffic density lead to increasing atmospheric deposits of acidic SO_2 and NO_x gases. In the study area, the use of domestic power generators is widespread in an attempt by individual households to ameliorate the high rate of power failure. This situation is further exacerbated by the low acid buffering capacity of the shallow

groundwater as depicted by the low level of alkalinity of 3.75 ± 0.75 , 4.9 ± 6.45 , 4.79 ± 9.02 and 7.5 ± 4.11 mg/l for May, July, September and December respectively. The entirety of the alkalinity recorded in this study area was contributed solely by bicarbonate. Table 2 shows that carbonate was below detection limit in all the wells throughout the study period. This observation aligns with those of Takem et al. (2015) who reported a total absence of carbonate in the shallow groundwater of Douala, Cameroon.

Electrical conductivity (EC) generally increased from the onset of rain around May (105.73 ± 107.46) to a maximum (164.6 ± 152.15) in September when rainfall is at a peak and then decreased to 152.6 ± 131.07 $\mu\text{S}/\text{cm}$ during the dry season in December. All samples investigated complied with the drinking water guideline of 1000 $\mu\text{S}/\text{cm}$ for EC. The slight increase in EC in the rainy season can be attributed to increased dissolution of soluble substance on the ground by rainwater before percolating into the soil. Open solid waste dumps and agricultural

lands also contribute significantly to dissolved solids in shallow groundwater in the study area. The problem of pollution from refuse heaps is greatest where high rainfall and shallow water table occur (Aboyeji, 2013). The values of TDS in this study were 63.36 ± 64.33 , 92.5 ± 90.53 , 164.6 ± 152.15 and 152.6 ± 131.07 mg/l for May, July, September and December respectively. These were similar to the TDS values reported by Mbaka et al. (2017) for shallow wells in Keiyo Highlands, Kenya but much higher than those reported by Das and Nag (2017) for the deep wells of Bankura District, West Bengal, India. This disparity between the TDS concentrations of deep and shallow groundwater can be attributed to the fact that water travels longer distances and spend more time in deep aquifer thus dissolving more aquifer materials. Most of the solids in the well water were present in suspended form. Turbidity was lowest in May (5.9 ± 6.82 NTU) and highest in December (22.3 ± 44.78 NTU). The high level of turbidity was caused by intrusion of surface runoff into the wells and dislodging of soil particles from the unlined walls and bottom of the wells especially during manual abstraction. High concentrations of particles enter the wells during the rainy season via surface runoff. However, because of the abundance of water in the wells, the particles easily settle out of the upper water column from which abstraction takes place. Hence, suspended particles accumulated in the bottom of the wells during the rainy season. In the dry season when the water level is low, attempts to collect water from the wells results in the disturbance of the loosely settled particles. Though turbidity has no direct health impact depending on the nature of the particles, it can provide harbourage for microorganisms and interfere with treatment processes especially disinfection. Huey and Meyer (2010) reported that turbidity was an effective indicator of *E.coli* and *Enterococcus* Spp. Mann et al. (2007) noted that outbreaks of gastrointestinal diseases have been traced to excessive levels of turbidity in water. Nasrabadi et al. (2016) further reported that turbidity can be used as a proxy for monitoring heavy metals influx into water. Obviously, the high level of turbidity in the water samples confirm that shallow well water in the study area is unfit for consumption without treatment. Over half (53%) of the water samples had turbidity higher than the recommended value of 5NTU. Besides, the associated health risk, turbidity can also present aesthetics and acceptability problems. Turbid water can cause stains on fittings and excessive accumulation of solids in water storage tanks.

The major cations and anions were present in low concentrations. Chromium was below detection limit in all the samples. However, iron, cadmium, lead and zinc violated recommended values (Table 3). All the samples collected in May, July and September exceeded guideline values for cadmium while all samples collected in May, September and December exceeded guideline values for lead. Studies have shown that low pH such as prevailed in shallow groundwater of the study area facilitates the mobilization of heavy metals. Besides, rise in urbanization and civilization has also encouraged the release of heavy metals such as lead and cadmium into the environment. Specifically, the high concentration of lead and cadmium in the water samples can be attributed to the leaching of these metals from lead-acid and nickel-cadmium accumulators and rechargeable batteries disposed in open dumps and fertilizer application. It has been reported that high concentrations of cadmium are associated with soft water of low pH (WHO, 2011). Cadmium is considered one of the most toxic metals with the ability to cause cancer and kidney damage (Lane et al., 2015). Despite the global reduction in the use of lead, high concentrations of lead remain a challenge in groundwater samples in many parts of the world (Katz et al., 1999). Katz et al. (1999) observed that the difference

in the total lead concentration among aquifer systems reflect combined influence of anthropogenic sources and chemical conditions of each system.

Figure 2 shows clearly that water quality parameters vary widely across the four sampling seasons. This was confirmed by analysis of variance of the water quality parameters over the four sampling seasons. Tukey honestly significant difference (HSD) was used to explore the source of water quality variation. Table 4 shows that the only parameters with significant seasonal variation are pH ($p = 0.00$), dissolved oxygen ($p = 0.04$), lead ($p = 0.01$) and zinc ($p = 0.04$) at 95% confidence level. This confirms that the distribution of contaminants in the environment is sensitive to varying climatic conditions. The lowest average pH of 4.56 and 5.20 were recorded in the rainy season months of July and September respectively. The highest average pH values were recorded in December (6.06) and May (5.43). The lowering of water pH was precipitated by intense evaporation which is characteristic of the dry season period. Besides, continuous abstraction of water without freshwater replenishment from rainwater can also alter groundwater pH. The onset of rain in April/May results in the generation of surface runoff and subsequent decline of shallow well water. The above inference is further corroborated by Table 4 which shows that there is an honest significant difference between pH values of water samples taken in December and July (HSD = 1.50) as well as between those taken in December and September (HSD = 0.863). Hence, July and September belong to the same homogenous subset while December and May belong to the same homogenous subset with respect to pH of the water samples investigated. Table 4 further shows that dissolved oxygen concentrations of the well water samples increased from an average value of 6.51 mg/l in May to a peak value of 7.4 mg/l in September (rainy season) and then dropped to 6.75 mg/l in December (dry season). This dissolved oxygen trend is consistent with the addition of freshwater from rain and surface runoff into the wells either by infiltration through the soil or other forms of intrusion such as lateral inflow. Detry et al. (2004) reported that the dissolved oxygen concentration in shallow groundwater increased with input of stormwater during rainfall. It has been observed that for most aquifers, oxygenation associated with water table peaking event overwhelms the oxygen consumption potential of microbial and mineral assemblage, resulting in elevated oxygen concentration (Yabusaki et al., 2017). There was a significant difference of 0.888, 0.753 and 0.653 mg/l between dissolved oxygen concentration measured in September and those recorded in the months of May, July and December. Detry et al. (2004) also reported seasonal variation in dissolved oxygen in shallow groundwater. There was also significant seasonal variation of lead concentration ($p = 0.01$). The highest mean concentration of lead was recorded in September and differed significantly from those of May (HSD = 0.322), July (HSD = 0.465) and December (HSD = 0.475). This suggests that the presence of lead in the water samples was due to surface runoff and that lead was mostly present in soluble form. These results contradict those of Buragohain et al. (2010) who reported that the concentration of lead in groundwater was higher in dry season (0.287 ± 0.01 ppm) than the rainy season (0.194 ± 0.011 ppm). However, the two studies confirm the preponderance of lead in shallow groundwater. This goes further to suggest that the major source of the lead in the water samples is anthropogenic activities and that surface runoff is the principal medium of lead mobilization. There was significant difference between the concentration of zinc recorded in May and those recorded in September and December with HSD of 4.22 and 4.12 respectively. The highest mean concentration of zinc was recorded in May when the water table was lowest and surface runoff

Table 4 Multiple comparison table of water quality parameters with significant seasonal variation

Parameter	Month (J)	Mean Difference (I - J)				Homogenous Subsets		
		Month (I)						
		May	July	September	December	1	2	3
pH (p = 0.00)	July	-.980*	0	-.637	-1.50*	4.563		
	September	-.343	.637	0	-.863*	5.200	5.200	
	May	0	.980*	.343	-.520		5.543	5.543
	December	.520	1.50*	.863*	0			6.063
DO (p = 0.04)	May	0	-.136	-.888*	-.236	6.514		
	July	.136	0	-.753*	-.100	6.650		
	December	.236	.100	-.653*	0	6.750		
	September	.888*	.753*	0	.653*		7.403	
Pb (p = 0.01)	December	-.153	-.010	-.475*	0	0.061		
	July	-.143	0	-.465*	.0100	0.071		
	May	0	.143	-.322*	.153	0.214		
	September	.322*	.465*	0	.475*		0.536	
Zn (p = 0.04)	September	-4.219*	-1.50	0	-.100	0.024		
	December	-4.119*	-1.400	.100	0	0.124		
	July	-2.719	0	1.50	1.40	1.524	1.524	
	May		2.719	4.219*	4.119*		4.243	

Table 5 Pearson Correlation between physicochemical parameters

	pH	TDS	Turbidity	DO	HCO ₃ ⁻	SO ₄ ²⁻	Cl	Na	K	Ca	Mg	Fe	Cd	Pb	Zn	As
pH	1															
TDS	-.367*	1														
Turbidity	-.026	.245	1													
DO	.263	-.247	-.349	1												
HCO ₃ ⁻	.351	.213	-.061	.198	1											
SO ₄ ²⁻	-.281	.348	.788**	-.446*	-.104	1										
Cl	-.367*	.987**	.212	-.256	.160	.319	1									
Na	-.405*	.825**	.188	-.091	.090	.193	.844**	1								
K	-.386*	.902**	.251	-.043	.302	.332	.900**	.780**	1							
Ca	-.217	.914**	.244	-.153	.323	.310	.881**	.680**	.815**	1						
Mg	-.475**	.661**	.139	-.013	-.090	.224	.664**	.719**	.722**	.487**	1					
Fe	-.075	.172	.822**	-.411*	-.151	.685**	.170	.148	.154	.160	.063	1				
Cd	.250	-.230	.047	.104	-.053	-.222	-.243	-.240	-.173	-.110	-.111	-.097	1			
Pb	-.077	-.001	.023	.394*	-.264	-.144	.042	.237	.074	-.025	.330	.006	-.006	1		
Zn	.096	-.025	.014	-.297	-.043	-.151	-.027	.008	-.134	.004	-.090	.193	.269	.068	1	
As	-.321	-.114	.269	-.169	-.346	.326	-.118	-.099	.032	-.203	.072	.294	-.192	-.002	-.092	1

severely limited. This suggests that the major contribution of zinc comes from the soil.

There was a very high correlation between Cl⁻ and the alkali and earth alkali metals at 95% confidence level as follows: Cl⁻ and K⁺ (r = 0.90), Cl⁻ and Ca²⁺ (r = 0.881), Cl⁻ and Na⁺ (r = 0.844), Cl⁻ and Mg²⁺ (r

= 0.664) as shown in Table 5. These values agree with those of Wan et al. (2017) who reported that Cl⁻ was strongly correlated with K⁺ (r² = 0.58), Na⁺ (r² = 0.82), Ca²⁺ (r² = 0.79) and Mg²⁺ (r² = 0.78). Takem et al. (2015) also recorded very high correlation between Na⁺ and Cl⁻ (r = 0.9) and K⁺ and Cl⁻ (r = 0.84) in shallow unconfined sandy aquifer of

Table 6 Seasonal water quality indices for various purposes

Drinking Water Quality Index															
Season	F1	F2	F3	WQI	Class	F1	F2	F3	WQI	Class	F1	F2	F3	WQI	Class
	NIS					WHO					EPA				
May	47	36	67	48	Poor	54	37	68	46	Poor	46	35	60	52	Marginal
July	53	27	78	43	Poor	68	29	79	40	Poor	55	26	73	46	Poor
September	40	28	84	44	Poor	46	32	83	42	Poor	36	28	79	47	Poor
December	40	28	81	45	Poor	46	27	82	43	Poor	36	24	75	50	Marginal
Irrigation Water Quality Index															
Season	F1	F2	F3	WQI	Class	F1	F2	F3	WQI	Class	F1	F2	F3	WQI	Class
	NIS					FAO					EPA				
May	50	39	40	57	Marginal	17	17	16	84	Good	33	26	25	72	Fair
July	50	31	0	66	Fair	33	6	28	75	Fair	33	17	68	55	Marginal
September	25	25	36	71	Fair	0	0	0	100	Excellent	17	17	30	78	Fair
December	25	19	0	82	Good	17	2	0	90	Good	17	13	0	88	Good
Livestock Drinking Water Quality Index															
Sample	F1	F2	F3	WQI	Class										
May	13	14	13	96	Excellent										
July	25	9	0	85	Good										
Sept.	13	13	0	90	Good										
Dec.	13	3	0	93	Good										

Douala, Cameroon. While Takem et al. (2015) attributed these high correlations to a combination of seawater intrusion and anthropogenic activities in their study area, those observed in this study can be attributed primarily to anthropogenic activities, specifically to fertilizer application and leaching from solid waste dumps. This was corroborated by Tiwari and Singh (2014) who noted that the strong positive correlation between Cl^- - Na^+ , Cl^- - TDS and Na^+ - TDS indicate that Cl^- and part of the Na^+ were derived from anthropogenic sources. The study area is semi-urban in nature with vast acres of undeveloped plots which serve as arable land for dwellers, especially the indigenes. Since most of these plots are cultivated every year, fertilizers are usually applied to boost crop productivity. There was also a strong negative correlation ($r = -0.744$) between pH and electrical conductivity (EC) which was much lower than the correlations of -0.49 , -0.238 and -0.2 obtained by Appleyard et al. (2004), Islam et al. (2017), and Tiwari and Singh (2014) respectively. The highest correlation ($r = 0.987$) was observed between Cl^- and TDS followed by Ca^{2+} and TDS ($r = 0.914$), and K^+ and TDS ($r = 0.904$). Table 5 shows very high significant correlation among the alkali and earth alkali groups of metals. A very strong correlation ($r = 0.833$) was obtained between turbidity and Fe owing to the fact that the soil is lateritic and therefore has a high Fe content. Significant negative correlation ($r = -0.411$) between DO and Fe can be attributed to the consumption of dissolved oxygen via oxidation of FeS yielding Fe (II) as opined by Yabusaki et al. (2017). Appleyard et al. (2004) stated that low pH is an indication that sulphides are being oxidized in groundwater flow path. In line with the findings of Khoud and Bhattacharya (2016), most of the heavy metals were weakly correlated with one another ($0.002 \leq r \leq 0.33$). This is an indication that the heavy metals in the groundwater samples were acquired from diverse and

unrelated sources; and their uncorrelated nature can be attributed to different degrees of solubility and conditions for mobilization of these metals.

Water Quality Indices and Suitability of Water for Various Purposes

The water samples were subjected to water quality indices analysis in order to ascertain its suitability for various purposes such as drinking, irrigation and livestock drinking. The drinking water quality indices obtained ranged from 43% - 48% for NIS, 40% - 46% for WHO and 46% - 52% for EPA (Table 6). These values clearly indicate that the well water samples are not fit for consumption without treatment. The disparity in the water quality indices obtained based on the various water quality guidelines can be attributed to the slight differences in the guideline values of the parameters used for computation. The slightly higher index values obtained using EPA guidelines is because of less stringent guideline values for cadmium (0.005 mg/l), lead (0.01 mg/l) and zinc (5 mg/l) as compared to the corresponding guideline values of 0.003 mg/l, 0.01 mg/l and 3 mg/l respectively stipulated by both WHO and NIS. Table 4 shows that the percentage of parameters that violated the guideline values (F_1) was higher for WHO compared to EPA and NIS. This is because of the extremely low WHO guideline value for conductivity (250 mg/l) compared to that of NIS (1000 mg/l). EPA has no guideline value for conductivity. This discrepancy was also seen in the values of the amplitude (F_3) which captures the degree of violation of guideline values. The overall degree of violation of guideline values can be ranked as follows: EPA < NIS < WHO. One-way analysis of variance (ANOVA) was used to ascertain whether these variations in water quality guidelines had significant effect on the water quality

Table 7 Seasonal variation of sodium absorption ratio and %Na

Well	May	July	Sept.	Dec.	May	July	Sept.	Dec.
	SAR				%Na			
A	0.232	0.157	1.818	0.361	1.50	1.50	25.00	3.10
B	0.584	0.346	0.703	0.293	1.90	2.20	2.80	1.90
C	0.303	0.254	0	0.546	1.20	1.40	7.50	2.50
D	2.542	0.835	2.81	0.755	32.00	15.00	35.30	10.40
E	0.775	0.24	0	0.232	2.50	2.40	2.00	1.50
F	1.854	0.179	1.13	0.393	10.40	0.80	2.60	1.80
G	-	1.643	2.373	1.671		20.20	48.00	23.00
H	2.455	1.711	2.145	1.494	28.00	18.00	29.80	15.30

Table 8 Principal components of well water quality parameters

	Component (80.5%)				
	1 (35.2%)	2 (17.1%)	3 (11.4%)	4 (8.9%)	5 (7.9%)
pH	-.423	.038	.704	.132	.201
TDS	.965	.125	.036	-.132	-.041
Turbidity	.137	.956	.026	.029	.041
DO	-.135	-.353	.345	.733	-.247
Bicarbonate	.224	-.107	.802	-.165	-.148
Sulphate	.231	.835	-.111	-.196	-.215
Chloride	.964	.104	-.010	-.110	-.033
Sodium	.889	.052	-.122	.125	-.004
Potassium	.922	.141	.077	.052	-.171
Calcium	.879	.139	.242	-.112	.032
Magnesium	.758	.028	-.307	.312	-.061
Iron	.073	.902	-.121	-.069	.113
Cadmium	-.193	-.006	.207	.196	.642
Lead	.127	-.002	-.262	.846	.138
Zinc	-.001	.026	-.121	-.155	.840
Arsenic	-.133	.339	-.504	.025	-.383

indices and it was found that there was significant difference between water quality indices computed using WHO and EPA guidelines ($p = 0.018$) at 95% confidence level. With respect to seasons, the water quality indices ranked as follows: May > December > September > July with average indices of 49%, 46%, 44% and 43% respectively. Hence, it can be seen that well water quality is lowest at the peak of the rainy season as a result of influx of dissolved contaminants into the wells via runoff. Unlike deep wells that are usually adequately protected from surface runoff and near-surface contaminants, these shallow wells are easily contaminated as a result of little or no bottom and wall lining as well as covers that are hardly watertight. This highlights the role of surface runoff as a major contributor to shallow groundwater contamination in the study area.

Table 7 shows that though the water samples are not fit for consumption, they can be conveniently used for irrigation and livestock

drinking without further treatment. The suitability of the shallow groundwater for irrigation is further corroborated by the excellent values of sodium absorption ratio (SAR) of the well water samples throughout the period of the study. The average values of SAR are 1.25, 0.67, 1.37 and 0.78 for May, July, September and December. SAR is a measure of salinity hazard resulting from lack of balance between Na^+ ions and $\text{Ca}^{2+} + \text{Mg}^{2+}$ ions in the soil. Use of water with high SAR values for irrigation will lead to accumulation of Na^+ ions in the soil and subsequent destruction of soil structure as a result of dispersion of clay soil particles (Das and Nag, 2017). High concentration of sodium in soil affects soil permeability, thus making the soil hard to plough and unsuitable for seedling emergency (Singh, et al., 2017). The hazard associated with high Na^+ concentration in soil was further investigated using $\% \text{Na}^+$ values which was found to vary from 1.5 to 32%, 0.8 to 20.2%, 2 to 48% and 1.5 to 23% in May, July, September and December

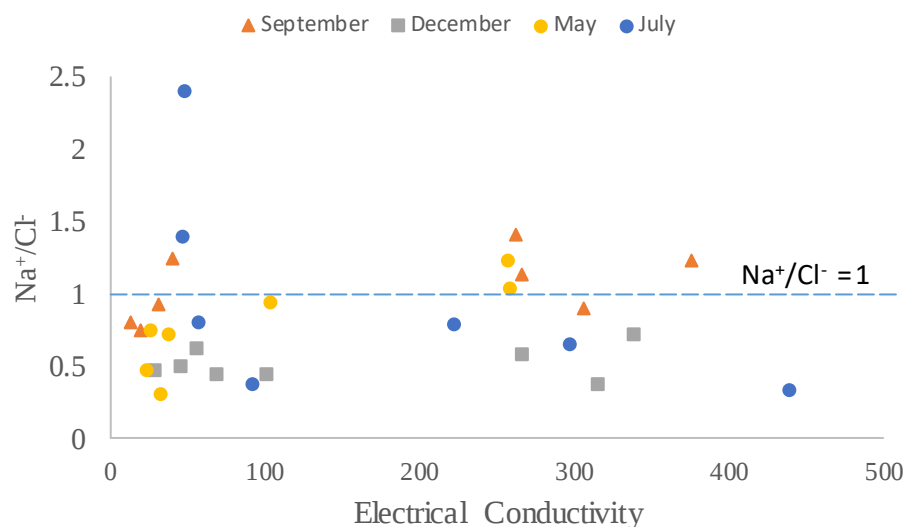


Figure 3 Na^+/Cl^- versus conductivity plot of well water samples

respectively. These values are considered acceptable for irrigation. Values of $\% \text{Na}^+ < 20\%$ are considered excellent while values $> 60\%$ are considered doubtful.

Environmental and Geochemical Assessment of Shallow Groundwater

The water quality data was subjected to principal component analysis with a view to identifying the possible sources of the chemical constituents. First, the data was subjected to Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity. The data was considered adequate for principal component analysis with a KMO value of 0.561. Thereafter, the principal components were extracted after fourteen iterations and then subjected to varimax rotation with Kaiser normalization. Five principal components with eigenvalues greater than one and accounting for 80.6% of the variance were extracted (Table 8). The first principal component (PC 1) accounting for over a third (35.2%) of the overall variance signifies the overwhelming influence of anthropogenic activities on shallow groundwater chemistry. PC 1 has very high significant loading on TDS (0.965), Cl^- (0.960), K^+ (0.931), Ca^{2+} (0.894), Na^+ (0.881) and Mg^{2+} (0.738). These ions are clearly leached from the numerous waste dumps, open market squares/stalls and agricultural farms within and around the city. Principally Na^+ and Cl^- can be leached from food waste which usually constitutes about 50% of solid waste in developing countries, fertilizers and septic tanks. The nearly equal proportions of Na^+ and Cl^- in the water samples suggest that a substantial fraction of these ions may have originated from the anthropogenic use of common salt. Septic tanks are the most common method of sewage disposal in the study area. In order to further trace the fate of Na^+ and Cl^- in the water samples, the Na^+/Cl^- ratio of the water samples was computed and plotted against conductivity (Figure 3). The values of Na^+/Cl^- ranged from 0.3 to 1.23 in May, 0.3 to 2.4 for July, 0.7 to 1.4 for September and 0.37 to 0.72 in December. Theoretically, water highly influenced by halite would have a molar Na^+/Cl^- ratio close to 1.0 (Long et al., 2015). A greater percentage (73.3%) of the Na^+/Cl^- value < 1 indicating the role of ion exchange from Ca^{2+} and Mg^{2+} in clays. It has been found that Na^+ is sequestered by soil and sediment by cation exchange as dissolved concentrations increase resulting in Na^+/Cl^- ratios < 1 (Long et al., 2015). Hence, the low values of Na^+/Cl^- during the dry season represents

a sequestering of Na^+ in soil and well sediments. Equal proportions (50% - 50%) of September well water samples had $\text{Na}^+/\text{Cl}^- > 1$ and $\text{Na}^+/\text{Cl}^- < 1$, indicating equal role of ion exchange and atmospheric contribution. The higher values of Na^+/Cl^- in the rainy season is because of continuous replenishment of Na^+ ion from runoff infiltrating the soil. This is not the case in the dry season when Na^+ ions removed from solution by ion exchange are not replenished, resulting in lower Na^+/Cl^- values. Pit latrines and septic tanks are the commonest methods of sewage disposal in the study area. However, Kiptum and Ndambuki (2012) noted that short separation distance between a pit latrine and water well means that the contaminants can travel from the pit latrine to the well in a few days resulting in higher levels of water contamination in the well. Pit latrines generally lack a physical barrier, such as concrete, between stored excreta and soil, accordingly, contaminants from pit-latrine excreta may potentially leach into groundwater, thereby threatening human health through well water contamination (Van Ryneveld and Fourie, 1997; Mahmud Mohammed Imam et al. 2018). This can lead to severe groundwater contamination in areas with shallow water table. Several studies have linked septic tank system to groundwater pollution. The serious problem with septic systems is magnified because those who use them often rely on nearby wells for drinking water (Weigman & Kroehler, 1990). The high loading of PC 1 on K^+ (0.931) also highlights the influence of agricultural activities, particularly fertilizer application on shallow groundwater quality.

PC 2 has a high loading on iron, turbidity and sulphate. The presence of iron in groundwater has been attributed to the weathering of rocks and minerals, sewage and iron related industries (Raju, 2006). Iron is also leached from the soil and rocks as rainwater percolates through the soil. Surface runoff in Nsukka is usually reddish-brown in colour which is an indication of dissolved iron. The area has rich deposit of laterite which is a highly weathered rock material rich in secondary oxides of iron. Srivastava et al., (2014) attributed the presence of iron in the shallow groundwater of Bhubaneswar City to lateritic formations. The overlying lateritic Nsukka formation consists of an alternating succession of sandstone, dark shale, sandy shale, thin coal seams at various horizons and thin beds of limestone towards the top (Ezim et al. 2017). High iron concentration in groundwater has also been associated with pump and pipe assembly of boreholes. This is not the case here as all wells studied were shallow wells from which water is abstracted

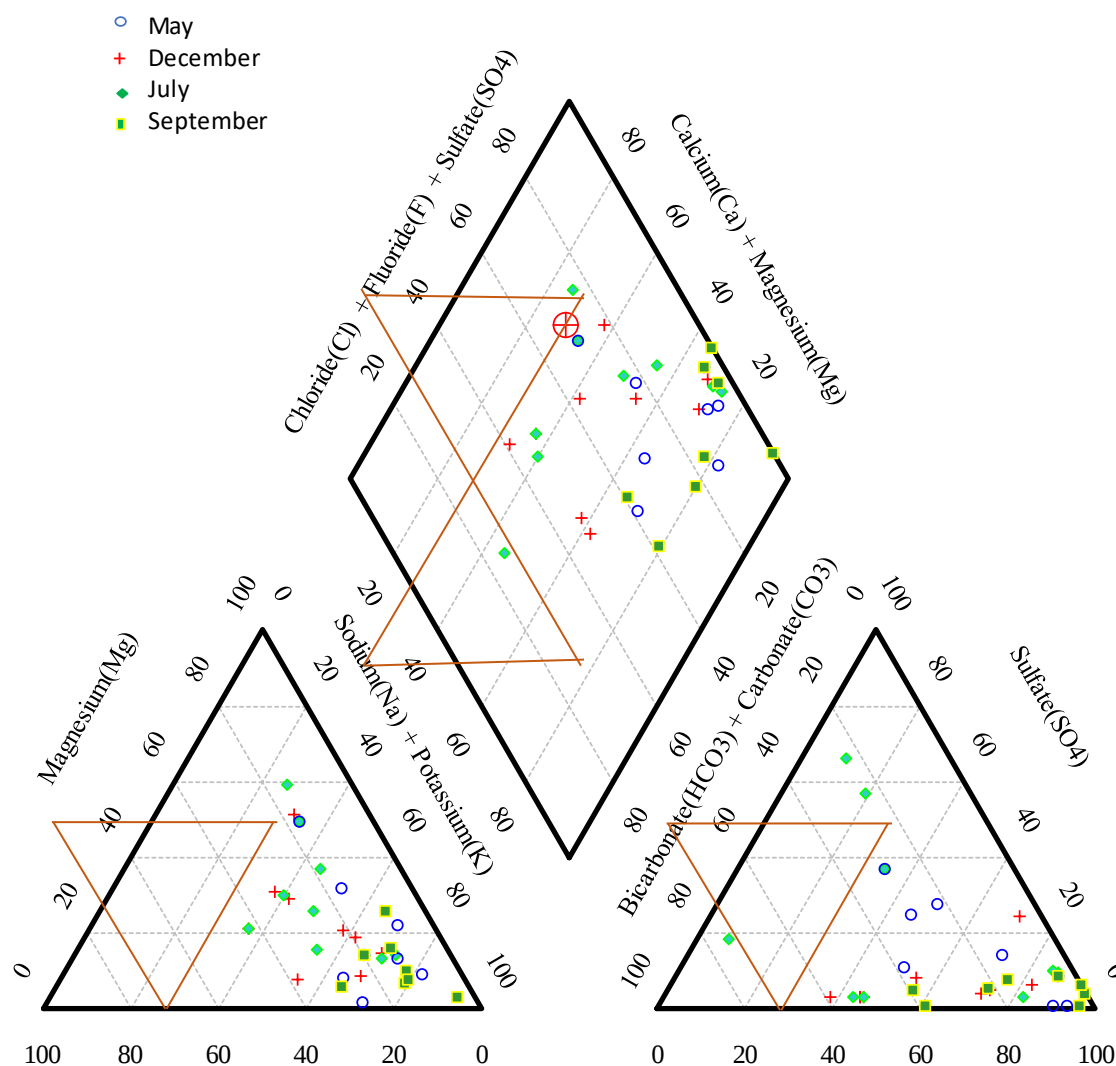


Figure 4 Geochemical classification of Well water

Table 9 Summary of geochemical distribution of well water by season

Class	May	July	September	December	Distribution (%)
Alkali earth metals exceed alkali	0%	62.5%	0%	37.5%	29%
Alkali metals exceed earth alkali	100%	37.5%	100%	62.5%	71%
Weak acids exceed strong acids	0%	37.5%	0%	37.5%	19.4%
Strong acids exceed weak acids	100%	62.5%	100%	62.5%	80.6%
Mg – HCO ₃ type	0%	37.5%	0%	12.5%	12.9%
Ca – Cl type	0%	12.5%	0%	0%	3.2%
Na – Cl type	85.7%	37.5%	100%	37.5%	64.5%
Na – HCO ₃ type	0%	0%	0%	0%	0%
No dominant type	14.3%	12.5%	0%	50%	19.4%

manually using rope and tube. Hence PC 2 represents the leaching of iron from the top lateritic soil deposit by rain. The leaching of iron from the soil by rain is further catalyzed by the acidic nature of rainwater resulting from the dissolution of acid-forming atmospheric gases. PC 3 represents the interaction between rainwater and atmospheric gases. Rainwater dissolves acid-forming atmospheric gases to form acid rain.

This rainwater reaches the water table in this acidic form, hence the low pH of the groundwater samples. Takem et al. (2015) observed that continuous infiltration of acid rainwater would cause acidification of soils thereby leading to the deterioration of the soil's ability to absorb acidic input. Other sources of acid-forming atmospheric gases include emissions from automobiles, generators and motorcycles which

constitute a substantial part of the transportation system. The acidic nature of the water samples may have been exacerbated by dissolution of weak acid in the soil during rainwater percolation. Acidic water is corrosive and facilitates the mobilization of heavy metals in the soil, causing them to pass into solution. The elevated levels of iron, cadmium, lead, zinc and arsenic can be attributed to low pH. PC 4 has a high positive loading on lead (0.846) while PC 5 has high positive loadings on cadmium (0.642) and zinc (0.840). These two principal components together account for 16.8% of the total variance in water quality parameters. These pollutants cannot be traced to any singular source but to diverse and diffuse sources and therefore represent the impact of industrialization. Several studies have traced the contamination of rainwater by zinc leached from galvanized roofing sheet. A significant proportion (37%) of the houses in the study are roofed with galvanized roofing sheets which can contribute to the elevated level of zinc in groundwater. It has been stated earlier that rainwater is the sole source of groundwater recharge and runoff from roofs contribute to this recharge. Atmospheric particulates and bulk deposits of lead and cadmium of surfaces such as roofs and road surfaces can also be leached into groundwater by rain and runoff. Road traffic emissions caused by both exhaust and non-exhaust sources contribute significantly to the particulate matter (PM) concentration in an urban atmosphere (Penkala, *et al.*, 2018). Cadmium, lead and zinc are commonly released into the atmosphere through vehicular brake and tire abrasions.

Piper's trilinear plots (Figure 4) show that the $\text{Na}^+ - \text{Cl}^-$ type is the most dominant irrespective of season, but prevailed mostly in the peak of the rainy season with 100% of the water samples taken in September falling into this category. Alkali metals exceeded alkali earth metals in 71% of the samples while strong acids exceeded weak acids in 80.6% of the samples (Table 9). In terms of season, alkali metals exceeded alkali earth metals in all the samples except those of July, whereas strong acids exceeded weak acids in all the samples irrespective of season. This is different from the findings of Das and Nag (2017) who reported the dominance of the $\text{Ca} - \text{Mg} - \text{HCO}_3$ type in the deep groundwater of West Bengal, India.

CONCLUSION

The phreatic groundwater quality in Nsukka, Nigeria was investigated and was found unsuitable for immediate consumption without treatment. The water samples were found to be generally acidic for all the sampling seasons. Turbidity, iron, cadmium, lead, zinc and arsenic exceeded stipulated guideline values of WHO, EPA and NIS. Though the groundwater was unsuitable for consumption as revealed by the physicochemical results and water quality indices, it was suitable for irrigation and livestock drinking. The high concentration of NaCl was traced to anthropogenic sources such as fertilizer application, septic tanks, pit latrines and solid waste dumps. From principal component analysis, the physicochemical quality of groundwater in the study area is influenced by anthropogenic activities, leaching of minerals from lateritic soil formation and dissolution of atmospheric gases in rainwater before percolation into the soil. The predominant geochemical facies of groundwater is the $\text{Na} - \text{Cl}$ type.

REFERENCES

1. Aboyeji, O.O. (2013). Freshwater Pollution in Some Nigerian Local Communities, Causes, Consequences and Probable Solutions. *Academic Journal of Interdisciplinary Studies*. MCSER Publishing, Rome-Italy. 2(13), 112-117.

2. Adejuwon, O. J., & Mbuk, J. C. (2011). Biological and physiochemical properties of shallow wells in Ikorodu town, Lagos Nigeria. *Journal of Geology and Mining Research*. 3(6), 161-168.
3. Aidoo, A. E. (2013). Effect of Pit Latrines on Dug-Well Water Quality- A Case Study of the Asankrangwa Community in the Wassa Amenfi West District of Ghana (Doctoral dissertation).
4. Appleyard, S., Wong, S., Angeloni, J., & Watkins, R. (2004). Groundwater acidification caused by urban development in Perth, Western Australia: source, distribution, and implications for management. *Australian Journal of Soil Research*. CSIRO Publishing. 42, 579-585.
5. Balke, K.-D., & Zhu, Y. (2008). Natural water purification and water management by artificial groundwater recharge. *Journal of Zhejiang University SCIENCE B*. <https://doi.org/10.1631/jzus.B0710635>.
6. Banda, L. Mbewe, A. Nzala, S. and Halwindi, H. (2014), Effect of Siting Boreholes and Septic Tanks on Groundwater Quality in St. Bonaventure Township of Lusaka District, Zambia, *International Journal of Environmental Science and Toxicology Research*, 2(9), 191-198.
7. Buragohain M., Bhuyan B. and Sarma H.P (2010). Seasonal variations of lead, arsenic, cadmium and aluminum contamination of Groundwater in Dhemaji district, Assam, India. *Environmental Monitoring and Assessment*. 170, 345-351. DOI 10.1007/s10661-009-1237-6.
8. Chukwurah, E.I (2001). Aquatic Microbiology. Otopa Press Limited, Onitsha, Nigeria.
9. Detry T., Malard F. and Gibert J. (2004). Dynamics of Solutes and Dissolved Oxygen in Shallow Urban Groundwater below a Stormwater Infiltration Basin. *Science of the Total Environment*. 329, 215-229.
10. David Chikodzi, Linda Yeukai Mapfaka. (2018). Spatio-temporal variations of wetlands in Masvingo district of Zimbabwe and influences of climate change and variability. *Climate Change*, 4(15), 235-247
11. Ezim, E. O., Obiadi, I. I., & Akaegbobi, M. I. (2017). The use of statistical grain-size method in analysing borehole and evaluating aquifer parameters. A case study of Ajali Sandstone formation, southeastern Nigeria. *Global Journal of Geological Sciences*, 15(1), 77-92.
12. Frederick Bloetscher, Colin Polsky, William Schnabel, Billy Connor. (2016). Assessing Climate Vulnerability in Disparate Places—Alaska and South Florida. *Climate Change*, 2(8), 526-550
13. Graham, J. P., & Polizzotto, M. L. (2013). Pit latrines and their impacts on groundwater quality: A systematic review. *Environmental Health Perspectives*. <https://doi.org/10.1289/ehp.1206028>.
14. Huey, G. M., & Meyer, M. L. (2010). Turbidity as an Indicator of Water Quality in Diverse Watersheds of the Upper Pecos River Basin. *Water*, 2(2), 273-284. <https://doi.org/10.3390/w2020273>.
15. Iloje, N. (1995). A new geography of Nigeria, Revised Ed. Lagos: Longman.
16. Islam, S. M. D.-U., Bhuiyan, M. A. H., Rume, T., & Azam, G. (2017). Hydrogeochemical Investigation of Groundwater in Shallow Coastal Aquifer of Khulna District, Bangladesh. *Applied Water Science*. <https://doi.org/10.1007/s13201-017-0533-5>.
17. Katz, B. B. G., Berndt, M. P., Bullen, T. D., Hansard, P., & Survey, U. S. G. (1999). Factors Controlling Elevated Lead Concentrations in Water Samples from Aquifer Systems in Florida Water Resources Investigations Report 99-4020. Water.
18. Khound, N. J., & Bhattacharyya, K. G. (2016). Multivariate Statistical Evaluation of Heavy Metals in the Surface Water Sources of Jia Bharali River Basin, North Brahmaputra Plain, India. *Applied Water Science*, 7(5), 2577-2586. <https://doi.org/10.1007/s13201-016-0453-9>.
19. Kiptum, C.K., & Ndambuki, J.M. (2012). Well water contamination by pit latrines: A case study of Langas. *International Journal of Water Resources and Environmental Engineering*. 4(2), 35-43.

20. Lane, E.A., Canty, M.J., & More, S.J. (2015). Cadmium exposure and consequence for the health and productivity of farmed ruminants. *Research in Veterinary Science*, 101, 132-139.
21. Lenntech, B. V. (1998). Water Treatment and Purification. *Rotterdamseweg 402M*, 2629.
22. Magreth S Bushesha. (2018). The influence of climate change on migration drivers: a qualitative analysis. *Climate Change*, 4(16), 789-803
23. Mahmud Mohammed Imam, Ibrahim L Kankara, Yagana Abba. (2018). Determination of some heavy metals in borehole and well water from selected industrial areas of Kaduna metropolis. *Discovery Science*, 14, 93-99
24. Mann, A.G., Tam, C.C., Higgins, C.D and Rodrigues, L.C (2007). The Association between Drinking Water Turbidity and Gastrointestinal Illness: A Systematic Review. *BMC Public Health*. 7(256), 1-7.
25. Manti Patil, Arnab Saha, Sateesh Karwariya, Santosh M Pingale, Vikash Chandra Goyal, Devendra Singh Rathore, Nihar Behera. (2019). Assessment of rainfall recharge using rainfall infiltration factor method and empirical equations. *Discovery Nature*, 13, 1-8
26. Mbaka, P. K., Mwangi, J. K., & Kiptum, C. K. (2018). Assessment of water quality in selected shallow wells of Keiyo Highlands, Kenya. *African Journal of Science, Technology, Innovation and Development*, 00(0), 1–10. <https://doi.org/10.1080/20421338.2017.1327476>.
27. Nag, S. K., & Das, S. (2017). Assessment of groundwater quality from Bankura I and II Blocks, Bankura District, West Bengal, India. *Applied Water Science*, 7(6), 2787–2802. <https://doi.org/10.1007/s13201-017-0530-8>
28. Nasrabadi, T., Ruegner, H., Sirdari, Z.Z., Schwientek, M. & Grathwohl, P. (2016). Using total suspended solids (TSS) and turbidity as proxies for evaluation of metal transport in river water. *Applied Geochemistry*. Elsevier. 68, 1-9.
29. Penkala, M., Ogrodnik, P., & Rogula-kozłowska, W. (2018). Particulate Matter from the Road Surface Abrasion as a Problem of Non-Exhaust Emission Control, *Environments*. (5) 9, 1–13. <https://doi.org/10.3390/environments5010009>.
30. Roy, B., Vilane, T., & Dlamini, T. L. (2016). An Assessment of Groundwater Pollution from On-Site Sanitation in Malkerns, Swaziland. *Journal of Agricultural Science and Engineering*.
31. Sarun S, Sheela AM. (2018). Grass root-level planning perspective for the tropical region for addressing implication on climate change for NRM sectors. *Climate Change*, 4(13), 69-79
32. Singh, U., Lutchmanariyan, R., Wright, J., Knight, S., Jackson, S., Langmark, J., Rodda, N. (2013). Microbial quality of drinking water from ground tanks and tankers at source and point-of-use in eThekweni Municipality, South Africa, and its relationship to health outcomes. *Water SA*. <https://doi.org/10.4314/wsa.v39i5.11>.
33. SRIVASTAVA, S. K., Bhargav, J. S., & Kumar, Y. S. (2014). Contamination of shallow groundwater of Bhubaneswar city due to urbanization. *EM International*, 33(01), 139-145.
34. Takem G.E., Kultcha D., Ako A.A., Mafany G.T., Takonjou-Fouepe A., Ndjama J., Ntchancho R., Ateba B.H. (2015). Acidification of Shallow Groundwater in the Unconfined Sandy Aquifer of the City of Douala, Cameroon, Western Africa: Implications for groundwater quality and use. *Environmental Earth Science*. DOI 10.1007/s12665-015-4681-3.
35. Twari A.K and Singh A.K (2014). Hydrogeochemical Investigation and Groundwater Quality Assessment of Pratapgarh District, Uttar Pradesh. *Journal Geological Society of India*. 83, 329-343.
36. Umo, A. E., & Okoye, C. O. B. (2006). Quality of borehole waters in Nsukka Area, Enugu State, Nigeria. *Annals of Natural Sciences*, 6(2), 121.
37. Uzoije, A. P., Onunkwo, A. A., Ibeneme, I. S., & Obioha, E. Y. (2014). Hydrogeology of Nsukka south-east-a preliminary approach to water resources development. *American J. Engnr Res*, 3(1), 150-162.
38. Van Ryneveld, M. B., & Fourie, A. B. (1997). A strategy for evaluating the environmental impact of on-site sanitation systems. *Water SA-Pretoria*, 23, 279-292.
39. Weigman, D. L. and Kroehler, C. J., (1990). Threat to Virginia's Groundwater. VPI&SU: Virginia Water Resources Research Centre. USA.
40. WHO. (2006). A compendium of standards for wastewater reuse in the eastern Mediterranean region. Geneva: WHO.
41. World Health Organisation (WHO) (2011). Cadmium in Drinking-water. Background document for the development of WHO *Guidelines for Drinking-water Quality*. Geneva, Switzerland.
42. Yabusaki, S.B., Wilkins M.J., Fang, Y., Williams, K.H., Arora, B., Bargar, J., Beller, H.R., Bouskill, N.J., Brodie E.L. (2017). Water Table Dynamics and Biogeochemical Cycling in a Shallow, Variably-Saturated Floodplain. *Environmental Science and Technology*. 51, 3307-3317.

Authors' Contribution

Chidozie Charles Nnaji designed the research, participated in data analyses and manuscript drafting. Kenneth Onuigbo undertook the field and laboratory studies and participated in data analyses. John Precious Nnam participated in data analyses and manuscript drafting.

Conflict of Interest

We declare that there are no conflicts of interest in carrying out this research.

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