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ORIGINAL ARTICLE

Principal component analysis of groundwater sources pollution in Omu-Aran Community, Nigeria

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Abstract
Most developing countries rely on water sources that are usually not protected making them unsafe for drinking. It is imperative to ensure regular assessment and proper monitoring to evaluate their quality and ensure they meet standards before use. This study was aimed at identifying pollution sources of groundwater in the study area of Omu-Aran and assessing the wáter quality under varying temporal conditions. Ninety-six groundwater samples were collected from eight locations during the dry and wet seasons of 2019–2020. These samples were examined for water quality parameters ($n = 10$) using standard methods. The study adopted the use of principal component analysis (PCA), water quality index (WQI) and independent sample t test to analyze water pollution sources, fully assess water quality and examine temporal variations in the sampling stations respectively. The mean values for measured parameters all fall within the Nigerian Standard Drinking Water Quality guideline values with the exception of pH, nitrite, dissolved oxygen and T. coliform. This pollution was attributed to sewage pollution arising from anthropogenic sources. Water quality decreased during rainy season as compared to the dry season with significant differences ($P < 0.05$) between these periods except for pH, total hardness and fluoride. WQI ranged from 28.17 to 108.15 which lies on the "*good*" to *"unsuitable for drinking"* spectrum. Three latent factors were extracted for both the wet and dry seasons from measured parameters by means of PCA. They explain natural pollution and soil erosion phenomenom due to seasonal changes while organic matter oxidation and mineral dissolution are also identified as factors that affect the water quality in the study area. In conclusion, the study has been able to integrate the use of PCA and WQI to analyse recorded data for pollution source identification and water quality interpretation in the study area. Regular assessment and proper monitoring to evaluate the quality of these sources should be done in order to ensure they meet standards before use. Users should be encouraged to carry out disinfection and ensure their water sources are protected and not left exposed.

Keywords Water quality index (WQI) · Contamination · Groundwater · Principal component analysis (PCA) · Omu-Aran · *t* test

Abbreviations

APHA	American public health association
Chloride	Chloride
DO	Dissolved oxygen
E	East
EC	Electrical conductivity
k	Constant of proportionality
L	Liter
Mg	Milligram
MLR	Multiple linear regression
NSDWQ	Nigerian drinking standard water quality
N	North
NTU	Nephleometric turbidity unit
PCA	Principal component analysis
PC1	The first rotated component
PC2	The second rotated component
PC3	The third rotated component
PC4	The fourth rotated component
PCs	Principal components
pH	PH (Hydrogen potential)
Si	Standardized maximum concentration
Std. dev	Standard deviation
T. coliform	Total coliform

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t test	Gosset's student distribution
TDS	Total dissolved solids
TH	Total Hardness
V_{io}	Ideal value of ith parameter
V_n	Measured value of the ith parameter
WAWQI	Weighted average water quality index
WHO	World health organization
W_i	Relative weight
WQI	Water quality index

Introduction

Fresh water such as groundwater is distributed in many parts of the world and is usually abstracted for domestic, industrial and agricultural uses. Groundwater is always thought to be a safe source of drinking water as a result of low microbial load with little need for treatment before use (Palamuleni and Akoth 2015). This has proven not to be the case especially in developing countries where poor waste management may degrade their quality (Ferronato and Torretta, 2019). Anthropogenic activities have been found to influence groundwater quality (Moyo, 2013; Elemile et al. 2019a,b) and majority of the microbial contaminants come from fecal sources of animals and humans (Takal and Quaye-ballard, 2018). Pathogenic microorganisms should not be found in water resources as disease outbreaks, including cholera and dysentery, are often the result of such contamination, according to the World Health Organization (WHO) According to Elemile et al. (2021), health challenges are the resultant effect of water pollution. Therefore, providing safe potable water, adequate sanitation and hygiene, are essential in protecting health, and directly contribute to achieving good health and well-being (United Nations 2018). According to Rajasingham et al. (2020), the transmission of diseases such as acute watery diarrhea can be mitigated if potable water is made accessible. Research often shows impaired access can lead to health risk (Nayebare et al. 2020). Water quality which is a major challenge for developing countries, including Nigeria, is usually the result of unequal access to potable water supply. Nigeria has only 19% of its population with access to safe drinking water and 67% of people have basic water supply (Odume and Slaughter, 2017). This has forced many communities to adopt the current trend of abstraction of groundwater via boreholes and hand dug wells especially in rural areas. This is often the result when there is an inability to match the ever-increasing demand for water by government and its agencies (Palamuleni and Akoth 2015). Many of these sources are not regulated as they are done by private individuals while appropriate steps ensuring safe and sustainable water supply are often ignored. These water sources become easily polluted from waste arising from human activities, infiltrating sewage effluent and wash-down of contaminated soil surfaces (Dzwairo et al. 2006; Saria and Thomas 2012; Elemile et al 2019a,b). The soil media can also play a major role in polluting groundwater. This is because soils can be laden with toxic metals and harmful organic substances which eventually find their way into water streams via infiltration (Elemile et al. 2019a,b). In studies regarding water quality, surface waters and boreholes (deep wells) have received majority of the attention (Mbaka et al. 2017) whereas there is limited information on the status of shallow wells, but shallow wells are among the most important water sources in many sub-Saharan African rural areas (Foster et al. 2012; Gowing et al. 2016). The findings from this study provides useful information which could improve the use of shallow wells in order to solve water quality problems faced by the community. Apart from making information available, it is also necessary to provide it in a manner that makes it suitable for use and easy to interprete. One method often employed is the use of multivariate statistical tools such as Cluster Analysis and Principal Component Analysis (PCA). PCAs are one of the most widely used statistical technique in which variables from composite datasets which are interrelated are reduced into explantory principal components (Herojeet et al. 2016). It utilizes the variance in the entire data set and projects it in new dimensions, thereby reducing the number of parameters but retaining maximum variance (Tripathi and Singal 2019). Several researchers have shown the efficacy of this tool in the field of water quality analysis which includes data reduction and interpretation (Gangopadhyay et al. 2001; Khan 2011; Sghaier et al. 2011; Papazova and Simeonova 2012). In view of the numerous physicochemical and microbial variables usually associated with water quality, this tool will be invaluable in giving adequate and comprehensive information to stakeholders and policy makers. Another method is the water quality index (WQI). The concept of WQI was first used by Horton, (1965) and was further improved upon by Brown et al. (1970) with alterations and modifications by scientist and authorities over the years (Tyagi et al. 2013). According to (Saleem et al. 2016), this is an effective tool that transforms large data quantities into distinct numbers making it easy for consumers, stakeholders and policy makers to take decisions. The WQI contains water quality parameters which are transformed to a common scale thereby normalizing the effect of different units. The result of this transfomation is a sub-index value which is aggregated to form a final index value (Sutadian et al. 2016).

Several researchers have proposed different methods and indices for evaluation of groundwater quality data which are often based on the nature as well as the number of parameters considered.

A number of WQI's have been developed over time to evaluate the quality of wáter in a general context usually comprising of physico-chemical parameters such as

NSFWQI (National Sanitation Foundation Water Quality Index), CCMEWQI (Canadian Council of Ministers of the Environment), Oregon Water Quality Index, OWQI (Oregon Water Quality Index) and WAWQI (Weighted Average Water Quality Index). Other índices have been used to determine the effect of pollution sources on wáter bodies including groundwater such as Landfill Water Pollution Index (LWPI), Nemerow index comprehensive evaluation method, and Backman's contamination index (Baghanam et al. 2020; Dąbrowska et al. 2018; Fouillac et al. 2009; Sołtysiak et al. 2018). The WAWQI will be adopted for assessing wáter quality in the study área. The motivation for using this index lies in its effectiveness for communication of overall water quality information to the concerned citizens and policy makers. Moreover, It goes on to describe the suitability of both surface and groundwater sources for human consumption which is lacking for other indices. WAWQI has been adopted by various researchers in different countries; Shimoga, India (Yogendra and Puttaiah 2008), Shatt Al- Kufa, Iraq (Kizar 2018), Vea dam, Bongo District, Ghana (Boah et al. 2015), Ado-Ekiti, Nigeria (Oni and Fasakin 2016), Gujarat, India (Shah and Joshi 2017). The objective of this study is to identify the pollution sources of groundwater in the study area, and the assessment of water quality under varying temporal conditions.

Materials and methods

Description of the study area and context

The study area, Omu-Aran, is the Administrative Headquarters of Irepodun Local Government area of Kwara State, in the Northcentral axis of Nigeria. Omu-Aran is situated on latitude 8°08′00″N and longitude 5°06′00″E with an average elevation of 564 m above sea level as illustrated in Fig. 1. The climatic condition of the study area alternates between wet and dry which is known as rainy and harmattan respectively. The wet season usually last for seven months (April to October) with about 1100–1500 mm of rainfall while the dry season starts November and ends March. Omu-Aran falls within the Southern limit of the tropical Savanah zone of Nigeria which allows for a variety of vegetation outcrop (Iheme et al. 2018). The study area is underlain by the precambrian and cambrian-age complex rocks. (more than 90% of the study area) while the remaining parts is underlain by

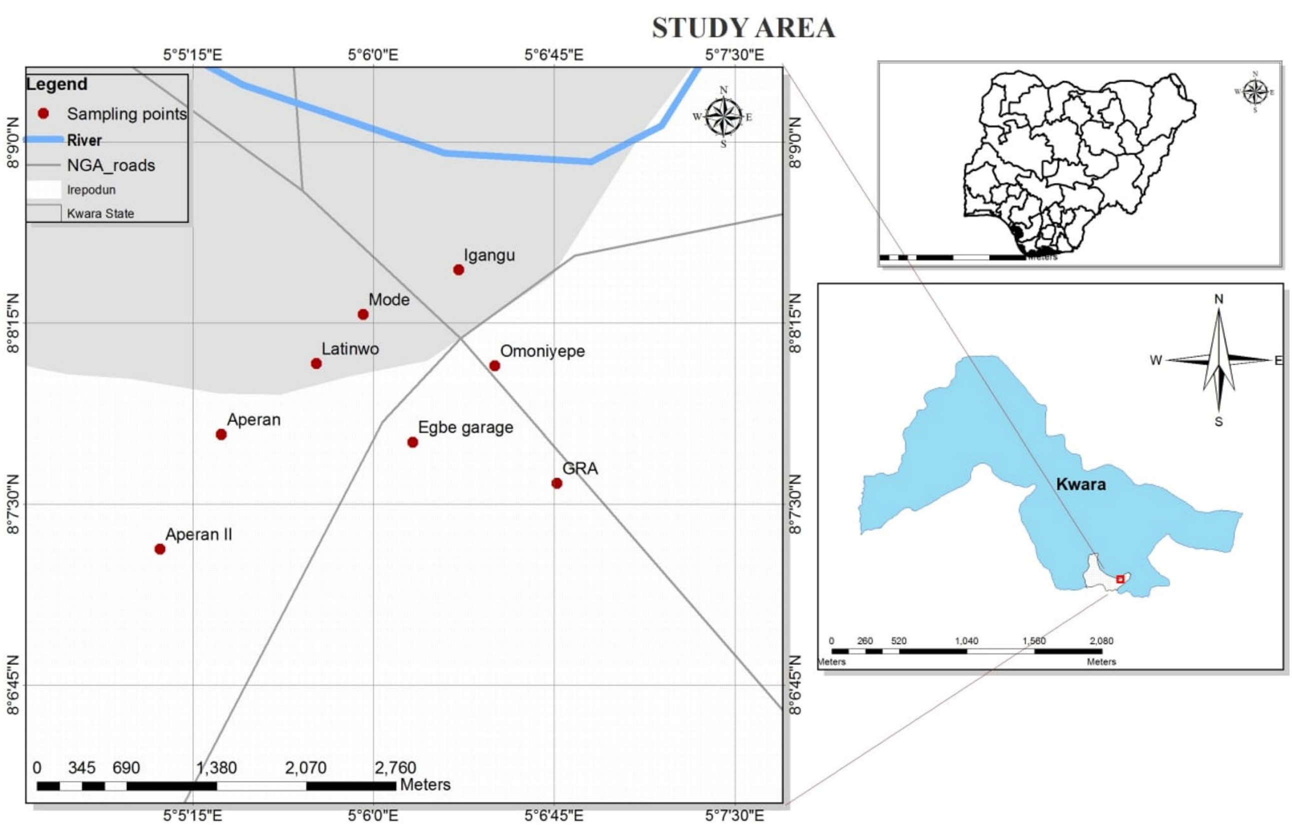

Fig. 1 Geographic location of the study area in Omuaran in Kwara State

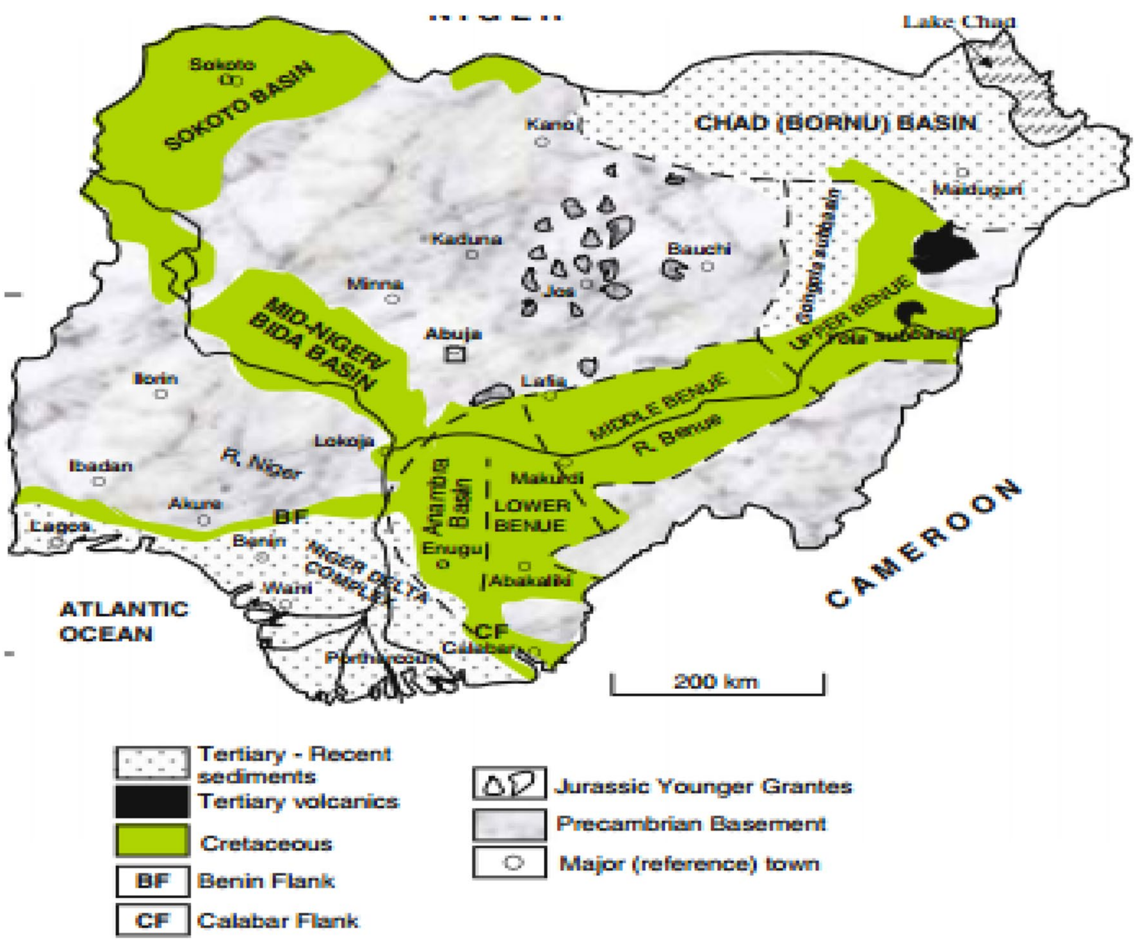

Fig. 2 Geological map of Nigeria showing major geological components (Adapted from Obaje 2009)

Cretaceous and Younger sediments (Obaje 2009) as shown in Fig. 2. There are many rock types found in the study area including; biotite-granite, granite-gneiss with the occurrence of meta-sediments which are mainly quartz-mica schist and quartzite (Iheme et al. 2018). Boulders of laterite may also occur as superficial deposits that obscure underlying geology.

Field survey and sampling

The field survey has 2 (two) distinct phases; The first of which is exploratory; The objective of the first is to determine and select sampling points to be investigated. Sampling points were marked with a gps device while the data was uploaded into the ArcGIS framework (V.10.3.1) for for a spatial representation of the well points. The second phase consist of on-site measurements and collection of water samples for laboratory analysis. The method for 'collection of samples' is described in the next section.

Collection of samples

A total of eight sampling sites were selected which comprise hand dug wells at Aperan, Egbe garage, Mode, Latinwo, Igangu, G.R.A., AperanII and Omoniyepe. These wells were assessed twice each month for three months (August to October) and from (September to January) to account for both wet and dry seasons respectively. A total of 96 samples were obtained across the study area using pre-sterilized screw capped bottles (500 ml) in collecting water samples for microbial and physicochemical analysis which were kept in an ice filled cooler prior to analysis as described by (Muzenda et al. 2019). The bottles were sterilized to ensure the sampling bottles are not contaminated in anyway especially by microbial agents. Sampling locations were recorded using portable GPS device (Fig. 1).

Laboratory analysis

Water samples were evaluated for their physicochemical quality according to the American Public Health Association

(APHA) Standard Methods (APHA, 2005). Onsite testing for parameters such as pH, Dissolved Oxygen and Turbidity using mobile field kits was done immediately after sampling since they were sensitive and subject to change. Electrical conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), Chloride, Fluoride as well as Nitrite were analyzed in the laboratory using standard methods (APHA, 2005). Microbiological examination of the water samples was done by plate count method using Mac-Conkey agar as the growth medium incubated for 24 ± 1 h at 37 °C according to the standard methods (APHA, 2012). The result of the analysis was reported as coliform forming unit (cfu/mL).

Data analysis

Data for physio-chemical and microbial parameters were recorded for each location. Analysis of results were carried out using descriptive statistics and presented as mean and standard deviations and compared to Nigerian Standard Drinking Water Quality. The two sample *t* test was used show if any significant difference exists for the measured parameters across the locations due to seasonal variation. Level of significance was taken as ($\alpha = 0.05$). All statistical and data analysis were done using SPSS V.22.0.

Multivariate statistical analysis

Multivariate statistical techniques have been used to evaluate and characterize water quality as well as analyze data. In this study, principal component analysis (PCA) has been employed as the technique to analyze the observed physico-chemical and microbial variables associated with water quality in the study area. PCAs are one of the most widely used statistical technique in which variables from composite datasets are reduced into explantory principal components (PCs). This allows significant parameters to be identified while maintaining the integrity of the information (Singh et al. 2004; Herojeet et al. 2016). In carrying out the PCA, the number of PCs to be retained (to explain underlying data structure) are identified (Moyel, 2015; Banda and Kumarasamy, 2020). The use of scree-plots, eigen values from observed data or randomly generated eigen values can be used to accomplish this (Banda and Kumarasamy 2020). The components in this study were subjected to varimax rotation. The following equation is used to express the principal component analysis (Baluch and Hashmi 2019):

$$Z_{ij} = aijxij + a_{i2}x_{2j} + \ldots\ldots\ldots\ldots + a_{im}x_{mj} \quad (1)$$

where *Z*, *a* and x is the component score, component loading, and the measured value of the variable respectively while I, j and m represent the component, sample and total number of variables respectively.

Development of water quality index

Water Quality Index (WQI) shows the composite impact of various water quality parameters. It tries to give a single value which represents the entire constituents measured. All ten parameters were considered for developing the WQI. The Weighted Average Water Quality Index (WAWQI) first proposed by Horton, (1965) was used to describe the quality of water obtained from hand dug wells and hence its suitability for use. The computation is given in four steps as described below:

Step 1: Proportionality constant "*K*" is estimated from the inverse of the standardized maximum concentration (Si). The value of *k* depends on the amount of parameters involved in the study (Aliyu et al. 2019). This is shown in Eq. 2.

$$K = \frac{1}{\Sigma_{i=1}^{n} \frac{1}{Si}} \quad (2)$$

where, *K* is the constant of proportionality, *n*, is the number of computed variables and Si, is the standardized maximum concentration usually given by local authorities and international organizations.

Step 2: The relative weight (Wi) was then computed by using the following equation

$$W_i = \mathrm{K/S_i} \quad (3)$$

Step 3: The quality rating is obtained by diving measured parameters with standard concentration given by NSDWQ guideline. It is shown in Eq. 4.Moreover, it could be significant

$$\mathrm{Qi} = 100 * \left[\frac{Vn - Vio}{Si - Vio}\right] \quad (4)$$

where; Qi is sub-quality index rating. V_{n} and V_{io} is the measured value and the ideal value of ith parameter respectively. (V_{io} for DO is 14.6 mg/L, and 7.0 for pH).

Step 4: Finally, the water quality index, WQI was computed using this mathematical expression given in Eq. 5

Table 1 Weighted average water quality classification for drinking water

WQI value	Water quality rating	Class
0–25	"Excellent"	A
26–50	"Good"	B
51–75	"Poor"	C
76–100	"Very Poor"	D
Above 100	"Unsuitable for drinking"	E

$$\text{WQI} = \sum WiQi / \sum Wi \quad (5)$$

The water quality of different sites has been rated according to the WQI as given (Table 1).

Results and discussion

The results of the analyzed physicochemical and microbial parameters, their abbreviations as well as units are presented in (Table 2).

Turbidity

Turbidity is a measure of the amount of light scattered and indirectly, the level of suspended particle in water. Usually particulate matter such as plankton, silt or clay could affect the appearance of water by obstruction of light. The mean turbidity values for each location as compared to NSDWQ values are displayed in Fig. 3. There are relatively higher levels during rainy season (0.94 ± 0.53) NTU as compared to the dry (0.72 ± 0.32) NTU. However, there was no significant difference for the two periods as shown in Table 3 (alpha level of 0.05). The relatively higher turbidity levels during the rainy season is a result of runoff and percolation of water into receiving wells. These wells are not properly lined and as such are left exposed to sediments from runoff during this season. High turbidity values, apart from making the water undesirable due to aesthetic concerns could affect effective disinfection (Patil and Patil 2011; WHO 2006). Turbidity could also indicate the presence of microbial contamination (Aghaarabi et al 2014; Dandadzi et al. 2020).This is usually the product of the rather adsorptive characteristics of colloids as well as their ability to shield microorganisms from disinfection (Mbaka et al. 2017).

pH

pH is important in assessing water quality and seen as a significant parameter (Mbaka et al. 2017). Therefore, although it does not have a direct impact on human health, it is necessary for adequate water quality analysis to be carried out. The mean values of pH for each location as compared to NSDWQ values fall below acceptable limits as displayed in Fig. 4. Significant differences were observed in pH values (Table 3) for dry (6.39 ± 0.52) and wet conditions (6.49 ± 0.45) and could be a result of increased cations from chemical compounds and effluents. The differences in pH values across sampling points all fall below acceptable limits, except G.R.A, Aperan II and Omoniyepe. Water becomes corrosive at low pH values which gives organoleptic concerns, (Sorlini, et al. 2013). Generally, lower pH levels tend to increase the corrosion level. Water that is acidic in nature causes rust in construction materials used for well services such as casings and screens while household utensils are also not left out.

Electrical conductivity

The presence of dissolved ions in water affects conductivity. The importance of EC is its salinity measure which usually affects the taste and therefore the acceptance of water by the user. The mean EC values for each location as compared to NSDWQ values are displayed in Fig. 5. They all fall within the maximum guideline requirement of 1000 µS/cm with the exception of Igangu that exceeds this value for rainy season. This is probably because the well is often exposed to the weather elements since it is usually left open. Analysis reveal that there was no significant difference between EC values for both rainy and dry periods as shown in Table 3 (alpha level of 0.05) although there were relatively higher EC levels during rainy season (394.45 ± 403.19) µS/cm as compared to the dry (304.51 ± 273.20) µS/cm. The water is fresh water in nature since it does not exceed 1500 µs/cm which is a standard value for freshwater according to Mondal et al. (2008).

Total dissolved solids

TDS concentration represents inorganic salts and small quantities of organic compounds (Anna 2018). It is one of the attributes that determines the quality of drinking water. The mean values of TDS for each location as compared to NSDWQ values are well within acceptable limits with the exception of Igangu (Fig. 6). The maximum guideline requirement of 500 mg/L was exceeded in Igangu during the rainy season. There was no observable significant difference between TDS values for both rainy and dry periods as shown in Table 3 (alpha level of 0.05) although there were relatively higher TDS levels during rainy season (202.33 ± 211.60) mg/L as compared to the dry (149.76 ± 132.66) mg/L. Water is often polluted with high TDS levels when untreated wastewater is disposed of into pits and surface waters that ultimately flow down to the water table (Rawat and Siddiqui, 2019). Water could become corrosive destroying storage containers and unfit to drink (Elemile et al. 2019a,b).

Total hardness

Total hardness is important when considering water for domestic purposes. There have been reports that it plays a role in the formation of kidney stones and cause cardiac

Table 2 Characteristics of samples from selected locations “All values are in mg/l except for pH (unitless), EC ($\mu S/cm$), T.coliform (cfu/ml)”

	Aperan		Egbe garage		Mode		Latinwo		Igangu		G.R.A		Aperan II		Omoniyepe	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Turb	0.87	0.72	0.58	0.81	1.20	0.74	0.92	0.8	1.23	1.02	1.95	0.95	0.77	0.70	0	0
NSDWQ	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Sd	0.00	0.11	0.24	0.12	0.12	0.17	0.09	0.15	0.25	0.31	0.05	0.07	0.05	0.00	0.10	0.09
pH	6.17	5.97	6.12	6.27	6.08	6.01	6.19	5.91	6.38	5.91	6.60	6.69	7.24	7.16	7.15	7.17
NSDWQ*	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50
Sd	0.03	0.01	0.17	0.12	0.05	0.04	0.03	0.05	0.05	0.06	0.05	0.09	0.00	0.06	0.00	0.05
Nitrite	0.03	0.01	0.10	0.15	0.10	0.12	0.38	0.25	0.69	0.55	0.05	0.014	0.01	0.01	0.02	0.02
NSDWQ	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Sd	0.17	0.01	0.00	0.00	0.00	0.00	0.03	0.02	0.67	0.34	0.50	0.02	0.50	0.29	1.50	0.82
Chloride	19.68	5.88	19.22	4.42	47.31	36.55	56.97	11.82	29.32	36.09	4.85	4.87	5.25	5.40	36.00	37.00
NSDWQ	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00
Sd	2.13	0.41	4.17	5.06	1.21	8.67	5.03	4.28	1.19	8.28	0.05	0.05	0.05	0.08	0.75	0.82
T.Coliform	2.83	1.67	16.83	14.00	58.67	49.89	39.33	36.11	58.33	60.67	34.50	34.00	16.00	10.00	34.00	35.00
NSDWQ	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Sd	0.62	1.25	1.55	2.42	0.62	4.43	2.25	3.00	15.86	0.47	8.50	2.94	2.00	0.74	4.50	0.82
EC	53.03	48.77	259.11	192.06	807.90	553.54	118.92	118.79	1217.48	822.20	70.30	70.27	130.85	131.80	498.00	498.67
NSDWQ	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00
Sd	1.85	1.52	4.71	24.25	9.33	74.14	5.50	13.76	52.17	68.10	0.30	0.12	0.05	1.20	0.00	0.47
DO	6.07	6.28	5.97	6.23	6.03	5.96	6.24	6.06	6.22	6.01	6.09	6.11	6.02	6.08	6.03	5.98
NSDWQ	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Sd	0.12	0.05	0.04	0.20	0.05	0.21	0.17	0.33	0.16	0.09	0.09	0.06	0.04	0.03	0.20	0.10
TDS	27.31	24.42	121.62	96.08	423.38	275.17	60.83	59.82	635.50	394.61	35.5	35.73	65.45	64.87	249.00	247.33
NSDWQ	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
Sd	1.64	1.44	13.33	10.68	7.82	39.62	1.42	6.47	32.13	50.28	0.10	0.68	0.05	0.66	2.50	1.25
TH	31.48	49.69	136.67	66.47	135.78	84.92	77.77	30.78	117.60	76.25	65	63.33	77.50	76.33	84.00	85.33
NSDWQ	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Sd	9.15	21.39	35.76	72.28	31.86	56.53	13.47	11.82	19.84	43.40	0.50	2.49	0.50	1.70	1.00	1.89
F	1.44	0.14	0.49	0.14	0.87	0.23	1.31	0.11	0.62	0.22	0.12	0.07	0.21	0.22	0.31	0.17
NSDWQ	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Sd	0.02	0.08	0.04	0.04	0.03	0.02	0.06	0.12	0.04	0.04	0.04	0.07	0.06	0.06	0.07	0.03

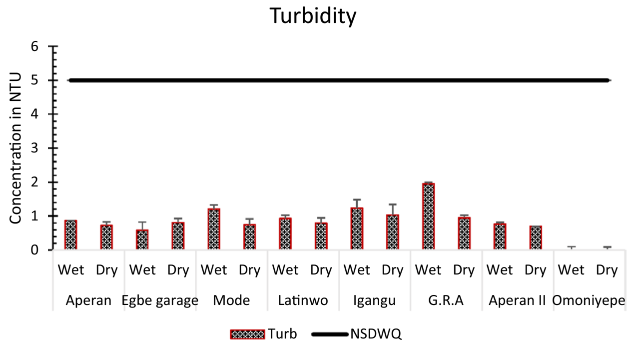

Fig. 3 Turbidity values for each location as compared to NSDWQ values

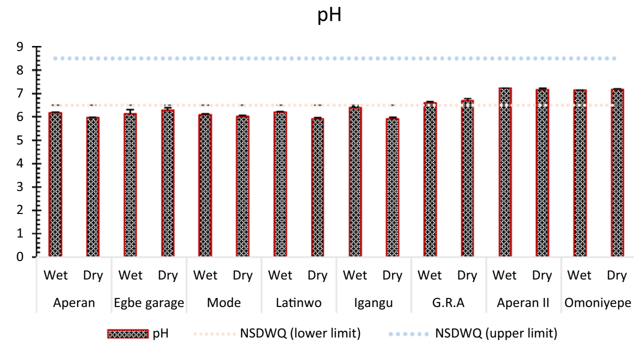

Fig. 4 pH values for each location as compared to NSDWQ values

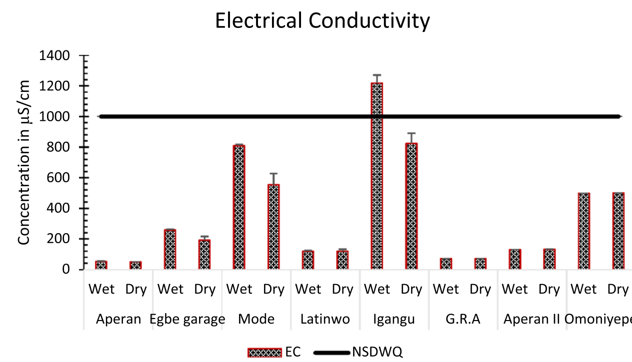

Fig. 5 EC values for each location as compared to NSDWQ values

problems. (Jameel 1998; Rohi 2019). The mean turbidity values for each location as compared to NSDWQ values are displayed in Fig. 7. The values of TH ranged from 31.48 to 136.67 mg/l and all values were within the limits allowed by the NSDWQ at 150 mg / L. Results show relatively higher levels exist during rainy season (90.73 ± 38.55) mg/L as compared to the dry (66.64 ± 35.63) mg/L. Significant differences exist across the varying rainy and dry periods as shown in Table 3 (alpha level of 0.05). Hardness in essence a combination of both calcium and magnesium ions. Hence, it is possible that rainfall would eventually bring an increase in water hardness due to dissolution of calcium and magnesium containing minerals.

Nitrite

The long-term effect arising from elevated nitrate and nitrite levels (usually due to intense agricultural practices and use of nitrogen-based chemicals) on the quality of ground water is global (Hansen et al. 2017). It is therefore paramount in understanding the quality of water systems. The mean nitrite values displayed in Fig. 8 for each location do not meet the guideline values of 50 mg/L which is the maximum limit set by the NSDWQ. The well at Igangu was observed to have extremely high values of 1.57 mg/L compared to other locations. This could be due to poor maintenance and constant exposure (no lid) making it susceptibile to contamination. There are relatively higher levels during the rainy season (0.31 ± 0.54) as compared to the dry (0.06 ± 0.16) mg/L. However, the nitrate values did not vary significantly for both wet and dry seasons as seen in Table 3 ($\alpha = 0.05$). This result agrees with similar study carried out by (Nezhad, et al.

Table 3 Effect of precipitation on water quality of hand dug wells

Parameter	Mean ± SD		Significance
	Wet	Dry	*P*
Turbidity (NTU)	0.95 ± 0.54	0.72 ± 0.32	> 0.05
pH	6.49 ± 0.45	6.39 ± 0.52	< 0.05
EC	394.45 ± 403.19	304.51 ± 273.20	> 0.05
TDS (mg/L)	202.33 ± 211.60	149.76 ± 132.66	> 0.05
TH (mg/L)	90.73 ± 38.55	66.64 ± 35.63	< 0.05
Nitrite (mg/L)	0.31 ± 0.54	0.06 ± 0.165	> 0.05
Chloride (mg/L)	27.33 ± 18.09	17.76 ± 15.57	> 0.05
Fluoride (mg/L)	0.67 ± 0.48	0.17 ± 0.08	< 0.05
Dissolved Oxygen (mg/L)	6.08 ± 0.14	6.09 ± 0.18	> 0.05
T. coliform (mg/L)	24.75 ± 23.39	22.42 ± 22.20	> 0.05

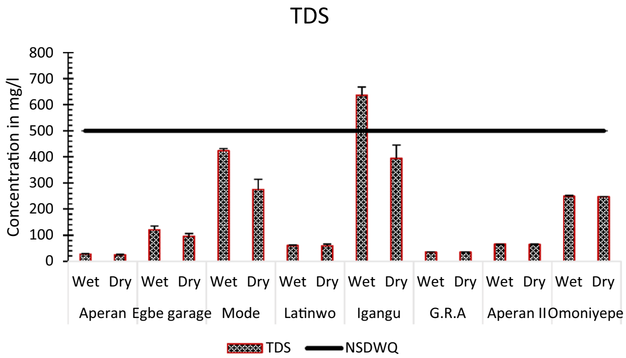

Fig. 6 TDS values for each location as compared to NSDWQ values

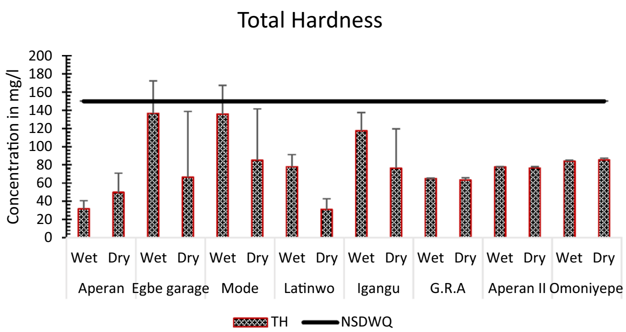

Fig. 7 Total Hardness values for each location as compared to NSDWQ values

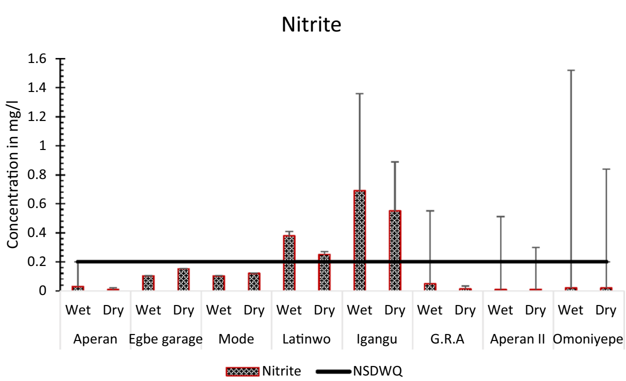

Fig. 8 Nitrite values for each location as compared to NSDWQ values

2017). It has been reported that occurrence of elevated nitrite concentration is mostly common in shallow dug wells immediately after heavy precipitation. Also, the presence of nitrites and nitrates in groundwater may also be a sign of sewage pollution derived from the effluent discharged from seepage beds (Crabtree 1972). Increase

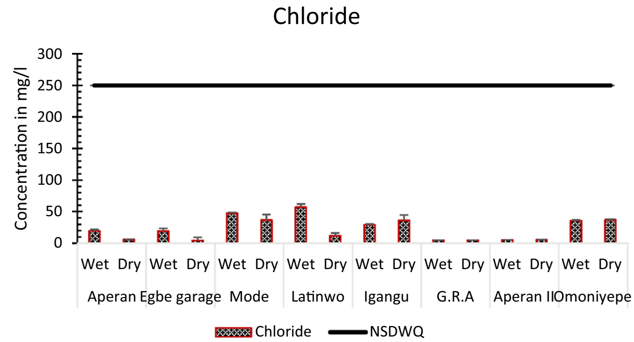

Fig. 9 Chloride values for each location as compared to NSDWQ values

in nitrate and nitrate levels above the permissible level can lead to health problems like methemoglobinemia especially in children (Maxwell et al. 2010). Therefore, it is of necessity to make only potable water which has been treated available for drinking especially to infants (Sojobi et al. 2016). Alternative potable groundwater sources should be utilized especially boreholes which can be treated before consumption.

Chloride

Chloride values ranged from 4.42 ± 5.06 to 47.30 ± 1.21 mg/L (Fig. 9). The values were observed to be significantly different. The well at Mode was found to be the highest, although it was still below the permissible guideline value (WHO) which is 250 mg/L. The values were akin to the values reported by (Elemile et al. 2019a,b) done in the same study area. There are relatively higher levels during the rainy season (27.33 ± 18.09) as compared to the dry (17.76 ± 15.57) mg/L. Chloride does not vary temporally and differences are insignificantly both wet and dry seasons as illustrated in Table 3 (alpha level of 0.05). Kharti and Tyagi (2015) suggested natural causes of chloride could be a result of rainfall as well as dissolution of chloride-bearing minerals whereas anthropogenic sources may be derived from extensive use of fertilizers, landfill leachates and via effluents of inappropriately constructed soak-away pits which increase chloride concentration. Moreover, it could be significant in detecting sewage contamination of groundwater (Elemile et al. 2019a,b).

Fluoride

The fluoride values ranged between 0.07 ± 0.07 and 1.44 ± 0.02 mg/L. The values at Aperan gave the highest value of 0.67 ± 0.66 mg/L while the lowest was recorded at GRA and this could be a result of the varying aquifer

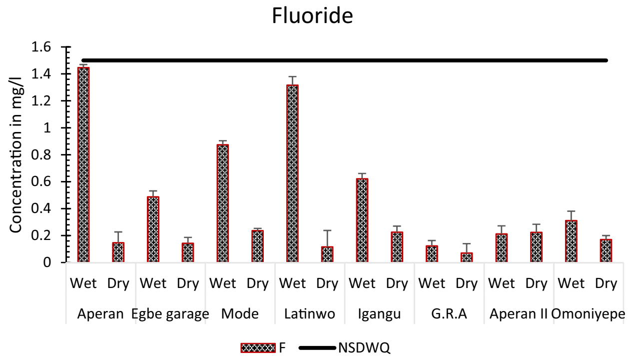

Fig. 10 Fluoride values for each location as compared to NSDWQ values

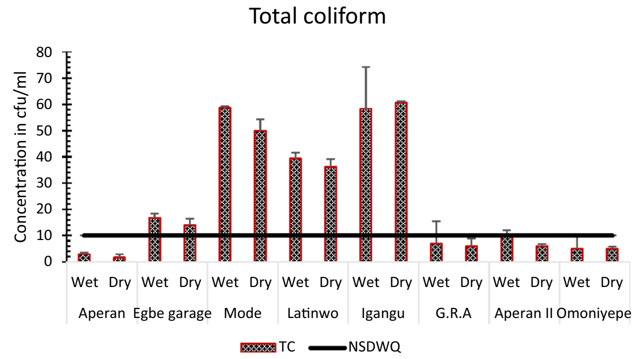

Fig. 12 Total Coliform values for each location as compared to NSDWQ values

conditions. There could also be a possibility of infiltration of dissolved chemical fertilizers arising from agricultural practices (Amiri et al. 2014). While all values were below permissible values given by WHO and SON (Fig. 10), on the other hand, they were above values (0.17 ± 0.22) mg/L reported by (Sorlini et al. 2013). Fluoride occurs naturally as a result of weathered run-off from fluoride-containing rocks and leaching from soils into groundwater (Kharti and Tyagi 2015). Exposure to high levels of fluoride can lead to mottling of teeth and, in severe cases, crippling skeletal fluorosis. Water containing high fluoride concentrations may be treated by mixing it with a water solution having a lower level of fluoride. This process is often known as *blending* and where this cannot be done, de-fluoridation becomes the desirable technique employed to prevent fluorosis (Fawell et al. 2006).

Dissolved oxygen

Dissolved oxygen have been used to evaluate water quality across different locations and in different water bodies (Kannel et al. 2007). DO values range from 5.96 ± 0.21

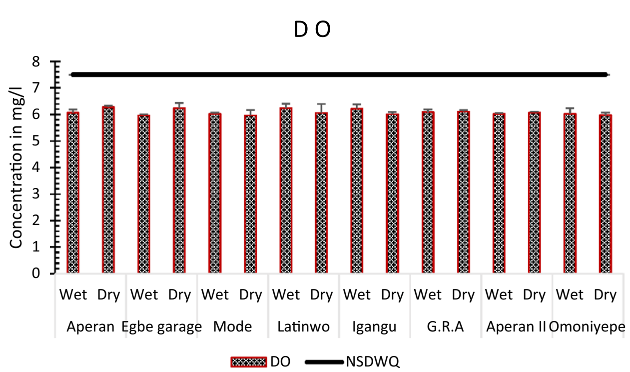

Fig. 11 Dissolved Oxygen values for each location as compared to NSDWQ values

to 6.24 ± 0.20 mg/L while they were observed to be lower than recommended guideline values (i.e. they fall below the standard values of 7.5 mg/L) by NSDWQ as displayed in Fig. 11. Lower DO values was recorded for Mode which is probably a result of presence of organic matter and microorganisms as they tend to influence oxygen levels through metabolism. Figure 12 shows high coliform content contamination in Mode. There are relatively lower levels during the rainy season (6.08 ± 0.14) as compared to the dry (6.09 ± 0.18) mg/L. However, this temporal variation was not significantly different as illustrated in Table 3 (alpha level of 0.05). Values are comparably higher than values from a previous study carried out by (Elemile et al. 2019a,b).

Total coliform count

The presence of coliform bacteria in drinking water usually indicates risks of microbial contamination through human or animal excreta (Laluraj et al. 2006); it is usually taken as a fecal contamination indicator (Nawab et al. 2017). The coliform count was seen to be higher during the months with peak rainy periods than the dry periods although it was not significantly different as shown in Table 3. The mean values of coliform count for each location as compared to NSDWQ values are displayed in Fig. 12. Although, the WHO has specified a zero limit contamination for coliform, NSDWQ recommends 10 cfu/ml as the guideline value and even this was exceeded in all locations except Aperan, GRA and Omoniyepe. The health of the public can be seriously affected by threat posed by bacteriological contamination in the form of a coliform organism (Mohan et al., 2018). Coliforms can cause a variety of waterborne illnesses from diarrhea to typhoid and even infections of the urinary system.

Principal component analysis (PCA)

The principal component analysis takes into account physicochemical and microbial variables common to every sample

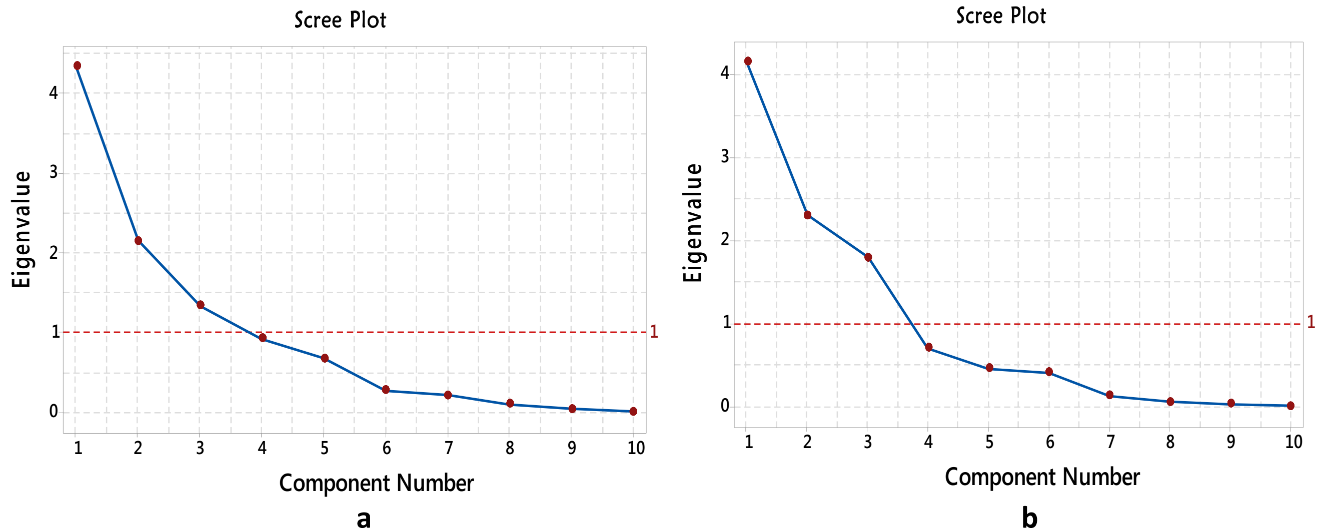

Fig. 13 Scree plots used to idenify number of principal components in principal component analysis obtained from eigen values (> 1) (**a**) wet season (**b**) dry season.

including Turbidity, pH, EC, TDS, TH, NO_3^-, Cl, F, DO and T.Coliform. Eigen values greater than one were retained which are the first three PCs (Fig. 13). They explained up to 78.1% and 82.4% of the total variance in the water quality datatsets for wet and dry season respectively. According to Gradilla-Hernández et al. (2020), any value between 70%—90% is acceptable. The suitability of PCA was tested using the Kaiser–Meyer–Olkin (KMO) and Barlett tests (Table 4). They show adequacy of samples and independence of variables (Sun et al. 2013). Results are displayed for KMO = 0.55 (> 0.5) and Barlett test value = 0.00 (< 0.05) indicating suitability. The loadings of the factors in 3-dimensional space are shown shown in Fig. 14. In choosing the variables that correlate with each PCs, Chounlamany et al., (2017) classified the factor loadings as "strong" when > 0.75, "moderate" when between 0.5 and 0.75, and "weak" when between 0.3 and 0.5 which was adopted for this study.

Wet season

The first rotated component (PC1), accounting for 43.4% of the total data variance has a strong positive loading on EC, TDS, TH and TC. This suggest natural pollution and soil erosion phenomenom due to seasonal changes which influences wáter quality. Top soil which could be contaminated as a result of human and animal interaction could get eroded and enter vulnerable wells thereby altering its physico-chemical and microbial properties. This deposition is usually pronounced during the heavy rainfall as they aid in transporting debris and waste into these wells. It has also been reported that increase in surafce runoff tends to increase sediment transport into water bodies (Ogwueleka 2015; Calijuri et al. 2015). Recharged water interacts with soil, weathered materials and/or fractured rocks during infiltration, and transports pollutants emitted by the land use activities (Rao 2014). The second rotated component (PC2) which accounts for 21.4% has strong positive loading with NO_2, F and Cl, moderate$^-$ loadings on TC while inversely proportional to pH. The positive loading of NO_2 and TC may be a result of anthropogenic influences. Previous researches have attributed positive loading of NO_3^- to industrial as well as domestic wastes (Dinkaa et al. 2015; Herojeet et al. 2016). High concentration of chloride in natural wáter sources could be a result of domestic waste and disposal by human activities. It can also be attributed to agricultural and industry based activities (Prasad 2005; Tariq 2014). High fluoride content can be attributed to rock types within the study area (biotite-granite, granite-gneiss). The existence of fluoride rich groundwater has been often reported in relation to crystalline basement rocks such as granitic gneiss (Ozsvath 2006; Saxena and Ahmed 2003). Therefore, local basement rocks could be major donors of fluoride in groundwater. On the other hand, the negative loading of pH can be associated with organic matter oxidation due to anthropogenic activities. Rain has also been reported to increase water acidity and where these hand dug Wells are not protected/properly covered, this outcome will most likely take place. Thus, this principal component is associated with anthropogenic pollution (due to organic loading) and from geogenic sources (such as water dissolution of flouride rich rock types).

Table 4 PCA compatibility with samples using Kaiser–Meyer–Olkin (KMO) and Barlett tests

Variable	Turb	pH	Nitrate	Chloride	TC	EC	DO	TDS	TH	F
a) Wet period										
Turb	1.000	– 0.289	0.050	– 0.221	0.307	0.037	0.343	0.057	0.015	– 0.047
pH		1.000	– 0.525	– 0.392	– 0.459	– 0.126	– 0.111	– 0.130	– 0.196	– 0.661
Nitrite			1.000	0.741	0.712	0.303	0.497	0.305	0.409	0.439
Chloride				1.000	0.610	0.349	0.352	0.352	0.311	0.580
T.Coliform					1.000	0.752	0.458	0.761	0.615	0.272
EC						1.000	0.199	1.000	0.592	– 0.076
DO							1.000	0.212	0.062	0.325
TDS								1.000	0.589	– 0.064
TH									1.000	– 0.208
F										1.000
KMO (Kaiser–Meyer–Olkin) 0.501										
Bartlett's test of Sphericity 0.000										
b) Dry season										
Turb	1.000	– 0.516	0.183	– 0.216	0.421	0.030	0.385	– 0.030	1.220	0.128
pH		1.000	– 0.510	– 0.059	– 0.624	– 0.158	– 0.058	– 0.150	0.309	– 0.049
Nitrite			1.000	0.000	0.465	– 0.040	0.045	– 0.033	– 0.246	– 0.058
Chloride				1.000	0.612	0.911	– 0.322	0.921	0.481	0.505
T.Coliform					1.000	0.730	– 0.280	0.725	0.107	0.406
EC						1.000	– 0.364	0.999	0.393	0.506
DO							1.000	– 0.364	0.337	0.212
TDS								1.000	0.412	0.512
TH									1.000	0.523
F										1.000
KMO (Kaiser–Meyer–Olkin) 0.512										
Bartlett's test of Sphericity 0.000										

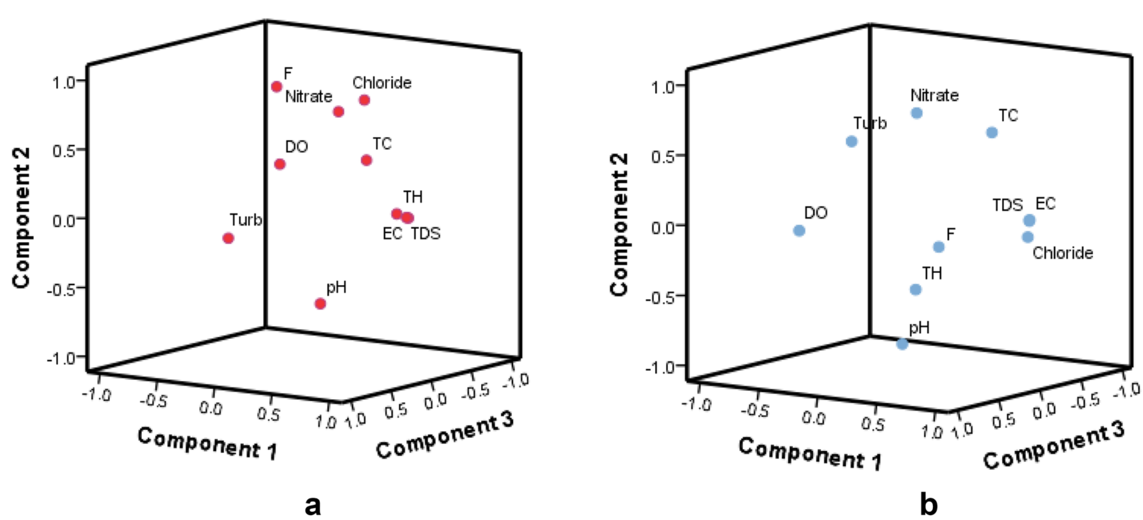

Fig. 14 Loadings of first three factors in 3-dimensional space showing correlation between water quality variables. **a** Wet season, **b** dry season

PC3 explains 17.9% of total variance and has strong and moderate negative loadings on turbidity and DO respectively. The negative loadings of turbidity and DO are related to pollution sources that are of anthropogenic origin. According to (Chounlamany et al. 2017), past studies show negative correlation exist between anthropogenic pollution and these parameters which corroborates our findings.

Dry season

For the dry season, PCA shows that there are at least three latent factors that account for 82.4% of the total variaton (Table 5). The first rotated component (PC1), accounting for 41.5% of the total data variance has a strong positive loading on EC and TDS attributable to pollution influenced by anthropogenic factors (Ganiyu et al. 2018). Strong and moderate positive loadings also can also be seen on Cl and T.Coliform which suggest anthropogenic pollution from human and animal waste. Moderate loadings on F and TH can be intepreted as rock water interaction and mineral dissolution (Ganiyu et al. 2018). PC2 explains 23% of the total variance and has strong positive loadings on pH while having moderate negative loadings on turbidity, nitrate and T.Coliform. This would suggest more of a geogenic origin having to do with the predominant rock type. The third rotated component (PC3) which accounts for 17.9% of the variation has strong positive loading on DO and moderate loadings on turbidity and hardness which points to organis loading. This takes place when Dissolved oxygen content is used up during the breakdown of dissolved organic matter (anaerobic process). The result leads to the formation of organic compounds such as ammonia and organic acids and this in turn decreases pH content via hydrolysis (Table 5).

Quality indices

The water quality index gives an overview of the quality status of a water source and can also show how temporal and spatial variations influence water quality. Another major use is its interpretability and ease of comprehension as discussed earlier. Therefore, the computed WAWQI fulfills this purpose. The results of the water quality index are shown in Table 6. Aperan and Egbe garage were classified as excellent and good for respective dry and wet seasons. Mode and Latinwo were classified as good in both temporal conditions although microbial contamination make this water unsuitable for drinking if no proper treatment (such as chlorination) is adopted. The major contributing parameters to the low water quality represented by the index were EC, Nitrite, and Coliform count especially at Mode, Latinwo and Igangu hence their poor state. It was observed also that water quality was relatively better during low rainfall periods as compared to higher rainfall periods (Fig. 15). The resulting contamination of effluents coming from nearby dumps, poor drainages and compromised soak away pits could during peak rainfall periods could be a major cause, which was the situation at Igangu, Mode and Latinwo.

Table 5 Principal component analysis for measures of water quality (significant loadings in bold)

Variables	Wet Season				Dry season			
	PC 1	PC 2	PC 3	Communalities	PC 1	PC 2	PC 3	Communalities
Turb	0.015	− 0.052	**− 0.961**	0.927	− 0.072	− 0.629	0.595	0.75
pH	− 0.051	**− 0.711**	0.279	0.586	− 0.07	**0.904**	− 0.017	0.82
Nitrite	0.375	**0.778**	− 0.103	0.757	− 0.034	− 0.730	− 0.139	0.55
Chloride	0.363	**0.812**	0.237	0.847	**0.953**	0.048	− 0.078	0.91
T.Coliform	**0.769**	0.497	0	0.939	0.703	− 0.685	0.000	0.96
EC	**0.942**	0.055	− 0.043	0.892	**0.974**	− 0.078	− 0.071	0.96
DO	0.163	0.437	− 0.530	0.499	− 0.34	− 0.001	**0.849**	0.84
TDS	**0.940**	0.061	− 0.062	0.891	**0.978**	− 0.071	− 0.061	0.96
TH	**0.794**	0.060	0.023	0.635	0.506	0.362	0.644	0.8
F	− 0.230	**0.885**	− 0.010	0.836	0.619	0.066	0.524	0.66
Eigenvalue (> 1.0)	4.33	2.14	1.33		4.14	2.29	1.79	
Proportion	43.4	21.4	13.3		41.5	23	17.9	
Cumulative	43.4	64.8	78.1		41.5	64.5	82.4	

Table 6 Result of water quality index for each location, quality rating and Inference

Sample location		Index value	Quality rating	Quality Class	Inference (Remark)
Aperan	Wet	82.06	Very poor	D	Drinking: It can be used for drinking with proper treatment. Other uses: Suitable for use
	Dry	40.14	Good	B	
Egbe garage	Wet	60.63	Poor	C	Drinking: Water should be properly treated with chlorine and other effective means before use (However coliform contamination is heavy and improved water sources should be provided). Other uses: Can be used for washing and cleaning. It must be mixed with disinfectant before bathing
	Dry	44.27	Good	B	
Mode	Wet	108.15	Unsuitable	E	Drinking: Water use is strongly discouraged and should not be used for drinking. Other use: Because of it poor quality, water use should be limited to laundry and washing
	Dry	79.73	Very poor	C	
Latinwo	Wet	105.00	Unsuitable	B	Drinking: Water use is strongly discouraged and should not be used for drinking. Other use: Because of it poor quality, water use should be limited to laundry and washing
	Dry	66.80	Poor	C	
Igangu	Wet	93.93	Very poor	D	Drinking: Water use is strongly discouraged and should not be used for drinking. Other use: Because of it poor quality, water use should be limited to laundry and washing
	Dry	90.15	Very poor	D	
G.R.A	Wet	57.17	Poor	C	Drinking: Water should be properly treated with chlorine and other effective means before use (However coliform contamination is heavy and improved water sources should be provided). Other uses: Can be used for washing and cleaning. It must be mixed with disinfectant before bathing
	Dry	50.00	Good	C	
Aperan II	Wet	31.24	Good	B	Drinking: It can be used for drinking with proper treatment. Other uses: Suitable for use
	Dry	28.17	Good	B	
Omoniyepe	Wet	47.81	Good	B	Drinking: It can be used for drinking with proper treatment. Other uses: Suitable for use
	Dry	43.63	Good	B	

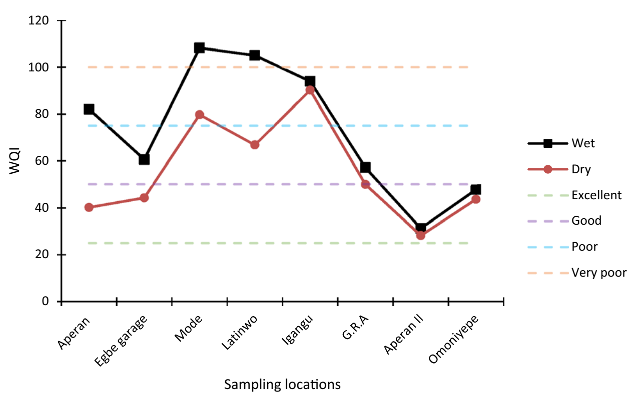

Fig. 15 Weighted average water quality index for selected study area

Conclusion

The pollution sources and water quality of the groundwater sources were considered at spatial levels while the seasonal variation was taken into account. The conclusions were thus;

The mean values for Turbidity, Electrical conductivity, Total dissolved solids, Total hardness, Chloride and Fluoride were within the Nigerian Standard Drinking Water Quality guideline values of 5 NTU, 1000 µS/cm, 500 mg/L, 150 mg/L, 250 mg/L and 1.5 mg/L respectively. On the other hand, key parameters such as pH, Nitrite, Dissolved oxygen and T. Coliform exceed standard limits for drinking wáter of 6.5 NTU, 7.5 mg/L, 10 cfu/mL respectively. The T. Coliform and Nitrite contamination is suspected to be from anthropogenic source such as faulty sewage and septic tanks.

PCA was used to derive three explanatory latent factors for both the wet and dry seasons; The loadings on the factor explains natural pollution and soil erosion phenomenom due to seasonal changes. Organic matter oxidation and mineral dissolution are also identified as factors that affect the water quality in the study area. The general temporal trend show a relatively higher concentration of parameters during the rainy season than for the dry “spell” periods. However, no significant difference was observed except for pH, Total hardness and Fluoride.

The water quality index as computed gives relevant information showing selected locations as classified as Excellent, Good, Poor and Unsuitable for drinking. The major contributing parameters to the low water quality represented by the index were Nitrite, and T. Coliform count especially at Igangu hence its poor state. It is recommended that water be treated before consumption while special care should be given to ensure wells are protected from contamination.

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Author contributions All authors had full access to the data in the study and take responsibility for the integrity and accuracy of the data análisis. EI wrote the manuscript. OE: provided materials, experimental design, formulated study aim and goals and graphical presentation. OF: proof read the manuscript. RA: data analysis. PE: laboratory analysis and collection of the water samples. All authors read and approved the final manuscript.

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Data availability The authors confirm that the data supporting the findings of this study are available within the article.

Declarations

Ethics approval and Consent to participate Not applicable to this manuscript.

Consent for publication The authors have given their approval for the manuscript to be published by the manuscript.

Conflict of interest The authors declare that there are no competing interest. The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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