ISSN:
Print - 2277 - 0593
Online - 2315 - 7461
© FUNAAB 2024

Journal of Natural Science, Engineering and Technology

GROUNDWATER QUALITY ASSESSMENT WITHIN THE FEDERAL UNIVERSITY OF AGRICULTURE, ABEOKUTA, OGUN STATE, NIGERIA: PHYSICOCHEMICAL PROPERTIES, HEAVY METALS POLLUTION INDICES, AND HEALTH RISK

***[1]M.A. NOFIU AND [2]A.M. GBADEBO**

*[1]Department of Environmental Management and Toxicology,
Federal University of Agriculture, Abeokuta, Nigeria
[2]Department of Geology, Federal University of Agriculture, Abeokuta, Nigeria
***Corresponding Author**:nofiu.monsurua@pg.funaab.edu.ng; Tel: +2347032236031

ABSTRACT

Access to potable water has become a perpetual problem to people worldwide; hence, their preferences shift to groundwater utilization for their socio-economic survival. This study assessed the physicochemical properties, heavy metal pollution indices and health risk assessment of groundwater quality within the Federal University of Agriculture, Abeokuta (FUNAAB), Ogun State, Nigeria. Twenty (20) groundwater samples were collected from 20 stations during the rainy season and analysed for physicochemical, heavy metals, and health risk characteristics using the standard methods. All sampled waters were clear, colourless, and odourless. Water pH samples ranged from 7.66 to 9.75; electrical conductivity ranged from 191.0 to 1110.0 µS/cm; total dissolved solid ranged from 95.0 to 555.0 mg/L and total hardness ranged from 1.58 to 5.63 mg/L. Levels of cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) in water samples ranged from 1.00 to 6.97 mg/L, 1.60 to 16.5 mg/L, 5.00 to 74.20 mg/L and 1.00 to 17.50 mg/L. Levels of anions (HCO_3^-, Cl^- and SO_4^{2-}) in water samples ranged from 1.20 to 6.20 mg/L, 18.00 to 334.00 mg/L and 1.13E-03 to 37.26E-03 mg/L, respectively. The concentrations of chloride ion (334.0 mg/L) and electrical conductivity (1110.0 µS/cm) in groundwater sample at FUNAAB Zoological Park (2) were higher than the World Health Organization (WHO) allowable limits of 250.0 mg/L and 1000 µS/cm for drinking water. Heavy metals analysis results showed that Al, Fe, Hg and Sc in six selected groundwater were above the WHO's permissible limits. The total hardness, Ca, Mg, Na, K and Cl^- had significant positive correlation with electrical conductivity and total dissolved solids. Pipe Plot Analysis revealed sodium and chloride as the groundwater type of the study area. Also, the pollution indices (HPI, HEI and Cd) for the majority of heavy metals in six selected groundwater were categorised as low contamination. Only cancer risk (CR) values of Fe were higher than the acceptable range of $\leq 1 \times 10^{-6}$ to 1×10^{-4} set by the USEPA. Multivariate analysis predicted that lithogenic and anthropogenic factors were the probable sources of groundwater pollution of the heavy metal in the study area. Hence, there is a need for periodic monitoring and thorough treatment of all groundwater samples within the Federal University of Agriculture, Abeokuta; at least once in every two years to curb the incidences of contamination observed in this study.

Keywords: Borehole, Heavy metals, Groundwater, Health Risk, Pollution Indices, Total hardness

INTRODUCTION

Groundwater is utilized for home, farming, and commercial purposes and is one of the world's main sources of fresh water. Groundwater provides drinking water to almost one-third of the world's population (International Association of Hydrogeologists, 2020). It is a very valuable resource in dryland areas with insufficient surface water and precipitation (Li *et al.,* 2017). However, the quality of groundwater is seriously threatened by industrialization, urbanization, climate change, and agricultural practices (Ravindra and Mor, 2019). Elemalai *et al.* (2020) reported that natural and man-made sources could both contaminate groundwater. Groundwater contamination affects both humans and ecosystem services on a global scale (Li *et al.,* 2021).

The constituents of pollutants in groundwater could be organic and inorganic origin depending on the geological formation of such locations (Kwaya *et al.,* 2019). The organic pollutants in groundwater include: pharmaceuticals and personal care products, pesticides, veterinary products, industrial compounds or by-products, food additives and nanomaterials (CABI, 2018). The inorganic contaminants in groundwater include zinc, thallium, sodium, silver, selenium, uranium, sulphate, carbonate, nitrite, nitrate, nickel, mercury, manganese, lead, iron, hardness, fluoride, dissolved solids, cyanide, copper, chloride, cadmium, beryllium, barium, arsenic and antimony (Peng *et al.,* 2012; Wang *et al.,* 2021).

This study focuses on inorganic pollutants in groundwater. The presence of inorganic pollutants in groundwater is more of anthropogenic sources rather than the natural sources (Kwaya *et al.,* 2019). The heavy metals presence in groundwater has been investigated to cause serious health effects to human health and the environment (Nafeesa *et al.,* 2022). Heavy metals intake by man enhances oxidative stress, and obstructs cellular redox control, thus, initiating oxidative harm on macromolecules such as lipids, proteins and deoxyribonucleic acid, DNA. They can damage microRNA expression in the brain (Wallace *et al.,* 2020). The imbalance in the levels of essential metals (e.g., Fe which plays a key role in oxygen circulation, Zn in metabolism, Mn and Se are crucial in antioxidant protection) in human body can hinder enzymes function, causing the manifestation of diseases (Wolonciej *et al.,* 2016). Heavy metals can initiate neurological impairments as they spread across the blood-brain barrier and trigger harm by bringing on free radicals within cell organelle e.g mitochondria. Heavy metal toxicities in human brain inflict stress to brain cells, which may have negative effects on the motor, sensory, cognitive and psychological potentials of the human brain. Lead, cadmium, mercury, arsenic, nickel, aluminium, gold, thallium and titanium are the major culprits of these neurological dysfunctions (Singh *et al.,* 2011; Kippler *et al.,* 2012; Schofield, 2017). Carcinogenic dangers associated with intake of packaged groundwater from Abeokuta and Sagamu, Ogun State, Nigeria polluted by heavy metals were published by Taiwo *et al.* (2023).

A number of studies have been conducted in the six geo-political zones of Nigeria on groundwater pollution assessment; Southwest (Adeyemi and Ojekunle, 2021), North-central (Kana, 2022), Southsouth (Nnoli *et* *al.,* 2021), Southeastern (Obasi and Akudinobi, 2019), Northwest (Grema *et al.,* 2022), Northeast (Agada *et al.,* 2020), and other parts of the globe. It is clear that the extent of groundwater contamination arising from anthropogenic and geogenic sources are yet to be demystified, and the public have no alternatives other than to use groundwater within their reach to make ends meet. Also, public and private organizations are not exempted to contribute their quotas to salvage the groundwater pollution occurrences within our localities.

The measurement of the physical and chemical properties of groundwater and the comparison of their values with standards alone may not give holistic evaluation of groundwater quality due to the fact that there are different routes of exposure of heavy metals to groundwater pollution. Thus, the adoption of Piper, Stiff plots and Multivariate statistical techniques will assist greatly in evaluating the groundwater quality, water type and sources of contaminants (Affum *et al.,* 2015). Also, some practical indices (Heavy metal pollution index (HPI), Heavy metal evaluation index (HEI), Degree of contamination (C_d) and Hazard index, HI) have been employed in literatures to quantify the level of heavy metal pollution in groundwater. These indices will aid the measurement of health risk associated with groundwater consumption and utilization by humans (Singh *et al.,* 2017; Wagh *et al.,* 2018).

Additionally, Clean Water and Sanitation, with Good Health and Well-being are parts of the Sustainable Development Goals (SDGs) that find expression in this study due to the fact that availability of boreholes in the study area enhances the socio-economic lives of people working and residing within the academic milieu. Provision of boreholes within the Federal University of Agriculture, Abeokuta, Ogun State (FUNAAB) proffers a relief to the age-long water scarcity confronting this Institution of learning. At least 50 boreholes were constructed within FUNAAB in the last two decades, coupled with the dam project near completion. Despite these lofty efforts, some boreholes were no longer functioning. The assessment of the selected boreholes out of the remaining working groundwater helps to ascertain the current status of groundwater pollution in FUNAAB. The quality of groundwater in the above named institution might have been investigated in the past, yet there is still room for more periodic monitoring and evaluation of the occurrences, levels and distribution patterns of pollutants in the FUNAAB's Groundwater. Hence, this study aimed to measure the quality and the health risk associated with the use of groundwater in FUNAAB. It is expected that the results of this study will add to the body of knowledge on borehole water in FUNAAB Community and to increase the data base on groundwater quality.

MATERIALS AND METHODS

Location and climate setting

The study area (Figure 1) is the permanent site of the Federal University of Agriculture, Abeokuta (FUNAAB), Ogun State, Nigeria. It is situated in the North-East of Abeokuta, in Odeda Local Government of Ogun State, Nigeria. It lies between latitudes 7^{o}12□ □ 7^{o}14′ and longitudes 3^{o}08□ □ 3^{o}26′. It is located in the urban setting of the medium-sized city of Abeokuta (population range of 500,000-1,000,000 inhabitants), Ogun State. The study area is characterized by a tropical climate with alternate wet and dry seasons. The quantity of rainfall (750 mm-1000 mm) varies between March and October in the rainy season and 250 mm-500 mm between November and March in the dry season. It has a mean annual temperature of 26 °C (Akanni, 2000).

Geology of the study area

The study area is underlain by basement complex. The basement complex rocks in the study area are of metamorphic and characterize by various folds, structures of complexity and landform changes. These rocks extend from the north eastern part of Ogun State, running southwest, dipping towards the coast (Ako, 1979). Major rocks commonly found in the area are gneiss, schist, quartzite, granite, granitic gneiss and pegmatite (Okunlola *et al.,* 2009). The weathered and fractured parts of basement complex formation determined hydrologic features of the study area (Akanbi, 2018).

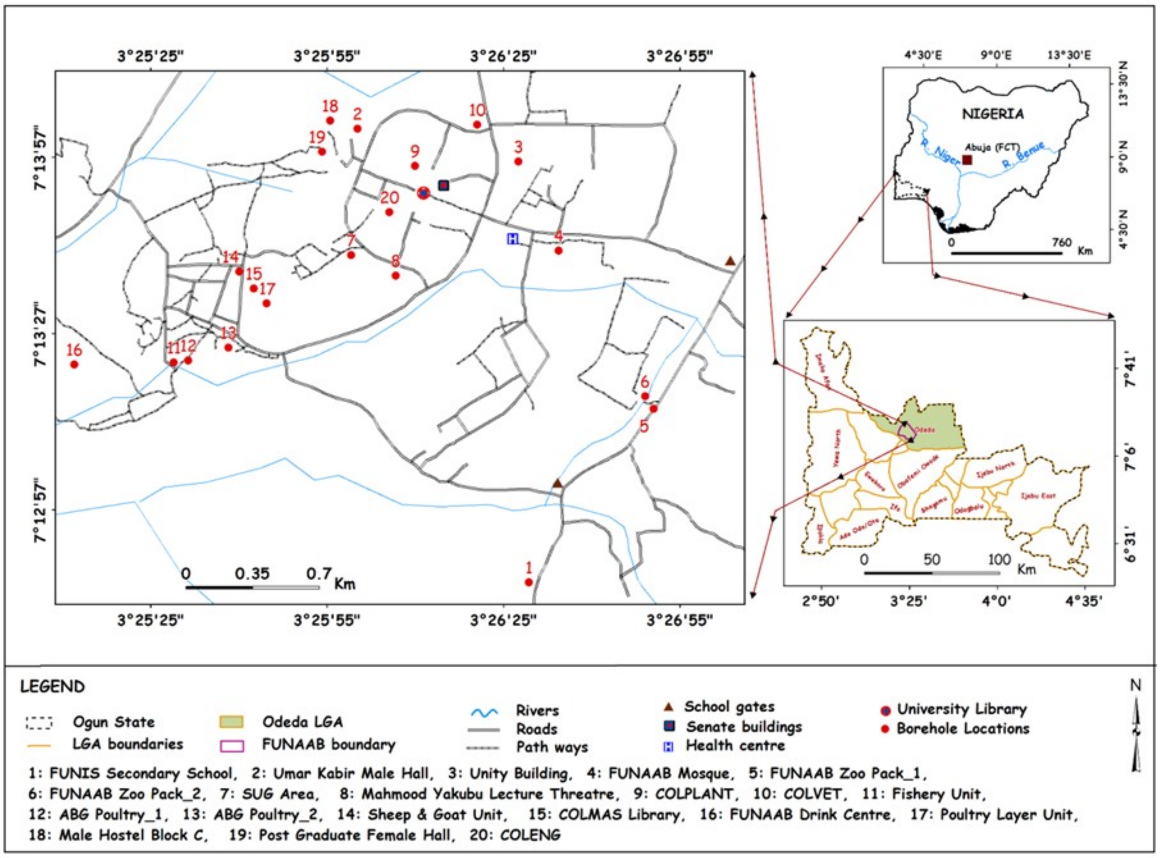


Figure 1: Groundwater Sampling Points of the study area

Chemicals and reagents

All glassware and polyethylene bottles used in the study were washed, rinsed with doubly distilled water, and soaked in 10 % HNO_3 (v/v) for 72 h. The glass wares were rinsed once more three times with deionized water and finally oven dried before use. All chemicals used were of analytical grade, and the water used for all the preparations was doubly distilled water.

Sampling

Twenty groundwater samples were collected from 20 stations in FUNNAB during the rainy season (between April and May, 2015) according to standard procedures of the American Public Health Association (APHA, 2017). Groundwater samples were collected in triplicates. The coordinate of each sampling point was taken with the Global Positioning System (Germin GPS 12 XL). Water samples from boreholes were collected after it was pumped for 30 minutes, and the first few buckets were poured away before sampling. Samples meant for metal analysis were preserved with 5 mL of pure nitric acid on the spot. Samples for anions were collected into cleaned polythene bottles of 2 litres capacity, which were rinsed with water to be sampled before collection. Water samples from the field were kept in ice chess cooler, transferred to the laboratory, stored in a refrigerator at 4 ^{0}C and analysed within a week after collection.

Sample analysis

The physicochemical parameters such as pH, temperature, electrical conductivity (EC), total dissolved solids of the boreholes were measured in-situ on the field using the Hannah Combo Metre (HI 98129, 2004).

Anions

The anions and the hardness of the water samples were determined titrimetrically according to APHA (2017). The chloride content of the water sample was determined by Mohr's method and the sulphate content was measured at absorbance of 420 nm using a Cecil UV-visible spectrophotometer (CE 7200, 2010).

Metals analysis

The preserved water samples were taken out from the refrigerator and kept at room temperature until it thawed and attained the room temperature. Prior to cations analysis, 100 mL of water samples were digested with 10 mL of concentrated hydrochloric acid (HCl) in a 250 mL conical flask. The mixture was evaporated to half of its volume on a hot plate, after which it was allowed to cool and then filtered. Cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) in water samples were analysed using a Systonic Flame Photometer (S-935, 2010) at FUNAAB. The in-situ measurement of ECs in the groundwater samples guided the selection of six water samples for heavy metals analysis. The analyses of alkali and alkaline metals, trace metals and heavy metals in six selected water samples were carried out using the Inductively Coupled Plasma Mass Spectrometer (ICP-MS) in Canada.

Quality control

Replicate blanks and reference materials, NIST 1640 (a) were used for the method of validation and quality control. After each batch of five samples, the control sample was analysed to check the accuracy of the analysis. Recovery rates for each element were in allowable ranges (87.3□ 95.1%). The concentrations of heavy metals in the groundwater were reported in µg/L.

Pollution evaluation indices

The formulae listed below were employed for the calculation of heavy metal pollution index (HPI), heavy metal evaluation index (HEI) and degree of contamination (C_d) in a bid to evaluate the drinking water quality.
The HPI is based on the weighted arithmetic quality mean method which is developed in two basic steps (Prasad and Bose, 2001). A rating scale was developed for each of the selected parameters upon which the index is based on. The rating is an arbitrary value between 0 and 1 and its selection indicates the relative importance of individual quality considerations. The weightage can be assessed by making value inversely proportional to the recommended standard (S_i) for corresponding parameter (Prasad and Bose, 2001; Edet and Offiong, 2002; Kwaya *et al.,* 2017). The HPI model (Prasad and Bose, 2001) is computed using the following Eq. (1):

$$HPI = \sum_{n=1}^{n} WiQi$$
$$\sum_{n=1}^{n} Wi$$

where Q_1 and W_1 are the sub-index and unit weight of the ith parameter, respectively, and n is the number of parameters considered. The sub-index (Q_1) is calculated according to:

$$Q_1 = \sum_{n=1}^{n} \frac{Mi - Ii}{Si - Ii} X100$$

where M_p, I_p and S_i are the monitored heavy metal, ideal, and standard values of the ith parameter, respectively.

Heavy metal evaluation index

HEI method gives the overall quality of the water with respect to heavy metals (Edet and Offiong, 2002; Kwaya *et al.,* 2017). HEI is calculated from the following Eq. (2):

$$HEI = \sum_{i=0}^{n} Hc/Hmac$$

H_c is the monitored value of the ith parameter and H_{mac} is the maximum admissible concentration of the ith parameter.

Contamination index (C_d)

The degree of contamination considers both the number of parameters that exceed the upper permissible limit or guide values of potentially harmful elements and the concentrations exceeding these limit values (Edet and Offiong, 2002). The degree of contamination (C_d) is calculated separately for each sample of water analysed as the sum of water contaminant factor of the individual components exceeding the upper permissible values and is calculated using Eq. (3):

$$C_d = \sum_{i=1}^{n} Cfi$$

$$\text{where } C_{fi} = \frac{CAi}{CNi} - 1$$

where C_{fi}; C_{Ai} and C_{Ni} represent contamination factor, analytical value and upper permissible concentration of the ith component respectively. N denotes the 'normative value' and CNi is taken as maximum admissible concentration (MAC).

Potential health risk assessment of metals in groundwater samples

The assessment of health risk via oral consumption pathway necessitates the estimation of the likely duration and severity of adverse health consequences as a result of using contaminated groundwater over a lifetime (Osipova *et al.,* 2015; Ogundele *et al.,* 2019). Oral reference dose values for heavy metals such as Cd (0.0005 mgkg/day), Cu (0.0035 mgkg/day), Zn (0.3 mgkg/day), Fe (0.7 mgkg/day), Mn (0.014 mgkg/day), As (0.0003 mgkg/day), Ni (0.02 mgkg/day), and Cr (0.003 mgkg/day) were employed to compute hazard quotient for non-carcinogenic health effects for adults (Table 1). Egbueri (2020) reported the average daily dose (ADD) of metals in groundwater via oral ingestion route using Eq. (4):

$$ADD = \frac{(Ci\ X\ IR\ X\ EF\ X\ ED)}{(\mathrm{BW\ X\ AT})}$$

where C represents the concentration of metal in water (mg/L), IR signifies the oral ingestion rate (0.75, 1, and 2 L/day for infant, child, and adult), EF is the exposure frequency in the water (365 days/year), ED is the exposure duration time (70 years as adult ED, while 10 years as child ED). The body weight (BW) was 60 kg and the averaging time in days (AT) was 70 x 365 for carcinogenic effects for adults (Table 2).

The non-carcinogenic was computed using Eq. (5):

Hazard quotient (HQ) = $\frac{ADD}{RfD}$

where RfD signifies the oral reference dose of a specific metal (mg/kg/day).

Table 1. The toxicity responses (dose response) to heavy metals as the oral reference dose (RfD)

Heavy metals	Oral RfD (mg/kg/day)
Cd	5.0×10^{-4}
Cu	4.0×10^{-2}
Pb	3.5×10^{-3}
Zn	0.3
Fe	0.7
Mn	0.014
As	0.0003
Ni	0.02
Cr	0.003
Hg	0.003

Sources: Ukah *et al.* (2019), Egbueri (2020)

Table 2. Input parameters to characterize the ADD value

Exposure parameters	Symbols	Units	Value
Concentration of water	C	mg/L	Table 6
Ingestion rate	IR	kg/day	2.2
Exposure frequency	EF	Days/year	365
Exposure duration	ED	Years	70
Body weight	BW	Kg	60
Average time	AT	Years	(365 x ED = 25,550 days)

Cancer risk (CR)

The probability of cancer risk of drinking groundwater was evaluated as the incremental likelihood of human being developing cancer over a life span, resulting from the exposure to a prospective carcinogenic element (Ukah *et al.,* 2019; Egbueri and Mgbenu, 2020).

The CR is computed using Eq. (6):

$$CR = ADD\ X\ SFi$$

where SF$_i$ is the slope factor (mg/kg/day). The tolerable CR value is within 1 x 10^{-6} to−1 x 10^{-4} (Ukah *et al.,* 2019; Egbenu and Mgbenu, 2020).

STATISTICAL ANALYSIS

Data obtained were analysed using descriptive and inferential methods of statistical analysis. The set of data from the physicochemical properties of groundwater samples were entered into Microsoft Excel spreadsheets and exported into the Statistical Package for Social Science (SPSS 22.0) software for analysis. Descriptive statistical tools (frequency, range, percentage, mean and standard deviation) were employed to summarize the data collected. The relationship that exists between the physicochemical parameters of the water samples was analysed using the Pearson correlation. The pollution indices and health risk of the water samples were estimated with proven equations.

RESULTS

Physical and chemical characteristics

Water temperature, electrical conductivity (EC), total dissolved solids (TDS) and total hardness (TH) ranged from 28.0 to 35.0 ^{o}C, 191.0 to 1110.0 µS/cm, 95.0 to 550.0 mg/L and 1.6 to 5.6 mg/L, respectively (Table 3). Except for groundwater at FUNAAB Zoological Park (2) with higher level of TDS, all other TDS and TH values were within the allowable limits of 500 mg/L and 15 mg/L, respectively (Nigerian Standard for Drinking Water Quality (NSDWQ), 2015). Water pH varied from 7.66–9.75, the lowest value found at FUNAAB Zoological Park (2), while the highest value was obtained at FUNAAB Drink Centre (Figure 2). A significant number of measured water pH (90%) was above the maximum limit of pH 8.5 for drinking water (WHO, 2018). Level of chloride ions in the groundwater samples ranged from 18.00 to 334.00 mg/L (Figure 3). The concentrations of SO_4^{2-} in the water samples varied from1.13E-03 to 37.26E-03 mg/L (Figure 4). The levels of HCO_3^- in the groundwater samples fell in the ranges of 1.20–6.20 mg/L (Figure 5). The HCO_3^- levels in all the samples were in acceptable range of drinking water endorsed by the SON (2007). The concentrations of chloride ion (334.0 mg/L) and electrical conductivity (1110.0 µS/cm) in groundwater sample at FUNAAB Zoological Park (2) were higher than the World Health Organization (WHO) allowable limits of 250.0 mg/L and 1000 µS/cm for drinking water. Levels of cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) in water samples ranged from 1.00 to 6.97 mg/L, 1.60 to 16.5 mg/L, 5.00 to 74.20 mg/L and 1.00 to 17.50 mg/L (Table 4). The concentrations of alkali and alkaline earth metals in sampled waters were within the acceptable limits set by the WHO (2008). The mean values of chromium, cadmium, lead, arsenic, nickel, copper, zinc, iron, manganese, mercury, aluminium, cobalt, barium, scandium, tin and silver were 39.62±8.59 µg/L, 2.01±4.75 µg/L, 2.20±3.29 µg/L, 2.79±0.16 µg/L, 11.69±2.84 µg/L, 16.57±2.27 µg/L, 129.42±52.08 µg/L, 1792.67±2023.53 µg/L, 27.41±34.09 µg/L, 17.70±2.41 µg/L, 2120.7±2750.9 µg/L, 4.60±10.19 µg/L, 165.2±163.3 µg/L, 65.7±19.9 µg/L, 9.4±4.9 µg/L and 12.4±4.2 µg/L (Table 5). Levels of Al, Fe, Hg and Sc in six selected groundwater were above the WHO permissible limits. The piper plot revealed the nature of dominant cations (Mg^{2+}, Ca^+, Na^+ and K^+) and anions (Cl^-, CO_3^-, HCO_3^- and SO_4^{2-}) largely controlling the groundwater chemistry in FUNAAB. The groundwater is Sodium and Chloride water type (Figure 6).

Table 3. The physical and chemical characteristics of groundwater samples within the Federal University of Agriculture, Abeokuta, Ogun State, Nigeria

SP	Long.	Lat.	Temp ^{0}C	EC (µS/m)	TDS (mg/L)	TH (mg/L)	Environmental Conditions of the Boreholes
L_1	$3^0.4415'$	$7^0.2124'$	29.1	359.0	179.0	2.9	It was made with concrete located near the FUNIS dining hall
L_2	$3^0.1881'$	$7^0.2331'$	31.0	316.0	158.0	2.2	It was made with concrete located at entrance of the Male Hostel Hall
L_3	$3^0.4410'$	$7^0.2323'$	33.8	610.0	305.0	3.2	It was made with concrete located in open space
L_4	$3^0.1429'$	$7^0.2270'$	30.1	841.0	420.0	5.6	It was made with concrete located beside the Funaab mosque

Table 3. Contd.

SP	Long.	Lat.	Temp ^{0}C	EC (µS/m)	TDS (mg/L)	TH (mg/L)	Environmental Conditions of the Boreholes
L_5	$3^0.4474'$	$7^0.2206'$	29.3	279.0	139.0	1.9	It was made with concrete located in front of the Funaab zoo administrative office (1)
L_6	$3^0.4470'$	$7^0.2212'$	29.3	1110.0	555.0	5.6	It was made with concrete located beside the Funaab zoo administrative office (2)
L_7	$3^0.1885'$	$7^0.2281'$	34.8	275.0	137.0	1.7	It was made with concrete located opposite of Funaab Flora Kitchen
L_8	$3^0.1352'$	$7^0.2258'$	35.0	345.0	172.0	2.6	It was made with concrete located at back of the Mahmoud Yakubu Lecture Theatre
L_9	$3^0.4006'$	$7^0.2322'$	31.0	191.0	95.0	2.3	It was made with concrete located within the College of Plant Science
L_{10}	$3^0.4402'$	$7^0.2337'$	33.5	790.0	394.0	4.2	It was made with concrete located beside the Veterinary College
L_{11}	$3^0.4247'$	$7^0.2228'$	28.0	388.0	193.0	3.9	It was made with concrete located in front of the Fishery Building
L_{12}	$3^0.4254'$	$7^0.2229'$	29.5	281.0	140.0	2.3	It was made with concrete located beside the Poultry Building
L_{13}	$3^0.4273'$	$7^0.2235'$	29.4	271.0	135.0	2.3	It was made with concrete located beside the Poultry Building

Table 3. Contd.

L_{14}	**$3^{0}.4278'$**	**$7^{0}.2271'$**	**29.9**	**352.0**	**176.0**	**3.3**	**It was made with concrete located at the entrance FUNAAB Livestock Unit**
L_{15}	$3^{0}.4285'$	$7^{0}.2263'$	28.0	259.0	179.0	2.8	It was made with concrete located at the back of COMAS Library
L_{16}	$3^{0}.4200'$	$7^{0}.2227'$	28.9	409.0	204.0	3.2	It was made with concrete located within Funaab Drink Centre
L17	$3^{0}.4291'$	$7^{0}.2256'$	28.5	255.0	127.0	1.6	It was made with concrete located beside the Poultry Building
L_{18}	$3^{0}.4004'$	$7^{0}.2329'$	29.3	600.0	259.0	3.6	It was made with concrete located at the back of Male Hostel Block C
L_{19}	$3^{0}.4325'$	$7^{0}.2319'$	29.9	531.0	266.0	3.5	It was made with concrete located at the back of PG Female Hostel
L_{20}	$3^{0}.4349'$	$7^{0}.2299'$	29.6	210.0	105.0	2.0	located at the back of the College of Engineering
(NSDWQ, 2015)				1000.0	500.0	15. 0	
(WHO, 2018)				500	500.0		

SP– Sampling points, PG – Post graduate, Temp – Temperature, EC – Electrical conductivity, TDS – Total dissolved solids, TH – Total hardness, COMAS – College of Management Science, Long. – Longitude, Lat. – Latitude, NSDWQ – Nigerian Standard for Drinking Water Quality, WHO – World Health Organization

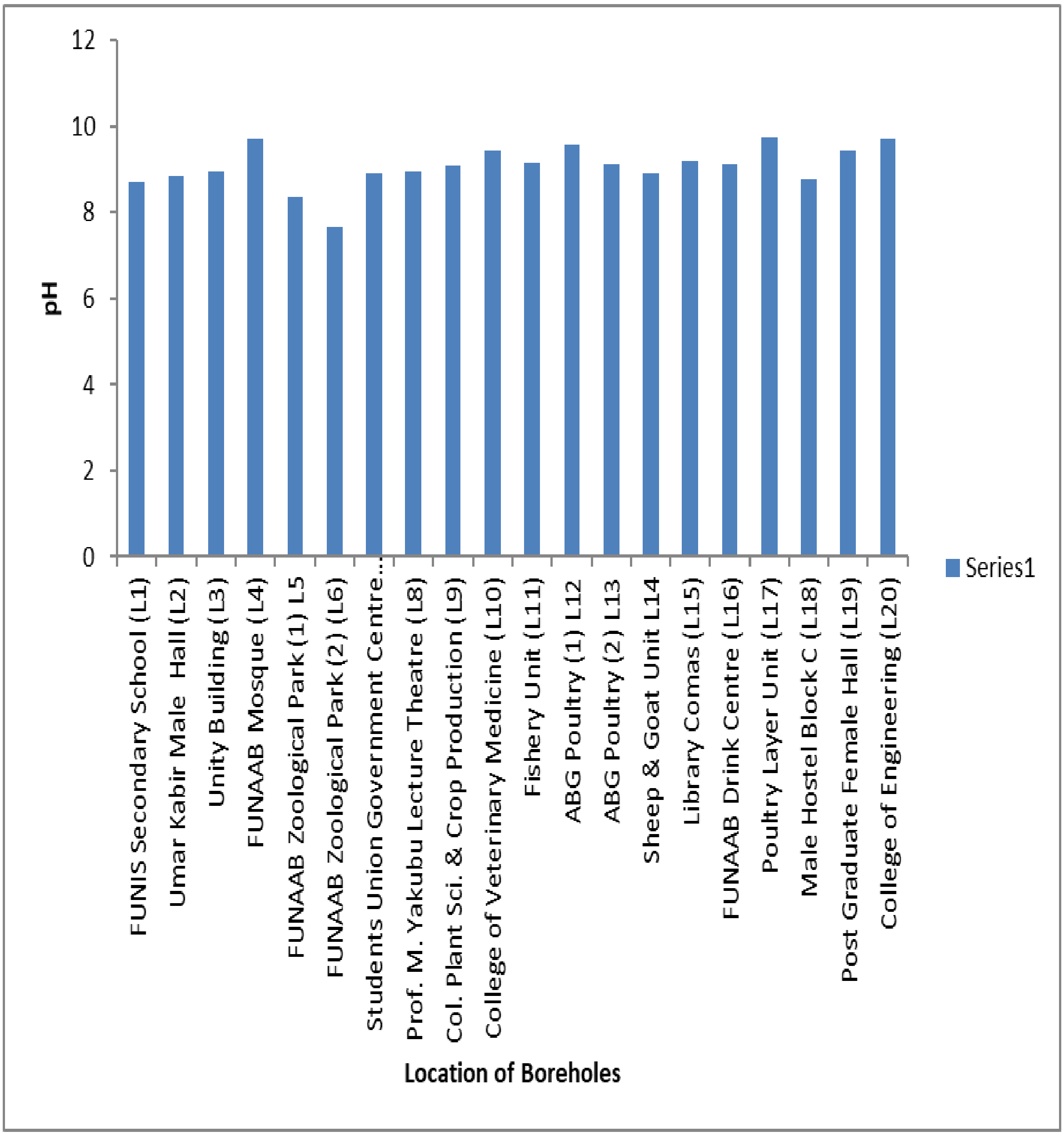


Figure 2: pH values of groundwater samples collected in FUNAAB
Permissible range of pH values according to the NSDWQ (2015) and WHO (2018) – 6.5-8.5

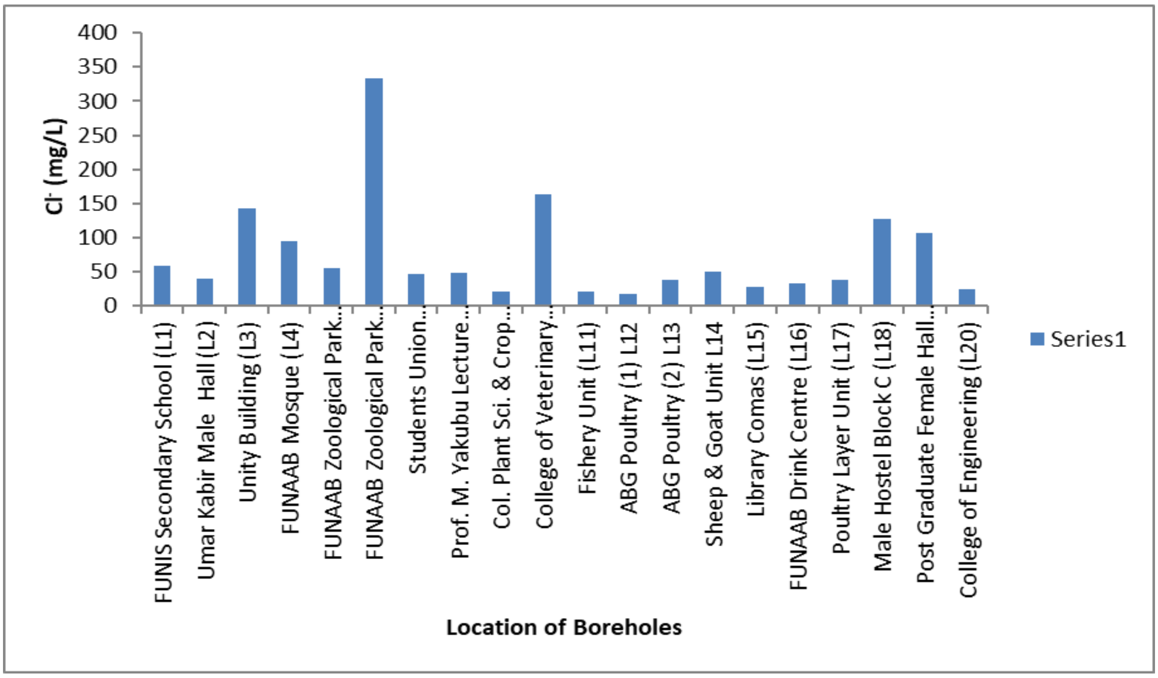


Figure 3. Chloride ion values of groundwater samples collected in FUNAAB Permissible chloride ion value according to the WHO (2018) – 250 mg/L

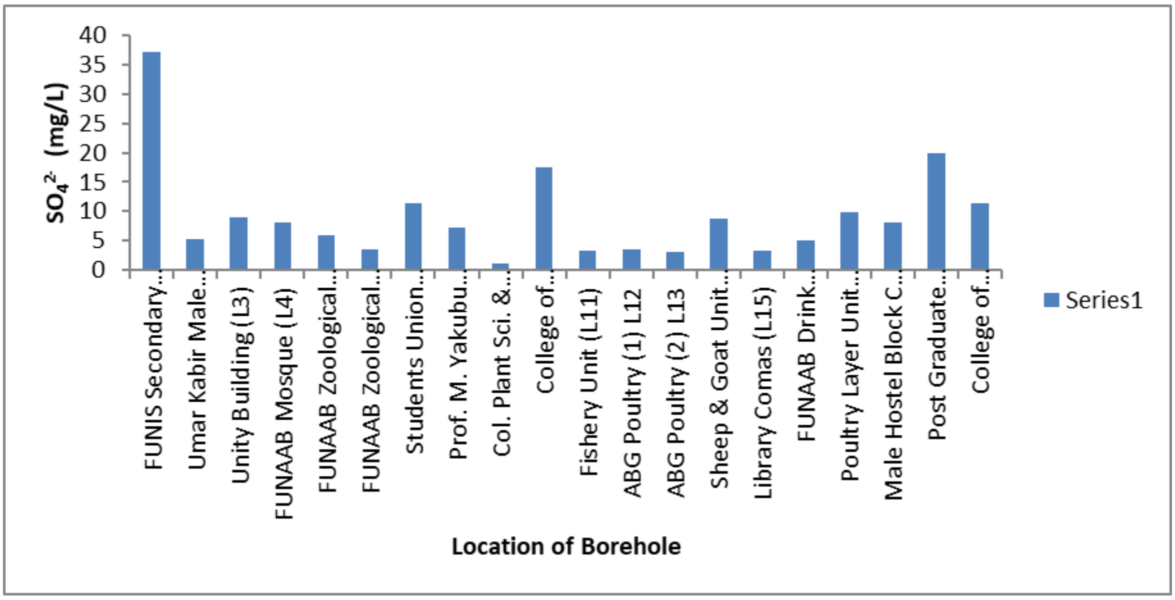


Figure 4: Sulphate ion values of groundwater samples collected in FUNAAB Permissible SO_4^{2-} value according to WHO (2018) – 250 mg/L

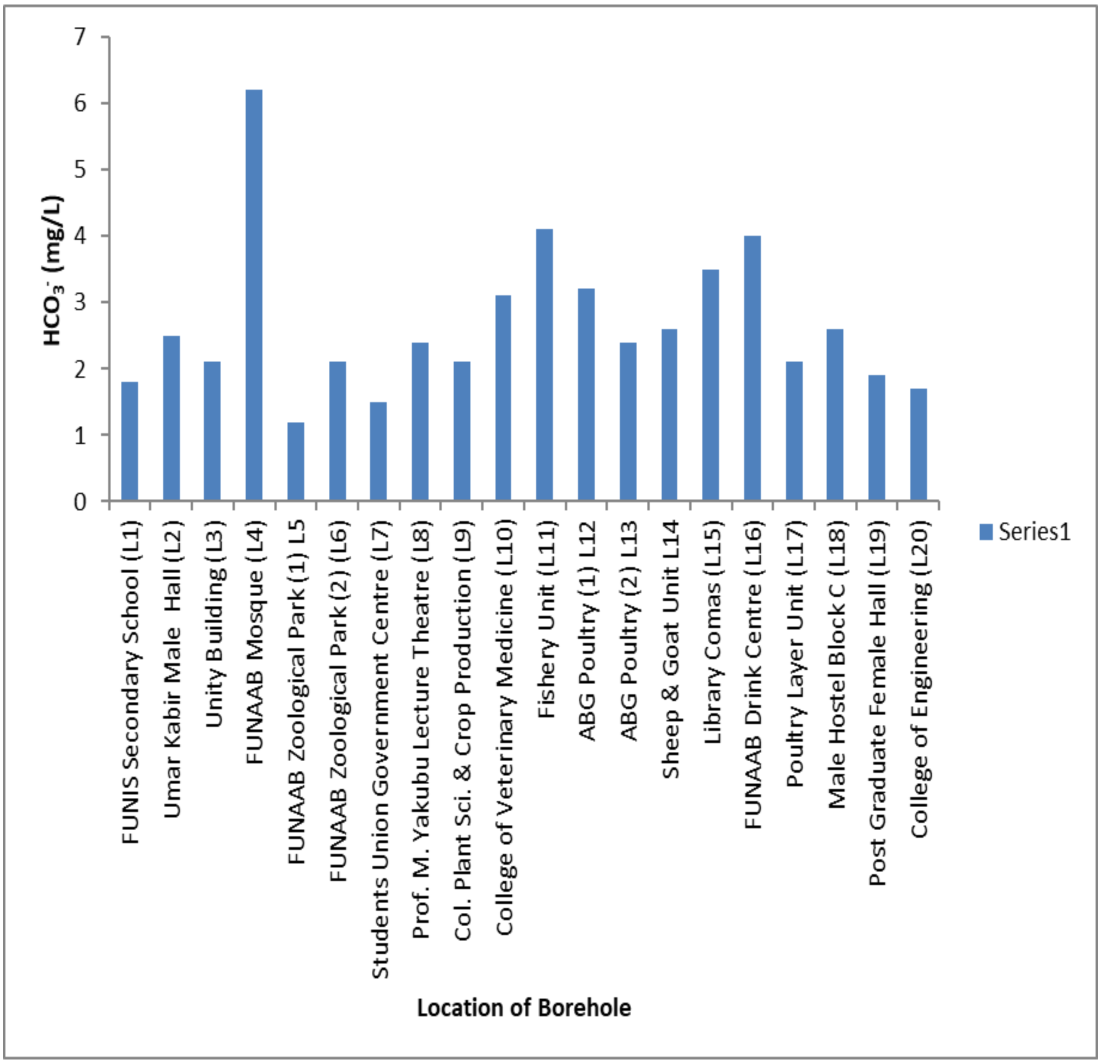
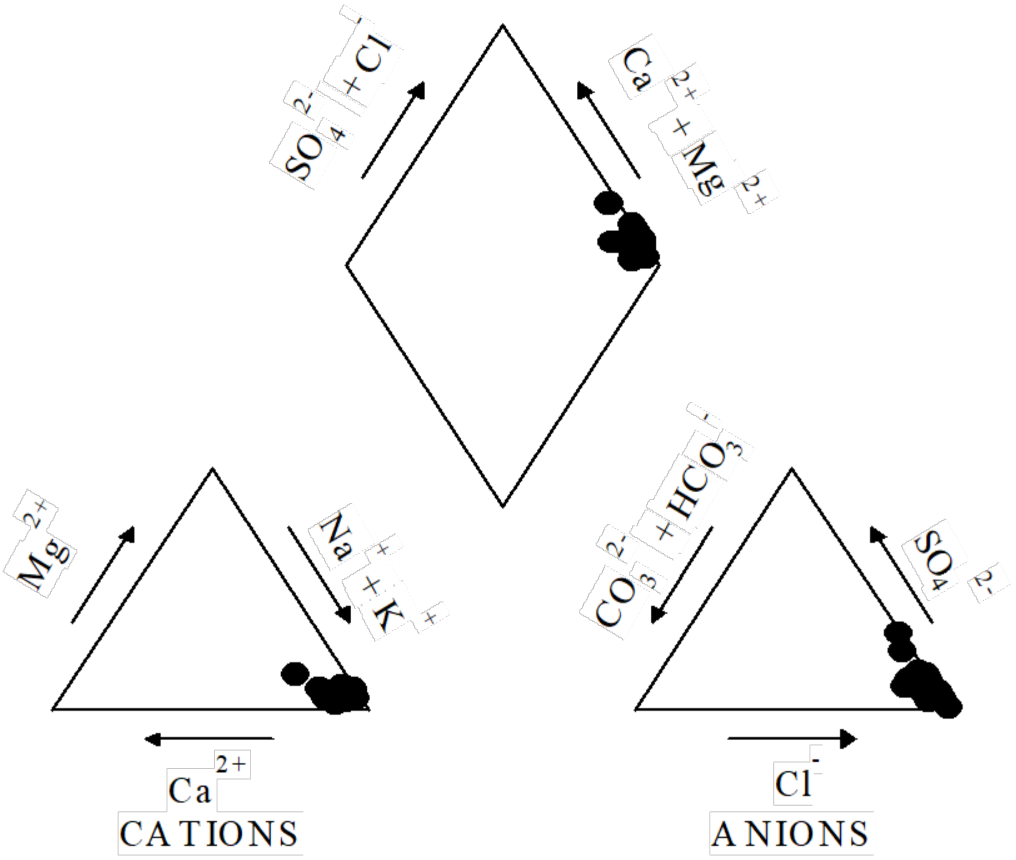


Figure 5: Bicarbonate ion values of groundwater samples collected in FUNAAB
Permissible HCO_3^- value according to WHO 2006 (SON, 2007) – 240(3) mg/L
WHO: World Health Organisation, SON: Standard Organisation of Nigeria

Table 4. Mean concentrations of Alkali and Alkaline Earth Metals (mg/L) in groundwater of Study Area

Locations	Na	Mg	K	Ca
L_1	27.90	3.33	3.89	66.79
L_2	5.00	1.60	2.00	6.20
L_3	11.00	5.20	2.00	4.40
L_4	68.60	5.67	3.94	57.26
L_5	6.00	3.20	2.00	2.40
L_6	74.20	16.50	17.50	69.77
L_7	6.00	2.20	2.00	3.00
L_8	7.00	3.60	2.00	4.60
L_9	6.00	4.00	1.00	2.40
L_{10}	14.00	4.60	3.00	9.20
L_{11}	6.00	3.80	2.00	9.40
L_{12}	8.00	2.40	1.00	5.20
L_{13}	8.00	3.40	1.00	3.60
L_{14}	30.10	4.39	2.80	69.45
L_{15}	10.00	4.00	2.00	4.60
L_{16}	10.00	4.00	1.00	6.20
L_{17}	10.00	3.00	1.00	1.40
L_{18}	11.00	2.20	2.00	1.08
L_{19}	7.00	1.00	2.00	1.00
L_{20}	23.50	3.31	3.49	45.41
(SON, 2007)		20.00	NP	NP
(WHO, 2008)	200.00	150.00	200.00	75.00



The groundwater is Sodium and Chloride water type

Figure 6: A piper plot of groundwater samples within FUNAAB

Table 5. Heavy metals (µg/L) in six selected groundwater samples in study area

Location	Al µglL	Cr µglL	Mn µglL	Fe µglL	Co µglL	Cu µglL	Ba µglL	Pb µglL
L_1	587.0	28.2	8.4	625.0	0.41	16.6	66.3	0.08
L_4	2370.0	44.7	24.9	1760.0	0.45	18.2	59.0	2.02
L_6	1120.0	48.3	95.0	952.0	25.40	19.7	492.0	0.09
L_9	7550.0	48.1	8.5	5840.0	0.47	16.5	117.0	8.57
L_{14}	581.0	36.1	22.2	855.0	0.46	15.2	144.0	2.33
L_{20}	516.0	32.3	5.5	724.0	0.42	13.2	113.0	0.09
Mean	2120.7	39.6	27.4	1792.7	4.60	16.6	165.2	2.20
Stdev	2750.9	8.6	34.1	2023.5	10.19	2.3	163.3	3.29
Minimum	516.0	28.2	5.5	625.0	0.41	13.2	59.0	0.08
Maximum	7550.0	48.3	95.5	5840.0	25.40	19.7	492.0	8.57
(WHO, 2008)	200.0	50.0	100.0	300.0	50.0	50.0	700.0	10.0
(USEPA, 2011)	-	100.0	-	-	-	-	2000.0	15.0

Location	Hg µglL	As µglL	Ni µglL	Sc µglL	Sn µglL	Ag µglL	Zn µglL	Cd µglL
L_1	17.7	2.61	12.70	80.5	7.1	15.5	99.0	0.08
L_4	18.8	2.93	11.25	66.3	6.1	11.4	186.0	0.08
L_6	17.3	2.97	16.55	96.8	9.0	18.6	178.0	0.06
L_9	13.2	2.88	9.45	50.4	19.2	7.0	47.5	0.08
L_{14}	19.8	2.71	8.44	56.2	8.4	9.4	120.0	0.08
L_{20}	19.4	2.63	11.75	43.8	6.5	12.4	146.0	11.70
Mean	17.7	2.79	11.69	65.7	9.4	12.4	129.4	2.01
Stdev	2.4	0.16	2.84	19.9	4.9	4.2	52.1	4.75
Minimum	13.2	2.61	8.44	43.8	6.1	7.0	99.0	0.06
Maximum	19.8	2.97	16.55	96.8	19.2	18.6	178.0	11.70
WHO 2008	1.0	10.0	20.0	10.0	4.9	-	5000.0	30.0
USEPA 2011	2.0	-	-	-	-	-	-	50.0

Stdev: Standard deviation

Heavy metal pollution indices

The HPI values in the groundwater samples varied from 6.9 to 5640.0 (Table 6). Based on the adopted class ranges (HPI < 100 – low, HPI = 100 – medium; HPI > 100 – high) proposed by Edet and Offiong (2002), 68.3% of the collected groundwater samples were grouped as low pollution, while 31.7% were highly polluted with HPI values above 100. With the exception of Zn, Fe, Mn and Cd at College of Engineering, the mean HPI values indicated that all other heavy metals assessed had HPI values less than the threshold limit of 100.

Table 6. Heavy metal pollution index (HPI) in six selected groundwater samples of study area

Sample number	Cr	Cd	Pb	As	Ni	Cu	Zn	Fe	Mn
L_1	54.58	46.00	98.40	7.63	14.60	98.34	245.05	425.00	122.94
L_4	88.96	46.00	59.60	11.63	17.50	98.18	240.73	1560.00	118.78
L_6	96.46	47.00	98.20	12.13	6.90	98.03	241.10	752.00	101.25
L_9	96.04	46.00	71.40	10.00	21.10	98.35	247.63	5640.00	122.88
L_{14}	71.04	46.00	53.40	8.88	23.12	98.48	244.00	655.00	119.45
L_{20}	63.13	535.00	98.20	7.88	16.50	98.68	242.70	524.00	123.63
Mean	78.37	127.67	78.87	9.69	16.62	98.34	243.53	1592.67	118.16
Stdev	17.91	199.55	20.97	1.90	5.69	0.23	2.61	2023.53	8.52

Stdev: Standard deviation

The HEI values ranged from 0.009 to 119.800 (Table 7). Based on Kwaya *et al.* (2017)'s classification (HEI < 10 – low , HEI = 10-20 – medium and HEI > 20 – high) applied in this study, 88.0% of the groundwater samples fell within the low zone, 11.7% fell within the medium, while none found within the high zone.

Table 7. Heavy metal evaluation index (HEI) in six selected groundwater samples of study area

Sample number	Cr	Cd	Pb	As	Ni	Cu	Zn	Fe	Mn
L_1	0.564	0.027	0.008	0.261	0.181	0.008	0.033	2.083	0.168
L_4	0.874	0.027	0.202	0.293	0.161	0.009	0.062	5.867	0.498
L_6	0.966	0.020	0.009	0.297	0.236	0.009	0.059	3.173	1.900
L_9	0.962	0.027	0.857	0.288	0.135	0.008	0.016	19.467	0.170
L_{14}	0.722	0.027	0.233	0.271	0.121	0.008	0.040	2.850	0.444
L_{20}	0.646	3.900	0.009	0.263	0.168	0.007	0.049	2.413	0.110
Mean	0.790	0.670	0.230	0.280	0.170	0.080	0.040	5.980	0.550
Stdev	0.170	1.580	0.330	0.020	0.040	0.000	0.020	0.750	0.680

Stdev: Standard deviation

The contamination index (C_d) values varied from -0.038 to 18.47 (Table 8). Based on Edet and Offiong (2002)'s ranking system ($C_d < 1$– low, $C_d =$ 1-3–medium and $C_d > 3$ – high) employed in this research, 78.4% of the collected groundwater samples were classified as low zone, 8.3% as medium zone and 13.3% as high zone.

Table 8. Degree of contamination (C_d) in six selected groundwater samples of study area

SN	Cr	Cd	Pb	As	Ni	Cu	Zn	Fe	Mn
L_1	-0.436	-0.973	-0.992	-0.739	-0.819	-0.992	-0.967	1.083	-0.832
L_4	-0.106	-0.973	-0.798	-0.707	-0.839	-0.991	-0.938	4.867	-0.502
L_6	-0.034	-0.980	-0.991	-0.703	-0.764	-0.990	-0.941	2.173	0.900
L_9	-0.038	-0.973	-0.143	-0.712	-0.865	-0.992	-0.984	18.467	-0.830
L_{14}	-0.278	-0.973	-0.767	-0.729	-0.879	-0.992	-0.960	1.850	-0.556
L_{20}	-0.354	2.900	-0.991	-0.737	-0.832	-0.993	-0.951	1.413	-0.890
Mean	-0.210	-0.330	-0.780	-0.720	-0.830	-0.990	-0.960	4.970	-0.450
Stdev	0.170	1.580	0.330	0.020	0.040	0.000	0.010	6.750	0.680

Stdev– Standard deviation, SN – Sample Number

Human health risk assessment

The HQ values fell in the ranges of 1.39E-08 to 1.43E-05 (Table 9). The computed HQ values in all of the water samples were less than 1, indicating that all assessed heavy metals (e.g., Cr, Cd, Pb, As, Ni, Cu, Zn, Fe and Mn) contributed no significant inputs to the occurrence of non-cancer health risks among adults that utilized the groundwater in the study area.

Table 9. Hazard quotient (HQ) of heavy metals in six selected groundwater samples of study area

Sample Number	Cr	Cd	Pb	As	Ni	Cu	Zn	Fe	Mn
L_1	5.76E-07	9.79E-08	1.39E-08	5.33E-08	3.89E-07	2.54E-07	2.01E-07	5.47E-07	3.67E-07
L_4	9.12E-07	9.79E-08	3.53E-07	5.98E-08	3.44E-07	2.79E-07	3.79E-07	1.54E-08	1.09E-07
L_6	9.86E-07	7.35E-08	1.57E-08	6.06E-08	5.07E-07	3.02E-07	3.63E-07	8.33E-07	4.16E-07
L_9	9.82E-07	9.79E-08	1.49E-06	5.88E-08	2.89E-07	2.53E-07	9.69E-08	5.11E-08	3.72E-07
L_{14}	7.37E-07	9.79E-08	4.07E-07	5.53E-08	2.58E-07	2.33E-07	2.45E-07	7.48E-07	9.71E-07
L_{20}	6.59E-07	1.43E-05	1.57E-08	5.37E-08	3.60E-07	2.02E-07	2.97E-07	6.33E-07	2.40E-07

The cancer risk (CR) values varied from 4.96E-13 to 6.30E-06 (Table 10). The CR values of all the heavy metals (Cr, Cd, Pb, As, Ni, Cu, Zn and Mn) were within the acceptable range (≤ 1 x 10^{-6} to 1 x 10^{-4}) set by the USEPA (2011), indicating no probable development of cancer by consumers. Only CR values of Fe exceeded the permissible range. All the monitoring sites revealed higher Fe cancer risks for consumers.

Table 10. Cancer risk (CR) of heavy metals in six selected groundwater samples of study area

Sample Number	Cr	Cd	Pb	As	Ni
L_1	3.28E-08	6.17E-10	4.40E-08	2.42E-09	8.70E-09
L_4	5.19E-07	6.17E-10	1.12E-11	2.73E-09	7.71E-09
L_6	5.62E-09	1.54E-10	4.96E-13	2.75E-09	1.13E-08
L_9	5.60E-09	6.17E-10	4.73E-11	2.67E-09	6.47E-09
L_{14}	4.19E-09	6.17E-10	1.28E-11	2.52E-09	5.78E09
L_{20}	3.79E-09	1.54E-07	4.96E-13	2.45E-09	8.05E-09

Table 10. Contd.

Sample Number	Cu	Zn	Fe	Mn
L_1	1.39E-08	7.09E-08	2.24E-06	1.05E-08
L_4	1.53E-08	1.33E-07	6.30E-06	3.14E-08
L_6	1.65E-08	1.27E-07	3.39E-06	1.20E-07
L_9	1.38E-08	3.40E-08	2.09E-06	1.07E-08
L_{14}	1.28E-08	8.59E-08	3.06E-06	2.79E-08
L_{20}	1.11E-08	1.05E-07	2.59E-06	6.94E-08

A strong significant positive correlation ($r = 0.99$, $p<0.01$) occurred between TDS and EC (Table 11). Total hardness and EC had a strong positive relationship ($r = 0.91$, $p<0.01$) together with TH and TDS ($r = 0.91$, $p<0.01$). Also, bicarbonate ion (HCO_3^-) had strong positive correlation with Ca ($r = 0.77$, $p<0.01$), moderately correlated with TH ($r = 0.59$, $p<0.01$) but low correlation with Mg ($r = 0.46$, $p<0.01$). Chloride ion (Cl^-) had strong positive correlation with EC ($r = 0.91$, $p<0.01$), TDS ($r = 0.89$, $p<0.01$), TH ($r = 0.70$, $p<0.01$), Na ($r = 0.77$, $p<0.01$) and K ($r = 0.89$, $p<0.01$), moderately correlated with Mg ($r = 0.67$, $p<0.01$) but negatively correlated with pH ($r = -0.55$, $p<0.05$).

Table 11. Relationship between the physical and chemical parameters of groundwater samples in study area

	Temp	pH	EC	TDS	TH	Ca	Mg	Na	K	HCO_3^-	Cl^-	SO_4^{2-}
Temp	1											
pH	-0.03	1										
EC	0.09	-0.33	1									
TDS	0.09	-0.32	0.99^{**}	1								
TH	-0.09	-0.20	0.91^{**}	0.910^{**}	1							
Ca	-0.08	0.19	0.52^{*}	0.50^{*}	0.72^{**}	1						
Mg	-0.05	-0.17	0.79^{**}	0.82^{**}	0.80^{**}	0.38	1					
Na	-0.05	-0.33	0.72^{**}	0.73^{**}	0.61^{**}	0.12	0.54^{*}	1				
K	0.00	-0.64^{**}	0.76^{**}	0.77^{**}	0.61^{**}	-0.02	0.69^{**}	0.66^{**}	1			
HCO_3^-	-0.22	0.39	0.33	0.35	0.59^{**}	0.77^{**}	0.46^{*}	0.11	-0.10	1		
Cl^-	0.13	-0.55^{*}	0.91^{**}	0.89^{**}	0.70^{**}	0.14	0.67^{**}	0.77^{**}	0.89^{**}	-0.67		
SO_4^{2-}	0.09	0.07	0.08	0.06	0.02	0.17	-0.17	-0.12	-0.01	-0.25	0.02	1

DISCUSSION

Water temperatures were within the recommended standards of 25-35 °C. A significant number of measured water pH (90%) were above the maximum limit of pH 8.5 for drinking water (NSDWQ, 2015; WHO, 2018). The groundwater pH range (7.66 – 9.75) of all sampled waters in the study area was of moderate alkaline. This pH range was not consistent with the results reported by Falola *et al.* (2021) whose groundwater pH values ranged between 6.30 and 7.36. Acidic conditions of some hand-dug wells reported by Falola *et al.* (2021) in Abeokuta North Municipality, was a confirmation of groundwater susceptibility to high human-induced activities compared to boreholes assessed in this study with less of such occurrences (Njoku *et al.,* 2024).

Electrical conductivity is an essential water quality parameter that measures how groundwater conducts electricity and is a function of its ionic content (Duncan, 2020), and higher EC indicates higher water contamination (Florescu *et al.,* 2011). The highest value of EC was observed at FUNAAB Zoological Park (2), while the lowest was obtained at College of Plant Science and Crop Production. In this study, 30% of the water samples had higher EC values than the permissible level of 500 µS/cm in drinking water (WHO, 2018), showing that these water samples possessed higher levels of dissolved ions. High levels of dissolved ions could be linked to the nature of parent rocks and land use pattern existing in the study area (Vasanthavigar *et al.,* 2010).

Total dissolved solid measures the total concentration of inorganic salts dissolved in water (Mollo *et al.,* 2022). The total dissolved solids (TDS) values of the water samples fell within the acceptable range of levels set by the NSDWQ (2015) and the WHO (2018). Only FUNAAB Zoological Park (2) had TDS value beyond 500 mg/L recommended by the two regulatory bodies. Also, total hardness is an important water quality and measures the quantity of dissolved calcium and magnesium in the groundwater. Water migrating through soil and rock dissolves naturally available minerals and leaches them into the groundwater. In this study, the total hardness range of 1.58 to 5.56 mg/L was within the allowable limits of 200 mg/L (WHO, 2017). The levels of cations and water total hardness in all water samples fell below the permissible limits set by the World Health Organisation guidelines for drinking water.

Highest level of chloride ions was observed at FUNAAB Zoological Park (2), while the lowest was obtained nearby ABG Poultry Unit. Levels of chloride ions in 19 water samples fell below the permissible limits of WHO (2018), indicating low salinity in the groundwater of the study area. The maximum levels of chloride ions in the study area were higher than those measured by Ram *et al.* (2021). Chloride's detection in groundwater might come from rocks that formed soil of the study area or through the leaching of waste containing chloride into the groundwater. High level of chlorine in groundwater constitutes a threat to human health (Sadat-Noori *et al.,* 2014).

Presence of sulphate ions in groundwater might arise from the oxidation of sulphur of the igneous rocks or the dissolution of the other minerals with the soil containing sulphur. Sedimentary rocks have components that contain sulphur which can undergo oxidation reaction (Rahman *et al.,* 2013a, b). Similarly, bicarbonate's occurrence in groundwater can be linked to organic matter's availability in the aquifer capable of undergoing oxidation to yield carbon dioxide, which enhances dissolution of minerals. Presence of calcite and dolomite in the aquifer can contribute to the availability of biocarbonate ions in the groundwater. It might be as a result of weathering of rocks containing silicate minerals (Gastmans *et al.,* 2010). Highest value of SO_4^{2-} was observed at FUNNIS Secondary School, while lowest was obtained at College of Plant Science and Crop Production of the Institution. Also, highest level of HCO_3^- was observed at nearby FUNAAB Mosque, while lowest was obtained at FUNAAB Zoological Park (1). Levels of SO_4^{2-} and HCO_3^- in groundwater samples of the study area were within the permissible limits of the WHO standards. A study by Saha *et al.* (2019) reported higher values of bicarbonate ions compared to this study. However, levels of sulphate ions in this study surpassed the work of Saha *et al.* (2019). The discrepancy in the findings could be attributed to geological difference and the nature of sampling equipment employed (Kwaya *et al.,* 2019).

Highest values of Na, Mg, K and Ca were found at FUNAAB Zoological Park (2), indicating that the groundwater was having high loads of cations. Levels of the aforementioned cations across all the sampling locations apart from FUNAAB Zoological Park (2), fell below the acceptable standards set by the WHO (2017). Levels of Na, Mg and Ca in the study area were lower compared to the report of Ram *et al.* (2021). However, K levels in this study were higher than those reported by the same researchers. The disparity in results could be referenced to varied nature of rocks and environmental operations taking place in both study areas (Boateng *et al.,* 2019).

Levels of Fe in six selected groundwater samples exceeded the WHO permissible limit of 300 μg/L. Elevated concentrations of Fe in the water samples might be an indication that the groundwater of the study area was drawn from aquifers with high iron content. Iron is an important element in the body that forms the integral part of haemoglobin. However, at increased level in the body, it can bring about the manifestation of conjunctivitis, choroiditis, and retinitis (Satyanarayana *et al.,* 2013). High concentrations of Fe in groundwater may alter its taste. Similarly, Ganiyu *et al.* (2021) reported higher levels of Fe in the groundwater sampled in high density residential urban area of Ibadan, Oyo State, than the values obtained in this study, which is a peri-urban area of Abeokuta, Ogun State. Also, the mean level of Fe in this study was higher than the value published by Grema *et al.* (2022). The inconsistencies in findings could be ascribed to different natural and anthropogenic activities happening in the study areas (Obasi and Akudinobi, 2015).

Levels of Hg in six selected groundwater samples were above the WHO limit of 0.06 μg/L. This implies high level of Hg contamination in the groundwater sources of the study area. Natural disintegration of minerals in rocks and soil, which could have been accelerated by wind and water interactions with the study area's rocks, might be the cause of the high concentration of mercury in the groundwater. Elevated levels of mercury in the analyzed groundwater may arise from inappropriate disposal of solid waste (e.g., agricultural, medical, construction or business) that contained mercury pollutant in the study area. Also, soil runoff from nearby commercial business (e.g., quarry and block industries) might contribute to high level of Hg (Government of Canada, 2021). In this study, the detected mercury levels in water samples were 132 times lower than those stated by Obasi and Akudinobi (2020). One possible explanation for the variation in the results could be linked to different man-made activities occurring in the two research areas. In contrast to this study, where learning and agricultural activities were more prevalent, Obasi and Akudinobi (2020) conducted their groundwater quality assessment in the Abakaliki Communities, Southeast, Nigeria, where mining activities were common. Apart from mercury toxicity to water quality in the research area, mercury pollution can also be harmful to farming, land usage, aquatic life, and other aspects of ecological inequity (Koki *et al.,* 2015).

The concentrations of Cr, Mn, Co, Cu, Ba, Pb, Zn, Cd, As and Ni in water samples did not exceed the acceptable limits endorsed by the WHO. The mean levels of these metals (Pb, As, Ni, Zn and Cu) in water samples of the study area were lower than the values reported by Kana (2022). Land use activities disparities taking place in the two research areas might be the cause of the discrepancies in the results. For example, an evaluation of the groundwater quality was conducted in a portion of Karu, North Central, Nigeria, where the area was characterized by waste dumpsites, block industry, poultry and fish farming, and stone quarrying, as opposed to this study where there were fewer human-related activities.

This study adopted the classification for the HPI: (HPI < 100 − low, HPI = 100 − medium; HPI > 100 − high) proposed by Edet and Offiong (2002). With the exclusion of Zn, Fe, Mn and Cd at College of Engineering, the mean HPI values indicated that all other heavy metals assessed had HPI values less than the threshold of 100. This result shows that 68.3% of the water samples are having low level of contamination. In addition, different grouping systems had been employed by researchers to classify HPI values in the literatures, Grema *et al.* (2022) proposed a new classification system based on large values they obtained in their work (HPI < 100 − low, HPI ≤ 100−1000 − medium; HPI > 1000 − high). These investigators had suspicions that Edet and Offiong (2002) classification might not give lucid explanation to the largeness of their values. Similarly, by adopting Grema *et al.* (2022) proposition in this study, only 3.3% of the water samples were found in high contamination zone. The HPI values from this study were lower than the HPI value of 518.55 published by Ojekunle *et al.* (2016). The dissimilarity in results might occur due to soil runoff, agricultural activities and land use pattern in the study area (Kana, 2022).

Heavy metal evaluation index (HEI) assesses water quality with respect to heavy metal level in groundwater of the study area in likeness to the HPI. The proposed HEI criteria are as follows: low (HEI < 10), medium (HEI = 10−20) and high (HEI > 20). The HEI results showed that 88.0% of the samples fell within the low zone, 11.7% fell within the medium zone and none found within the high zone. It implied that the HEI values of the selected groundwater could be categorised as having very low level of contamination. This finding agreed with the report of Kwaya *et al.* (2019) in Zamfara State, who described the HEI value of their study area as low.

The contamination index (C_d) values might be classified into three categories as follows: low ($C_d < 1$), medium ($C_d = 1 - 3$) and high ($C_d > 3$) in agreement with Edet and Offiong (2002) and Backman *et al.* (1997) classification. Regarding the above classification, 78.4% of the samples were grouped as low zone, 8.3% as medium zone and 13.3% as high zone. The C_d index showed that a few number of the groundwater samples was polluted. This result was at variance with the report of Boateng *et al.* (2019) in Ghana, whose C_d values for all water samples exceeded the permissible limits of 3. The contradiction in result could be related to leachate percolation from landfill site to groundwater in the study area in Ghana, in contrast to this study, which groundwater is free of leachate from landfill.

The benefits of heavy metals to humans at specified concentrations are worth mentioning but beyond the guideline limits, they become toxic to human health and the environment (Ma *et al.,* 2016). It is desirable that health risk associated with volume of drinking water consumed daily and the weight of the individual are investigated. In this regard, heavy metals hazard quotient (HQ) assessment in adults was computed using the concentration of Cr, Cd, Pb, As, Ni, Cu, Zn, Fe, Mn and Hg in six selected groundwater. The computed HQ values in adults were less than 1, indicating that all assessed heavy metals contributed no significant inputs to the occurrence of non-cancer health risks among adults that utilized the groundwater. This result was in agreement with the research conducted in Jos Plateau by Badamasi *et al.* (2023), which observed that all heavy metal non-cancer risk (HQ) values in water samples (for both adults and children) were within acceptable limits.

The cancer risk (CR) values of Fe (for adults) were higher than the acceptable range of $\leq 1 \times 10^{-6}$ to 1×10^{-4}, suggesting probable carcinogenic risk (USEPA, 2011). Iron impacted more to the CR evaluation than other heavy metals for adults in the study area. This observation contradicted the findings of a study conducted in Ibadan by Ganiyu *et al.* (2021), which found that the CR values of Pb and Cd contamination (child and adult) were higher than the permissible limits. The reason for inconsistency in results could be linked to high rate of urban growth and diverse nature of human activities occurring in researchers' study locations, in contrast, to this study area.

There was a strong significant positive correlation between (total hardness) TH and EC ($r = 0.91$, $p<0.01$), and TH and TDS ($r = 0.91$, $p<0.01$). Calcium had moderate positive correlation with TDS ($r = 0.50$, $p<0.05$), Mg had strong positive correlation with EC ($r = 0.79$, $p<0.01$), TDS ($r = 0.82$, $p<0.01$) and TH ($r = 0.80$, $p<0.01$). The results showed that Mg had greater influence on the levels of dissolved ions in the groundwater samples compared to Ca. Sodium had strong positive correlation with EC ($r = 0.72$, $p<0.01$), TDS ($r = 0.73$, $p<0.01$), but moderate positive correlation with TH ($r = 0.61$, $p<0.01$), Mg ($r = 0.54$, $p<0.05$), low positive correlation with Ca ($r = 0.12$, $p<0.05$). Potassium had strong positive correlation with EC ($r = 0.76$, $p<0.01$), TDS ($r = 0.77$, $p<0.01$), moderately correlated with TH ($r = 0.61$, $p<0.01$), Mg ($r = 0.69$, $p<0.01$), Na ($r = 0.66$, $p<0.01$), but negatively correlated with pH ($r = -0.64$, $p<0.01$). This result inferred that Na and K contributed in no small measure to dissolved ions levels in the water samples. The Pipe Plot corroborates that sodium chloride is the groundwater type existing in the study area. Also, bicarbonate ion (HCO_3^-) had strong positive correlation with Ca ($r = 0.77$, $p<0.01$), moderately correlated with TH ($r = 0.59$, $p<0.01$), but low correlation with Mg ($r = 0.46$, $p<0.01$). Chloride ion (Cl^-) had strong positive correlation with EC ($r = 0.91$, $p<0.01$), TDS ($r = 0.89$, $p<0.01$), TH ($r = 0.70$, $p<0.01$), Na ($r = 0.77$, $p<0.01$) and K ($r = 0.89$, $p<0.01$), moderately correlated with Mg ($r = 0.67$, $p<0.01$), but negatively correlated with pH ($r = -0.55$, $p<0.05$). It means that as the level of chloride ion increases, the pH of the water decreases towards slight alkalinity. A significant negative correlation existed between pH and K^+ ($r = -0.64$, $p<0.01$) and pH and Cl^- ($r = -0.55$, $p<0.05$), while other physicochemical parameters showed no significant association with the pH of the water samples. Similarly, this result partially agreed with the work of Grema *et al.* (2022) whose pH of their water samples had no significant relationship with the physicochemical parameters of the water samples.

CONCLUSION

Physicochemical characteristics, pollution indices and health risk of heavy metals in the groundwater within the Federal University of Agriculture, Abeokuta (FUNAAB), Ogun State, Nigeria, were investigated. The research established the general pH range (7.66 -9.75) of all sampled waters in the study area were of moderate alkaline. Levels of EC, TDS and Cl^- in groundwater at FUNAAB Zoological Park (2) only exceeded the recommended limits of WHO and NSDWQ. The concentrations of Al, Fe, Hg and Sc in the water samples were beyond the safe limits set by World Health Organization. The calculated pollution indices that comprised HPI, HEI and C_d, revealed low contamination values for 68.3, 88.0 and 78.4%, respectively. The obtained HQ results were < 1 for all assessed heavy metals, indicating absence of non-cancer health risk for users. Only cancer risk (CR) values of Fe were higher than the acceptable range of $\leq 1 \times 10^{-6}$ to 1 x 10^{-4}. The observed sources of heavy metal contamination of groundwater in the study area were of lithogenic and anthropogenic factors. For continual use of the groundwater in the study area, periodic surveillance and thorough treatment, particularly for lethal metals, is suggested.

CONFLICTS OF INTEREST

Authors report no conflict of interest

FUNDING

None

REFERENCES

Adeyemi, A., Ojekunle, Z. O. 2021. Concentrations and health risk assessment of industrial heavy metals pollution in groundwater in Ogun state, Nigeria. *Scientific African* 11: 1–11.

Affum, A.O., Osae, S.D., Nyarko, B.J., Afful, S., Fianko, J.R., Akiti, T.T., Adomako, D., Osafo, A. S., Dorleku, M., Antoh, E., Barnes, F., Acheampong, E.A. 2015. Total coliform, arsenic and Cadmium exposure through drinking water in the Western Region of Ghana. Environmental monitoring and assessment: application of multivariate statistical technique to groundwater quality. *Environmental Monitoring Assessment* 187(1): 1–23.

Agada, L.E., Adetola, S.O., Osita, M. 2020. Evaluation of Groundwater Potential in Gashua Northeast Nigeria Using Electrical Resistivity Method. *Communication in Physical Sciences* 5(3): 281-290.

Akanbi, O.A. 2018. Hydrological characterization and prospect of basement aquifers of Ibarapa region, southwestern Nigeria. *Applied Water Science* 8: 89.

Akanni, C.O. 2000. Physical Environment in **Onakomaiya, S.O., Odugbemi, O.O., Oyesiku, O.O. and Ademiluyi, I.A.** (eds). Ogun State, local and regional perspectives, centre for sandwich programmes (cesap) Ogun State University, Ago-Iwoye, Pp. 14-25. Ashgate Publishing Limited, Avebury.

Ako, B.D. 1979. Geophysical prospecting for groundwater in parts of south-western Nigeria. Ph.D. Thesis, Department of Geology, University of Ife, Ile-Ife, Nigeria.

American Public Health Association (APHA), American Water Works Association (AWWA), Water Environment Federation (WEF) 2017. Standard Methods for the Examination of Water and Wastewater. 23th edition, APHA, Washington, DC.v.6.

Backman, B., Bodiš, D., Lahermo, P., Rapant, S., Tarvainen, T. 1997. Application of a groundwater contamination index in Finland and Slovakia. *Environmental Geology* 36(1-2): 55–64.

Badamasi, H., Adedeji Olusola, J., Sunday Durodola, S., Kolawole Akeremale, O., Timothy Ore, O., Abiodun Bayode, A. 2023. Contamination Levels, Source Apportionments, and Health Risks Evaluation of Heavy Metals from the Surface Water of the Riruwai Mining Area, North-Western Nigeria. *Pollution* 9(3): 929-949.

Boateng, T.K., Opoku, F., Akoto, O. 2019. Heavy metal contamination assessment of groundwater quality: a case study of Oti landfill site, Kumasi. *Applied Water Science* 9, 33.

Centre for Agriculture and Bioscience International (CABI), 2018. Emerging Contaminants- a growing concern?*https://*

blog.cabi.org/2018/02/12/emerging-contaminants-a-growing-concern/ Accessed: 17th June, 2023.

Duncan, A.E. 2020. The Dangerous Couple: Illegal mining and water pollution—a case study in Fena river in the Ashanti region of Ghana. *Journal of Chemistry* 2378560.

Edet, A.E., Offiong, O.E. 2002. Evaluation of water quality pollution indices for heavy metal contamination monitoring. A study case from Akpabuyo- Odukpani area, Lower Cross River Basin, (Southeastern Nigeria). *GeoJournal* 57:295–304.

Egbueri, J. C. 2020. Heavy metals pollution source identification and probabilistic health risk assessment of shallow groundwater in Onitsha, Nigeria. *Analytical letters* 53 (10): 1620-1638.

Egbueri, J.C., Mgbenu, C.N. 2020. Chemometric analysis of pollution source identification and human health risk assessment of water resources in Ojoto Province, southeast Nigeria. *Applied Water Science* 10: 98.

Elumalai, V., Nethononda, V.G., Manivannan, V., Rajmohan, N., Li, P., Elango, L. 2020. Groundwater quality assessment and application of multivariate statistical analysis in Luvuvhu catchment, Limpopo, South Africa. *Journal of African Earth Sciences* 171:103967.

Falola, T.O., Adetoro, I.O., Idowu, O.A. 2021. Assessment of Groundwater Quality in Abeokuta North, Nigeria. *American Journal of Water Resources* 9(2): 41-48.

Florescu, D., Ionete, R., Sandru, C., Iordache, A.M., Culea, M. 2011. The influence of pollution monitoring parameters in characterizing the surface water quality from Romania southern area, Romania. *Journal of Physics* 56; 1001–1010.

Ganiyu, S.A., Oyadeyi, A.T., Adeyemi, A.A. 2019. Assessment of heavy metals contamination and associated risks in shallow groundwater sources from three different residential areas within Ibadan metropolis, southwest Nigeria. *Applied Water Science* 11: 81.

Gastmans, D., Chang, H.K., Hutcheon, I. 2010. Groundwater geochemical evolution in the northern portion of the Guarani Aquifer system (Brazil) and its relationship to diagenetic features. *Applied Geochemistry Journal* 25: 16–33.

Government of Canada 2021. Sources of mercury. https://www.canada.ca/en/environment-climate-change/services/pollutants/mercury-environment/about/sources.html Accessed 15th April, 2024.

Grema, H.M., Hamidu, H., Suleiman, A., Kankara, A.I., Umaru, A.O., Abdulmalik, N.F. 2022. Cadmium Geochemistry and Groundwater pollution Status Evaluation using Indexing and Spatial Analysis for Keffe Community and Environs Sokoto Basin, North Western Nigeria. *Nigerian Journal of Basic and Applied Sciences* 30(1): 05-23.

International Association of Hydrogeologists 2020. Groundwater — more about the hidden resource. Retrieved from https ://iah.org/educa tion/general-publi c/groun dwater-hidde n-resource. Accessed 23rd April, 2024.

Kana, A.A. 2022. Heavy metal assessment of groundwater quality in part of Karu, Central Nigeria. *Water Practice & Technology* 17(9):1802 doi: 10.2166/wpt.2022.10

Kippler, M., Tofail, F., Hamadani, J.D., Gardner, R.M., Grantham-McGregor, S.M., Bottai, M., Vahter, M. 2012. Early-life cadmium exposure and child development in 5-year-old girls and boys: a cohort study in rural Bangladesh. *Environmental Health Perspectives* 120: 1462-1468.

Koki, I.B., Bayero, A.S., Umar, A., Yusuf, S. 2015. Health risk assessment of heavy metals in water, air, soil and fish. *African Journal Pure and Applied Chemistry* 9(11): 204–210.

Kwaya M.Y., Hamidu H., Kachalla M., Abdullahi I.M. 2017. Preliminary Ground and Surface Water Resources Trace Elements Concentration, Toxicity and Statistical Evaluation in Part of Yobe State, North Eastern Nigeria. *Geosciences* 7(4): 117-128. doi: 10.5923/j.geo.20170704.02.

Kwaya, Y.M., Hamidu, H. Mohammed, A.I., Abdulmumini, N.Y., Adamu, I.H., Grema, H.M., Dauda, M., Halilu, F.B., Kana, A.M. 2019. Heavy metals pollution indices and multivariate statistical evaluation of groundwater quality of Maru town and environs. *Journal of Materials and Environmental Sciences* 10: 32-44.

Li, P., Tian, R., Xue, C., Wu, J. 2017. Progress, opportunities and key fields for groundwater quality research under the impacts of human activities in China with a special focus on western China. *Environmental Science and Pollution Research* 24:13224–13234.

Li, P., Karunanidhi, D., Subramani, T., Srinivasamoorthy, K. 2021. Sources and Consequences of Groundwater Contamination. *Archives of Environmental Contamination and Toxicology* 80:1–10.

Ma, Y., Egodawatta, P., McGree, J., Liu, A., Goonetilleke, A. 2016. Human health risk assessment of heavy metals in urban stormwater. *Science of the Total Environment* 557-558; 764–772.

Mollo, V.M., Nomngongo, P.N. Ramontja, J. 2022. Evaluation of surface water quality using various indices for heavy metals in Sasolburg, South Africa. *Water* 14; 2375.

Nafeesa Baby, T.P., Vineethkumar, V., Shimod, K.P., Vishnu, C.V., Jayadevan, S. 2022. Heavy metal contamination in water sources of Thaliparamba municipality, Kerala, India. *Radiation Protection Environment* 45: 54-61.

Nigerian Standard for Drinking Water Quality (NSDWQ) 2015. Nigerian Industrial Standard (NIS)554, Standard Organization of Nigeria:30p.

Njoku, K.L., Osunkoya, O.O., Ude, E.O., Iheme, P.O., Onuaguluchi, P.N. 2024. Health risk assessment of groundwater from selected areas of Ijebu North, Ogun State, Nigeria. *Aswan University Journal of Environmental Studies* 4(5): 1-11.

Nnoli, N.G., Olomukoro, J.O., Odii, E.C., Ubrei-Joe, M.M., Ezenwa, I.M. 2021. Another insight into the contamination levels at Ogoniland in Niger Delta, Nigeria, with focus on Goi Creek. *Environmental Science and Pollution Research* 28: 34776–34792.

Obasi, P.N., Akudinobi, B.E.B. 2015. Geochemical assessment of heavy metal distribution and pollution status in soil/ stream sediment in the Ameka mining area of Ebonyi state, Nigeria. *African Journal of Geo-Sciences Research* 3(4):01–07.

Obasi, P.N., Akudinobi, B. E. B. 2019. Heavy metals occurrence, assessment and distribution in water resources of the lead–zinc mining areas of Abakaliki, Southeastern Nigeria. *International Journal of Environmental Science and Technology* 16(12): 8617-8638.

Obasi, P.N., Akudinobi, B.B. 2020. Potential Health Risk and Levels of Heavy Metals in Water Resources of Lead-Zinc Mining Communities of Abakaliki, South-east Nigeria. *Applied Water Science* 10: 86.

Ogundele, L.T., Adejooro, I.A., Ayeku, P.O. 2019. Health risk assessment of heavy metals in soil from an abandoned industrial waste dumpsite in Ibadan, Nigeria. *Environmental Monitoring Assessment* 191:290.

Ojekunle, O.Z., Ojekunle, O.V., Adeyemi, A.A., Taiwo, A.G., Sangowusi, O.R., Taiwo, A.M., Adekitan, A.A. 2016. Evaluation of surface water quality indices and ecological risk assessment for heavy metals in scrap yard neighbourhood. *Springer Plus* 5:1–16.

Okunlola, O.A., Adeigbe, O.C., Oluwatoke, O.O. 2009. Compositional and petrogenetic features of schistose rocks of Ibadan area, southwestern Nigeria. *Earth Sciences Research Journal* 3(2): 20–43.

Osipova, N.A., Kate, A.F., Anna, V.T., Egor, G.Y. 2015. Geochemical approach to human health risk assessment of inhaled trace elements in the vicinity of industrial enterprises in Tomsk, Russia. *Human Ecological Risk Assessment International Journal* 21(6): 1664–1685.

Prasad, B., Bose, J.M. 2001. Evaluation of the heavy metal pollution index for surface and spring water near a limestone mining area of the lower Himalayas. *Environmental Geology* 41:183–188.

Peng, C., Andrew S. Hill, A.S., Friedman, M.J., Valentine, R.L., Larson, G.S., Romero, A.M.Y., Reiber, S.H. and Korshin, G.V. 2012. Occurrence of trace inorganic contaminants in drinking waterdistribution systems. Journal-American Water Works Association. Retrieved from: http://dx.doi.org/10.5942/jawwa.2012.104.0042 Accessed 24th April, 2024.

Rahman, M.A., Alam, M.J., Siddique, N.E.A., Alam, A.M.S. 2013a. Distribution of arsenic with iron, manganese and copper in borehole sediments of the Tista and Jamuna. *International Dhaka University Journal of Science* 61(2): 207–210.

Rahman, M.M., Reza, A.H.M.S., Rahman, M.M., Islam, R., Rahman, M.A. 2013b. Geochemical characterization of groundwater in Bhangamor Union, Fulbari Upazila, Kurigram. *International Journal of Chemistry and Material Sciences* 1(2):022–035.

Ram, A., Tiwari, S.K., Pandey, H.K., Chaurasia, A.K., Singh, S., Singh, Y.V. 2021. Groundwater quality assessment using water quality index (WQI) under GIS framework. *Applied Water Science* 11: 46.

Ravindra, K., Mor, S. 2019. Distribution and health risk assessment of arsenic and selected heavy metals in groundwater of Chandigarh, India. *Environmental Pollution*

250, 820–830.

Sadat-Noori S.M., Ebrahimi, K., Liaghat, A.M. 2014. Groundwater quality assessment using the Water Quality Index and GIS in Saveh-Nobaran aquifer. *Iranian Journal of Earth Sciences* 71: 3827–3843

Saha, S., Selim Reza, A.H.M., Roy, M.K. 2019. Hydrochemical evaluation of groundwater quality of the Tista floodplain, Rangpur, Bangladesh. *Applied Water Science* 9: 198.

Satyanarayana, P., Raju, N.A., Harikrishna, K and Viswanath, K. 2013. Urban Groundwater Quality Assessment: A Case Study of Greater Visakhapatnam Municipal Corporation Area (Gvmc), Andhra Pradesh, India. *International Journal of Engineering Science Invention* 2(5): 20-31.

Schofield, K. 2017. The Metal Neurotoxins: An Important Role in Current Human Neural Epidemics? *International Journal of Environmental Research and Public Health* 14: 1511.

Singh, R., Gautam, N., Mishra, A., Gupta, R. 2011. Heavy metals and living systems: An overview. *Indian Journal of Pharmacology* 43: 246-253.

Singh, R., Venkatesh, A.S., Syed, T.H., Reddy, A.G.S., Kumar, M., Kurakalva, R.M. 2017. *Environmental Earth Science* 76 (16): 566.

Standard Organization of Nigeria (SON) 2007. Nigerian Standard for Drinking Water Quality, ICS 13.060.20,Approved by Standard Organization of Nigeria (SON) Governing Council, Lagos and Abuja.

Taiwo, A.M., Ogunsola, D.O., Babawale, M.K., Isichei, O.T., Olayinka, S.O., Adeoye, I.A., Adekoya, G.A., Tayo, O.E. 2023. Assessment of water quality index and the probable human health implications of consuming packaged groundwater from Abeokuta and Sagamu, Southwestern Nigeria. *Sustainability* 15(4): 1-16.

Ukah, B.U., Egbueri, J.C., Unigwe, C.O., Ubido, O.E. 2019. Extent of heavy metals pollution and health risk assessment of groundwater in a densely populated industrial area, Lagos, Nigeria. *International Journal of Energy and Water Resources* 3(4): 291-303.

United States Environmental Protection Agency (USEPA) 2011. Integrated risk information system. Environmental Protection Agency Region. Washington DC, 20460. Retrieved from http:// www. epa. gov. iris. Accessed 20th April, 2024.

Vasanthavigar, M. Srinivasamoorthy, K., Vijayaragavan, K., Rajiv Ganthi, R., Chidambaram, S., Anandhan, P., Manivannan, R., Vasudevan, S. 2010. Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. *Environmental Monitoring and Assessment* 171: 595–609.

Wagh, V.M., Panaskar, D.B., Mukate, S.V., Gaikwad, S.K., Muley, A.A. and Varade, A.M. 2018. Health risk assessment of heavy metal contamination in groundwater of Kadava River Basin, Nashik, India. *Modelling Earth Systems and Environment* 4(3): 969-980.

Wallace, D.R., Taalab, Y.M., Heinze, S., Tariba Lovakovic, B., Pizent, A., Renieri, E., Tsatsakis, A., Farooqi, A.A., Javorac, D., Andjelkovic, M., Bulat, Z., Antonijevic, B., Buha Djordjevic, A. 2020. Toxic

-metal-induced alteration in miRNA expression profile as a proposed mechanism for Disease development. *Cells* 9: 901.

Wang, F., Song, K., He, X., Peng, Y., Liu, D., Liu, J. 2021. Identification of groundwater pollution characteristics and health risk assessment of a landfill in a low permeability area. *International Journal Environmental Resource Public Health* 18(14):7690.

Woloncіej M, Milewska E, Roszkowska-Jakimiec W. 2016. Trace elements as an activator of antioxidant enzymes. *Advances in Clinical and Experimental Medicine* 70: 1483-1498.

Wongsasuluk, P., Chotpantarat, S., Siriwong, W., Robson, M. 2014. Heavy metal contamination and human health risk assessment in drinking water from shallow groundwater wells in an agricultural area in UbonRatchathani province, Thailand. *Environmental Geochemical Health* 36:169–182.

World Health Organization (WHO) 2006. Protecting Groundwater for Health: Managing the Quality of Drinking-water Sources. Schmoll, O., Howard, G., Chilton, J., Chorus, I (Eds.) ISBN:1843390795. Published by IWA Publishing, London, UKwww.ielrc.org/content/e9302.pdf. Accessed 20th April, 2024.

World Health Organization (WHO) 2008. Guidelines for drinking water quality, 3rd edition. Geneva.

World Health Organization (WHO) 2017. *Guidelines for drinking-water quality:* fourth edition incorporating the first addendum. *G*eneva, Switzerland. Licence: CC BY-NC-SA 3.0 IGO.

World Health Organization (WHO) 2018. Guidelines for drinking water quality. 4th edition Geneva.

(Manuscript received:23rd May, 2023; accepted: 22nd July, 2024).