Applied Journal of Physical Science
Volume 5(2), pages 44-53, April 2023
Article Number: C0E9BB6A2
ISSN: 2756-6684
https://doi.org/10.31248/AJPS2023.091
https://integrityresjournals.org/journal/AJPS

Full Length Research

Geoelectrical, hydrochemical, and health risk assessment of groundwater quality in Fountain University, Osogbo, Nigeria

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Received 28th February 2023; Accepted 12th April 2023

ABSTRACT: Geoelectrical method and physiochemical analyses were applied to obtain subsurface resistivity variation and water quality assessment respectively in Fountain University, Osogbo, Osun State. A young academic institution with a measurable growing population is seriously concerned with the hygienic situation within its environment, especially water quantity and quality. The geophysical method was employed to determine the subsurface groundwater potentials via vertical electrical sounding (VES) using the Schlumberger array. Ten (10) water samples were collected from different locations within the study area and analyzed for physiochemical parameters and trace metals using standard procedure. Water quality index (WQI), exceedance, and human health risk index were determined. All parameters estimated were below the WHO permissible limits except the pH and iron concentration. WQI values of the ten collected water samples reflected 100% excellent grade for drinking. Chronic dietary intake (CDI) is in the order of Fe >Zn > Cu for both children and adults. The VES (9 location points were studied) data revealed four to five geo-electric layers which corresponded to the topsoil, lateritic clay, weathered layer, fractured basement, and fresh basement with thickness ranges of 0.5 to 39.6 m, while resistivity values vary from 27.5 to 5432.6 Ωm. The study observed and recommended that boreholes could be sunk at VES 1, 6, and 7 at depths between 26.1 to 39.6 m for exploitation of good quality water along with continuous monitoring of groundwater quality to maintain the good water quality area, hence the safety of the environment.

Keywords: Exceedance, geoelectrical techniques, Osogbo, physiochemical, vertical electrical sounding, water quality index.

INTRODUCTION

Water is life, as it is needed for all life processes by humans, plants and animals, especially domestic. With nearly 97% of the world's water in seas and oceans, which makes them salty or otherwise undrinkable, and another 2% locked in ice caps and glaciers, only about 1% is left for all of humanity's needs - agricultural, residential, manufacturing, community, and personal (Ali and Jabbar, 1992). Safe and sufficient water, which is essential for the practice of hygiene, aims to prevent diarrhea diseases, and acute respiratory infections, as well as various neglected tropical diseases (WHO, 2023).

The availability and accessibility of potable and quality water resources are of major concern in Nigeria. According to World Health Organization (WHO), about 80% of all diseases in human beings are caused by water (al-Hadithi, 2012). Access to safe drinking water, therefore, remains an urgent necessity, as 30% of urban and 90% of rural dwellers still depend majorly on untreated surface water – water from rivers, springs, lakes and ponds which are the easiest and most convenient way to meet the public demand for water, but are spatially distributed and most often highly polluted (Ariyo and Banjo, 2008). On the other hand, groundwater, which accounts for about 98% of the world's reasonably constant supply, and is not likely to dry up under natural conditions in the crust as compared to the surface water sources, is more preferred and a reliable source of safe water. Though groundwater is significantly protected from surface pollutants, the need to ensure that the real conditions of the aquifer are understood and delineated is highly desirable (Adiat *et al*., 2012).

Groundwater investigation requires the use of integrated geophysical techniques for successful and comprehensive knowledge of its occurrence and status (Rosival, 2011). Several geophysical methods have been employed in order to address the problems of groundwater pollution, caused by both natural and anthropogenic activities. These include Time Domain Electromagnetic (TDEM), Electrical Resistivity, Seismic refraction, Very Low frequency electromagnetic and Borehole logging techniques (Oyedele *et al.*, 2007). The electrical resistivity method is one of the most used geophysical methods to delineate subsurface geological structures and aquifer units in most geological terrains. It is the most preferred method in groundwater contamination investigation because it is cheap, fast and provides good electrical contrast between the target of interest and the host material (Olorunfemi and Okhue, 1992). Groundwater in sedimentary terrain is less difficult to exploit, while to locate groundwater in basement complex terrains are more challenging (Abdullahi *et al.*, 2014).

Groundwater contamination could be caused by presence and increase in concentration of anions and cations (Cu2+, Fe2+, Zn2+, NO3-) in water and the introduction of bacterial, viral and parasitic micro-organisms into water (Ayolabi *et al*., 2013). Drinking of water from polluted source by the local community without the adequate treatment in advance could cause serious health risk hazards. Hence, the need to carry out the comprehensive hydrochemical analysis of water samples to determine the water treatment necessary before consumption (Amadi, 2011). Water quality index (WQI) is essential because it is one of the most effective tools for the assessment and management of surface and groundwater. It provides a single number that expresses the overall quality of water at certain location and time based on several water quality parameters. The WQI is calculated from the point of view of suitability of the water for human consumption (al-Hadithi, 2012).

Fountain University, Osogbo, is a basement complex region that has been faced with the problem of scarcity of water and the problem is taking toll on the psychological/agitation status of the community especially the students. This therefore informed the use of electrical resistivity technique, hydrochemical analysis and water quality index (WQI) to delineate the aquifer unit(s) and to assess the vulnerability of the groundwater to contamination in the study area.

MATERIALS AND METHODS

Location and geological setting

The study area is located within Oke-Osun Local Government Area, Osogbo, Osun State, South-West Nigeria. The university is located on latitude 7° 20' 14'' N and longitude 4° 31' 23'' E as shown in Figure 1. It is surrounded by farmlands, small water sources and vegetation. It also has a sloppy terrain with hostel buildings. Osogbo, the administrative capital of Osun State which came into being in 1991, covers approximately 8,500 km^2 with prevailing distinctly tropical climate, with four climatic seasons: long dry or harmattan season, November - March; long wet season, March - July; short dry season, July – August; and short wet season, August - November (Ajeigbe *et al*., 2014).

Vertical Electrical Sounding (VES) Measurement

Nine (9) Vertical Electrical Sounding were acquired along three (3) traverses using Schlumberger electrode array within the study area and were geo referenced using Global Positioning System (GPS). Ten (10) groundwater samples were taken from nine boreholes and one hand dug well. The samples depicted as BH1 – BH10 were collected into two sized pre-cleaned plastic bottles: 0.75 L for trace metals, and 1.5 L for physiochemical tests.

The acquired electrical resistivity data using vertical electrical sounding (VES) technique was processed both quantitatively and qualitatively. The quantitative interpretation of the acquired VES data was carried out by using the partial curve matching technique (Bhattacharya and Patra, 1968). In order to do this, the VES data were plotted on a transparent paper overlay. The partial curve matching technique involved the use of a standard two-layer master curves and four auxiliary type curves (H, K, Q, and A). This procedure required segment-by-segment curve matching starting from the position with shorter electrode spacing and moving towards those with longer spacing.

The result of the VES curves obtained from the partial curve matching were then used to constrain the interpretation by the computer employing inversion software known as WinResist Software. This invariably reduces overestimation of depths. The geoelectric parameters obtained after iteration are resistivity, thickness and depth at the subsurface layers.

Analytical procedure

Physical parameters determined *in situ*: temperature, pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured with mercury in bulb thermometer (0–100°C), pH meter (HANNA HI 98107), conductivity meter (Mettler Toledo) and total dissolved solids meter

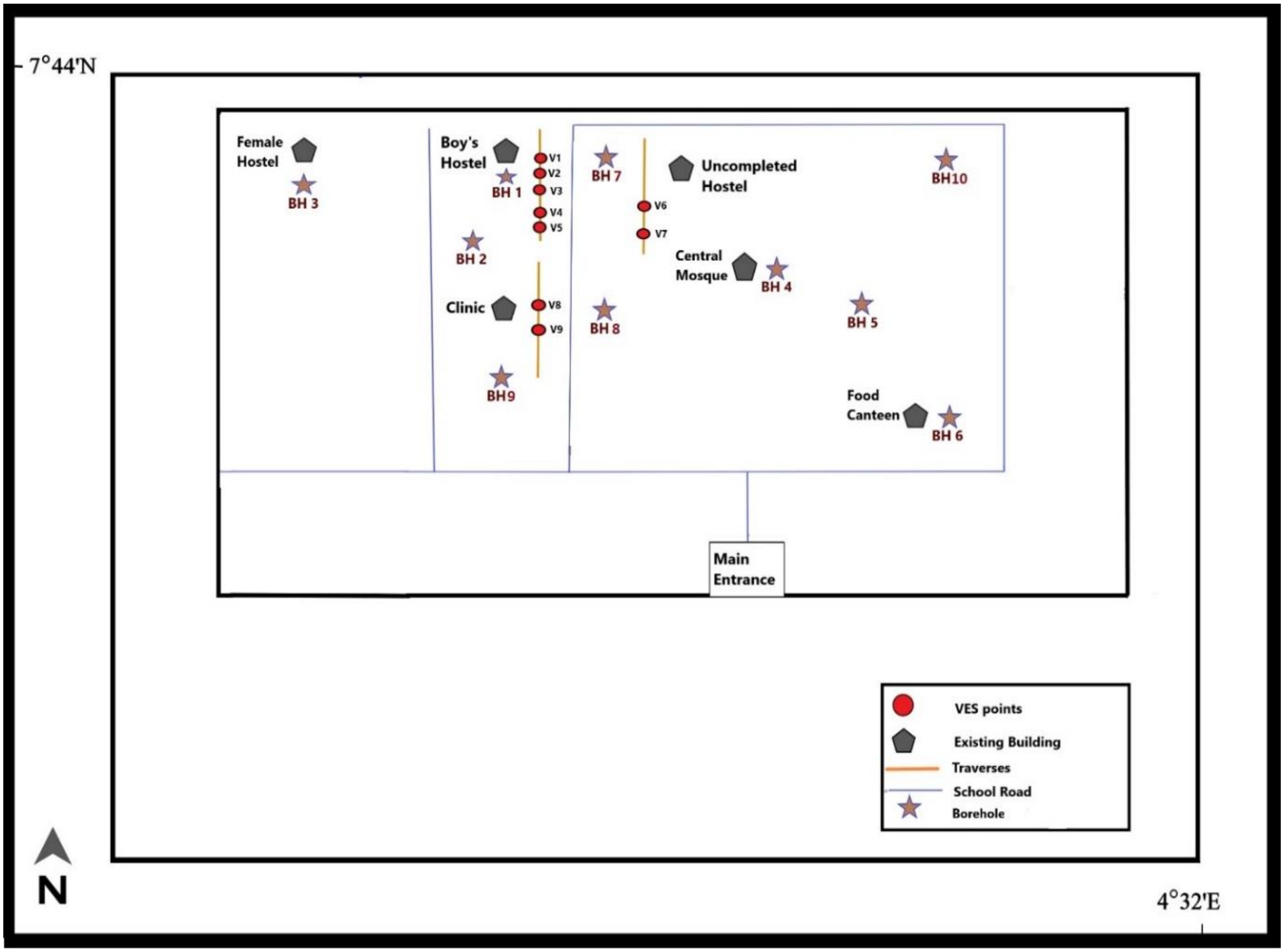

Figure 1. Base map of the study area.

respectively. Alkalinity and acidity were determined titrimetrically, and total hardness by complexometric method. Anions: chloride, sulphate, phosphate and nitrate were determined by titrimetry, turbidimetry, colorimetric and Ultraviolet Spectrophotometric Screening method respectively (WEF, 2005) respectively. Na+ and K+ were determined by flame photometry, while other trace metals were measured by atomic absorption spectrophotometry (Buck scientific 210VGP model).

Data treatment and statistical analysis

Descriptive statistics of water quality data generated was carried out using the software package - Statistics SPSS 20. Correlations efficiency was performed employing Pearson correlation analysis. Exceedance, Sodium adsorption ratio (SAR), and Water Quality Index (WQI) were also calculated. The extent by which some of the parameters used to compute water quality exceeded WHO acceptable limits was expressed as the exceedance level. It is a unitless concept, mathematically expressed as:

$$\text{Exceedance} = \frac{\text{Concentration of a quality parameter}}{\text{WHO acceptance limit}} \quad (1)$$

Water quality index (Weighted Arithmetic Method)

The weighted arithmetic Water Quality Index (WQI) method was adopted, comprising of three mathematical steps: the first step, each of the parameters has been assigned a weight (wi) according to its relative importance in the overall quality of water for drinking purpose. A maximum weight of 5 g has been assigned to nitrate due to its major importance in water quality assessment. The second step, the relative weight (Wi) is calculated from the following equation:

$$\text{Wi} = \frac{\text{wi}}{\sum_{i=1}^{n} \text{wi}} \quad (2)$$

Where Wi is the relative weight, wi is the weight of each parameter and n is the number of parameters.

The third step, a quality rating scale (qi) for each parameter is assigned by dividing its concentration of each water sample by its respective standard according to the guidelines.

$$\mathrm{qi} = \frac{\mathrm{Ci}}{\mathrm{Si}} \times 100 \quad (3)$$

Where: qi, Ci, and Si indicated quality rating scale, concentration of i parameter, and standard value of i parameter, respectively.

For calculating the WQI, the sub index (SI) is first calculated for each parameter, which is used to determine the WQI (equation 4 and 5).

$$\mathrm{SIi} = \mathrm{Wi} \times \mathrm{qi}, \quad (4)$$

$$\mathrm{WQI} = \sum_{i=1}^{n} \mathrm{SIi} \quad (5)$$

Non-carcinogenic health risk assessment in humans

The non-carcinogenic health risk assessment of the groundwater samples involves establishing the hazard quotient (HQ) and hazard risk index (HRI) of each water sample. HQ and HI were calculated after the chronic daily intake (CDI) was determined(Gholampour and Gitipour, 2022). Kanda *et al*. (2020) described how significant the CDI risk is by the ingestion of a single trace element over a long period of time, and is computed for children and adults. This is expressed in equation 6 and 7.

$$\mathrm{CDI} = \frac{Cw \times IRW \times EF \times ED}{BW \times AT} \quad (6)$$

Where CDI is the chronic daily intake or the exposure dose (mg/kg/day), Cw is the contaminant level in water (mg/L), IRW is the water ingestion rate (1 L for children and 2 L for adults), EF is the exposure frequency (365 days/year), ED is the exposure duration (6 years for children and 70 years for adults), BW is the bodyweight (15 kg for children and 70 kg for adults), and AT is the average exposure time, which is 2190 days for children and 25,550 days for adults (Egbueri and Mgbenu, 2020). HQ was evaluated for each of the single elements using Equation 7.

$$HQ = \frac{CDI}{RfD} \quad (7)$$

Where RfD is the reference dose of a specific element (mg/kg/day). The RfD equivalents for the PTMs are 0.0035 (Pb), 0.001 (Cd), 0.3 (Zn), 0.04 (Cu), 1.5 (Cr), 0.02 (Ni), and 0.7 (Fe) (Egbueri and Mgbenu, 2020). According to Equation 8, the hazard index (HI) is a summation of the hazard quotient (HQ) values.

$$\mathrm{HI} = \sum \mathrm{HQ} \quad (8)$$

The non-carcinogenic health risk of ingesting a particular element is above the acceptable limit when HI > 1, whereas with HI < 1, the non-carcinogenic risk is within the acceptance limit. Hazard Index, HI = 1 is the limit of acceptance. Non-carcinogenic risk is classified based on HI values into negligible, low risk, medium risk, and high risk (Egbueri and Mgbenu, 2020).

RESULTS AND DISCUSSIONS

Geoelectrical or electrical resistivity results

The geophysical investigation revealed a minimum of three and maximum of five geoelectric layers which are topsoil, weathered layer, lateritic clay, fractured basement and fresh basement. The curve types obtained were HA, KH, HAK and HAA which were characteristics of a basement complex terrain as shown in Table 1. The curve type HA occurred frequently in this study and revealed large fresh basement and steady increase in apparent resistivity with depth as the spread increased. The result suggests that VES (1, 6 and 7) are high groundwater potential zones because of the associated low resistivity values (103.9 - 222.2 Ωm) with overburden thicknesses of 26.1 - 39.6 m. These zones are suitable for groundwater exploitation.

Figure 2 shows the modelled lithological variation based on the resistivity and thickness of layers in the study area which was built with Rockworks geostatistical software. The suitable conductive zone for groundwater exploration is located toward the northern and southern part of the study area.

Groundwater quality analysis

The descriptive statistics of physiochemical parameters and potential trace toxic metals investigated in groundwater samples collected from boreholes and hand dug well in the study area is presented in Table 2. The pH value in this study ranges from 5.3 to 6.6 with an average value of 5.78. The entire water samples analyzed had pH values outside the WHO permissible range of 6.5 - 8.5. The acidic nature of the groundwater raises questions about health safety in respect to the potability of the water samples.

The pH imbalance can create several diseased conditions and abnormality which may be so severe as to become a life-threatening risk factor (Rosival, 2011). Total hardness (TH) is a water quality parameter that accounts for the total concentration of Calcium and Magnesium in water. TH values in the present study varies from 18.0 to

Table 1. Summary of the interpreted VES results with inferred lithology

Stations	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Curve type	Possible lithology
VES 1	1	27.5	0.7	0.7	KH	Topsoil
	2	182.9	13.2	13.9		Weathered layer
	3	103.9	12.2	26.1		Fractured basement
	4	931.1	--	--		Fresh basement
VES 2	1	91.0	0.7	0.7	HA	Topsoil
	2	82.9	9.8	10.6		Weathered layer
	3	354.9	18.8	29.4		Fractured basement
	4	3385.5	--	--		Fresh basement
VES 3	1	188.6	0.9	0.9	HA	Topsoil
	2	67.4	5.9	6.7		Weathered layer
	3	354.8	22.4	29.1		Fractured basement
	4	3093.4	--	--		Fresh basement
VES 4	1	337.0	0.6	0.6	HA	Topsoil
	2	38.0	5.3	5.9		Weathered layer (clay)
	3	339.8	27.4	33.3		Fractured basement
	4	5432.6	--	--		Fresh basement
VES 5	1	203.4	0.8	0.8	HA	Topsoil
	2	60.8	7.0	7.8		Weathered layer
	3	313.9	22.2	30.0		Fractured basement
	4	2924.9	--	--		Fresh basement
VES 6	1	300.4	0.5	0.5	HAA	Topsoil
	2	139.2	2.4	3.0		Weathered layer
	3	548.7	5.0	8.0		Lateritic clay
	4	149.0	31.6	39.6		Fractured basement
	5	1341.6	--	--		Fresh basement
VES 7	1	164.7	0.7	0.7	HAK	Topsoil
	2	135.0	3.3	3.9		Weathered layer
	3	1130.9	14.9	18.9		Lateritic clay
	4	4336.9	17.0	35.9		Lateritic clay
	5	222.2	--	--		Fractured basement
VES 8	1	503.7	0.7	0.7	HA	Topsoil
	2	312.7	8.9	9.6		Weathered layer
	3	627.2	22.8	32.4		Fractured basement
	4	2447.9	--	--		Fresh basement
VES 9	1	460.5	0.6	0.6	HA	Topsoil
	2	147.7	6.3	6.9		Weathered layer
	3	531.9	19.6	26.5		Fractured basement
	4	2851.5	--	--		Fresh basement

126.0 mg/L with average value of 63.3 mg/L. Sixty percent (60%) of the water samples investigated are categorized as soft, and 40% as moderately hard. Although hardness in water can be nuisance, it is not a health risk. World Health Organization (WHO) states that drinking water may be a contributor of calcium and magnesium in the diet and could be of importance to those who are marginal for calcium and magnesium intake (WHO, 2009).

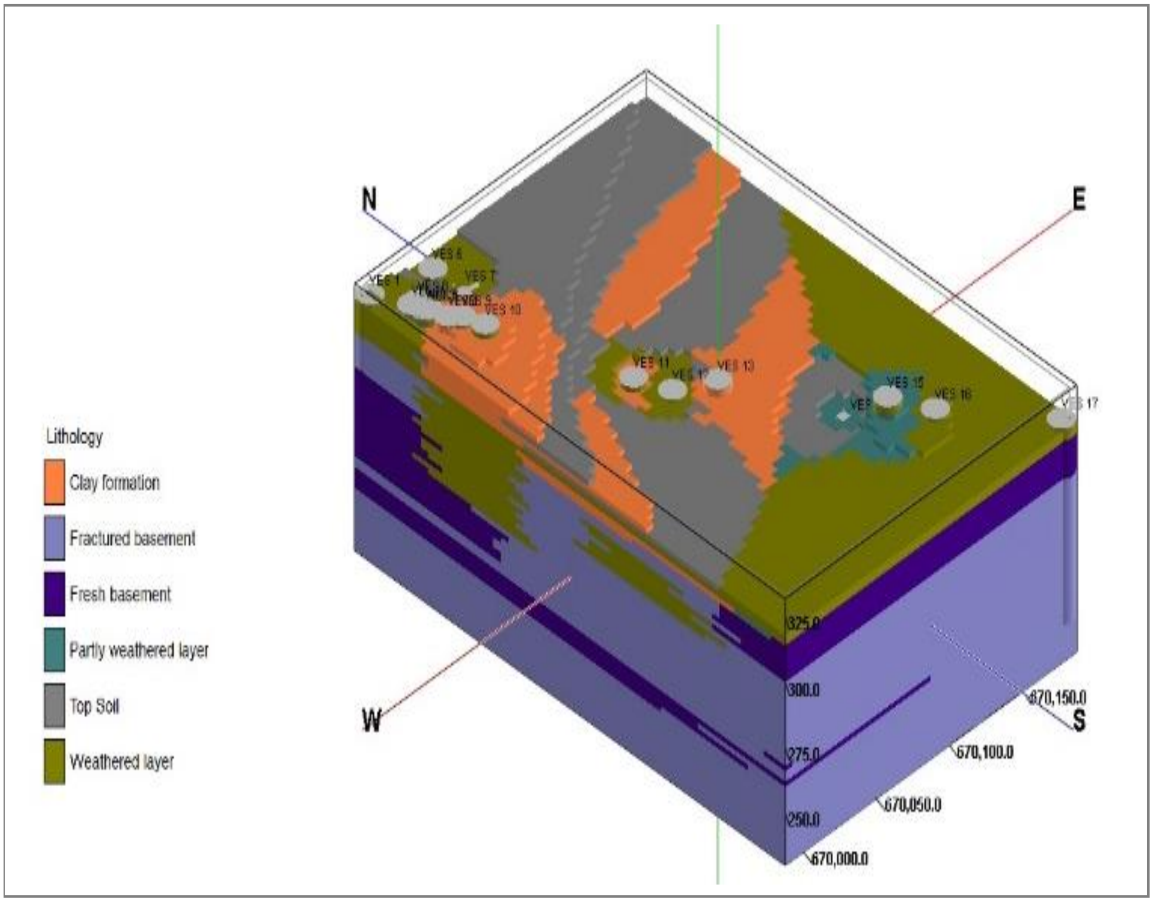

Figure 2. Geoelectrical model of the study area.

Total dissolved solids (TDS) is another important quality parameter in drinking water. It is the measure of dissolved minerals in water. TDS varies from 99.0 to 199.0 mg/L with the mean value of 219.1 mg/L. All TDS values observed in individual sampling locations are within the allowable limit of 1000 mg/L of WHO. The electrical conductivity (ECD) is a measure of capacity of a water (medium) to allow the passage of electrons through it. ECD is directly related to TDS. The electrical conductivity values in this study ranges from 131.0 to 499 µS/cm with the mean value of 365 µS/cm. The various ECD values observed are within the allowable limits of 1400 µS/cm for drinking water.

Basic anions investigated in this study are chloride, nitrates and phosphates with minimum and maximum levels observed as 39.8 - 151.9, 0.19 - 2.62 and 0.04 - 0.08 mg/L respectively and average values of 70.15, 1.11 and 0.06 mg/L respectively. The result of anions investigated in this study were lower when compared with Lagos (Osibanjo *et al*., 2017) and Ethiopia (Amsalu and Mojira, 2022) groundwater studies The mean values of Chloride, Nitrate and phosphate in Lagos study were 147 ± 110, 2.5 ± 1.4, 0.44± 0.3 mg/L respectively and 142.9, 1.26 and 0.05 mg/l. respectively for Ethiopia study.

All samples analyzed had chloride concentration within the permissible limits pointing at the potability of the water under investigation. A chloride concentration of 40 mg/L was used to indicate saltwater intrusion, while groundwater with chloride concentration greater than 100 mg/L was classified as zone of diffusion. Therefore, 80% of wells sampled show a probable influence of saltwater intrusion. Copper, Zinc, Lead, Iron, and Nickel are potentially toxic metals that were investigated. Nickel and Lead were found below the detection limit of the instrument, which accounts for their 0.00 values, while Copper and Zinc were observed to be at varying low concentrations, below the permissible limits by WHO in drinking water. Only Iron with the mean value of 1.60 mg/L was above the permissible limit of 0.3 mg/L. The case in this study is similar to that of Lagos study with the Fe level found higher than the WHO allowable limit (Osibanjo *et al*., 2017) while the iron in this study was however lower the Ethiopia study of 0.18 mg/l.

The general low level of parameters investigated point at the potability of the water in the study area. The result is also an indication of very low degradation of the environment, possibly due to the absence of visible sources of pollution in the area. Table 3 shows chemical interrelationship (correlation) among parameters investigated. TDS

Table 2. Physicochemical variables and trace metals concentration obtained from water samples collected within the study area.

code	Temp (°C)	pH	Alkal (mg/L)	Acid (mg/L)	Cl (mg/L)	TH (mg/L)	ECD (µS/cm)	TDS (mg/L)	Nitrate (mg/L)	PO_4^{3-} (mg/L)	Cu (mg/L)	Zn (mg/L)	Pb (mg/L)	Fe (mg/L)	Ni (mg/L)
FH1	29.20	5.50	10.89	22.44	72.32	26.00	290.00	174.40	2.62	0.06	0.09	0.61	0.00	0.61	0.00
FH2	30.40	5.60	6.93	23.46	151.90	40.00	359.00	215.00	1.79	0.06	0.03	0.74	0.00	0.00	0.00
FH3	30.40	6.30	47.52	43.86	74.13	80.00	499.00	299.00	0.40	0.08	0.05	0.62	0.00	1.87	0.00
FH4	30.50	6.20	15.84	21.42	57.90	86.00	419.00	251.00	0.90	0.06	0.01	0.30	0.00	0.04	0.00
FH5	31.00	6.00	12.87	28.56	65.10	68.00	423.00	255.00	0.19	0.04	0.02	0.33	0.00	5.79	0.00
FH6	30.20	6.40	229.90	34.68	48.81	62.00	392.00	234.00	0.91	0.08	0.04	0.76	0.00	0.00	0.00
FH7	30.40	5.70	9.90	15.50	34.35	18.00	131.00	79.00	1.75	0.05	0.03	0.34	0.00	0.00	0.00
FH8	30.90	5.80	17.82	64.26	90.39	80.00	494.00	297.00	2.18	0.06	0.02	0.35	0.00	3.08	0.00
FH9	30.60	5.30	6.93	32.64	66.89	46.00	262.00	157.70	1.9l	0.06	0.08	0.42	0.00	3.10	0.00
FH10	31.00	5.00	15.84	29.58	39.77	126.00	381.00	229.00	0.36	0.06	0.02	0.50	0.00	1.59	0.00
Mean	30.5	5.78	37.4	31.6	70.15	63.2	365	219.1	1.11	0.061	0.038	0.496	-	1.60	-
SD	0.5	0.5	68	13.9	33.2	332.	111.9	67.0	0.91	0.012	0.027	0.175	-	1.919	-
WHO		6.5-8.5			250	500	1400	1000	10	5.0	1.3	1.5	0.01	0.3	0.02
Exceedance		0.77			0.28	0.13	0.26	0.22	0.11	0.01	0.03	0.33	0.0	5.33	0.0

Table 3. Correlation coefficient analysis for parameters in groundwater samples at Fountain University, Osogbo.

	Temp	pH	ALK	ACD	Cl^-	TH	ECD	TDS	NO_3^-	PO_4^{3-}	Copper	Zinc	Lead	Iron	Nickel
Temp	1														
pH	-0.079	1													
Alkalinity	-0.162	**0.560**	1												
Acidity	0.347	0.183	0.153	1											
Chloride	-0.072	-0.031	-0.238	0.175	1										
TH	**0.612**	-0.027	0.056	0.400	-0.216	1									
ECD	0.338	0.444	0.186	**0.681***	0.274	**0.684***	1								
TDS	0.342	0.440	0.179	**.682***	0.273	**0.685***	**1.000****	1							
Nitrate	-0.596	-0.266	-0.208	.024	0.358	-0.650	-0.404	-0.403	1						
Phosphate	-0.480	0.099	0.387	-.343	-0.116	-0.105	-0.217	-0.225	-0.105	1					
Copper	-0.651*	-0.265	.067	-.059	0.034	-0.473	-0.338	-0.339	0.421	0.460	1				
Zinc	-0.482	0.111	0.553	-.034	0.397	-0.149	0.099	0.092	0.094	**0.615**	0.414	1			
Lead	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	1		
Iron	.542	-.074	-.278	.412	-.030	.244	.334	.342	-.382	-0.682*	-0.048	-0.461	.^{b}	1	
Nickel	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed); b. Cannot be computed because at least one of the variables is constant.

Table 4. Water quality classification based on WQI values.

WQI	Classification
< 50	Excellent
50 - 100	Good
100- 200	Poor
200 - 300	Very poor

Table 5. Water quality index of groundwater samples collected in the study area.

Code	pH	Cl	TH	ECD	TDS	Nitrate	Fe	WQI
FH1	5.50	72.32	26.00	290.00	174.40	2.62	0.61	35.0
FH2	5.60	151.90	40.00	359.00	215.00	1.79	0.00	38.8
FH3	6.30	74.13	80.00	499.00	299.00	0.40	1.87	45.9
FH4	6.20	57.90	86.00	419.00	251.00	0.90	0.04	41.3
FH5	6.00	65.10	68.00	423.00	255.00	0.19	5.79	40.2
FH6	6.40	48.81	62.00	392.00	234.00	0.91	0.00	39.1
FH7	5.70	34.35	18.00	131.00	79.00	1.75	0.00	21.6
FH8	5.80	90.39	80.00	494.00	297.00	2.18	3.08	49.8
FH9	5.30	66.89	46.00	262.00	157.70	1.9l	3.10	31.7
FH10	5.00	39.77	126.00	381.00	229.00	0.36	1.59	36.1
w_i	2	3	2	4	4	5	2	
W_i	0.100	0.150	0.100	0.200	0.200	0.250	0.100	
Standards	7.5	1400	500	1000	250	10	75	

Weight assigned = (w_i), Relative Weight = (W_i), Standards = WHO.

maintains strong correlations with TH, acidity and ECD with r value of 0.685, 0.682 and 1.0 respectively. Temperature/pH (r = 0.612), Alkalinity/TH (r = 0.560), ECD/TH (r = 0.684) and ECD/acidity (r = 0.681) were also observed. The observation speaks more of direct relationship between the correlated parameters in terms of their possible common sources. None of the anions investigated correlated with one another showing possible different sources in the study area. They are also probably from anthropogenic sources. The exceedance level is also not significant since most of the parameters were less than the WHO permissible limits and within range, except for iron with a value of 5.3, as shown in Table 2. This is however contrary to trend observed in Lagos study where the exceedance is a relatively more significant (Osibanjo *et al*., 2017).

Water quality index

Water quality classification based on WQI values, as shown in Table 4, categorises water samples into excellent, good, poor and very poor. The WQI for the groundwater samples collected in the university was calculated, and all the water quality index values were below 50, hence, a 100% excellent grade, as shown in Table 5. This further corroborates the low levels of water quality parameters shown in Table 2, indicating the good quality profile of groundwater being investigated. The result of the use of water quality in this study is similar to that reported in India groundwater assessment study (Ram *et al*., 2021).

Human health risks associated with groundwater in Fountain University

The result of the calculated chronic dietary intake (CDI), health quotient (HQ) and health risk indices or hazard index (HI) for selected potential toxic metals are presented in Table 6. The CDI values were found in the order of Fe >Zn > for both children and adult in groundwater around the study area. Both Pb and Ni were not accounted for in the CDI, since they were below the detection limits of the instruments used as shown in Table 6. CDI values for all the selected metals were found to be within the oral toxicity reference dose (R_fD) set by Olawoyin *et al.* (2012), pointing at the carcinogenic-free status of the water under investigation. The order of hazard index for the selected potential toxic metals were Cu > Fe > Zn and Fe > Zn > Cu for children and adults respectively, in groundwater samples in the Fountain University Osogbo. The data revealed that HI values for all the metals investigated were within the safe limit (HI < 1.0) suggesting no health risk,

Table 6. Chronic daily intake (CDI), Health quotient (HQ) and Hazard index (HI) ug/(Kg.day) of potential toxic metals, toxic through water consumption.

Code	CDI Cu		CDI Zn		CDI Fe		HQ Cu		HQ Zn		HQ Fe	
	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult	Children	Adult
FH1	0.006	0.0026	0.041	0.0174	0.0087	0.017	0.15	0.0001	0.0123	0.00522	0.00609	0.0119
FH2	0.002	0.0008	0.049	0.021	0	0	0.05	3.20E-05	0.0147	0.0063	0	0
FH3	0.003	0.0014	0.041	0.0177	0.0267	0.053	0.075	5.60E-05	0.0123	0.00531	0.01869	0.0371
FH4	0.0007	0.0003	0.02	0.0086	0.0006	0.001	0.0175	1.20E-05	0.006	0.00258	0.00042	0.0007
FH5	0.0013	0.0006	0.022	0.0094	0.0827	0.165	0.0325	2.40E-05	0.0066	0.00282	0.05789	0.1155
FH6	0.0026	0.0011	0.051	0.0217	0.000	0.000	0.065	4.40E-05	0.0153	0.00651	0.000	0.000
FH7	0.002	0.0009	0.023	0.0097	0.000	0.000	0.05	3.60E-05	0.0069	0.00291	0.000	0.000
FH8	0.0013	0.0006	0.023	0.01	0.044	0.088	0.0325	2.20E-05	0.0069	0.003	0.0308	0.0616
FH9	0.0053	0.0023	0.028	0.012	0.044	0.088	0.1325	9.20E-05	0.0084	0.0036	0.0308	0.0616
FH10	0.0013	0.0006	0.033	0.0143	0.0227	0.048	0.0325	2.30E-05	0.0099	0.00429	0.01589	0.0315
Mean	0.00255	0.0011	0.01418	0.0142	0.02294	0.046	0.06375	0.000044	0.00993	0.00425	0.01606	0.0320
SD	0.0018	0.0008	0.0117	0.0049	0.0274	0.055	0.044	0.00003	0.00008	0.0015	0.0014	0.038
HI							0.6375	0.00044	0.0993	0.04254	0.16058	0.3199

Table 7. Non-carcinogenic Hazard Index (HI) Classification.

Risk level	Hazard index	Chronic risk	% Samples in children	% Samples in adults
1	< 0.1	Negligible	33.3	66.7
2	>0.1< 1.0	Low	66.7	33.3
3	>1.0< 4.0	Medium	-	-
4	>4.0	High	-	-

if the water is consumed. Table 7 presents details of non-carcinogenic hazard index (HI) classification.

Conclusion

Vertical electrical sounding (VES) using Schlumberger electrode array revealed groundwater potential zones VES (1, 6 and 7) at depths ranged 26.1 - 39.6 m for groundwater exploitation. Water quality index (WQI), exceedance and human health risk index (HRI) were also employed in this study. The physical parameters (pH, Temperature, Alkalinity ECD, TDS); Anions (Chloride, nitrate, phosphate), and potentially toxic metals (Cu, Zn. Fe, Pb and Ni) of the groundwater samples were determined and found to be within the WHO allowable limits except for Iron, which had a value beyond the allowable limit as revealed in its exceedance level. This is possibly due to the nature of rocks or soil composition in the study area. WQI revealed 100% excellent grade for all the water samples analyzed for drinking purposes. Thus, this shows that the water at the Fountain University is highly potable, and poses little to no health risk to residents. This was further demonstrated by the CDI values. Chronic dietary intake (CDI) values were in the order of Fe >Zn > Cu for both children and adult. CDI values for the metals determined were found within the oral toxicity reference dose (R_fD) pointing at the carcinogenic-free status of the water under investigation. The order of hazard index for the selected potential toxic metals were Cu > Fe > Zn and Fe > Zn > Cu for children and adults in this study area. The iron content in the water needs to be looked into, as an excess of it could lead to a poisoning of body organs. Therefore, there must be planned periodic monitoring and treatment of water in the borehole system to reduce the amount of Iron, either through chemical oxidation or sedimentation and filtration processes.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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