Ajayi Crowther Journal of Pure and Applied Sciences
https://acjpas.acu.edu.ng

Ajayi Crowther J. Pure Appl. Sci. 2023, 2(2), pp. 87-106.
https://doi.org/10.56534/acjpas.2023.02.02.87

Article

Potability and Health Risk Assessment of Some Potentially Toxic Elements in Groundwater Around Some Residential Areas in Ibadan Southwestern Nigeria

***Roland Anthony Isibor, Joseph Ayofe Aderogbin, Mujidat Omotayo Ogundiran**

Department of Earth Sciences, Ajayi Crowther University, Oyo, Oyo State, Nigeria.
ra.isibor@acu.edu.ng (R.A.I.); ja.aderogbin@acu.edu.ng (J.A.A.); mamatee4me63@gmail.com (M.O.O.)

* Correspondence: ra.isibor@acu.edu.ng

Article history: *received, May 15, 2023; revised, May 30, 2023; accepted, June 9, 2023; published: June 12, 2023.*

Abstract

Diseases worldwide are increasingly linked to consumption of contaminated water, necessitating safety assessment of domestic and drinking water in every locality. Consequently, this study aimed to assess the potability and possible health risk associated with the borehole water around Adegbayi, Celica, Iyana Agbala and Alakia residential areas in Ibadan, Southwestern Nigeria. Twenty borehole raw water samples were collected and examined for major cations and anions and other physicochemical parameters using standard procedures of flame photometry and spectrometry techniques. Selected potentially toxic elements such as lead (Pb), Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Cobalt (Co), Chromium (Cr), Nickel (Ni), and Cadmium (Cd) were analyzed by Atomic Absorption Spectrometry (AAS) method. All the physicochemical parameters were within the permissible limit of WHO for drinking water and the result of major cations and anions revealed a cations sequence of Ca> Mg> Na> K, while for the major anions HCO_3^- > SO_4^{2-} > Cl^- > NO_3^{2-}. The groundwater facies type is $CaHCO_3$. The calculated Average Daily Dose (ADD), Hazard Quotient (HQ), Total hazard index (HI) and Cancer Risk (CR) assessment of selected PTEs across different age groups (adults, children, and infants) revealed that Fe has the highest dose for all categories (0.1139 $mg^{-1}kg^{-1}$ day^{-1} $bodyweight^{-1}$ in infants, 0.025 $mg^{-1}kg^{-1}$ day^{-1} $bodyweight^{-1}$ in adults, and 0.07595 mg^{-1} kg^{-1} day^{-1} $bodyweight^{-1}$). The estimated hazard quotients (HQ) obtained revealed that HQ of Cr for children (1.523) and infants (1.2025) was greater than 1 (HQ > 1) which signifies non carcinogenic adverse effects. However, the HQ values for Pb, Ni, Cd, Fe, Cu, and Zn were less than 1 (HQ < 1). The total hazard index (HI) for children (2.356) and infants (2.453) were greater than 1 (HI > 1). However, the HI for adults (0.546) was found to be less than 1 (HI < 1) this inferred a high health impact for children, and infants. The groundwater should be treated before consumption to avoid all associated health risks.

Keywords: Groundwater potability, Health risk, Chronic Daily Ingestion, Hazardous Quotient, Ibadan.

1. Introduction

Water, a strategic resource, is essential for human survival and well-being and also important to most sectors of the economy including industrial, commercial, and agricultural. Studies on water quality have become an important activity in the field of environmental studies because of the fact that water use for various human endeavors such as industrial, agricultural, construction, and domestic demands certain quality control to assure their suitability. Although the link between contaminated water and diseases was not properly understood until the latter half of the 19th century, polluted water has always been known to cause diseases and may lead to death [1] establishing the fact that an adequate supply of safe drinking water is one of the major prerequisites for a healthy life.

Among the contaminant commonly found in water, chemical pollutants including potentially toxic elements (PTEs) pose serious health risks to water consumers, and physical parameters which include colour, taste, and odour make water unpleasant to drink [2]. Furthermore, most PTEs including Cd. Hg, As, and Pb provide no health benefits to man but rather their ingestion is associated with various diseases like cardiovascular disorders, renal injuries, and cancer [3].

The oceans account for about ninety-seven percent of the world's water while only 2.5% is non-saline fresh water [4]. Resulting from the high population density, most urban cities have difficulties finding adequate supplies of fresh water to meet ever-increasing needs, and maintaining its quality is becoming a problem. Although water availability is not a problem on a global scale, it may be a problem finding high-quality fresh water at the required place, in the required quantity [5].

All over the world, there is an increasing demand for water and a shortage of supply. Therefore, it is necessary to increase the rate of water development. Water meant for drinking and other domestic purposes must meet certain physical, geochemical, and biological requirements [2]. Consequently, thorough examinations must be conducted on water used for daily living before consumption [6].

The availability of safe drinking water is a basic human right, as well as an index of healthy living [7]. However, water is increasingly contaminated worldwide, accounting for over 1.8 million deaths yearly [8]. Children are most frequently affected by contaminated water, and a minimum of 525,000 children worldwide die every year due to diarrheal illnesses, most of which are caused by contaminated water and poor sanitation and personal hygiene [7].

Groundwater quality depends on both natural and anthropogenic factors such as aquifer lithology, quality of recharge waters, interaction with other aquifers, and human activities. The effects of exposure to environmental contaminants are specific and include kidney disease, liver problems, and leukemia [3].

The Effluents from industries, domestic sewage, dump sites, and fertilizers all contributed to the contamination of groundwater by infiltrating into the underground aquifer and posing a potential risk to the consumers [9, 10]. The groundwater aquifer system once contaminated tends to remain for a long period of time, even if the source of pollution is eliminated.

Heavy metals of public health concern regarding water contamination include As, Cd, Ni, Hg, Cr, Zn, Cu, and Pb. The main sources of these metals in water are soil erosion, weathering, mining, industrial wastewater, urban runoff, sewage discharge, municipal wastes, and agrochemicals. Heavy metals generate reactive oxygen species in living organisms, thereby causing oxidative damage.

In Nigeria, the need for adequate and potable water for residents is met mostly through the drilling of private boreholes and wells. Therefore, groundwater pollution and vulnerability studies are essential and necessary in high-population areas such as the Ibadan metropolis. Ibadan is one of the large cities in Nigeria with fast population growth, leading to high demand for clean and potable drinking water.

Consequently, this study is aimed at determination of the concentration of major cations and anions, determination of the hydrochemical facies of groundwater, the determination of the concentration of some selected PTEs, and the assessment of the health risk status of the groundwater in the study area using Average Daily Dose (ADD), Hazard Quotient (HQ), Hazard Index (HI) and Cancer Risk (CR).

2. Methods

2.1 Study Area

The study area is located between latitude 7^0 22' 20''N and 7^0 23'20''N and longitude 3^0 58'40''E and 4^0 00'40'' E (Fig. 1).

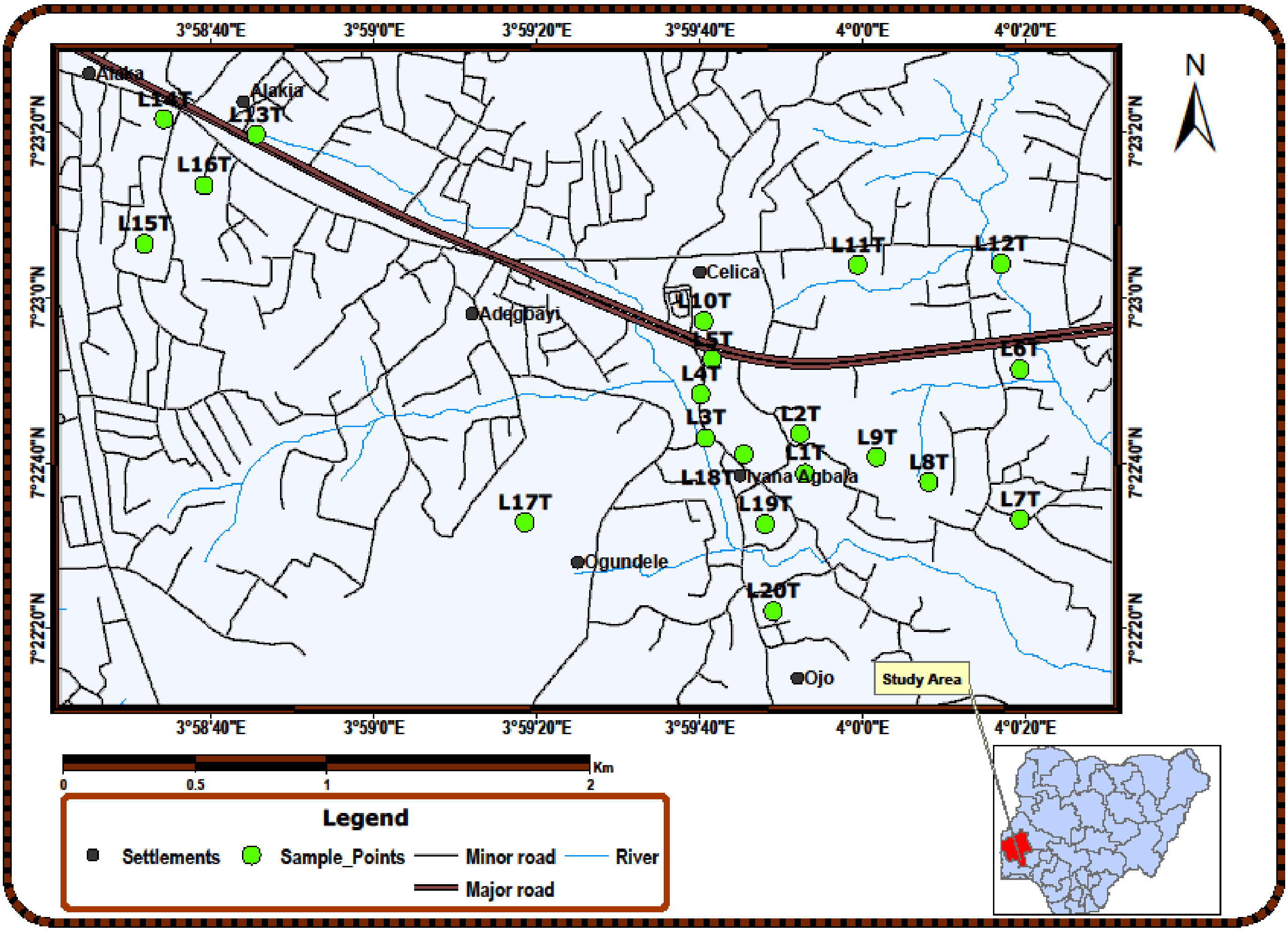

Figure 1: Samples Locations and Accessibility Map of the Study Area.

The lowest elevation in the area is 220 meters and the highest elevation is 280 meters above the level. Areas with highest elevations include Adegbayi and Iyana Agbala while areas with low elevation are found around Celica area. The drainage pattern of the area is dendritic reflecting the aquitard nature of the underlying rocks. The area is located within the tropical climate with averagely high temperatures, high relative humidity and generally two rainfall maxima regimes during the rainfall period of March to October. The mean temperatures are highest at the end of the Harmattan (averaging 28^{0}C), that is from the middle of January to the onset of the rains in the middle of March. The vegetation of the area belongs to the typical rainforest.

The study area Iyana Agbala, Celica, and some parts of Alakia in Ibadan, Southwestern, Nigeria lies in the region affected by the Late Precambrian to Early Proterozoic orogeny, more precisely the area is underlain by Muscovite Granite Gneiss, Biotite Granite Gneiss, Quartzite and Quartz Schist and Undifferentiated Gneiss/ Schists (Fig. 2).

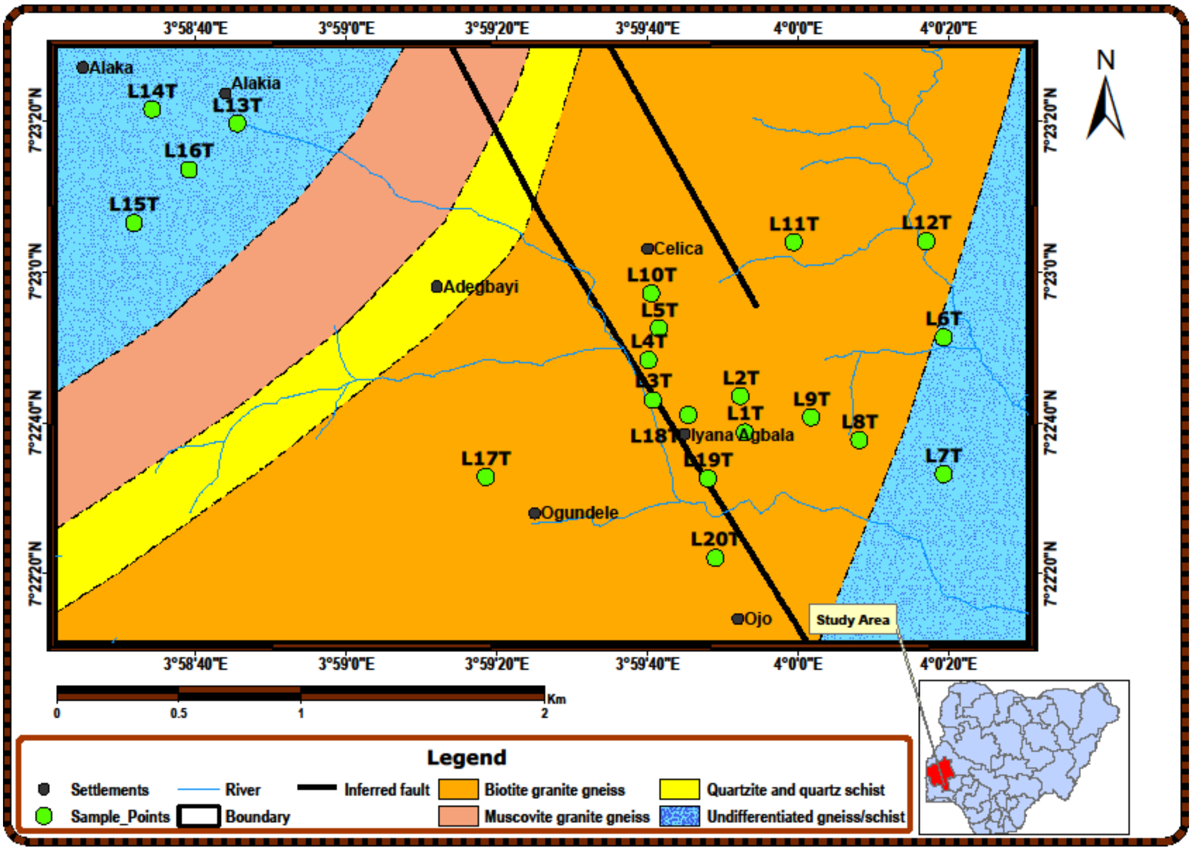

Figure 2: Geological map of the study area [11].

2.2 Sample Collection

Twenty raw water samples from twenty boreholes were randomly collected from Iyana-Agbala, Celica, Adegbayi and Alakia area of Ibadan city. The plastic containers used for sample collection were thoroughly washed and rinsed, and properly labeled. Distilled water served as control for this study. A global positioning system (GPS, Garmin make, GPS e Trex 10J) was used for determining precise sampling point.

2.3 Analytical Methods

2.3.1 Determination of Physicochemical Parameters

Physical tests such as hydrogen ion concentration (pH), Colour, Turbidity, and Total Dissolved Solids (TDS), were carried out using standard instruments. Jenway's pH meter was used to measure the pH of the water samples. The electrode of the pH meter was placed in a sample bottle containing 100cm^3 of the water sample and the meter reading was recorded. This procedure was carried out for all the water samples collected.

The pH was expressed in pH unit, and it is a measure of the hydrogen ion concentration (H^+) as;

$$pH = -\log(H^+).$$

The turbidity of water was determined by the use of a turbidity meter as follows: The water sample was poured in the sample bottle to the mark on the bottle. The blank sample was placed in the cell holders on the meters; the blank sample was the distilled water in the blank sample bottle. The meter was turned on followed by pressing PRG 95 followed by Enter, then zero, the meter showed zero NTU. The water sample in the sample bottle was placed in the cell holder after removing the blank sample and the read button was pressed thereafter, the meter displayed the turbidity of the water in color's NTU.

The electrical conductivity of both raw and treated water was carried out using a conductivity meter. The water sample was poured into a beaker and the electrode of the conductivity meter was rinsed in distilled water and placed in the water sample. The conductivity meter was then switched on to display the conductivity of the water sample, either raw or treated. It is expressed in µs/cm. The TDS test was carried out with the same procedure and meter as that of the conductivity test, and its value was selected from the conductivity meter.

The alkalinity of the water sample was determined as follows. 100 ml of water was measured into the conical flask and phenolphthalein indicator was added. If the colour remains unchanged, a methyl orange indicator was added which changed the colour to yellow. the mixture in the conical flask was titrated against 0.1M HCl until the colour became reddish marking the end-point of the first titration, and the reading taken. The mixture in conical flask was boiled and allowed to cool where the same 0.1M HCl was again titrated against the mixture i.e. the second titration up to the formation of faint yellow coloration, the second reading was taken. The first and second readings were summed and multiplied by 50 to obtain the total alkalinity in mg/l.

The Total Hardness of the water samples was determined as follows: 50 ml of raw water was measured into a separate conical flask. 2 ml of buffer solution was added to each sample, and the colour remained unchanged. A small amount of eriochrome black T was added to each sample and, a pink colouration was observed. The samples were titrated with diamine tetraacetic acid (EDTA) up to the observance of blue colouration and the titre values was recorded.

2.3.2 Determination of Anions Concentration

Anions concentration in the water samples were determined using the Spectrophotometer. The parameter to be analyzed for was selected from the test manager of the spectrophotometer. Two 10ml sample cells were filled with the sample to be tested, 1 pillow of tested parameter was added to one of the sample in the sample cell and shaken, then it was allowed to stay for reaction time depending on the tested parameter e.g. (0, 5, 10,) minutes.

2.3.3 Determination of Cations Concentration

Cations like Sodium, Potassium, Magnesium and Calcium were done by Flame Photometry method. Sample were aspirated into the flame through an inlet hose, in which the Flame Photometer has been calibrated by series of known standard of the tested parameters, the concentration of the tested parameter will be displayed on the screen.

2.3.4 Sample Analysis for Trace Elements

The digested samples were analyzed for the presence of lead, cadmium, manganese, chromium, nickel, copper, iron, and zinc using the Buck Scientific 210VGP atomic absorption spectrometer. The digested samples were analyzed in duplicates with the average concentration of the metal present being displayed in ppm by the instrument after extrapolation from the standard curve.

2.3.5 Human Health Risk Assessment Indices

Possible health hazards that may result from the consumption of the sampled groundwater were assessed for cancer-causing and non-cancer-causing impacts of the studied potentially toxic elements for various age groups; adult, children, and infants [12]. The toxicity variables evaluated are the reference dose (RfD) for non-cancer-causing risk and slope factor for cancer-causing hazard index [13]. The average daily dose (ADD) was calculated by the methodology reported by Taiwo and Awomeso [14] as stated in Eq. (1).

$$ADD = C \times IR \times ED \times (EF / BW) \times AT \quad \ldots (1)$$

Where ADD equals the average daily dose as a result of ingestion, C is the studied metals' mean value, while IR is the rate of water intake; 2, 1, and 0.75 L/day for an adult, child, and infant respectively, ED represents the exposure duration, which was taken as 30 years [12], the frequency to pollutants Enrichment Factor (EF) is equal to 365 days/year, BW, the average body weight in kg is 5, 10 and 60 kg for an infant, child, and adult respectively. AT is the time of exposure to the pollutants, which was taken as 30 years ×365 days/year [15].

The Hazard Quotient which is the non-cancer-causing index as a result of water ingestion was determined using Eq. (2).

$$Hazard\ quotient\ (HQ) = ADD/RfD \qquad \ldots (2)$$

The value of RfD by Integrated Risk Information was utilized for this study.

An HQ value higher than 1 is the probability of no cancer causing impacts on human health. HQ value under 1 show that the ingestion of groundwater would not possibly have any consequence on the occupants [16].

The possible health risk to human from the combination of all elements was evaluated in Eq. (3);

$$Hazard\ index\ (HI) = \sum HQ \qquad \ldots (3)$$

The carcinogenic risk was determined using Eq. (4) [15].

CR is the risk of ingestion of studied metals groundwater, ADD, and cancer slope factors are in (mg/kg/day). (Joel *et.al* 2018).

$$CR = ADD \times CSF \qquad \ldots (4)$$

3. Results and Discussion

3.1 Physicochemical Parameters

The results for the physio-chemical parameters of the studied groundwater are presented in Tables 1 to 5. Hydrogen ion concentration (pH) ranged from 6.89 for location 15 to 7.12 for location 11 with a mean value of 7.32, while the electrical conductivity (EC) ranged from 270μS/cm to 360 μS/cm with a mean of 290 μS/cm and TDS range from 190 ppm to 240 ppm with an average of 205.5 ppm. Total hardness (TH) range from 200 ml/L to 280 ml/L with an average of 227.3 ml/L while Alkalinity range from 200 ml/L to 269 ml/L with a mean value of 238.55 ml/L and Turbidity ranged from 0.00 to 0.03 NTU with a mean value of 0.0045 NTU (Table 1).

The result for the physicochemical parameters as presented in Table 1 revealed that the value for all the tested parameters falls within the permissible limit of World Health Organization standard for drinking water both in the range and the mean values.

3.2 Coefficient of Correlation for the Physicochemical Parameters

Pearson's correlation coefficient was calculated for the Potentially Toxic Elements (PTE) in the borehole water in order to determine the correlation and interrelationship among the elements (Table 2). Table 2 showed the relationship between the physicochemical parameters of the sampled water. Total hardness showed strong positive correlated with Total alkalinity (0.912) likewise Total dissolved solid showed strong positive correlated with Electrical conductivity (0.995). In a like manner pH, total hardness and alkalinity showed positive correlation in the water samples, but turbidity on the other hand showed poor correlation no relationship with all other parameters.

Table 1: Result of physio-chemical characteristics of studied groundwater

Sample/ Code	pH	EC	TDS	Turbidity	TH	Alkalinity
L1T	7.08	320.00	215.000	0.000	216.000	210.000
L2T	7.03	360.00	240.000	0.000	222.000	218.000
L3T	7.00	300.00	200.000	0.000	200.000	206.000
L4T	6.90	320.00	215.000	0.000	210.00	210.00
L5T	7.10	280.00	190.000	0.000	230.000	230.000
L6T	7.03	300.00	200.000	0.010	220.00	222.00
L7T	7.11	330.00	220.000	0.010	206.000	200.000
L8T	7.05	270.00	180.000	0.030	212.000	210.000
L9T	7.00	310.00	210.000	0.010	230.000	240.000
L10T	7.06	280.00	190.000	0.000	242.000	240.000
L11T	7.12	300.00	200.000	0.000	280.000	260.000
L12T	7.00	320.00	215.000	0.000	266.000	260.000
L13T	7.06	300.00	200.000	0.000	272.000	256.000
L14T	6.94	290.00	195.000	0.010	206.000	206.000
L15T	6.89	340.00	230.000	0.020	218.000	220.000
L16T	6.91	320.00	215.000	0.000	246.000	269.000
L17T	7.03	300.00	200.000	0.000	232.000	230.000
L18T	7.03	290.00	195.000	0.000	220.000	226.000
L19T	7.06	310.00	210.000	0.000	208.000	220.000
L20T	7.01	280.00	190.000	0.000	210.000	218.000

pH, hydrogen ion concentration; EC, Electrical Conductivity; TDS, Total Dissolved Solid; TH, Total Hardness

Table 2: Correlation Coefficient of the physiochemical parameters

Correlations							
		pH	**EC**	**TDS**	**Turbidity**	**TH**	**Alkainity**
pH	Pearson Correlation	1	-.280	-.306	.[a]	.229	.018
	Sig. (2-tailed)		.232	.189	.	.332	.942
	N	20	20	20	20	20	20
EC	Pearson Correlation	-.280	1	.995**	.[a]	-.018	-.026
	Sig. (2-tailed)	.232		.000	.	.940	.913
	N	20	20	20	20	20	20
TDS	Pearson Correlation	-.306	.995**	1	.[a]	-.031	-.020
	Sig. (2-tailed)	.189	.000		.	.895	.933
	N	20	20	20	20	20	20
Turbidity	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.		.	.
	N	20	20	20	20	20	20
TH	Pearson Correlation	.229	-.018	-.031	.[a]	1	.912**
	Sig. (2-tailed)	.332	.940	.895	.		.000
	N	20	20	20	20	20	20
Alkainity	Pearson Correlation	.018	-.026	-.020	.[a]	.912**	1
	Sig. (2-tailed)	.942	.913	.933	.	.000	
	N	20	20	20	20	20	20

***. Correlation is significant at the 0.01 level (2-tailed). a. Cannot be computed because at least one of the variables is constant. pH, hydrogen ion concentration; EC, Electrical Conductivity; TDS, Total Dissolved Solid; TH, Total Hardness*

3.3 Chemical Parameters

3.3.1 Major Cations and Anions

Table 3 present the individual concentration of major cations and anions in the analysed water samples in the study area. In the cations sequence Ca> Mg> Na> K in all sample location across the study area, while for the anions HCO_3^- > Cl^-> SO_4^2 > NO_3^{2-}. The results showed that concentrations of cations and anions are within permissible limits of WHO standards for drinking water. color

Table 3: Result of major cations and anions of the studied groundwater samples

	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	CO_3^{2-}
S/Code	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**Ppm**	**ppm**	**ppm**	**ppm**
L1T	61.61	17.36	19.18	9.36	210	24	53.25	6.36	0
L2T	63.2	18.31	17.93	10.48	218	26	53.96	3.84	0
L3T	55.18	17.73	14.66	8.14	206	20	40.47	4.09	0
L4T	56	20.02	12.96	10.12	200	22	53.25	5.36	0
L5T	55.6	26.03	15.11	9.92	230	30	50.06	6.41	0
L6T	58.01	21.45	18.16	9.36	222	26	49.69	4.12	0
L7T	50.4	22.88	10.96	7.11	200	18	49.69	3.04	0
L8T	51.98	23.45	12.18	9.00	210	20	50.41	5.73	0
L9T	60.11	22.88	15.01	10.02	240	28	42.6	2.36	0
L10T	56,41	28.89	10.82	7.93	240	30	46.15	4.62	0
L11T	64.00	34.32	14.08	10.11	260	40	60.7	8.32	0
L12T	62.4	31.46	12.94	10.1	258	42	49.69	4.63	0
L13T	60.8	34.89	14.21	9.98	256	42	60.35	6.05	0
L14T	54.4	20.02	10.32	7.91	206	24	40.47	4.32	0
L15T	47.21	28.61	10.02	8.11	220	26	42.6	4.48	0
L16T	63.2	25.17	12.81	9	260	34	37.63	2.44	0
L17T	60.01	23.45	15.11	10.14	230	30	50.41	5.48	0
L18T	57.6	21.74	11.89	8.43	226	32	36.21	3.48	0
L19T	59.2	17.16	12.3	8.96	220	26	35.5	1.36	0
L20T	58.4	18.31	11.99	9.14	218	28	35.86	2.01	0
Mean	57.8584211	23.7065	13.632	9.166	226.5	28.4	46.9475	4.425	0
Stdv	4.60241756	5.48213488	2.5945035	0.96039137	9.91429	6.52839054	7.71890016	1.71786434	0

3.3.2 Coefficient of Correlation for Major Ions

Bicarbonate shows a very strong relation with Ca^{2+} and Mg^{2+}, while Ca^{2+}, Mg^{2+} and K^+ exhibited a strong correlation with one another. Mg on the other hand showed negative correlation with Na. Chloride showed a positive correlation with all the metals and anions showing a very strong positive correlation (0.8) with NO_3^{2-} (Table 4)

Table 4: Correlation Coefficient for major cations and anions in water samples

Correlations										
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	CO_3^{2-}
Ca^{2+}	Pearson Correlation	1	.113	.555*	.686**	.614**	.199	.235	.085	.c
	Sig. (2-tailed)		.636	.011	.001	.004	.400	.318	.723	.
	N	20	20	20	20	20	20	20	20	20
Mg^{2+}	Pearson Correlation	.113	1	-.230	.184	.764**	.520*	.493*	.514*	.c
	Sig. (2-tailed)	.636		.329	.437	.000	.019	.027	.021	.
	N	20	20	20	20	20	20	20	20	20
Na^{+}	Pearson Correlation	.555*	-.230	1	.608**	.032	.052	.445*	.269	.c
	Sig. (2-tailed)	.011	.329		.004	.893	.826	.049	.251	.
	N	20	20	20	20	20	20	20	20	20
K^{+}	Pearson Correlation	.686**	.184	.608**	1	.420	.228	.509*	.348	.c
	Sig. (2-tailed)	.001	.437	.004		.065	.333	.022	.132	.
	N	20	20	20	20	20	20	20	20	20
HCO_3^-	Pearson Correlation	.614**	.764**	.032	.420	1	.406	.198	.182	.c
	Sig. (2-tailed)	.004	.000	.893	.065		.076	.402	.443	.
	N	20	20	20	20	20	20	20	20	20
SO_4^{2-}	Pearson Correlation	.199	.520*	.052	.228	.406	1	.413	.235	.c
	Sig. (2-tailed)	.400	.019	.826	.333	.076		.070	.319	.
	N	20	20	20	20	20	20	20	20	20
Cl^-	Pearson Correlation	.235	.493*	.445*	.509*	.198	.413	1	.800**	.c
	Sig. (2-tailed)	.318	.027	.049	.022	.402	.070		.000	.
	N	20	20	20	20	20	20	20	20	20
NO_3^-	Pearson Correlation	.085	.514*	.269	.348	.182	.235	.800**	1	.c
	Sig. (2-tailed)	.723	.021	.251	.132	.443	.319	.000		.
	N	20	20	20	20	20	20	20	20	20
CO_3^{2-}	Pearson Correlation	.c	.c	.c	.c	.c	.c	.c	.c	.c
	Sig. (2-tailed)	.	.	.	.	.	.	.	.	
	N	20	20	20	20	20	20	20	20	20

**. Correlation is significant at the 0.05 level (2-tailed).*

***. Correlation is significant at the 0.01 level (2-tailed).*

c. Cannot be computed because at least one of the variables is constant.

3.4 Hydrogeochemical Facies

The chemical character of water in hydrologic systems has been determined with the concept of hydrochemical facies [17]. The hydrochemical facies reflect the effects of hydrochemical processes occurring between the minerals within the rocks and groundwater. The concept of hydrochemical facies has been widely used in many studies for chemical assessment of groundwater and surface water. The Piper diagram [18] is a graphical applications used in the determination of hydrogeochemical facies of water. The diagram is made up of two triangles, one for plotting cations and the other for plotting anions. The cations and anion fields are combined to show the total ionic concentration in a diamond- shaped field, from which inferences is drawn on the basis of hydrogeochemical facies concept (Back and Hanshaw,1965).

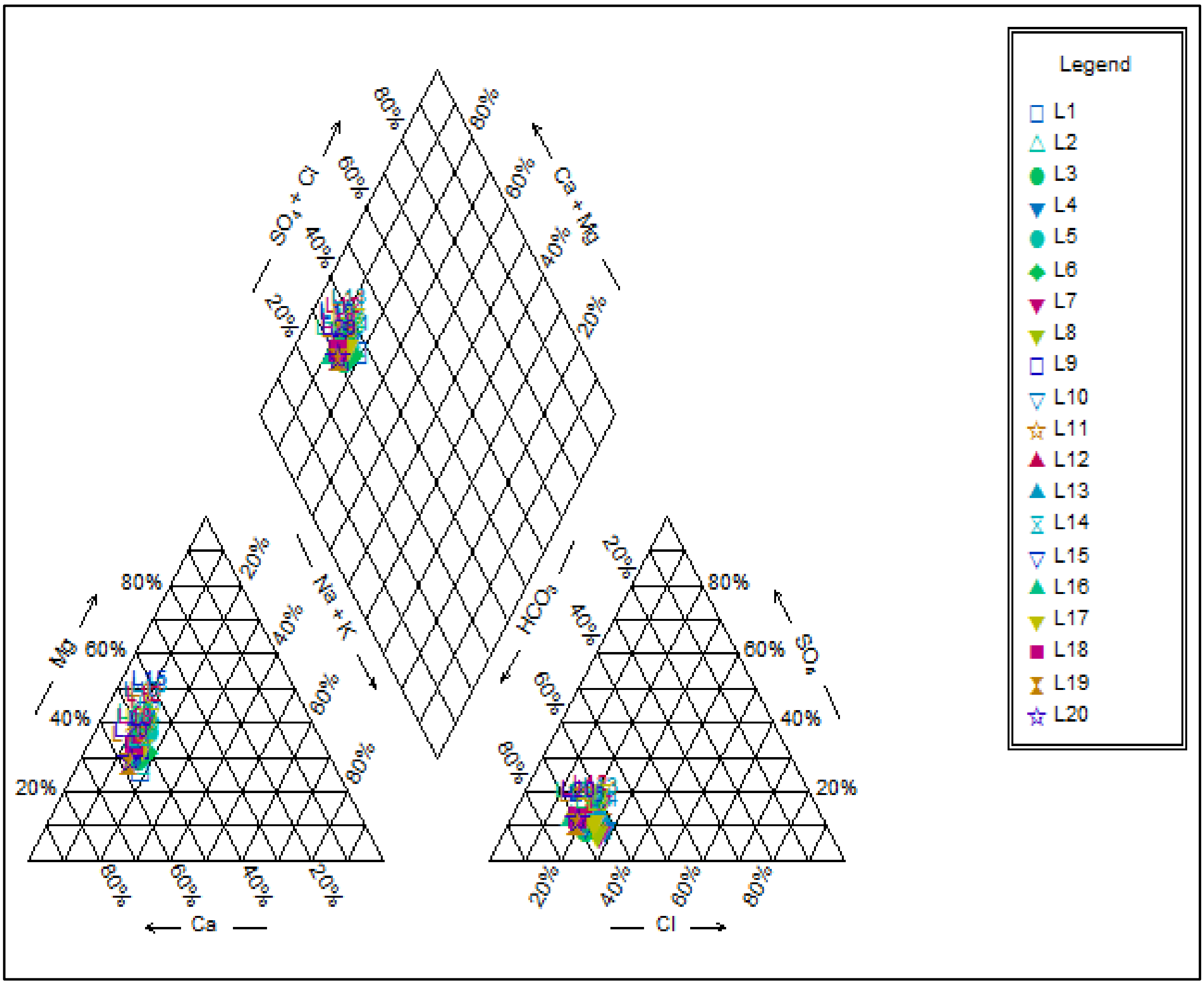

Figure 3: Hydrochemical Facies of the water samples (Piper's Diagram)

Hydrochemical facies of the groundwater was determined from the piper plot of the water samples (Fig 3). Piper diagram is a useful tool to identify different hydrochemical facies or origins of groundwater by plotting the content of major cations and anions in groundwater, indicating the origin, source of dissolved salts and processes that affect the characteristics of these natural waters. Figure 3 showed that calcium-bicarbonated water type (Ca^{2+}-HCO_3^{-}) predominates in the study area.

3.5 Concentration of Potentially Toxic Metals and their Potential Health Effects

The analytical result of the concentration of the potential toxic elements is presented in Table 5. Potentially toxic elements at excess concentrations can become toxic to man, plants and aquatic life and can lead to damage to some internal organs, reduce energy levels, mental and central nervous dysfunction [20]. The effects of long term exposure may result in slowly progressing physical, muscular and neurological degenerative processes [21].

Results showed that Pb concentrations in the water samples ranged between 0.009ppm and 0.017 ppm with a mean concentration of 0.0612 ppm (Table 5) (Fig. 4). Pb is very mobile in water especially, at low ph. WHO proposed a health guideline value of 0.01 ppm [22]. This review was necessary on the basis that Pb is a cumulative poison and that there should be no accumulation of body burden of lead.

Table 5: Potentially Toxic element concentrations in groundwater of the study area

S/Code	Fe ppm	Pb ppm	Cu ppm	Cr ppm	Mn ppm	Zn ppm	Ni ppm	Co ppm	Cd ppm
L1T	0.839	0.014	0.038	0.012	0.051	0.016	0.003	0.004	0.002
L2T	0.781	0.015	0.039	0.015	0.048	0.019	0.006	0.007	0.002
L3T	0.900	0.012	0.036	0.012	0.040	0.013	0.004	0.003	<0.002
L4T	0.703	0.015	0.029	0.009	0.045	0.012	0.003	0.005	0.003
L5T	0.949	0.017	0.039	0.011	0.047	0.015	0.005	0.006	0.002
L6T	0.630	0.012	0.034	0.013	0.042	0.016	<0.003	<0.003	<0.002
L7T	0.621	0.014	0.032	0.009	0.053	0.012	0.005	0.008	0.003
L8T	0.897	0.017	0.036	0.014	0.055	0.013	0.004	<0.003	<0.002
L9T	0.775	0.014	0.042	0.012	0.048	0.014	0.006	0.004	<0.002
L10T	0.705	0.015	0.035	0.009	0.048	0.014	0.003	0.003	<0.002
L11T	0.797	0.013	0.041	0.012	0.044	0.012	0.005	0.006	0.002
L12T	0.668	0.01	0.042	0.014	0.046	0.013	0.003	0.005	<0.002
L13T	0.735	0.014	0.039	0.011	0.048	0.017	0.005	0.006	0.003
L14T	0.705	0.013	0.033	0.013	0.046	0.016	0.003	0.005	0.002
L15T	0.885	0.016	0.042	0.015	0.050	0.015	0.005	0.007	0.003
L16T	0.639	0.012	0.027	0.013	0.038	0.012	0.003	0.004	<0.002
L17T	0.654	0.009	0.030	0.010	0.031	0.011	<0.003	0.003	<0.002
L18T	0.796	0.014	0.038	0.016	0.047	0.012	0.004	0.003	0.002
L19T	0.739	0.012	0.037	0.013	0.046	0.010	0.004	0.003	<0.002
L20T	0.772	0.014	0.040	0.014	0.049	0.013	0.003	0.003	<0.002
RANGE	0.621- 0.949	0.009-0.017	0.027-0.042	0.009-0.016	0.031-0.055	0.010-0.017	0-0.006	0-0.008	0-0.003
MEAN	0.7595	0.0161	0.042	0.0024	0.0467	0.0178	0.0037	0.00425	0.003
WHO (2017)	0.30	0.01	2.0	0.05	0.05	3.0	0.07		0.003

The World Health Organization (WHO) guidelines gave a provisional health-based guideline value of 2 ppm for copper [2]. Copper values of the samples ranged from 0.027 to 0.042 ppm with a mean of 0.042 ppm (Table 6). Figure 5 indicated that the concentration of copper in the study area is below the WHO (2011) guideline for drinking water. Copper is essential for good health. However, exposure to higher doses can be harmful. Drinking water that contains higher than normal levels of copper, may cause nausea, vomiting, stomach cramps or diarrhea. High intake of copper can cause liver and kidney damage and even death. The concentrations of chromium in the groundwater samples ranged between 0.009 and 0.016 ppm, with an average of 0.0024ppm (Table 5) (Fig. 6).

Ni occurs naturally in water, with concentrations normally less than 0.02 ppm WHO (2011). Food is the dominant source of nickel exposure in the non-smoking, non-occupationally exposed population, while water is generally a minor contributor to the total daily oral intake [23]. The analytical result showed that Ni concentrations in the water samples ranged from 0 to 0.006 ppm with an average of 0.0037 ppm (Table 5) (Fig. 7).

The analytical result showed that the concentration of Mn in the groundwater ranged from 0 .031 ppm to 0.055ppm, with a mean value of 0.0457 ppm (Table 5) (Fig. 8).

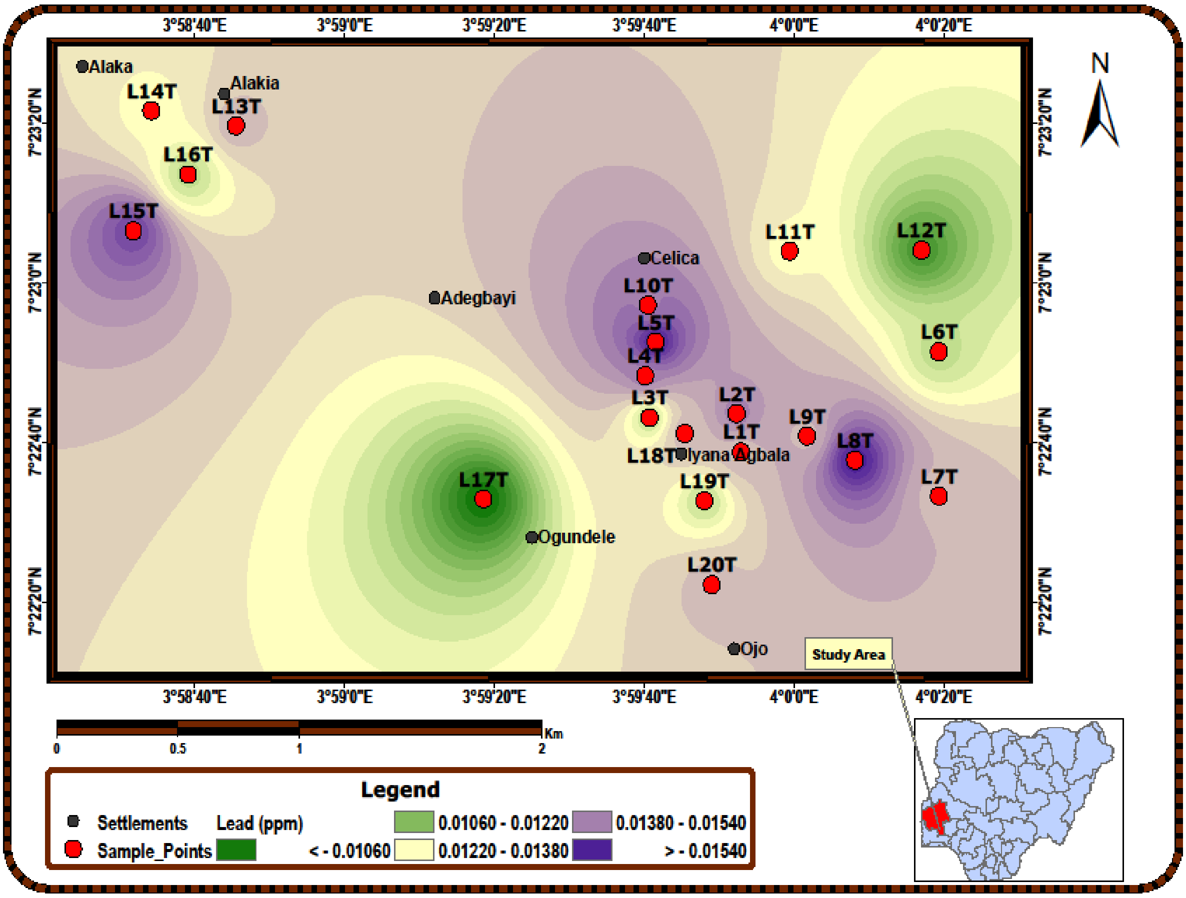

Figure 4: Iso-concentration map of lead across the study area.

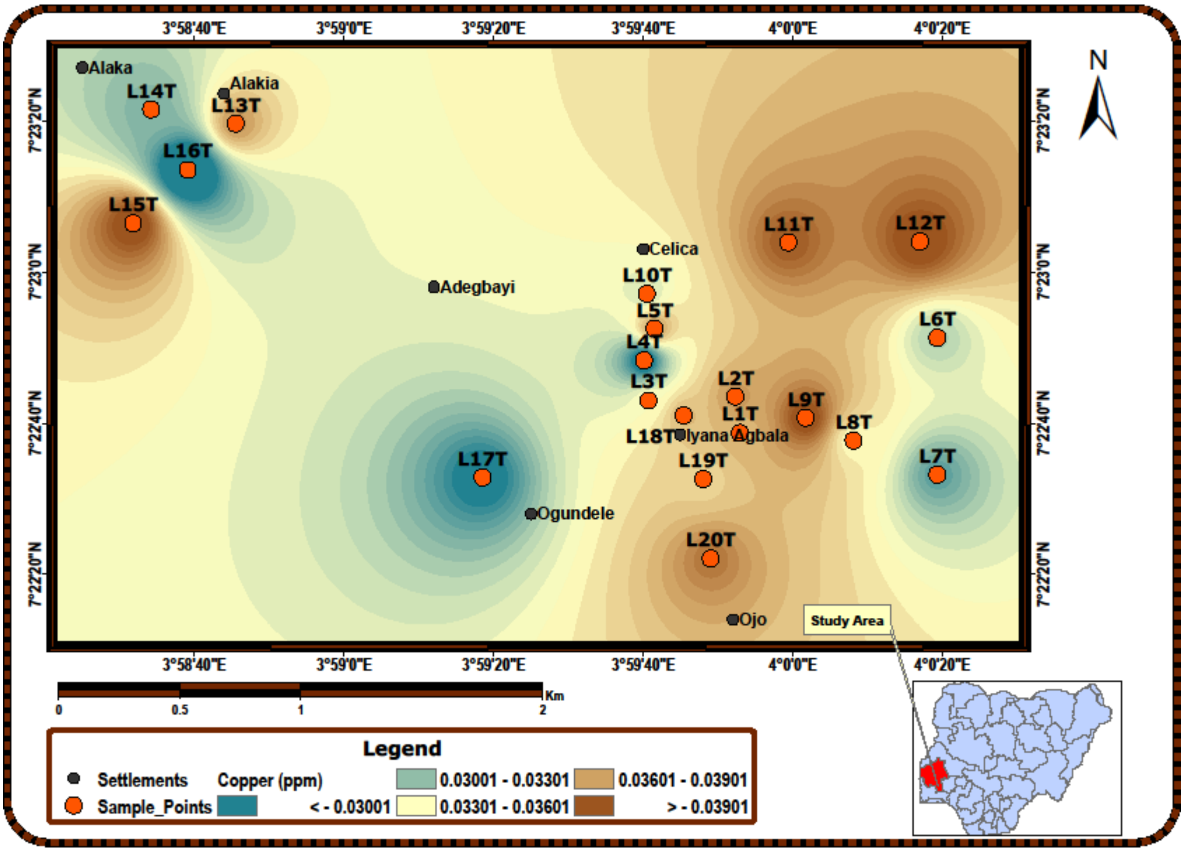

Figure 5: Iso-concentration map of Copper across the study area.

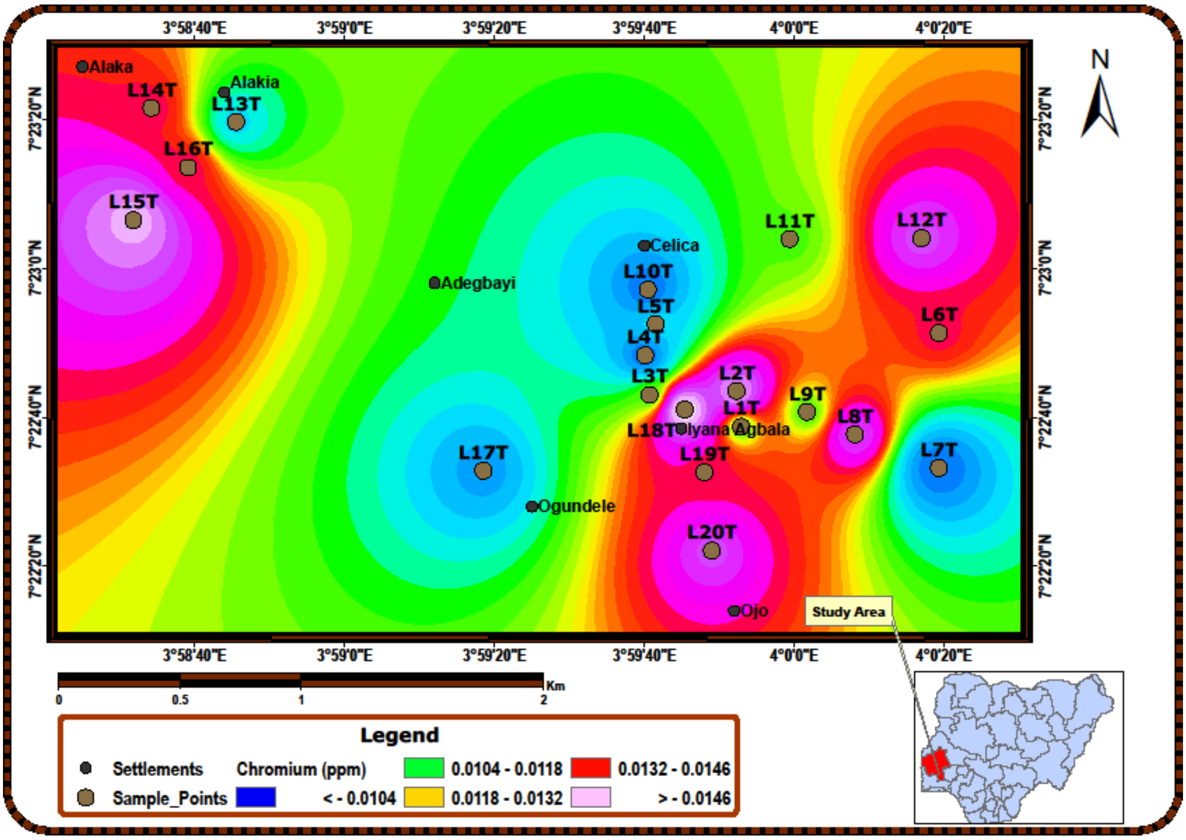

Figure 6: Iso-concentration map of Chromium across the study area.

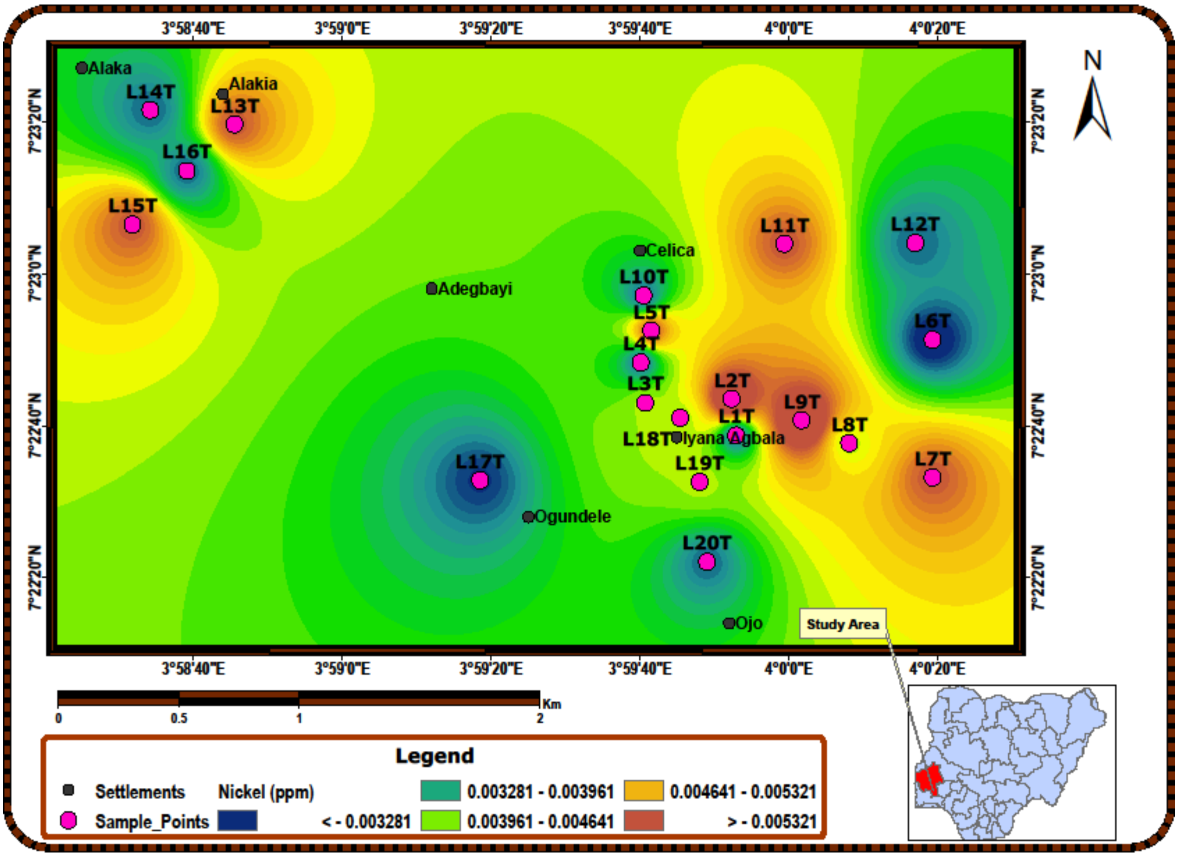

Figure 7: Iso-concentration map of Nickel across the study area.

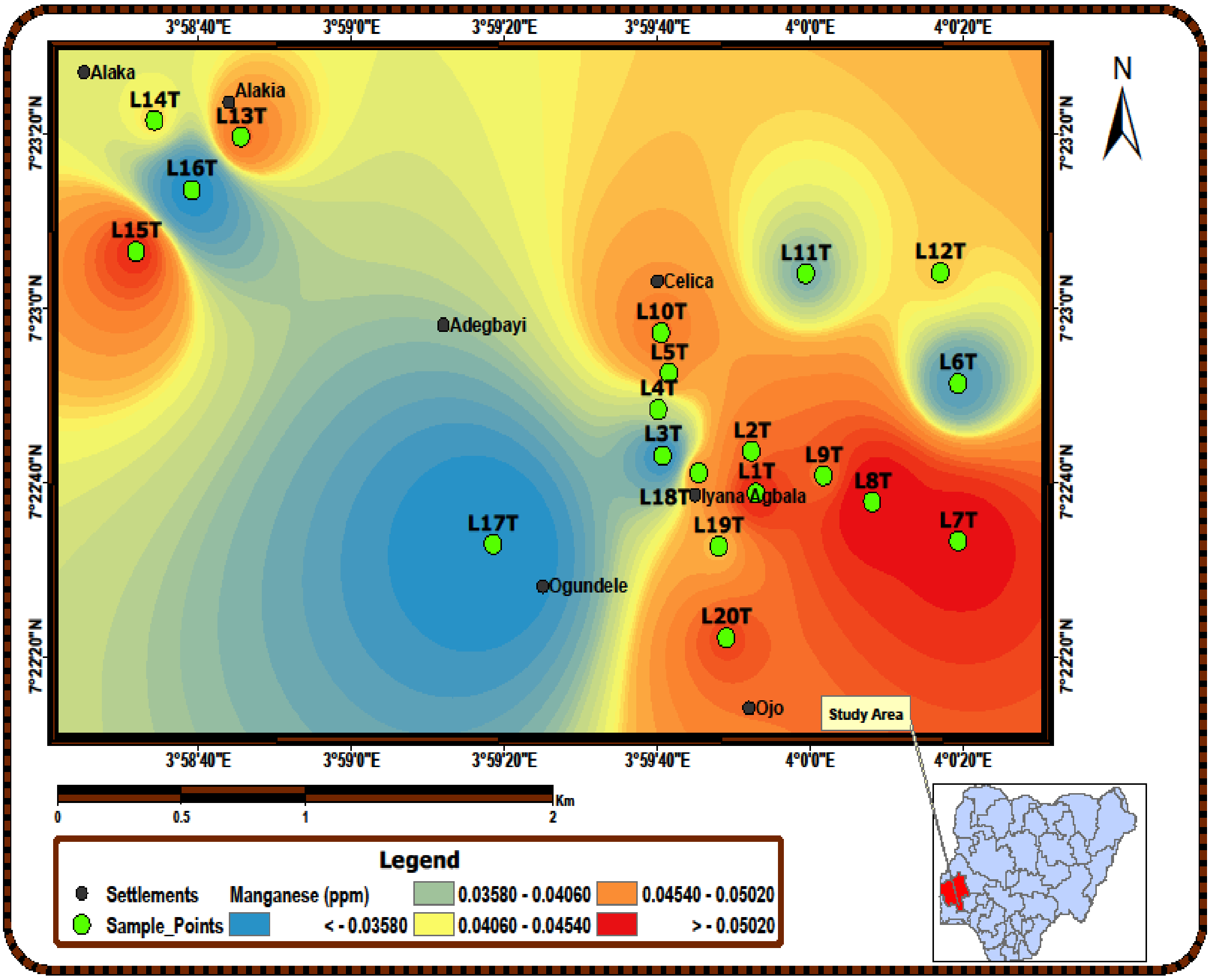

Figure 8: Iso-concentration map of Mn across the study area

Concentration of Cadmium in drinking water are usually less than 1 ppm [24]. The analytical result of the groundwater samples indicated that Cd ranged from 0 to 0.003 ppm (Table 5, Fig. 9). The concentration of Cd in all the samples are within permissible limit of the WHO (2011) guideline value of 0.003 ppm for drinking water.

Analytical results of the groundwater showed that Cd ranged from 0.010to 0.017 ppm (Table 5, Fig. 10). Although WHO (2011) does not state a permissible limit for zinc, concentration between 3.0 and 5.0 ppm is good for healthy living [25]. This result indicates that Zinc content of samples are lower than the permissible limit (10).

The analytical result showed that the concentrations of cobalt in the groundwater ranged from 0 to 0.008 ppm with an average of 0.00425 ppm (Table 5, Fig 11). The concentration of iron in analyzed water samples from the study area have an average of 0.7595 ppm and ranged from 0.621 to 0.949 ppm. These are found to be higher than permissible limit of 0.3 ppm by WHO (Table 5, Fig. 12).

3.6 Correlation Coefficient for the Potentially Toxic Elements

Pearson correlation was obtained for the potentially toxic element. Fe showed a low positive correlation with Mn, Pb, Zn, Cr and Cu. Pb has a very strong positive correlation with Zn and Cr, a negative correlation with Cu and a very low positive correlation with Fe and Mn. Cu showed negative correlation with Pb, Mn, Cr and Zn but a very low positive correlation with Fe. Cr showed a very strong positive correlation with Pb and Zn but a negative correlation with Cu (Table 6).

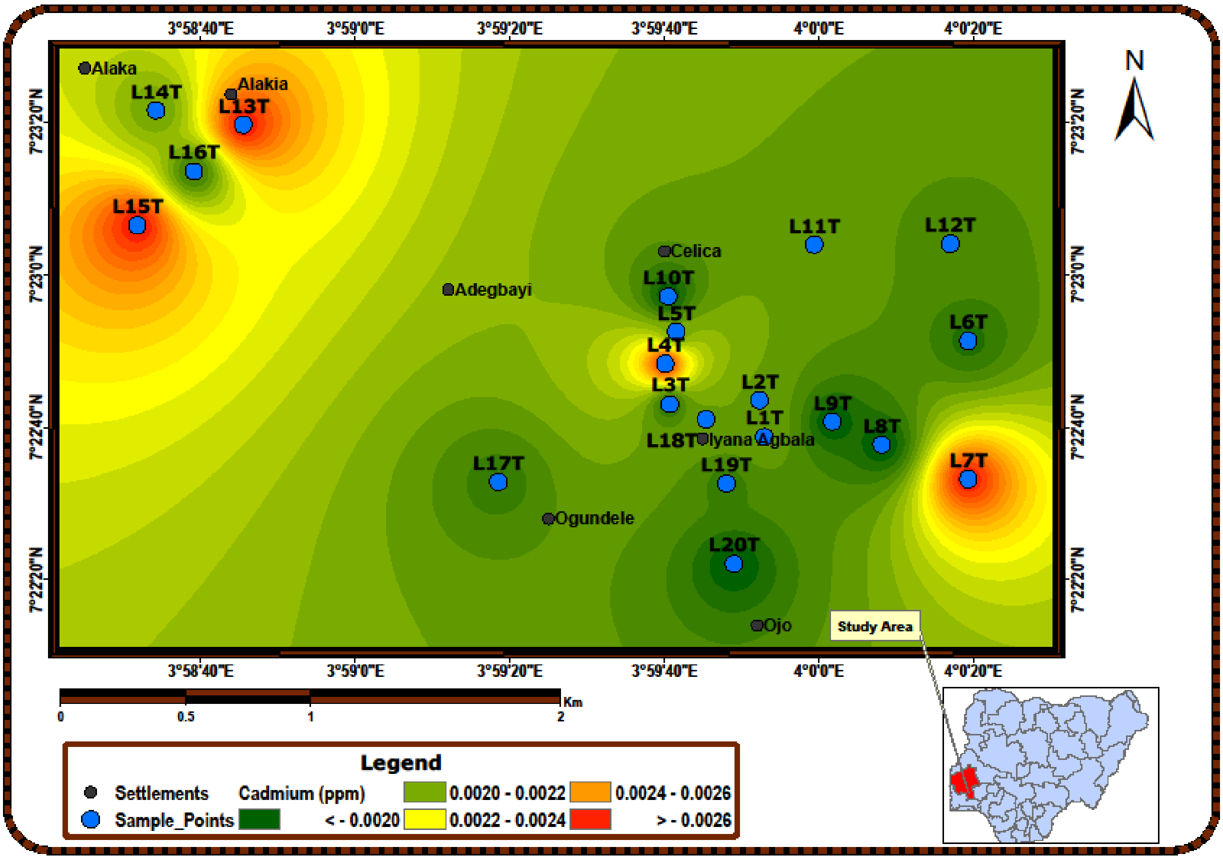

Figure 9: Iso-concentration map of Cadmium across the study area.

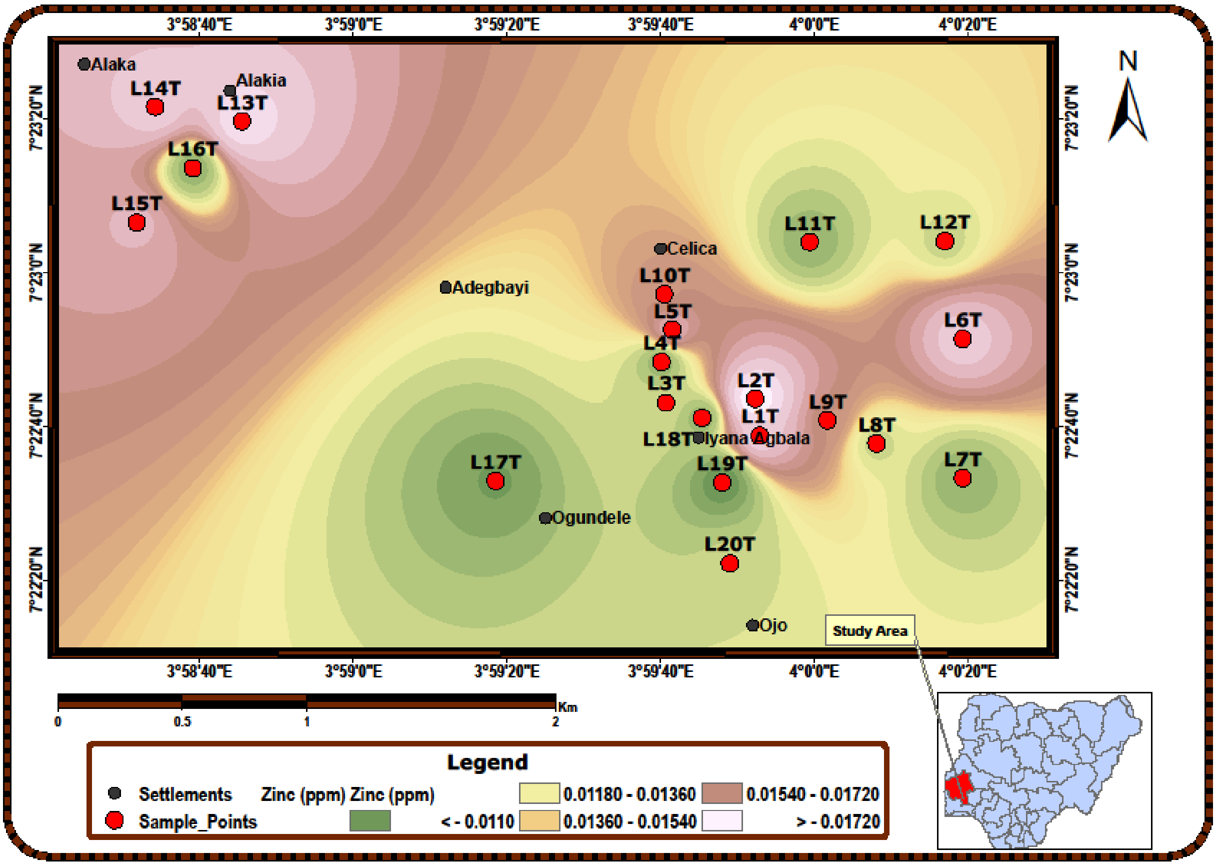

Figure 10: Iso-concentration map of Zinc across the study area.

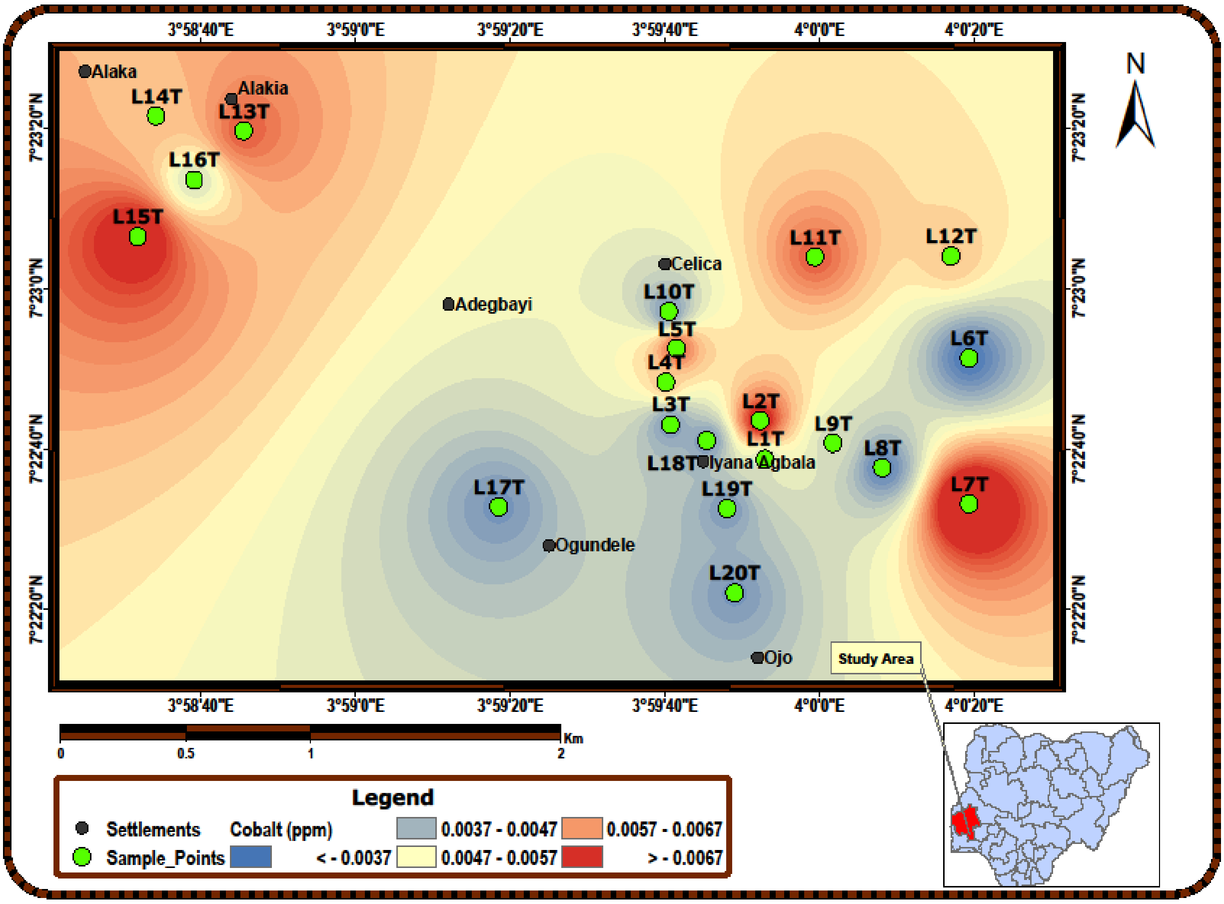

Figure 11: Iso-concentration map of Cobalt across the study area.

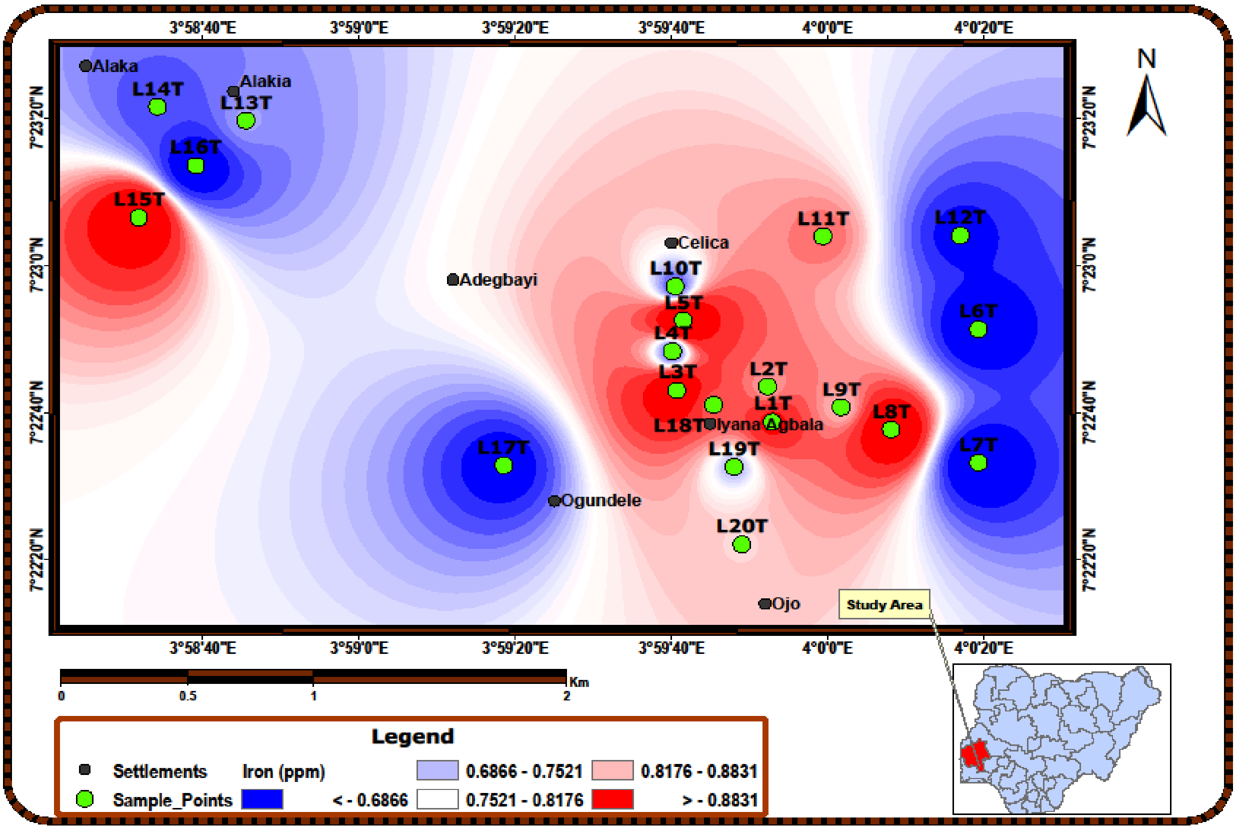

Figure 12: Iso-concentration map of Iron across the study area.

Table 6: Correlation Coefficient for the Potentially Toxic Elements in the sampled water

Correlations										
		Fe	**Pb**	**Cu**	**Cr**	**Mn**	**Zn**	**Ni**	**Co**	**Cd**
Fe	Pearson Correlation	1	.268	.003	.268	.224	.268	.[a]	.[a]	.[a]
	Sig. (2-tailed)		.253	.991	.253	.343	.253	.	.	.
	N	20	20	20	20	20	20	20	20	20
Pb	Pearson Correlation	.268	1	-.198	1.000**	.030	1.000**	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.253		.403	.000	.901	.000	.	.	.
	N	20	20	20	20	20	20	20	20	20
Cu	Pearson Correlation	.003	-.198	1	-.198	-.047	-.198	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.991	.403		.403	.844	.403	.	.	.
	N	20	20	20	20	20	20	20	20	20
Cr	Pearson Correlation	.268	1.000**	-.198	1	.030	1.000**	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.253	.000	.403		.901	.000	.	.	.
	N	20	20	20	20	20	20	20	20	20
Mn	Pearson Correlation	.224	.030	-.047	.030	1	.030	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.343	.901	.844	.901		.901	.	.	.
	N	20	20	20	20	20	20	20	20	20
Zn	Pearson Correlation	.268	1.000**	-.198	1.000**	.030	1	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.253	.000	.403	.000	.901		.	.	.
	N	20	20	20	20	20	20	20	20	20
Ni	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.	.	.		.	.
	N	20	20	20	20	20	20	20	20	20
Co	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.	.	.	.		.
	N	20	20	20	20	20	20	20	20	20
Cd	Pearson Correlation	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]
	Sig. (2-tailed)	.	.	.	.	.	.	.	.	
	N	20	20	20	20	20	20	20	20	20
**. Correlation is significant at the 0.01 level (2-tailed).										
a. Cannot be computed because at least one of the variables is constant.										

3.7 Health Risk Assessment

The non-carcinogenic risk assessment of the studied metals in the study area across different age groups (adults, children, and infants) is presented in Tables 7. The average daily dose of the studied metals obtained showed Fe has the highest dose for all categories (0.1139 $mg^{-1}kg^{-1}$ day^{-1} $bodyweight^{-1}$ in infants, 0.025 $mg^{-1}kg^{-1}$ day^{-1} $bodyweight^{-1}$ in adults, and (0.07595 mg^{-1} kg^{-1} day^{-1} $bodyweight^{-1}$) as shown in Table 7.

The estimated hazardous quotients (HQ) obtained in study area for the analyzed samples reveal the HQ of Cr from groundwater taken by children (1.523) and infants (1.2025); found to be greater than 1 (HQ > 1) which signifies non-carcinogenic adverse effects. However, the HQ values for Pb, Ni, Cr, Fe, Cu, and Zn were less than 1 (HQ < 1). The total hazardous index (HI) of analyzed groundwater in the study area taken by children (2.356) and infants (2.453) were found to be greater than 1 (HI > 1). However, the HI for adults (0.546) was found to be less than 1 (HI < 1). The Total Hazard Quotient (HI) of the metals in the groundwater samples studied showed a high risk for both children, and infants. This outcome is alarming due to conceivable heavy metal bioaccumulation among the consumers of the groundwater. HQ values, in the study area, for Cr was greater than 1, and this indicates that Cr concentration in the groundwater through the ingestion posed a potential health risk to human health. HI of analyzed metals was found to be greater than 1(>1) for children and infants, posing a major health risk to children, and infants ingesting the groundwater.

Table 7: Calculated Human Health risk assessments for the Potentially Toxic Elements in the groundwater

Metal	Mean	RfD	Sf	ADD	ADD	ADD	HQ	HQ	HQ
ppm	ppm	ppm/kg/day		Adult	Child	Infant	Adult	Child	Infant
Fe	0.7595	0.7		0.025	0.07595	0.1139	0.036	0.1085	0.1627
Pb	0.0612	0.3	0.0085	0.00204	0.00612	0.00918	0.0068	0.0204	0.0306
Mn	0.0457	0.014		0.001523	0.000457	0.000686	0.1088	0.0326	0.4896
Cu	0.042	0.04		0.0014	0.0042	0.0063	0.035	0.105	0.1575
Ni	0.0037	0.02	0.91	0.000123	0.00037	0.00056	0.00617	0.0185	0.0278
Cr	0.024	0.0003	0.5	0.0008	0.002405	0.000361	0.267	1.523	1.2025
Zn	0.0136	0.3		0.000452	0.00136	0.00204	0.00151	0.0045	0.0068
Cd	0.0012	0.0005	15	0.00004	0.00012	0.00018	0.08	0.24	0.36
Co	0.00425	0.03		0.000142	0.000425	0.00064	0.0047	0.0142	0.0213
HI							0.546	2.356	2.453

3.8 Cancer Risk Analysis

The risk grade and results of cancer risk (CR) for Pb, Cd, Ni, and Cr in the analyzed samples are presented in Tables 8 and 9 respectively. The CR value for Pb ranged from infants (7.80×10^{-5}) to adults (1.730×10^{-5}), Cd ranges from children (1.80×10^{-3}) to adults (6.00×10^{-4}), Ni ranges from adults (1.12×10^{-4}) to infants (5.10×10^{-4}) and Cr ranges from infants (1.81×10^{-4}) to children (1.20×10^{-3}). The assessment of cancer risk from exposure to Pb, Cd, Cr, Ni, and collective cancer risk value in the current study was higher than the maximum standard range of 1.0×10^{-6} to 1.0×10^{-4}, indicating a possible carcinogenic risk.

The risk rating of the studied metals indicates Low-Medium risk for Pb, Medium- High risk for Cr and Medium- High risk for Ni (Table 9). The calculated CR for the groundwater in the study area showed that attention should be paid to the risk and action taken to solve the problem. [16] (Table 9).

Table 8: Risk grades and values of Cancer Risk Assessment Standards [16]

Risk grades	Range of risk value	Acceptability
Grade I (Extremely low risk)	$< 10^{-6}$	Completely accept
Grade II (Low risk)	10^{-6} - 10^{-5}	Not willing to care about the risk
Grade III (Low-medium risk)	10^{-6} - 5×10^{-5}	Do not mind about the risk
Grade IV (Medium risk)	5×10^{-5} - 10^{-4}	Care about the risk
Grade V (Medium-high risk)	10^{-4} -5×10^{-4}	Care about the risk and willing to invest
Grade VI (High risk)	5×10^{-4} - 10^{-3}	Pay attention to the risk and take action to solve it
Grade VII (Extremely high risk)	$> 10^{-3}$	Reject the risk and must solve it

Table 9: Cancer risk (CR) values for Pb, Cd, Ni, and Cr

Metal	CSF	ADD Adult	ADD Child	ADD Infant	CR Adult	CR ⚜child	CR Infant
Pb	0.0085	0.00204	0.00612	0.00918	1.73E-05	5.20E-05	7.80E-05
Ni	0.91	0.000123	0.00037	0.00056	1.12E-04	3.37E-04	5.10E-04
Cr	0.5	0.0008	0.002405	0.000361	4.00E-04	1.20E-03	1.81E-04
Cd	15	0.00004	0.00012	0.00018	6.00E-04	1.80E-03	2.70E-03

4. Conclusions

This study assesses the potability and health risk exposure of humans resulting from the ingestion of groundwater within a residential area in Ibadan. The physicochemical assessment of the water indicated that all parameters fall within the WHO permissible limits for drinking water. The cations level of concentration showed that Ca> Mg> Na> K in all the sample, while for anion HCO_3^- > SO_4^{2-} > Cl^- > NO_3^{2-} > CO_3^{2-}. The Piper plot showed a Ca^{2+}-HCO_3^- water facies type for the groundwater. The mean concentration of heavy metal in groundwater samples for Pb, Cd, Ni, Cr, Mn, Fe, Zn, Co and Cu were 0.0612, 0.0012, 0.0037,0.024, 0.0457, 0.7595, 0.0457, 0.0136, 0.00425 and 0.0420 ppm respectively. Hazard Index value (HI>1) of the metals in the groundwater samples showed unfavorable non-cancer-high risk in infants and children. This study revealed that infants were at greater cancer risk than adults and children. The calculated cancer risk (CR) for the groundwater in the study area showed a medium to high cancer risk particularly for infants and children. Consequently, there is a need for urgent attention to be paid to the risk involved and immediate action taken to solve the problem.

Funding: Not applicable.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: Not applicable

Conflicts of Interest: The authors declare no conflict of interest

References

1. World Health Organization (WHO) (2008) Guidelines for drinking water quality, 3rd edn. Incorporating the First and Second Addenda, 1, Recommendations. WHO, Geneva., 668.
2. WHO (2011) Guidelines for Drinking-Water Quality, (4th Ed.), Environmental health criteria, Geneva, Switzerland, 2011.
3. Nwachukwu, R. A., Vitus, N., Frances, J. (2014). Health risk assessment in relation to heavy metals in water sources in rural regions of south east Nigeria. *Int. J. Phys. Sci*. 9(6): 109-116.
4. Itodo, A.U., F.W. Abdulrahman, L.G. Hassan, S.A. Maigandi, and Itodo, H.U. (2010). GC/MS Batch Equilibrium study and Adsorption Isotherms of Atrazine Sorption by Activated H3PO4 – Treated Biomass. *Journal of American science* 6(7): 173-178.
5. Radojavic, M., and Vladimir, N.B., (1992). Bulletin of the Royal society of chemistry, London, 14.
6. Ademoroti, C.M.A. (1996) Standard Methods for Water and Effluent Analysis. Foludex Press Ltd., Ibadan.
7. Center for Disease Control and Prevention. Global WASH Health Burden. 2017. Available at https://www.cdc.gov/healthywater/global/healthburden.html#one
8. Philip, N. Obasi and B. B. Akudinobi (2020). Potential health risk and levels of heavy metals in water resources of lead–zinc mining communities of Abakaliki, southeast Nigeria. *Applied Water Science.* 10: 184.
9. Nalbantcılar, M.T., and Pınarkara, S.Y. (2015). Impact of industry on groundwater contamination: a case study in Konya city, Turkey. *Global NEST Int J.* 17(4): 796–815.
10. Rohul-Amin, S.S., Anwar Z, Khattak, J.Z.K. (2012). Microbial analysis of drinking water and water distribution system in New Urban Peshawar. *Curr Res J Biol Sci*. 4 (6): 731–737.
11. Nigeria Geological Survey Agency (NGSA) (2006). The Geological Map of Nigeria, A publication of Nigeria Geological Survey Agency, Abuja, Nigeria.
12. US Environmental Protection Agency (USEPA) (2001). Baseline Human Health Risk assessment, Vasquez Boulevard and I-70 Superfund site, U.S. Public Health Service, Denver, CO.
13. IARC (1993). Overall evaluations of carcinogenicity to humans: as evaluated in IARC monographs 1–82 (at total of 900 agents, mixtures and exposures). International Agency for Research on Cancer, Lyon
14. Taiwo, A.M. and Awomeso, J. A. (2017). Assessment of trace metal concentration and health risk of artisanal gold mining activities in Ijeshaland, Osun State, Nigeria –part 1, J. Geochem. Explor. 177, 1–10, doi: 10.1016/j.gexplo.2017.01.009
15. Ayedun, H. Gbadebo, A.M. . Idowu, O.A. and Arowolo T.A. (2015): Toxic elements in groundwater of Lagos and Ogun States, Southwest, Nigeria and their human health risk assessment, *Environ. Monit. Assess.* 187 (6) 351.
16. Joel, E.S., Maxwell, O. Adewoyin, O.O. Ehi-Eromosele., C.O. Embong, Z. and Oyawoye, F. (2018). Assessment of natural radioactivity in various commercial tiles used for building purposes in Nigeria. *MethodsX* 5: 8–19.
17. Back, W (1960). Origin of Hydrogeological Facies in Groundwater in the Atlantic Coastal Plain.
18. Piper, A.M. (1944) A Graphic Procedure in the Geochemical Interpretation of Water analysis. Transactions, American *Geophsical Union* 25: 914-923.
19. Back, W and Hanshaw, B.B. (1965). Chemical Geohydrology. In:Chow V T (Editor) Advances in Hydroscience. Academic Press, New York. 49-109.
20. Ayandiran, T.A., Dahunsi S.O (2016). Toxicological assessment of fish (Clarias gariepinus) from polluted Oluwa River, Nigeria. *Environ Monit Assess* 188: 1–18

21. Gerhat, J.M., Blomquist, J.D. (1992). Selected trace elements and organic contaminant in stream bed sediments of the Potomac River Basin. In: U.S. Geological Survey, Water Resources Investigation Report 95 – 4267, pp. 1–12
22. World Health Organization (WHO) (1984). Guidelines for drinking water quality. World Health Organization, Geneva, pp 99–102
23. Aremu, D.A., Olawuyi, J., Meshitsuka, S. (2002). Heavy metal analysis of groundwater from Warri, Nigeria. *Int J Environ Health Res* 12: 261–267
24. Elinder, C.G. (1992). Cadmium as an environmental hazard. *IARC Sci Publ* 118: 123–132.
25. Agency for Toxic Substances and Disease Registry (ATSDR) (2007). U.S. Department of Health and Human Services, Public Health Service, Division of Toxicology 1600, Atlanta, GA 30333.

Cite article as:

Isibor, R.A., Aderogbin, J.A., Ogundiran, M.O. Potability and Health Risk Assessment of Some Potentially Toxic Elements in Groundwater Around Some Residential Areas in Ibadan Southwestern Nigeria. *Ajayi Crowther J. Pure Appl. Sci.* **2023**, 2(2), pp. 87-106. | **doi:** https://doi.org/10.56534/acjpas.2023.02.02.87.