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Full Length Research

Spatial distribution and human health risk assessment of heavy metals in groundwater of Kolo- Creek and Environs, Eastern Niger Delta, Nigeria

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ABSTRACT: This study investigated the distribution of heavy metals and human health risk assessment of them in the groundwater of Kolo Creek and environs, Niger Delta, Nigeria. Groundwater samples were collected from ten geo-referenced borehole points drilled to depths of 6 m. An Atomic Absorption Spectrophotometer (AAS) was utilised to ascertain the pollutant concentrations in the conserved samples. The average mean concentrations of the heavy metals (Cu = 0.43 mg/l, Zn =0.97 mg/l), (Cr, Cd, Hg, and Al not detected) in this study area for the two seasons were below international recommended limits except Pb = 0.019 mg/l and Fe = 35.57 mg/l which are above the international recommended limits of 0.01 mg/l and 0.3 mg/l respectively. The HI average (non-carcinogenic risk) value (1.561) for adults in all the locations is greater than 1, suggestive of likely health problems. The average HI value for children in all the locations is also greater than 1 (3.698), three times the value of adults also suggestive of greater health problems due to presence of the metallic contaminants in the children compared to the adults. The average CR (carcinogenic risk) value for Pb in adults and children in all locations exceeded (> 10^{-6}) suggesting the possibility of cancer risk due to the intake of contaminated groundwater. Therefore, the results show that the children are at greater risk of cancer threefold more than the adults.

Keywords: Cancer, contamination, health risk, heavy metals, pollution.

INTRODUCTION

One of the planet's most important renewable resources that is also widely available is groundwater, which is also a major global source of water. The findings of Akakuru *et al.* (2017), Sodde *et al.* (2007) and Akakuru *et al.* (2021) indicated that approximately 98% of freshwater on earth originates from groundwater. Roughly one-third of the world's population, or two billion people rely on groundwater supplies. They consume between 600 to 700 m^3 of water in a year and 20% of the world's total water volume are mostly from shallow aquifers. This is due to the rapid increase in industrial, urban development and population growth. Natural ecosystems are under greater pressure from anthropogenic activities that release industrial and residential pollutants like heavy metals into the ecosystem. According to Akakuru *et al.* (2017), the existence of heavy metals in the environment is a serious worry that could endanger all living things, including humans, animals, and plants. It has been determined that the primary causes of heavy metal contamination in groundwater are both manmade activities and natural processes. High levels of heavy metals in groundwater represent a major hazard to aquatic ecosystems and human health, regardless of the source of the pollutants (Akakuru *et al.,* 2022). Numerous substances, such as hydrocarbons, inorganic cations, inorganic anions, radionuclides, and synthetic organic compounds, are contaminants in groundwater.

The availability of water is essential for life to exist in all environments.

One of the biggest environmental issues of the modern era is the leakage of pollutants and effluents into water bodies. Although the environment is also contaminated by natural sources, human intrusion into the surrounding areas is the primary cause of the ecosystem's greater pollution levels. It is well recognized that water pollution happens when a body of water is unintentionally impacted by the intentional addition of large amounts of various substances, rendering the water unfit for human use (Edori and Odoemelam, 2022). A resource that is necessary for all living things to live is water. (Enaregha *et al.,* 2022).

The coastal areas of Nigeria, particularly the Niger Delta Basin, have suffered debilitating environmental degradation and pollution from human activities such as oil industry operations, manufacturing, and municipal discharges. Urbanization and municipal activities have also contributed to the number of wastes such as solid, liquid, gaseous emissions, and heavy metals deposited in the environment and may result in the contamination of our environment (Eyankware *et al*., 2020). On the other hand, because of human and/or natural activities, these sources of “groundwater and surface water” are very susceptible to contamination or pollution (Etu-Efeotor and Akpokodje, 1990; Ibe *et al.,* 2003; Onyekuru *et al.,* 2012).

Some metals, like lead, mercury, and cadmium, are too toxic for living things to eat, others, like zinc and iron, are necessary for the growth and well-being of living things (Adeyemi and Ojekunle, 2021). Chromium (Cr) can lead to serious health issues such as kidney and lung damage, when their concentrations in food and water reach a dangerously high level. The USEPA and WHO have set tolerable limits for Cr in drinking water, which are 10 and 15 μg/L, respectively (Ke *et al.,* 2017; Mishra *et al.,* 2018). One heavy element that is particularly dangerous to human beings and which can cause cancer is lead (Pb). Exposure to high amounts of lead has been linked to complicated health problems such as behavioural disorders, dementia, and impaired learning capacity (Saleh *et al.,* 2019; Varol and Sünbül, 2018). At extremely high quantities, copper (Cu) can also be hazardous, causing weakness, vomiting, diarrhoea, and liver cirrhosis. When corroded copper precipitates out of pipes into the water, and the water takes on a blue-green tint (Chiarugi *et al.,* 2002). Iron (Fe) is another heavy metal to be wary of, particularly since ingesting nutritional supplements containing Fe can seriously injure young children. Many of iron's negative effects are caused by ingestion since iron is easily absorbed in the digestive system. High Fe concentrations can damage target organs such as the kidneys, liver, and cardiovascular system, and drinking water may taste metallic (Saleh *et al.,* 2019; UNICEF/WHO, 2001). Therefore, assessing the groundwater resource's potential on a regular basis is necessary towards determining its present and intended use-values, particularly in light of its implications on human health (Onyekuru *et al.,* 2012.).

MATERIALS AND METHODS

Location and geology of the study area

The location of gas and oil infrastructure close to the non-tidal freshwater zone around Kolo Creek has brought industrialization and urbanization to the area (Inengite *et al.,* 2010; Ajayi and Okeke, 2024). The research area is the Kolo Creek which rises at Okarki, Engenni, Rivers State, it flows through Ogbia Local Government Area, Bayelsa State, Nigeria. The coordinates of the Kolo Creek are latitude 04˚ 48′0′ and 05° 6′0′ North, and longitudes 06° 18′0′ and 06° 36′0′ East, while Figure 1 presents the coordinates of the sampling points. The entire length of Kolo Creek is around 85 km (about 52.82 mi), covering 1,625 square kilometres (Eli, 2012).

The geology of the study area is presented in Figure 2. The Benin, Agbada Formation and Akata Formation are the three lithostratigraphic units underlying the superficial alluvium deposits of the Quaternary to Recent age of the Sombreiro-Warri Deltaic Plain sands. The Quaternary to Recent Sombreiro-Warri Deltaic Plain sands is composed of sand silt, fine medium/coarse-grained unconsolidated sands, and brownish lateritic soils (clayey/silty sand). The Formation has a thickness of about 120 meters, but the lateritic unit has a thickness ranging from 4-5 meters (Aigberua *et al.,* 2017; Ajayi and Okeke, 2024).

The friable sands of the continental Eocene to Recent Benin Formation are intercalated with shale clay lenses up to 2000 meters deep, which increases in thickness towards the base. The Benin Formation is the name of the freshwater-bearing formation in the study area. The Agbada Formation sits directly beneath the Benin Formation composed of alternating sandstone and shales deposited where the lower deltaic plain and the continental shelf fronts of the delta converge (Short and Stäuble, 1967). The Agbada Formation began to form in the Eocene and is currently continuing to Recent.

The Agbada Formation, which is estimated to be about 3700 meters thick, is the primary unit that bears petroleum. The Agbada Formation sandstone is in the rollover anticlines associated with the growth faults that occurred concurrently with soil deposition. It contains most of the hydrocarbon accumulations in the Niger Delta (Doust *et al.,* 1990) The Paleocene to Recent Akata Formation is made up of a thick shale sequence (possible source rock) that is located beneath the expanding delta.

Groundwater data sampling

The materials used in this project were subjected to quality control checks before usage. The tools that were used included correctly calibrated apparatuses, reagents (non-solid materials for analysis), equipment (AAS model: FS

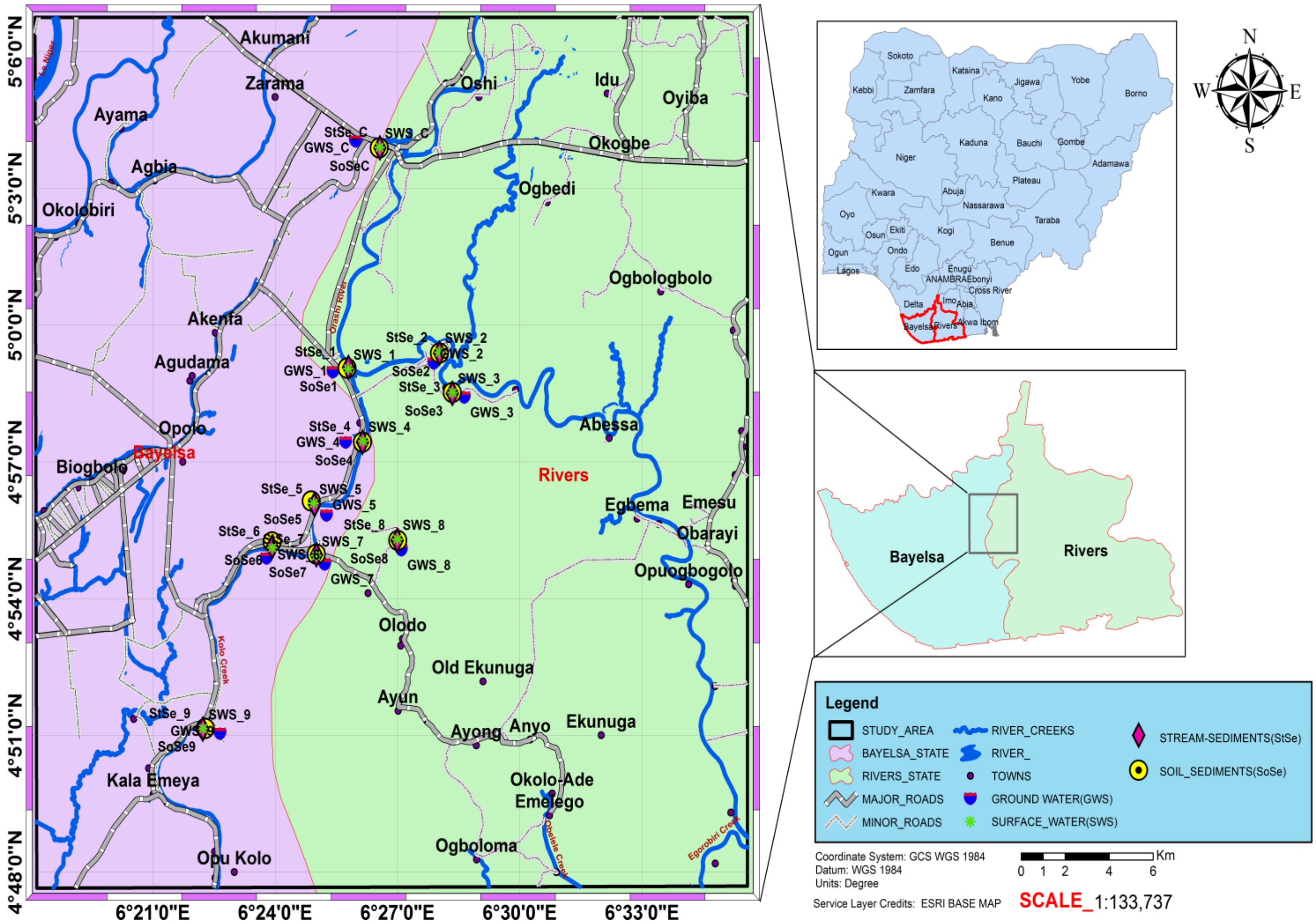

Figure 1. Location map of the study area (Ajayi and Okeke, 2024).

240 Varian Atomic Absorption Spectrophotometer), and software (ArcGIS, Surfer, and Geo-statistical Analysis, IBM SPSS 23 edition). Samples were taken throughout the wet season (May, June, and July) and the dry season (December, January, and February) in accordance with Ajayi and Okeke (2024). The sample beakers and containers were completely cleaned and immersed in distilled water that had been acidified with 1.0 millilitres of HNO^3 for three (3) days prior to the field sampling activity. After collecting groundwater, it was placed in polypropylene beakers for analysis and storage. To guarantee total removal of suspended particles, each sample was filtered into a sample bottle using single-use filters with a diameter of 0.45 m after the bottle was cleaned with the aliquot. To stop heavy metals from precipitating, 1.0 ml of concentrated HNO_3 was added to the samples in the field, and three drops of HNO_3 were added with fresh syringes to stop sorption. The samples were kept at 4 degrees Celsius in hermetically sealed, ice-packed beakers.

Groundwater samples were taken at ten georeferenced locations (Table 1). Ten shallow boreholes were drilled for 15 minutes to a depth of six meters (6 m), at Okarki, Igovia, Ikodu, Otegwe, Otuasega, Oruma, Obedum, Odan, Imiringi, and Mbiama locations. The samples were transported to the laboratory for analysis. The analysis of heavy metal was carried out according to regulatory standards as reported by Adeyemi and Ojekunle (2021) and Rice *et al*. (2012). Eight heavy metals were considered, which include copper, lead, cadmium, chromium, mercury, zinc, iron and Aluminum

RESULTS AND DISCUSSIONS

Tables 2 and 3 present the concentration values of the heavy metals across the study area during the wet and dry seasons. The values of iron in the dry season vary from 24.87 to 53.46 mg/l, with a control point value of 29.04 mg/l and a mean value of 37.75 mg/l, while in the wet season, it varies from 25.88 to 53.17 mg/l, with a control point value of 27.06 mg/l and a mean value of 36.40 mg/l (Figure 3). The value of Fe^{2+} is generally high during the dry season

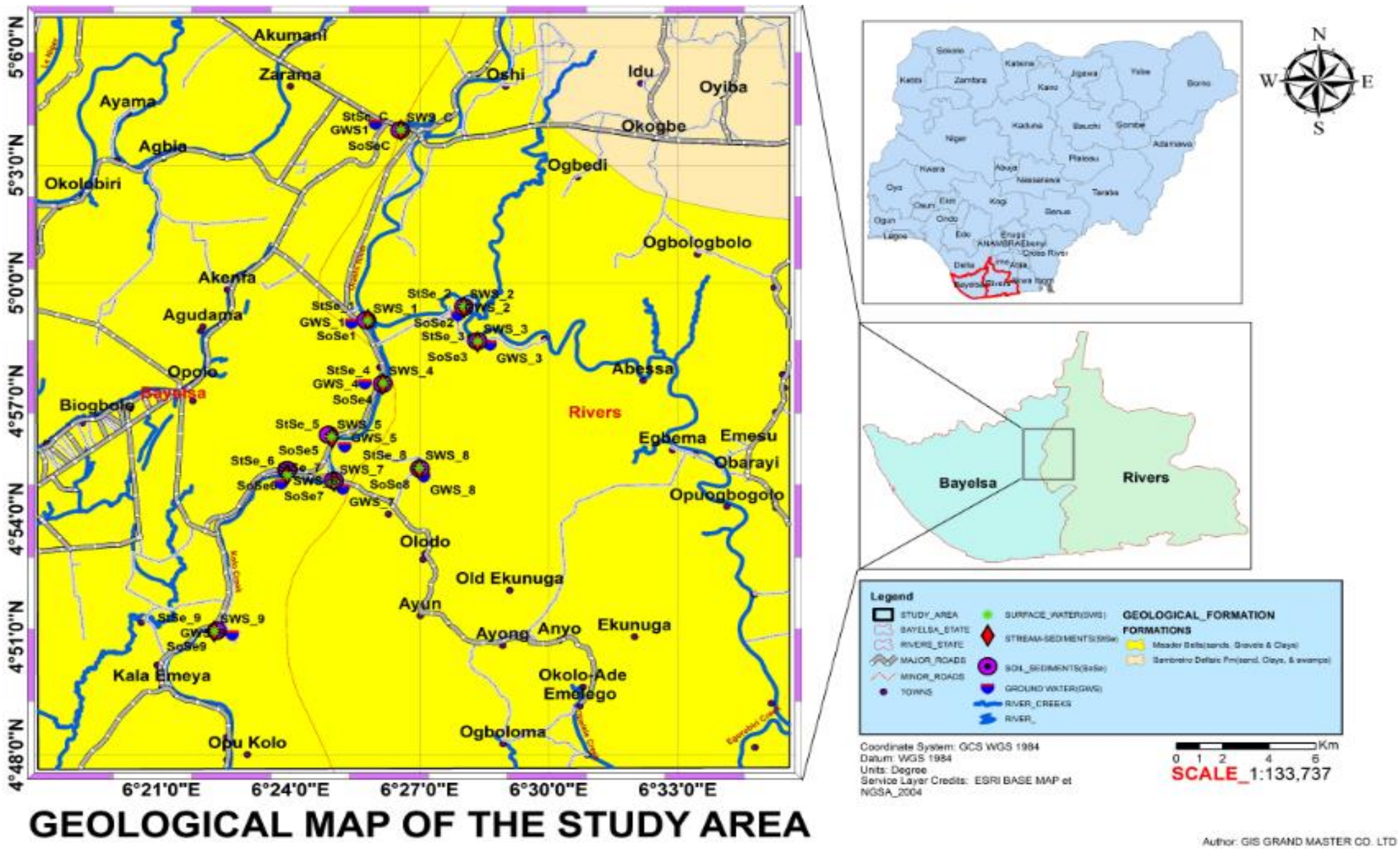

Figure 2. Geological map of the study area showing sampling points (Ajayi and Okeke, 2024).

Table 1. Ground water sample ID and coordinates.

Sample ID	Latitude	Longitude
GWS_C	5.0671	6.4329
GWS_1	4.9828	6.4237
GWS_2	4.986	6.4649
GWS_3	4.9735	6.4774
GWS_4	4.9571	6.4289
GWS_5	4.9304	6.421
GWS_6	4.9147	6.3965
GWS_7	4.9125	6.4203
GWS_8	4.9176	6.4516
GWS_9	4.8506	6.3775

and higher than in the wet season. The higher average Fe^{2+} concentration in the study area is believed to have been caused by groundwater recharge through deep percolation, prolonged rainfall, and greater dilution, whereby dissolved Fe^{2+} from specific scraps, metallic wastes, and lateritic Fe^{2+} inside soil particles are washed and leached into water bodies.

As a result, higher Fe^{2+} readings were obtained during the wet season compared to the dry season. This finding is in agreement with the work of (Amangabara and Ejenma, 2012). The value of Fe^{2+} in all the stations far exceeds the limit of the WHO (2017) for drinking water. The concentration value is quite high in Okarki, Igovia, and Otegwe communities because of the continuous discharge of wastes into the environment, which has greatly impacted the quality of the underground water. This assertion is

Table 2. Physiochemical properties of Kolo Creek ground water (dry season).

Station	Units	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	TM	Min.	Max.	WHO 2017
Coordinates	Latitude	5.06	4.98	4.99	4.98	4.96	4.93	4.92	4.92	4.92	4.85				
Parameters	Longitude	6.44	6.43	6.47	6.47	6.44	6.42	6.40	6.42	6.45	6.37				
Iron	mg/l	53.46	45.17	38.75	41.67	41.52	36.24	33.27	24.87	33.47	29.04	37.75	24.87	53.46	0.3
Lead	mg/l	0.01	0.01	0.00	0.01	0.01	0.03	0.01	0.00	0.01	0.00	0.01	0.00	0.03	0.01
Copper	mg/l	0.60	0.33	0.53	0.67	0.40	0.60	0.10	0.30	0.57	0.17	0.43	0.10	0.67	2.0
Cadmium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.003
Chromium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Zinc	mg/l	1.22	0.76	0.99	1.40	1.05	0.90	0.92	1.01	1.08	0.20	0.95	0.20	1.40	3.0
Mercury	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.006
Aluminum	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10max

TM = Total Mean, Min. = Minimum; Max. = Maximum.

Table 3. Physiochemical properties of Kolo Creek ground water (wet season).

Station	Units	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	TM	Min.	Max.	WHO 2017
Coordinates	Latitude	5.0648	4.9845	4.9897	4.9751	4.9572	4.9344	4.9189	4.916	4.9213	4.8523				
Parameters	Longitude	6.4428	6.43	6.4672	6.4725	6.4358	6.4161	6.3988	6.4169	6.4499	6.3704				
Iron	mg/l	50.23	53.17	45.33	28.11	36.24	29.55	30.14	25.88	38.26	27.06	36.40	25.88	53.17	0.3
Lead	mg/l	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.02	0.01
Copper	mg/l	0.73	0.40	0.33	0.80	0.23	0.57	0.07	0.43	0.63	0.10	0.43	0.07	0.80	2.0
Cadmium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.003
Chromium	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Zinc	mg/l	1.17	0.79	1.01	1.30	1.15	0.93	0.88	1.18	1.11	0.20	0.97	0.20	1.30	3.0
Mercury	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.006
Aluminum	mg/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10max

TM = Total Mean, Min. = Minimum; Max. = Maximum.

evident from the land use and cover map (Figure 8).

Cu^{2+} values range from 0.10 to 0.67 mg/l, with 0.17 mg/l at the control point and a mean value of 0.43 mg/l, while in the wet season, it ranges from 0.7 to 0.80 mg/l, with 0.43 mg/l at the control point and a mean value of 0.10 mg/l. The value of Cu^{2+} is approximately the same for the two seasons showing no significant change between the two seasons. The mean concentrations of zn^{2+} in the dry season vary along the stretch of the creek from 0.20 to 1.3 mg/l, with a control point value of 0.20 mg/l and a mean value of 0.97 mg/l. However, the mean concentrations of zn^{2+} in the wet season vary along the stretch of the creek from 0.24 to 1.40 mg/l with a control point value of 0.20 mg/l, the mean value is 0.95 mg/l (Tables 2 and 4). The zn^{2+} concentration is generally higher in the wet season

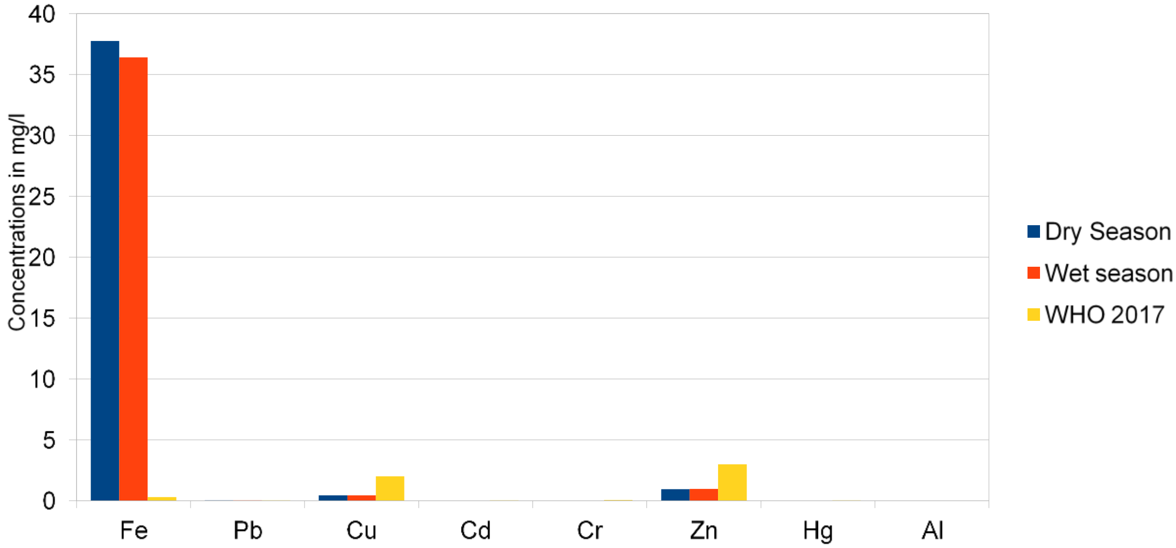

Figure 3. Mean concentration of heavy metals in Kolo Creek ground water.

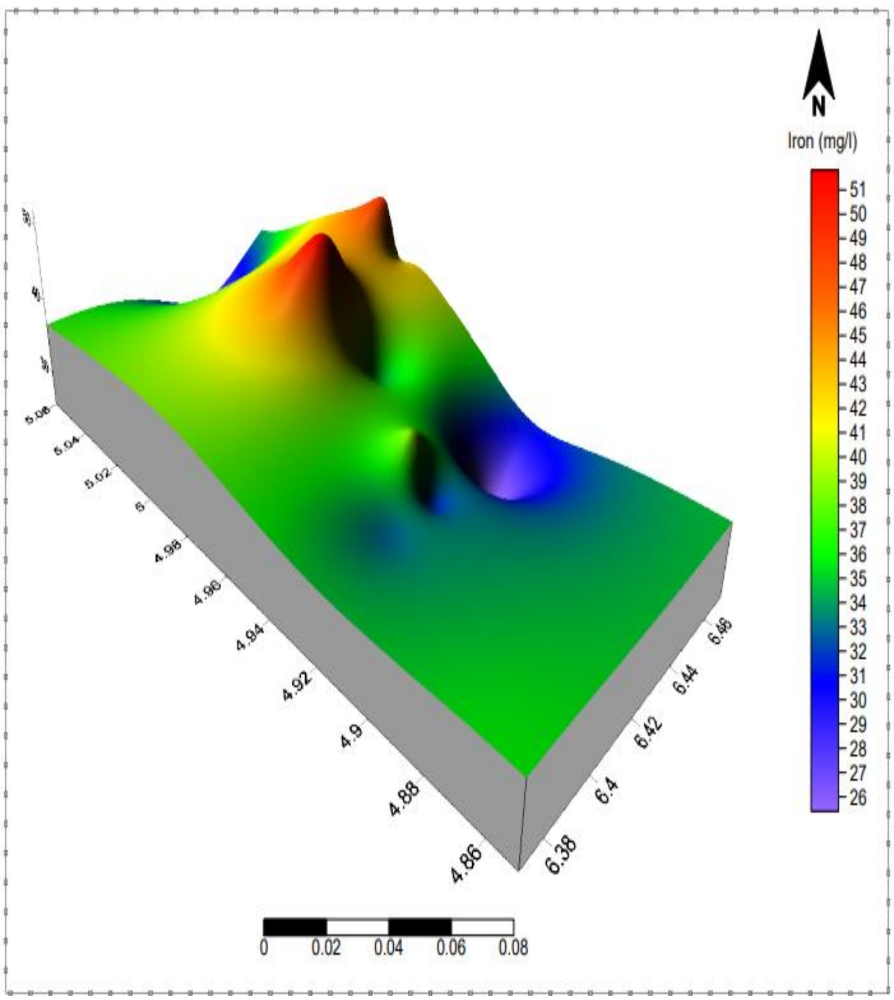

Figure 4a. 3D view of Iron in Kolo Creek groundwater.

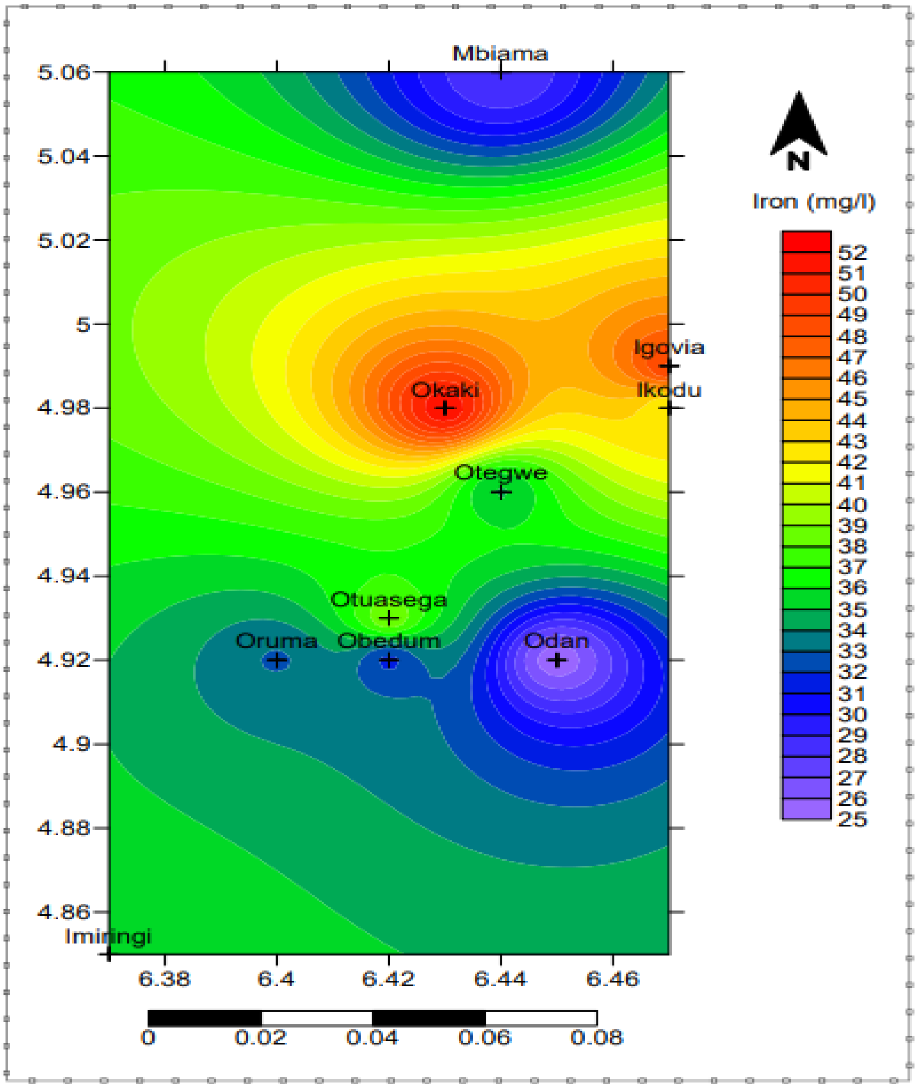

Figure 4b. Spatial Distribution of Iron in Kolo Creek groundwater.

than in the dry season. The concentrations of Pb^{2+} in the dry and wet seasons vary along the stretch of the creek from 0.00 to 0.05 mg/l, respectively, with no detection at the control point and a mean value of 0.03 mg/l slightly exceeding the WHO (2017) standard. The value of Pb^{2+} is generally the same in the two seasons. Figures 4 to 7 present the spatial distributions and 3D view plots of the heavy metals. The study indicates areas with high and low concentrations of heavy metals in the study area, while Figure 3 shows the mean concentration plot of the heavy metals.

Evaluation of health risk of the groundwater samples

Human health risk assessment (HHRA) deals with the potential harm to a population's health which can result from exposure to heavy metals. It is separated between risk assessments that are carcinogenic and those that are none carcinogenic (USEPA, 2011; Zheng *et al.,* 2010). The procedures adopted by Okafor *et al.* (2024) were used to determine the HHRA for the 10 groundwater samples that were analyzed. The equations utilized were Chronic Daily Intake by Ingestion (CDI ing, equation 1).

CDI_{ing} = …………........... (1)

Where CS is the concentration of the constituent of interest and IR is the ingestion rate, exposure frequency (EF) is 350 days; exposure duration (ED) is 48.9 years and 6 years for adults and children; conversion factor (CF) is 1.00E-06; body weight (BW) is 70 kg and 15 kg for adults and children

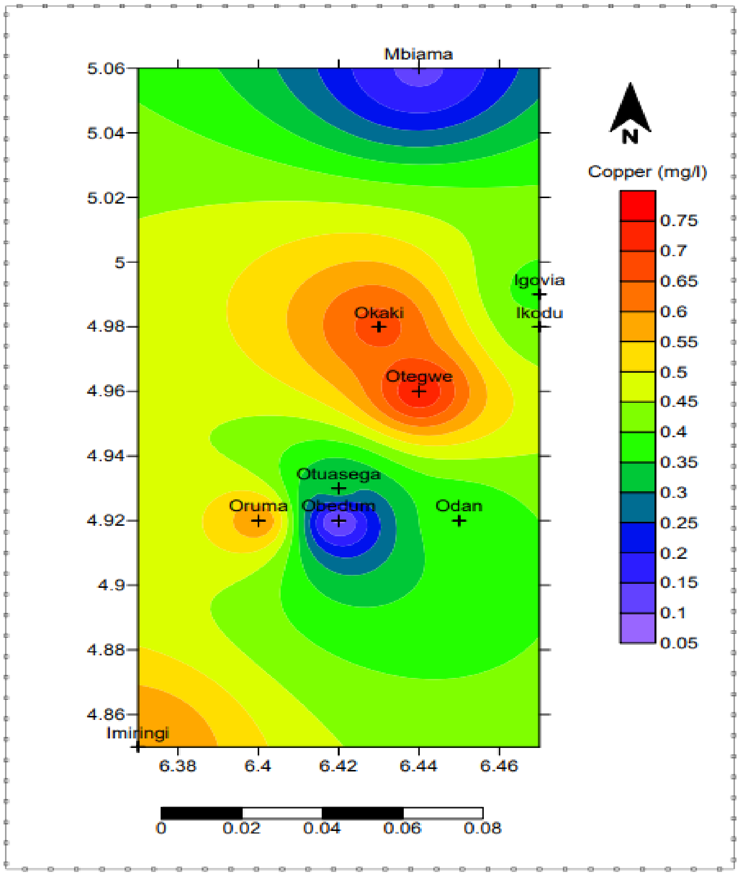

Figure 5a. Spatial distribution of copper in Kolo Creek groundwater.

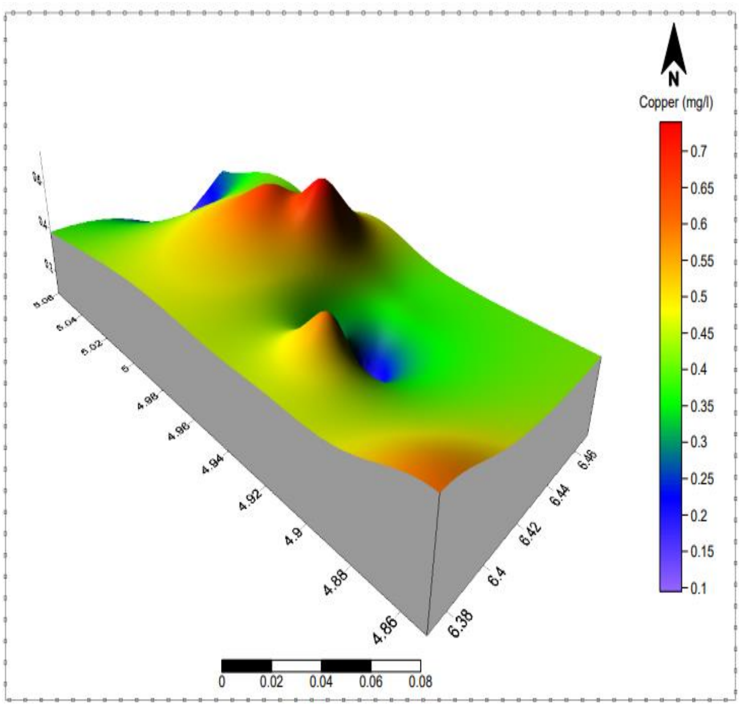

Figure 5b. 3D view of copper in Kolo Creek groundwater.

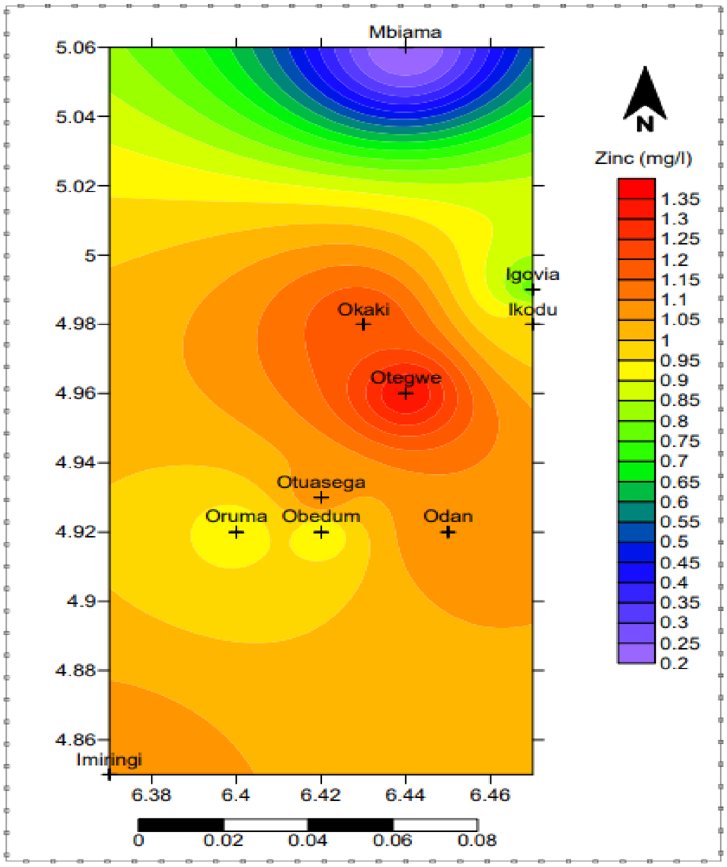

Figure 6a. Spatial Distribution of Zinc in Kolo Creek groundwater.

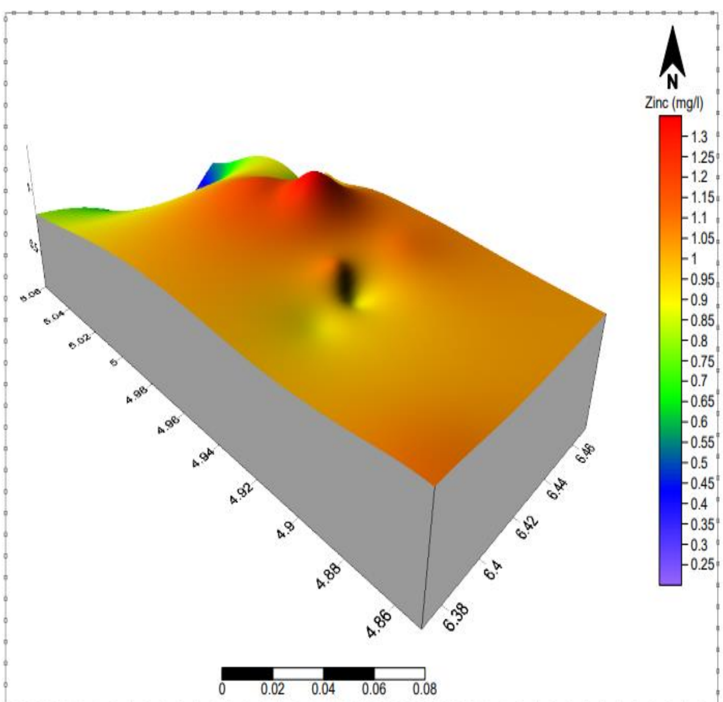

Figure 6b. 3D view of Zinc in Kolo Creek groundwater.

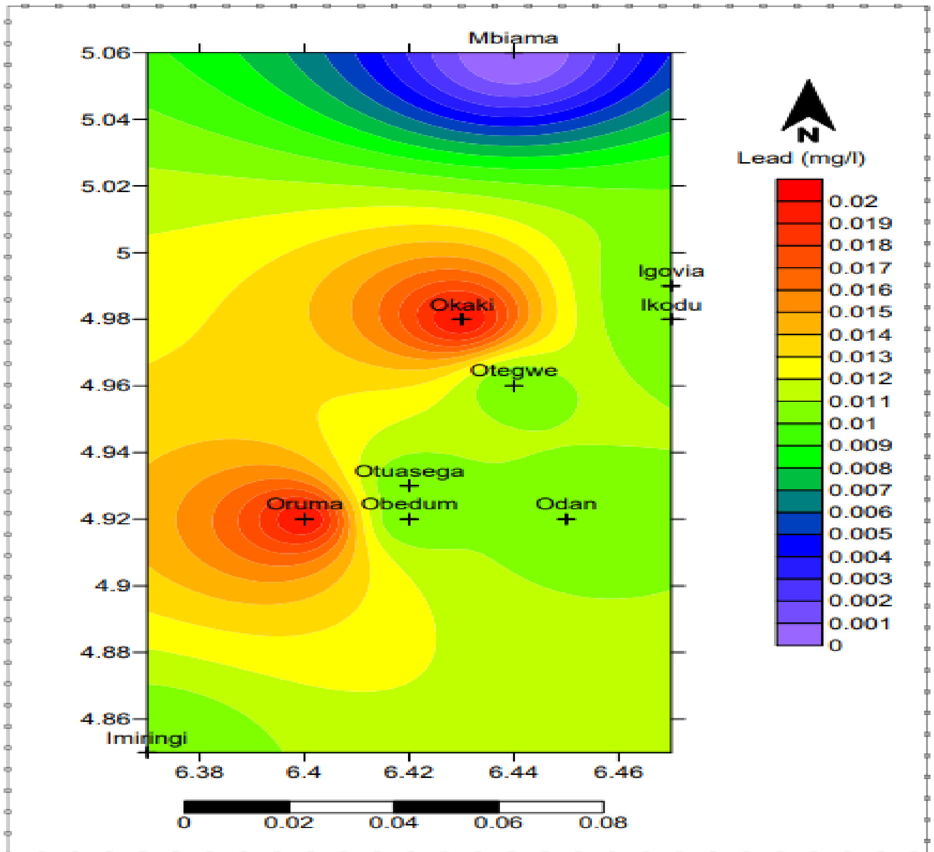

Figure 7a. Spatial Distribution of Lead in Kolo Creek groundwater.

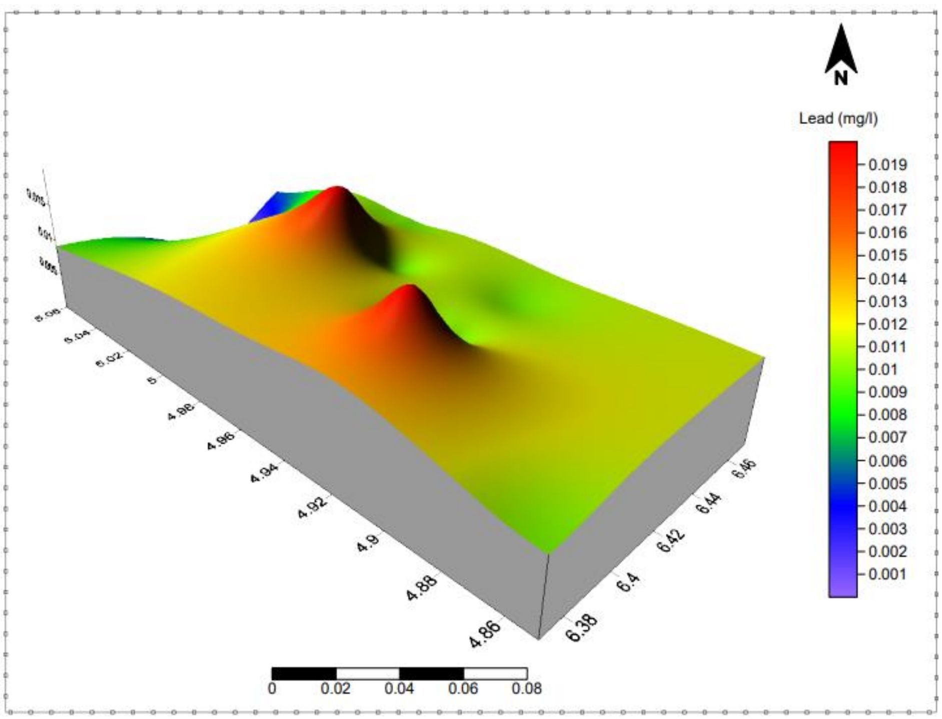

Figure 7b. 3D view of Lead in Kolo Creek groundwater.

Table 4. Risk grades and values of cancer risk assessment standards (Adeyemi and Ojekunle, 2021; Joel *et al.,* 2018).

Risk Grades	Range of Risk value	Acceptability
Grade I (Extremely Low Risk)	*<10−6*	Completely Accepted
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)	5×10−5,10−3	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

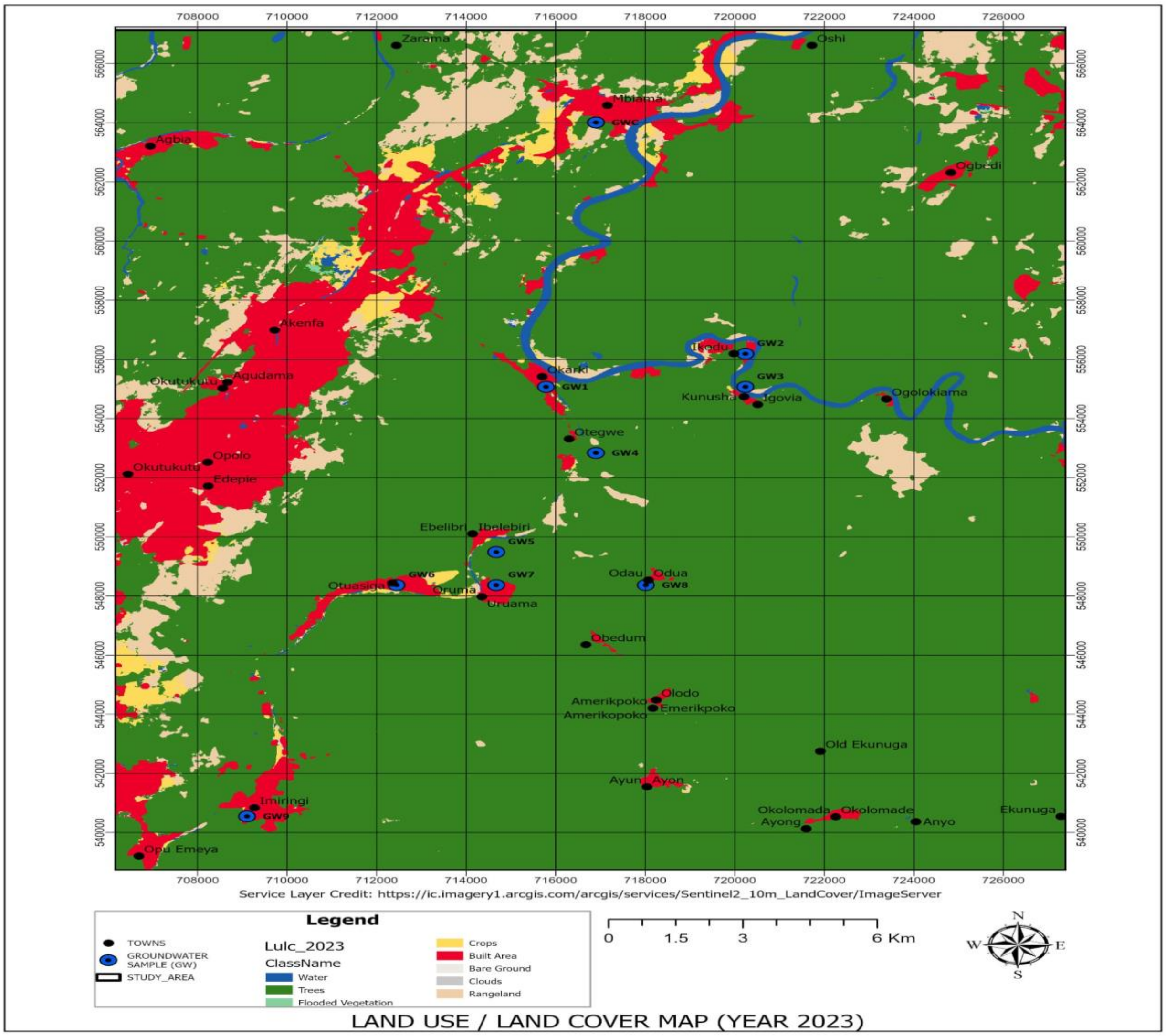

Figure 8. Land use/cover map of the study area.

respectively; average time (AT) is 70 × 365 for carcinogens and 2.2 L/day and 0.78 L/day for adults and children respectively (Okafor *et al.*, 2024).

The carcinogenic risk assessment is given in Equation 2:

$$Risk_{total} = Risk_{ing} = (CDI_{ing}) \times CSF \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Table 5. Hazard quotient and Hazard indexes of heavy metal in the groundwater samples (Ingestion)

Location	HQ(Adult)								HI
	Fe	Pb	Cu	Cd	Cr	Zn	Hg	Al	
S1	1.57554	0.250915	0.40251	0	0	0.085381	0	0	2.314346
S2	1.667542	0.125458	0.219551	0	0	0.058059	0	0	2.07061
S3	1.421854	0.250915	0.182959	0	0	0.0741595	0	0	1.9298875
S4	0.88155	0.188187	0.439102	0	0	0.0951388	0	0	1.6039778
S5	1.136647	0	0.128071	0	0	0.0839173	0	0	1.3486353
S6	0.926714	0.083638	0.311031	0	0	0.0683048	0	0	1.3896878
S7	0.945429	0.083638	0.036592	0	0	0.0641577	0	0	1.1298167
S8	0.811711	0.083638	0.237847	0	0	0.0863567	0	0	1.2195527
S9	1.200003	0.062729	0.347622	0	0	0.0812339	0	0	1.6915879
S10	0.848826	0	0.054888	0	0	0.0146367	0	0	0.918351
A	1.141582	0.1129118	0.2360173	0	0	0.07113454	0	0	1.561645

Table 6. Hazard quotient and hazard indexes of heavy metal in the ground water samples (Ingestion).

Location	HQ(Children)								HI
	Fe	Pb	Cu	Cd	Cr	Zn	Hg	Al	
S1	3.731619	0.5942857	0.9533333	0	0	0.202222222	0	0	5.4814603
S2	3.9495238	0.2971429	0.52	0	0	0.137511111	0	0	4.9041778
S3	3.367619	0.5942857	0.4333333	0	0	0.175644444	0	0	4.5708825
S4	2.0879238	0.4457143	1.04	0	0	0.225333333	0	0	3.7989714
S5	2.6921143	0	0.3033333	0	0	0.198755556	0	0	3.1942032
S6	2.1948952	0.1980952	0.7366667	0	0	0.161777778	0	0	3.2914349
S7	2.239219	0.1980952	0.0866667	0	0	0.151955556	0	0	2.6759365
S8	1.9225143	0.1980952	0.5633333	0	0	0.204533333	0	0	2.8884762
S9	2.8421714	0.1485714	0.8233333	0	0	0.1924	0	0	4.0064762
S10	2.010419	0	0.13	0	0	0.034666667	0	0	2.1750857
Average	2.703802	0.2674286	0.559	0	0	0.16848	0	0	3.69871

Where: Risk is the infinitesimal chance that a person will get cancer in their lifetime. Cancer slope factor (mg/kg/day) is known as CSF.

Equation 3 provides the non-carcinogenic risk assessment:

$HI=HQ_{ing}=$…................... (3)

The tendency to experience a health impact is represented by the hazard index (HI). The Hazard Quotient is HQ. A reference dose is defined as mg/kg/day. In Table 4, risk values categorized into seven tiers were displayed (Joel *et al.,* 2018).

The HQ results of the metals in adults and children are presented in Tables 5 and 6, respectively. The average HQ value of all the metallic elements where (Fe>Cu>Pb>Zn) and (Cr=Cd=Al =Hg) for children in the studied area is higher than one. The average HI (non-carcinogenic risk) value for adults is higher than 1, this also suggests that there would be health problems resulting from the consumption of the metallic contaminated groundwater samples by the children.

Also, the HI (non-carcinogenic risk) values for children range from 2.175 to 5.481, and the HI values of all the locations (S1–S10) are higher than 1, suggestive of health problems resulting from the consumption of heavy metals from the groundwater samples due to the presence of the investigated metallic contaminants by the children. The result revealed that the average CR (carcinogenic risk) value for Pb^{2+} in adults in all locations is 3.36E-06 which far exceeds $1×10^{−6}$ (> $10^{−6}$) as opined by Adeyemi and Ojekunle (2021) and Joel *et al.* (2018) (Table 4), suggestive of the possibility of carcinogenic risk due to prolonged intake of the contaminated groundwater system in all the study areas. The result also revealed that the average CR (carcinogenic risk) value of Pb^{2+} in children is 7.96E-06, exceeds $1×10^{−6}$ (> $10^{−6}$) and is higher than those of adults (Table 7) indicating the possibility of carcinogenic risk due

Table 7. Carcinogenic risk of heavy metals in the groundwater samples (Ingestion)

Locations	CR (Adult)			CR (Children)		
	Cd	Cr	Pb	Cd	Cr	Pb
S1	0	0	7.46E-06	0	0	1.768E-05
S2	0	0	3.73E-06	0	0	8.84E-06
S3	0	0	7.46E-06	0	0	1.768E-05
S4	0	0	5.6E-06	0	0	1.326E-05
S5	0	0	0	0	0	0
S6	0	0	2.49E-06	0	0	5.893E-06
S7	0	0	2.49E-06	0	0	5.893E-06
S8	0	0	2.49E-06	0	0	5.893E-06
S9	0	0	1.87E-06	0	0	4.42E-06
S10	0	0	0	0	0	0
Average	0	0	3.36E-06	0	0	7.96E-06

to the prolonged intake of groundwater in the study area. The cancer risk involved in the children of the study areas is three times higher than that of adults.

Conclusion

The present work studied the concentration of heavy metals such as Cd, Cr, Cu, Fe, Pb, Al, and Zn in groundwater ten wells along Kolo-Creek. The results of the present study indicated that among the eight (8) studied metals. There is an increasing concentration trend of Fe>Zn>Cu>Pb while Cr, Cd, Al and Hg were not detected. The concentrations of Fe^{2+} and Pb^{2+} exceeded the WHO (2017) standard level for drinking water quality in all the stations. Hence, they are considered a threat to human health.

The average HI (non-carcinogenic risk) values for adults and children in all the study areas are greater than 1, due to the consumption of the metallic contaminants in the groundwater. However, the average HI value of children is greater than the adult HI value, suggestive of likely greater health problems.

The CR (carcinogenic risk) values for Pb^{2+} in adults in all locations exceeded 1×10^{-6} ($> 10^{-6}$), showing the possibility of cancer risk due to the intake of the groundwater in the study area. At the same time, the average CR (carcinogenic risk) value for Pb for children far exceeded 1×10^{-6} ($> 10^{-6}$) and was higher than those of adults, also indicating the possibility of higher carcinogenic risk in children than adults.

CONFLICT OF INTEREST

The authors have no competing interests to declare that are relevant to this research article.

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