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Human health risk assessment of some toxic metals in groundwater around Iyuku, Ikpeshi district, Edo North, Edo State, Nigeria

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Abstract: The global increase in human activities has resulted in higher levels of heavy met in groundwater, which can pose a health risk through contaminated drinking water. This stu assessed the concentrations of selected heavy metals in 32 groundwater samples in Iyu Ikpeshi and environs, Edo State. The metals were analyzed using Atomic Absorpt Spectrometer (AAS). The evaluation of health risks involved determining the chronic da intake (CDI), Hazard Quotient (HQ), Hazard Index (HI), and cancer risks linked to the meta The average concentrations of most heavy metals were within the safety limits set by the WI and EPA for drinking water, except for iron, which had an average concentration of 1.28m The Average concentration of heavy metals was in decreasing or Fe>Zn>Cu>Mn>Ni>Pb>Cd. The overall hazard index including both ingestion and s contact risks was 1.547, exceeded the safety threshold for children, indicating potential n carcinogenic health hazards and was 0.592 for adults, which is below the threshold for conce Ingestion was identified as the primary exposure route. Additionally, the lifetime cancer r from lead exposure was within acceptable levels for drinking water. Still, there was significant total carcinogenic risk from Nickel (Ni) in the groundwater which was 2.29×1 for children and 8.74×10^{-4} for Adults, with children being more at risk than adults. The hea risk assessment of groundwater can be crucial for effective monitoring and management water resources in this area.

1. Introduction

The mechanization of mining in Nigeria began in 1939, driven by private enterprises. Since then, environmental degradation and public health issues associated with mining have worsened (Nwogha *et al.,* 2017). Despite research on these issues, mechanized quarrying continues to contribute to environmental hazards, particularly through the release of heavy metals. While these metals are naturally present, their elevated concentrations pose significant risks to humans and other organisms (Qasem *et al.,* 2021; Shakya and Agarwal, 2020; Karim *et al.,* 2019).

Water is much more than just a human need; it is the most vital element for life (Alilouch *et al.,* 2017). Therefore the sources of water of in an area play a central role in the satisfaction of the drinkable water requirements, in irrigation and in domestic use (El Mountassir *et al.,* 2017). In water systems, heavy metals are typically found in trace amounts, but even low concentrations can be toxic, damaging cell membranes, altering enzymes, and compromising DNA (Wu *et al.,* 2016). Chronic exposure to these metals can lead to a range of health issues, including gastrointestinal problems, kidney dysfunction, and even cancer (Egorova and Ananikov, 2017; Fernandez Azevedo *et al.,* 2012; Cobbina *et al.,* 2015). The toxicity of metals like mercury and lead can cause severe health complications, including renal failure (Bernnhoft, 2012). Several methods were proposed to remove these toxic metals to secure health and animals (Savaranan *et al.*, 2025; El Hammari *et al.*, 2022; Errich *et al.*, 2021; Deghles *et al.*, 2019).

As global concerns about water quality rise, understanding the contamination of water sources by heavy metals is crucial. These metals, though naturally occurring, are increasingly concentrated due to human activities like industrial manufacturing and mining (Omonona *et al.,* 2020; Yap and Al-Mutairi, 2021). The presence of heavy metals in water can result from natural processes, but human activities such as mining are the main sources of contamination (Taylor *et al.,* 2005). Mining contributes to heavy metal contamination through tailings and wastewater, which can affect land and water resources, even spreading over long distances.

While some trace metals are essential for life, others, like cadmium and lead, are toxic even in small quantities. Heavy metals, with high atomic density, are natural components of Earth's crust but can become dangerous when they accumulate in the environment (Garbarino *et al.,* 1995). Their toxic ionic forms can bind with biological molecules, creating stable, harmful compounds that are difficult to degrade (Duruibe *et al.,* 2007). This study aims to assess both the carcinogenic and non-carcinogenic risks associated with heavy metals found in groundwater from Ikpeshi, Iyuku and its surrounding areas in Edo North, Edo State, Nigeria. It will also provide data on the concentrations of these heavy metals in the groundwater samples.

2. Methodology

2.1. Regional geology of the *Study area*

Iyuku, Ikpeshi and environs area communities in Edo North, Edo State, Nigeria. is part of the southwestern section of the country's basement complex, which forms part of the Pan-African Mobile Belt. The region's geology is shaped by ancient crystalline rocks from the Precambrian era, including schists, granites, and gneisses, altered during the Pan-African Orogeny about 600 million years ago. The area is characterized by hills and valleys formed through faulting and folding (Oloto and Anyawu, 2013).

2.2 Local geology

The study area, Awa, is located in the southwestern part of Nigeria's basement complex, between latitudes 7° 07' 24"N and longitudes 6° 17' 03"E. The region is primarily composed of granite, gneiss, and schist, with a dendritic drainage system. The climate follows a tropical wet-dry cycle, with the rainy season from April to October and the dry season from November to March. The average annual rainfall ranges from 1,000 to 1,500 mm, with the heaviest rainfall in July and August, and a brief mid-August break (Olowojoba *et al.,* 2016).

2.3. Methodology

Sample collection:

Groundwater samples from the study area was obtained from boreholes and hand dug wells used by the local population. GPS coordinates were used to locate and mark each sample. To prevent contamination, clean, sterilized polyethylene bottles were used, and the initial liters were discarded to avoid surface runoff contamination. Samples were labeled with a unique site code, date, and time, then placed in an ice-packed cooler at 4°C for transport to the laboratory (APHA, 2005; USEPA, 2013; Mgbenu and Egbueri, 2019).

2.4. Laboratory analysis

A total of 32 groundwater samples were analyzed for toxic metal concentrations. The samples were first filtered using 0.45 µm membrane filters to remove particulate matter, ensuring accurate metal measurements. After filtration, they were stored in clean, labeled containers to prevent contamination. A 50 mL portion of each sample was treated with concentrated nitric acid (HNO_3) for acid digestion, which helps break down organic material and dissolve metals attached to particles (APHA, 2005). The samples were then heated in digestion vessels to ensure complete digestion. Toxic metals were analyzed using Atomic Absorption Spectrometry (AAS), a precise method for detecting low metal concentrations (Ukah *et al.,* 2018).

2.5. Carcinogenic and Non Carcinogenic risk assessment

Chronic daily intake (CDI) estimates the average daily exposure to a contaminant over a certain period (Nyambura *et al*., 2020). CDI was determined using the eqn 1 and 2 and values presented in Table 1. It is used in the cancer risk formula to estimate the probability of developing cancer as a result of that exposure.

Chronic Daily Intake (CDI):

$$CDI(ingestion). = \frac{C*IR*EF*ED}{BW*AT} \quad \text{eqn 1}$$

$$CDI(dermal) = \frac{C*SA*KP*ET*EF*ED*CF}{BW*AT} \quad \text{eqn. 2}$$

2.5.1 Carcinogenic risk

This is typically estimated using the Incremental Lifetime Cancer Risk (ILCR), which represents the likelihood of an individual developing any form of cancer over their lifetime due to daily exposure to a specific amount of a carcinogenic element (Sultana *et al.,* 2017).

Cancer Risk (CR): $CR = CDI * CSF$ Eqn. 3

CSF = Cancer Slope Factor

Table 1: Summary of exposure assumptions used to calculate carcinogenic and non-carcinogenic risk assessment through Ingestion and Dermal exposure.

EXPOSURE FACTOR	SYMBOLS	UNITS	ADULTS	CHILDREN	REFERENCE
Exposure frequency	EF	Years	365	365	(Duggal *et al.*, 2017)
Ingestion rate	IR	L/day	2	1.5	
Body weight	BW	Kg	70	20	
Average time	AT	Years	25550	3650	
Exposure time	ET	Hours/day	0.58	1	(USEPA, 2004)
Skin surface area	SA	cm^2	18000	6600	(USEPA, 2004)
Conversion factor	CF	L/cm3	0.001	0.001	

Kp= Skin permeability coefficient for Cu, Pb, Mn and Fe is 0.001, kp for Ni is 0.0002, and 0.0006 for Zn in this study. (Edokpayi *et al.*, 2018)

Table 2: Reference dose of selected heavy metals via ingestion and dermal pathways and cancer slope factor (CSF) (Joseph *et al.*, 2022; USEPA, 2002)

Heavy metals	Pb	Fe	Cu	Ni	Zn	Mn	Cd
Reference dose(ingestion)	0.0035	0.7	0.04	0.02	0.3	0.024	0.00002
Reference dose (dermal)	0.000525	0.14	0.012	0.0054	0.06	0.00096	0.00002
CSF	0.0085	-	-	0.91	-	-	0.38

2.5.2 Non Carcinogenic risk:

Evaluated using the Hazard Quotient (Das *et al.*, 2020)

HQ = $\frac{CDI}{RFD}$ Eqn. 4 (Das *et al.*, 2020).

2. Cumulative Hazard Index (HI): For multiple contaminants, the cumulative hazard index is calculated by summing the individual hazard quotients (HQs). The total of all the hazard quotients represents the overall potential health risk, or hazard index (Wongsasuluk *et al.,* 2014)

$HI = \sum HQ$ Eqn. 5 (Wongsasuluk *et al.,* 2014)

An HI value of less than 1 is considered safe, while an HI value greater than 1 indicates potential non-carcinogenic risk

3. Results and Discussion

3.1 Physico-chemical assessments

The result of concentration of heavy metals (Fe, Zn, Cu, Pb, Cd, Mn, Ni, Ca, Mg, K, and Na) analyzed in 32 groundwater samples and their comparison with WHO and U.S. EPA standards (WHO, 2011; EPA, 1992) is presented in Table 3. Iron concentrations in groundwater samples ranged from 0.285 mg/L to 2.754 mg/L, with an average of value of 1.28 mg/L. Zinc (Zn) levels ranged from 0.186 mg/L to 0.952 mg/L with an average value 0.63 mg/L and Copper (Cu) ranged from 0.126 mg/L to 0.564 mg/L with mean value of 0.48 mg/L. Manganese (Mn) ranged from 0.011 mg/L to 0.089 mg/L with mean value of 0.052 mg/L, and Nickel (Ni) ranged from 0.010 mg/L to 0.056 mg/L with an average value of 0.034 mg/L.

In this study, the mean concemtration of heavy metals and alkaline earths were in decreasing order of Mg>K>Fe>Ca>Zn>Cu>Na>Mn>Ni>Pb. Among heavy metals investigated, it was observed that Iron (Fe) and Manganese (Mn) concentration exceeded the WHO's recommended limit of 0.3 mg/L and 0.05mg/L respectively. Previous studies have shown that Fe and Mn naturally exist in groundwater sources (Hamer *et al.,* 2020; Koopmann *et al.,* 2020). This finding is in agreement with (Eyankware *et al.,* 2019) who attributed high maganese concentration in groundwater to industrial activities.

Table 3: Concentrations of heavy metals in groundwater samples (mg/L) and comparison with WHO and USEPA standards (WHO, 2011; USEPA, 1992).

Metals	Mean	WHO Standard	EPA Standard
Fe	1.28125	0.3	0.3
Zn	0.6319	5	5
Cu	0.4812	1.3	2
Pb	0.001	0.015	0.01
Cd	0.000	0.005	0.003
Mn	0.0527	0.05	0.1
Ni	0.0336	0.1	0.07
Ca	1.1199	-	100
Mg	5.0855	-	50
K	3.0572	-	-
Na	0.2301	-	200

High iron and manganese levels can cause health issues like gastrointestinal distress and organ damage, especially in individuals with conditions like hemochromatosis (EPA, 2021)., indicating the need for further monitoring and potential treatment. The concentrations of Zinc (Zn) and Copper (Cu) in the groundwater samples were below the (WHO, 2011 and USEPA 1992). limits, both also within safe limits. Although high concentrations of manganese have been associated with neurological effects (EPA, 2021), the levels detected in this study were within safe limits, and nickel concentrations were also below the 0.1 mg/L guideline.

The study found that calcium (Ca) and magnesium (Mg) concentrations in groundwater (1.1199 mg/L for Ca and 5.0855 mg/L for Mg) were within acceptable ranges and did not pose non-carcinogenic health risks. Lead (Pb) and cadmium (Cd), known carcinogens, were largely absent or below detectable levels, suggesting low carcinogenic risks from these metals. However, lead is linked to neurotoxicity and kidney damage, particularly in children, and cadmium is associated with renal issues and bone demineralization (WHO, 2011). Sodium (Na) concentrations, though not immediately concerning, could pose a cardiovascular risk for those with pre-existing conditions if consumed chronically, while potassium (K) levels were within safe limits, posing no significant health risks. However, some scientist believe that to evaluate the effects and health risk of exposure to heavy metals, more is needed to pay attention to the amount and concentration of these metals and ground water sources should be examined with other indicators (Dashtizadeh *et al.*, 2019). In a study, (Barzegar *et al.*, 2019) investigated the concentration of heavy metals for 29 samples of drinking water sources in Western Iran. The results of their research showed that the average concentration of some trace elements such as As, Pb and Zn was higher than the standards announced by the (WHO, 2011; Barzegar *et al.*, 2019). In another study, (Dashtizadeh *et al.*, 2019) evaluated the levels of heavy metals in the ground water sources of Zahedan city (south of Iran). Their research showed that the average levels of total trace metals were lower than the limits declared by the (USEPA 1992 and WHO, 2011). They also believed that based on these guidelines and standard, drinking water sources in Zahedan city lack health risks (Dashtizadeh *et al.*, 2019).

3.2 Human health risk assessment

The presence and distribution of heavy metals in groundwater samples may increase the risks to human health through various exposure routes (ingestion and dermal). The Assessment of human health hazards and risks involved the estimation of the type and level of negative health impacts that can develop in humans on exposure to toxic metals (USEPA, 2010)

3.2.1 Non carcinogenic risks

Human health risk evaluation is the process of assessing the nature and extent of potential adverse health effects in humans exposed to toxic metals in contaminated environments (Mohammadi *et al.*, 2019). In this study, health risks caused by ingestion and dermal exposure to toxic metals in groundwater were considered. The hazard quotient (HQ) was evaluated for both children and adults via ingestion and dermal pathways to determine potential non-carcinogenic risks associated with metal exposure. The results indicated that for children, the HQ values via ingestion followed the decreasing order: Cu > Mn > Zn > Ni > Fe > Pb > Cd, while the dermal exposure pathway showed the trend: Cu > Mn > Fe > Zn > Ni > Pb > Cd. In contrast, adults exhibited a different pattern. For ingestion, the HQ values were ranked as: Cu > Mn > Zn > Fe > Ni > Pb > Cd, whereas the dermal pathway followed the order: Mn > Cu > Fe > Zn > Pb > Ni > Cd as shown in Table 4 and Table 5.

The hazard index for both adults and children followed a similar decreasing trend with Cu > Mn > Zn > Fe > Ni > Pb > Cd via ingestion and dermal pathways.

Table 4: Summary of the Chronic daily intake (CDI), Hazard Quotient (HQ) Hazard Indices (HI) and Carcinogenic Risk (CR) associated with the ingestion and dermal exposure to selected heavy metals in groundwater among children in the study area.

METAL	CDI_{ing}	CDI(derm)	HQ_{ing}	HQ(derm)	HI	CR_{ing}	CR(derm)	TCR
Fe	0.09609	4.22×10^{-4}	0.13727	0.00301	0.1403	-	-	-
Zn	0.04739	1.25×10^{-4}	0.15797	0.00208	0.1601	-	-	-
Cu	0.03609	1.58×10^{-4}	0.90225	0.1323	0.9154	-	-	-
Pb	0.000075	3.3×10^{-7}	0.02142	0.000628	0.0220	6.375×10^{-7}	2.8×10^{-9}	6.4×10^{-7}
Cd	-	-	-	-	-	-	-	-
Mn	0.00395	1.73×10^{-5}	0.16468	0.01811	0.1827	-	-	-
Ni	0.00252	2.21×10^{-6}	0.12600	0.00041	0.1264	0.002932	2.01×10^{-6}	2.29×10^{-3}
			∑HQ= 1.50959	**∑HQ= 0.03746**				

Table 5: Summary of Hazard Quotient (HQ) and carcinogenic risk (CR), Hazard Index (HI) and Total Carcinogenic risk (TCR) via Ingestion and dermal pathways of heavy metals in groundwater for Adults in the study area.

METALS	CDI(ing)	CDI(derm)	HQ(ing)	HQ(derm)	HI	CR(ing)	CR(derm)	TCR
Fe	0.03660	1.91×10^{-4}	0.05229	0.00136	0.0536	-	-	-
Zn	0.01804	5.65×10^{-5}	0.06018	0.000941	0.0611	-	-	-
Cu	0.01374	7.17×10^{-5}	0.34371	0.00597	0.3496	-	-	-
Pb	0.00003	1.49×10^{-7}	0.00857	0.000284	0.0085	2.55×10^{-7}	1.26×10^{-9}	2.44×10^{-7}
Cd	-	-	-	-	-	-	-	-
Mn	0.00150	7.85×10^{-6}	0.06273	0.00818	0.0709	-	-	-
Ni	0.00096	1.002×10^{-6}	0.04800	0.000185	0.0482	0.000873	9.12×10^{-7}	8.74×10^{-4}
			∑HQ= 0.57548	**∑HQ= 0.01692**				

Although the HI for all metals was below 1, copper was identified as a concern, particularly for children, with an HI of 0.915, close to 1, signaling a higher potential risk (Badeenezhad *et al.*, 2023).

The calculated HQ values for all metals were below the threshold of 1, suggesting that these metals do not pose significant non-carcinogenic health risks (Guerra *et al.*, 2012). In this study it was observed that the hazard index (HI) in both children and adults via ingestion and dermal pathways suggests non-carcinogenic risk of metals (Tani *et al.*, 2005). The HI for Cu was 0.915 for children and 0.349 for Adults respectively (See Table 4 and 5). This indicates that Cu in groundwater pose the highest non carcinogenic risks among the heavy metals. Although the Cu had the highest HQs and His than those of other metals, they was still lower than 1 indicating that they are likely to have weak impact on human health. This findings is in agreement with (Wang *et al.*, 2021) who reported non carcinogenic risks of heavy metals in groundwater they investigated. Copper is crucial for several enzymes and essential in hemoglobin synthesis (Khan *et al.*, 2014). However, excessive ingestion of Cu can cause acute toxicity, leading to gastrointestinal distress, nausea, vomiting, and diarrhea (Lam *et al.*, 1985; Pizzaro et al., 1991). Nickel showed no non-carcinogenic risk, with an HI of 0.04819 for adults and 0.12641 for children. The most common health issue associated with Ni is contact dermatitis, particularly in women, due to dermal exposure, though some cases of systemic dermatitis through the oral route have been reported (Veien and Menne 1990). In this study, Pb was also below the threshold with an HI of 0.00842 for adults and 0.02205 for children, showing minimal non-carcinogenic risk. However, Pb toxicity is more harmful to children, as they excrete less Pb than adults. Lead (Pb) toxicity may cause neurodegenerative diseases, impair brain function, lower IQ, and prenatal exposure is linked to fetal abnormalities (NRC, 1993*;* Karri *et al.*, 2018).

For children, the total hazard index was 1.54, exceeding the threshold, while the THI for adults was 0.592, highlighting a greater non-carcinogenic risk for children (Adesanya *et al.*, 2020). This increased risk for children stems from their higher susceptibility to toxicity, influenced by factors like lower body weight, developing organs, and faster metabolism, making them more vulnerable to the harmful effects of toxic metals at lower exposure levels (Khalid *et al.*, 2022). These findings align with those reported in the Tarkwa Mining area of Ghana (Seidu and Ewusi2020), who examined the concentrations of heavy metals (Cd, Cu, Zn, As, Pb, Ni, Mn, Fe, Cr) in 39 groundwater samples from Tarkwa. Their results indicated that the HQ levels for all heavy metals were below one, suggesting no non-carcinogenic health risks in the area. Similarly, this study's results are consistent with those of (Dessie *et al.*, 2021) who found HQ values of less than 1 for both adults and children for Fe, Cu, Zn, Mn, Ni, Cr, Pb, and As.

3.2.2 Carcinogenic risks

Among the heavy metals assessed in this study, lead (Pb) exhibited the lowest carcinogenic risk, with estimated values of 6.4×10^{-7} and 2.55×10^{-7} for children and adults, respectively, via ingestion, and 2.8×10^{-9} and 1.26×10^{-9} via dermal exposure. These values fall well below the acceptable risk threshold, indicating minimal concern. In contrast, nickel (Ni) demonstrated the highest carcinogenic risk, with ingestion-related values of 2.29×10^{-3} for children and 8.74×10^{-4} for adults, and dermal exposure values of 2.01×10^{-6} and 2.9×10^{-3} for children and adults, respectively. The cancer risk (CR) values for Ni via ingestion for both age groups, as well as dermal exposure for adults, exceeded the (USEPA, 2011) acceptable limit of 1×10^{-4}, highlighting nickel as a potential carcinogenic hazard—particularly for children through the ingestion pathway.. This suggests that that they may have a considerable impact on human health in the area; consistent with the findings of this study (Mohammadi *et al.*, 2019) reported the Carcinogenic risk of Cr, Cd, and Ni in drinking water of khorramabad, Iran. Their research reported carcinogenic risk levels exceeding the acceptable threshold, which aligns with our current findings, indicating a substantial health concern. This outcome is particularly consistent with the elevated risk associated with nickel observed in our study.

4. Conclusion

This study aimed to assess the health risks associated with exposure to heavy metals in Iyuku, Ikpeshi and environs. Risk assessment was carried out through dermal and ingestion pathways using water samples from the region. The results showed that the average concentrations of heavy metals in the groundwater followed this order: Fe > Zn > Cu > Mn > Ni > Pb > Cd. The concentration of iron exceeded the maximum allowable limit, while the levels of Zn, Ni, Cu, Pb, Cd, and Mn were within the acceptable ranges set by both (WHO, 1995). The hazard quotient (HQ) values for these metals were all below 1, indicating a low non-cancer risk. However, the total hazard index (THI) for children was above 1, while for adults, it was below 1, suggesting that children face a higher non-carcinogenic risk due to their greater exposure and lower body weight. Immediate action is needed, including water treatment measures (e.g., nanofiltration, ultrafiltration) and efforts to reduce contamination sources. Public health campaigns and awareness programs are also crucial for promoting safe water practices. The government should establish a body responsible for eliminating heavy metals from water through both physical and chemical methods. Monitoring wells should be sited at strategic locations within the study area in order to carryout periodic assessments of contaminant levels in the groundwater. Hence further research on direction of groundwater flow in the area should be investigated for proper aquifer characterization and contamination control.

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Compliance *with Ethical Standards*: This article does not contain any studies involving human or animal subjects.

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