-Available online www.unicrossjournals.com

UNICROSS JOURNAL OF SCIENCE AND TECHNOLOGY, UJOST

RESEARCH ARTICLE VOL. 3(2) MARCH 31, 2024 ISSN:2814-2233
Date Approved June 30, 2024 Pages 95- 110

RISK ASSESSMENT OF HEAVY METALS IN GROUNDWATER FROM ASSIGA AND UGEP COMMUNITIES OF YAKURR LOCAL GOVERNMENT AREA OF CROSS RIVER STATE.

NKOM, P. Y. [1, 3,] ETINOSA-OKANKAN, 0.P. [2,3]

[1]Department of Chemistry, University of Cross River State, Calabar, Nigeria
[1]Department of Biochemistry, University of Cross River State, Calabar, Nigeria
[1]Environmental/Organic Research Group, Department of Chemistry, University of Cross River State, Calabar, Nigeria.
E-mail: patiencenkom6@gmail.com

Abstract

Human-induced activities in Yakuur Local Government Area has worsened water quality during the last ten years due to rapid urbanisation. Data was collected from two communities (Assiga and Ugep) to assess the impacts of heavy metals in groundwater quality. Samples were analysed for heavy metals such as Cr, Cu, Zn, Cd and Pb using Atomic Absorption Spectrophotometer (AAS). Results obtained from the two sampling sites followed the trend: Zn >Cr >Cu > Pb > Cd. Compared with WHO (2006) guidelines, results showed that groundwater samples were heavily contaminated with Cr and Cd, while others were within the WHO permissible limits. Results of the contamination factor index (CFI) for sample A reveals that Zn, Cu and Pb were low, while Cd and Cr had very high contamination factor index, indicating influx of cadmium and chromium containing waste at the site. Sample B also indicated low CFI for Zn, Cu and Pb, moderate CFI for chromium and very high CFI for Cd. Exposure risk reveals that children population are more vulnerable to the toxic effect of the metals in the groundwater from both communities. Ingestion route was the main exposure route for non-carcinogenic risk in adult and children. The carcinogenic risk shows that adult and children population are at risk of having cancer due to the ingestion of Pb and Cr in the groundwater over a life time period. There is therefore, need for regular monitoring and awareness creation by the Environmental Protection Agency (EPA) to curb anthropogenic activities that contaminants the groundwater (heavy metals) which may pose serious health risks to the inhabitants.

Keywords: Human-induced, heavy metals, groundwater, risk-assessment, contamination factor index.

1.0 Introduction

Heavy metals present in trace concentration play a key role in the metabolism and healthy growth of plants and animals, but their increased concentration may have several toxicological effects on human beings. There are two main sources of heavy metals in water (i) natural and (ii) human-induced. The natural sources comprise release of metals from rock weathering and their final leaching into groundwater by rock water interaction, while the human-induced sources include discharge of heavy metals into the atmosphere by burning of fossil fuels/industrial activities and, thereby, to the streams by rain, discharge of industrial effluents and sewage water into streams and surface water bodies and other activities (Purushotham *et al*., 2013). In recent years, problems of groundwater contamination by heavy metals have been a matter of great concern due to rapid industrialization and urbanization. These elements can accumulate in plants and animals then eventually gets to humans through the food chain (Singh *et al*., 2006). The major concern is their toxicity, persistence and bio-accumulative nature. Many researchers such as Ghose (2003) and Romic and Romic (2003) have worked on heavy metal contamination and its adverse effects on human body.

Heavy metals are usually found in small amounts in groundwater around industrial areas that use variety of chemicals in the manufacture of batteries, paints, pharmaceutical products, leather processing, agrochemicals, etc. These industries dispose the treated/partially treated wastewater that do/do not meet the standards in the surface water bodies such as rivers, lakes, ponds and into the sea in coastal areas. Contamination due to suite of heavy metals is also commonly reported around landfills (Bakis and Tuncan, 2011; Lu *et al.*, 2016). The other important contamination route is through excessive application of agrochemicals that are retained in the unsaturated zone and reach groundwater through irrigation return flow. Accumulation of the bio-toxic heavy metals in crops and subsequent transport in the food chain pose potential risk to human health.

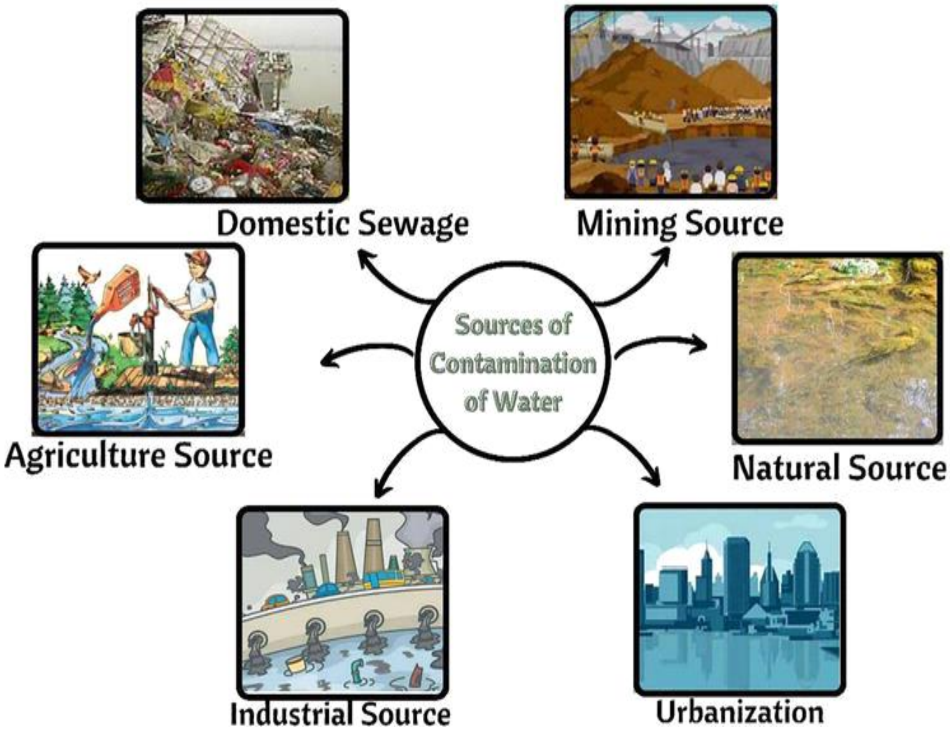

Fig. 1: Sources of heavy metals contamination in groundwater (SOURCE)

Groundwater depletion and quality deterioration has been the major concern in the area, and has been attributed to the inadequate rainfall, absence of perennial surface water resource, over exploitation and improper management of water resources and unscientific disposal of waste. Accumulation of the bio-toxic heavy metals in crops and subsequent transport in the food chain pose potential risk to human health studies. Research on heavy metal contamination in groundwater has been carried out in other parts of the country and around the world, but little or nothing has been done in Yakuur Local Government Area. It is therefore, against this background that the present investigation was carried out to assess the impact of heavy metals on these communities and to suggest adequate strategies and measures to be implemented to avoid further deterioration of groundwater in this area. The aim of this work was to determine the concentration and risk assessment of heavy metals in ground water from two communities in Yakurr Local Government Area of Cross River State and their health implications.

Table 1. Some heavy metals and their common sources (SOURCE)

Heavy metal ion	Common sources
Copper (Cu)	Fertilizers, tanning, and photovoltaic cells
Zinc (Zn)	cosmetics, and pigments
Ag) Refining of copper, gold, nickel, zinc	jewelry, and electroplating industries
Chromium (Cr)	Leather industry, tanning, and chrome plating industries
Arsenic [AS]	Wooden electricity poles that are treated with arsenic-based preservatives, pesticides, fertilizers, the release of untreated effluents, oxidation of pyrite (FeS) and arsenopyrite (FeAsS
Mercury (Hg)	Combustion of coal, municipal solid waste incineration, and volcanic emissions Cadmium (Cd) Paints, pigments, electroplated parts, batteries, plastics, synthetic rubber, photographic and engraving process, photoconductors, and photovoltaic cells
Lead (Pb)	PVC pipes in sanitation, agriculture, recycled PVC lead paints, jewelry, lead batteries, lunch

The study area is located in Yakurr Local Government Area of Cross River State on Latitude 5.8061^0 or $5^0$4822” North and Longitude 8.175^0 or $8^0$1030” East. It is one of the world’s richest biodiversity hot spots separated from the rest of the Upper Guinea Forest by the Dahomey Gap (Poorter *et al*., 2004). Yakuur, situated in the lower Guinea forest, covers a total area of 659.6 km^2, with a population of about 298,900 at the 2022 census. The hottest months of the year are February to April and the coolest month is August, having an average temperature of about 270C. There is a long-wet season from April to July, interrupted by a short dry season from September to October. Rainfall varies from 2500 mm to 3000 mm annually.

2.0 Materials and methods

Samples were collected from two (2) wells; one from Assiga (Sample A), the rural area of Yakurr and, the other from Ugep (Sample B) the capital of Yakurr Local Government Area, both in Cross River State. The two samples were collected and heavy metals concentration (Cu, Cr, Pb, Cd and Zn) were analyzed using Graphite Furnace Atomic Absorption Spectrophotometer.

Materials/Reagents: All reagents used were of analytical standard

2.1 Digestion

Samples A; Groundwater from Assiga community.

Samples B; Groundwater from Ugep community.

Two beakers were washed and dried, then labeled A and B. 100mls of water samples each from sample A and B were added to the beakers followed by 10mls of nitric acid and 5mls perchloric acid inside the beaker and heated on a hot plate until about 50mls of each sample was left. The process of heating of the water samples is called digestion. Then both samples were diluted with 100ml of distilled water and shaken, after which there were subjected to atomic absorption spectroscopy.

2.2 Health risk assessment

The potential human health risk associated with the use of borehole water from Assiga and Ugep community were evaluated using mathematical model proposed by the United States Environmental Protection Agency (USEPA). The model considers the major route in which humans are exposed to heavy metal contamination in water. The major routes are the ingestion and dermal absorption routes. The following equations below were use in the computation of the health risk associated with the borehole water.

$$XP_{ing} = \frac{C_{water} \times IR \times EF \times ED}{BW \times AT} \quad \text{Equation}$$

$$XP_{derm} = \frac{C_{water} \times SA \times KP \times ET \times EF \times ED \times CF}{BW \times AT} \quad \text{Equation}$$

Where XP_{ing} and XP_{derm} represents the exposure dose through ingestion and dermal contact (Mg/Kg/day). The parameters of the health risk assessment are represented in the table below for non-carcinogenic risks, the hazard quotients (HQs) for ingestion and dermal contact were evaluated using Equations 3 and 4. The hazard index (HI) was evaluated using Equation 5 and 6. The HQ or HI < 1, signifies no risk, while the HQ or HI l ≥ signifies risk.

Table 2: Parameters for health risk assessment

Parameter	Unit	Adult	Children
Concentration of water (C_{water})	Mg/l	-	-
Ingestion rate (IR)	L/day	2.2	1.8
Exposure frequency (EF)	Days/year	365	365
Exposure duration (ED)	Years	70	6
Average body weight (BW)	Kg	70	15
Average time	Days	365×70	365×6
Exposed skin area	Cm^2	18000	6600
Dermal permeability coefficient in water	Cm/h	Cu, Cd (0.001), Cr (0.002), Zn (0.0006), Pb (0.004)	Cu, Cd (0.001), Cr (0.002), Zn (0.0006), Pb (0.004)
Exposure time (ET)	h/day	0.58	1.0
Conversion factor (CF)	L/cm^3	0.001	0.001

$$HQ_{ing} = \frac{XP_{in}}{RFD_{ing}}$$ Equation 3

$$HQ_{derm} = \frac{XP_{derm}}{RFD_{derm}}$$ Equation 4

$$HI = \sum_{i=1}^{n} XP_{ing}$$ Equation 5

$$HI = \sum_{i=1}^{n} XP_{erm}$$ Equation 6

$$CR_{ing} = \frac{XP_{ing}}{SF_{ing}}$$ Equation 7

Where CR_{ing} and SF_{ing} represent carcinogenic risk and carcinogenic slope factor via ingestion route

Carcinogenic risk values which exceed 10^{-6} to 10^{-4} was assumed to cause cancer over a life time period.

Table 3: Reference doses and cancer slope factors for non-carcinogenic and carcinogenic risks (SOURCE)

Heavy metals (Mg/l)	Reference dose (Mg/Kg/day)		Slope factor (Mg/Kg/day)
	Ingestion	Dermal	Ingestion
Cd	0.001	0.000025	6.3
Cr	0.003	0.003	0.5
Pb	0.0014	0.000524	0.0085
Zn	0.30	0.06	-
Cu	0.04	0.012	-

3.0 Results and discussion

3.1 Concentration of heavy metals in samples A and B

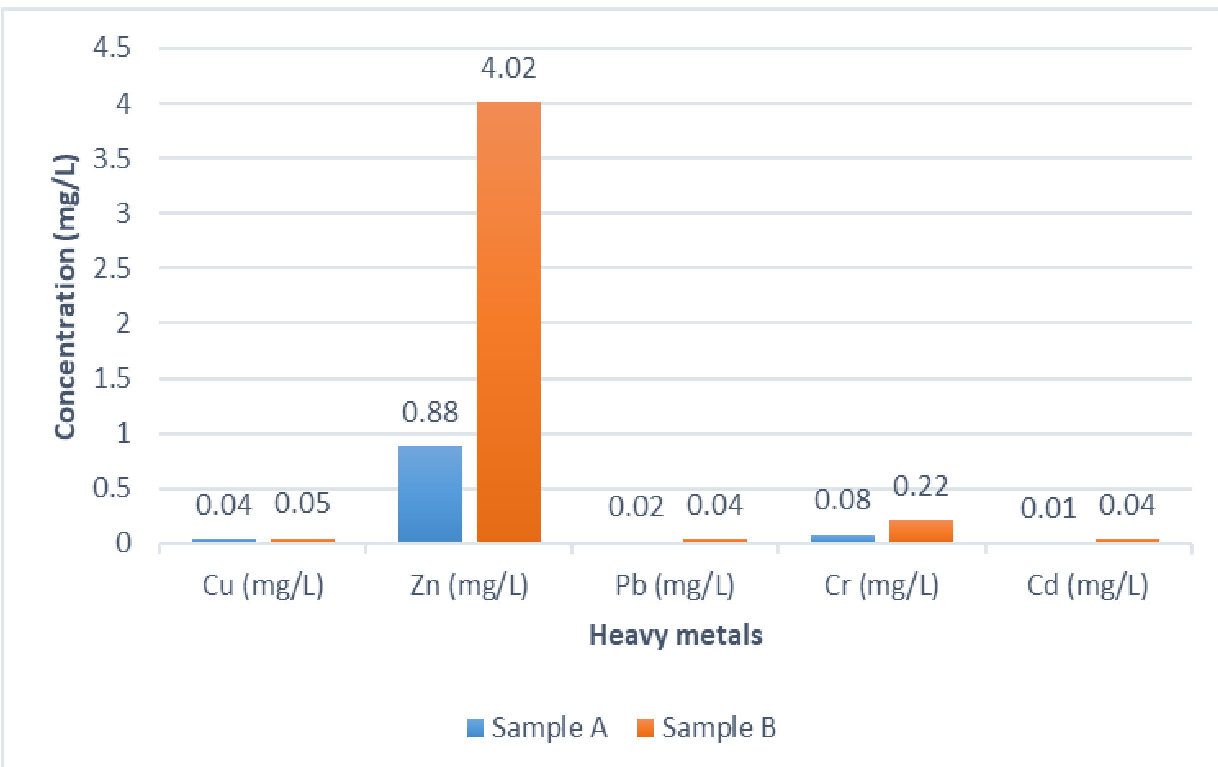

Fig. 3: Chart showing the concentrations of heavy metals in samples A and B

Table 4: Results of concentration of heavy metals in samples A and B

Sample	Cd (mg/L)	Cr (mg/L)	Pb (mg/L)	Zn (mg/L)	Cu (mg/L)
A (Assiga village	0.01	0.08	0.02	0.88	0.04
B (Ugep town)	0.04	0.22	0.04	4.02	0,05
WHO (2006) permissible values for water	0.001–0.005	0.10	0.10	5.00	3.00

The recorded values of heavy metal concentrations in sample A (Assiga) and B (Ugep) are presented in table 4 above. According to Twumasi *et al.*, (2016), the composition of the disposed waste materials and the rate of microbial decomposition significantly impacts on the heavy metals concentration in the soil. The concentration of heavy metals at the 2 sites generally follows the same trend: Zn >Cr >Cu>Pb>Cd.

Zinc concentration in sample A was 0.88 mgL^{-1}, while that of sample B was 4.02 mgL^{-1}. The presence of Zn within the sampling location may be linked to disposal of heavy metal substances which includes presence of dry cells, cosmetics and the burning of electronic waste (Twumasi *et al.*, 2016). Zn is a micronutrient which plays an important role in enzymatic reactions and its presence in the water may lead to less uptake of Cd by plants (Chahab *et al.*, 2010). The concentration of Zn in both samples was less than World Health Organization permissible concentration limit which is 5 mgL^{-1}.

Cadmium is an uncommon heavy metal but perceived as one of the most injurious heavy metals on the health of mankind (Kumar *et al.*, 2015). Results from this study revealed that cadmium concentrations in samples A and B were 0.01 mgL^{-1} and 0.04 mgL^{-1}, respectively, which were higher than the World Health Organization permissible limits (0.001-0.005 mgL^{-1}). The high concentration of Cd at the study site may be associated with high inputs of cadmium materials from sludge, batteries, Polyvinyl Chloride (PVC) materials, coatings and motor oils.

Lead (Pb) is considered a toxic heavy metal and affects humans if ingested into the body (Olayiwola *et al.*, 2017). At higher concentrations, Pb significantly interrupts water balances, enzyme activities and mineral nutrition. Pb at sample A was 0.02 mgL^{-1}, while that of sample B was 0.04 mgL^{-1}, slightly higher than World Health Organization permissible value of 0.1 mgL^{-1}. This could be attributable to the high disposal of waste materials containing batteries, food packaging material, PVC materials and insecticides (Twumasi *et al.*, (2016).

Copper (Cu) is one of the eight essential plant nutrients and is required for many enzymatic activities in plants and also for chlorophyll and seed production. Increased soil Cu concentrations cause toxic effects in plants and microorganisms (Koen *et al.*, 2012), and its deficiency can lead to increased exposure to diseases like ergot, which can cause significant yield loss in grains. Results from this study revealed that Cu concentrations in samples A and B were 0.04 mgL^{-1} and 0.05 mgL^{-1}, respectively, which was less than World Health Organization permissible limits (5 mgL^{-1}). The low concentration of Cu at the study site may be associated with low inputs of copper materials from fertilizers, animal manures, biosolids, and pesticides.

The presence of chromium (Cr) in the soil can be linked to various sources which includes contamination from human activities such as application of pesticides and fertilizers that contain chromium, improper disposal of industrial waste, and the disposal of fossil fuels. Its negative effects include reduced growth and development of plant tissues (Xu *et al*., 2023). Cr concentration in sample A was 0.08 mgL^{-1}, while that of sample B was 0.22 mgL^{-1}, higher than the WHO permissible limits (0.01 mgL^{-1}).

3.2 Result of the contamination factor

Result of the contamination factor of heavy metals in the two samples is as shown in table 5 below:

Table 5: Result of contamination factor

Sample	Metal	CFI	Interpretation
Sample A	Zn	0.02	Low contamination
	Cu	0.03	Low contamination
	Cd	20.00	Very high contamination
	Cr	8.80	Very high contamination
	Pb	0.40	Low contamination
Sample B	Zn	0.80	Low contamination
	Cu	0.02	Low contamination
	Cd	40.00	Very high contamination
	Cr	2.20	Moderate contamination
	Pb	0.40	Low contamination

Table 4: Interpretation scale for contamination factor

Range	Interpretation
CFI< 1	Low contamination
$1 \leq$ CFI < 3	Moderate contamination
$3 \leq$ CFI < 6	Considerable contamination
CFI ≥ 6	Very high contamination

Table 4 gives the interpretation scale for contamination factor index (CFI). Results indicated that Cu, Zn and Pb recorded low contamination factors in sample A While Cd and Cr recorded very high contamination factor. For sample B, Zn, Cu and Pb recorded low contamination as opposed to Cd with very high contamination factor and Cr with moderate contamination factor.

Table 5: Oral and dermal exposure dose to heavy metals in groundwater from Assiga and Ugep communities

Metals	Assiga community				Ugep community			
	Adult		Children		Adult		Children	
	Mg/kg/day				Mg/kg/day			
	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal
Cd	3.1×10^{-4}	1.5×10^{-6}	1.2×10^{-3}	4.4×10^{-6}	1.2×10^{-3}	1.0×10^{-5}	4.8×10^{-3}	1.8×10^{-5}
Cr	2.5×10^{-3}	2.6×10^{-5}	9.6×10^{-3}	7.0×10^{-5}	6.9×10^{-3}	6.6×10^{-5}	2.6×10^{-2}	1.9×10^{-4}
Pb	6.3×10^{-4}	1.9×10^{-5}	2.4×10^{-3}	3.5×10^{-5}	1.3×10^{-3}	2.4×10^{-5}	4.8×10^{-3}	7.0×10^{-5}
Zn	2.7×10^{-2}	7.9×10^{-5}	1.1×10^{-1}	2.3×10^{-4}	1.3×10^{-1}	3.6×10^{-4}	8.9×10^{-3}	1.1×10^{-3}
Cu	1.2×10^{-3}	5.9×10^{-6}	4.8×10^{-3}	1.7×10^{-5}	1.6×10^{-3}	7.5×10^{-6}	6.0×10^{-3}	4.0×10^{-7}

The mean concentration of heavy metals obtained in groundwater from the two communities were used to compute the health risk assessment that the heavy metals could cause on exposure to humans via oral and dermal route. The computation of the risk assessment was done in accordance to the model proposed by the United States Environmental protection agency (USEPA) and the values obtained are presented in table 5. The values showed that adult and children population from Ugep community are at an increased risk of the toxic effect of the metals in the groundwater when compared to those from Assiga community. This could be attributed to the fact that Ugep, being an urban community tends to have increased anthropogenic activity as compared to Assiga, a rural community which has fewer human activities. Although. The result shows that both adult and children population in both communities are vulnerable to the toxic effect of the heavy metals present in the groundwater, the children populations tend to be more vulnerable to the toxic effect of these metals upon consumption of the groundwater. This could be attributed to differences in body size and quantity of water consumed in a day. These findings agree with the work reported by Ihenetu *et al.,* (2021), where it was reported that children population was more vulnerable to the toxic effect of most of the metals studied in borehole water from Nwangele, Imo state.

Table 7: Non-carcinogenic health risk due to the ingestion of heavy metals from borehole in Assiga and Ugep communities

Metals	**Assiga community**				**Ugep community**			
	Adult		Children		Adult		Children	
	Hazard quotient				Hazard quotient			
	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal	Ingestion	Dermal
Cd	3.1×10^{-1}	6.0×10^{-2}	1.2×10^{0}	1.8×10^{-1}	1.2×10^{0}	4.0×10^{-1}	4.8×10^{0}	7.2×10^{-1}
Cr	8.3×10^{-1}	9.0×10^{-3}	3.2×10^{0}	2.0×10^{-2}	2.3×10^{0}	2.0×10^{-2}	8.7×10^{0}	6.0×10^{-2}
Pb	4.5×10^{-1}	4.0×10^{-2}	1.7×10^{0}	$7{,}0\times10^{-2}$	4.5×10^{0}	4.0×10^{-2}	3.4×10^{0}	1.3×10^{-1}
Zn	9.0×10^{-2}	1.3×10^{-3}	4.0×10^{-0}	$4{,}0\times10^{-3}$	4.3×10^{-1}	6.0×10^{-3}	3.0×10^{-2}	2.0×10^{-2}
Cu	3.0×10^{-2}	$5{,}0\times10^{-4}$	1.2×10^{-1}	1.0×10^{-3}	$4{,}0\times10^{-2}$	6.2×10^{-3}	1.5×10^{-1}	2.0×10^{-3}
Hazard Index	**1.71**	**0.11**	**6.62**	**0.23**	**8.47**	**0.47**	**17.1**	**0.93**

The non-carcinogenic health risk value due to the presence of heavy metals in the groundwater from Assiga and Ugep community is shown in table 7. The values show that all the individual heavy metals through ingestion and dermal route for adult in Assiga community were less than unity. Which suggest that the consumption of borehole water by adult population will not pose any adverse health effect. But the Hazard index, which is a cumulative effect of the heavy metals in the borehole water was above unity implying that cumulative presence of these heavy metal will have adverse health effect on the adult population from this community when ingested. The hazard quotient value for children in the same community shows that the presence of Cd, Cr, Pb and Zn were above unity. Suggesting that an adverse health effect will occur upon ingestion of the water containing these metals by the children population except Cu whose value was below unity. The non-carcinogenic health risk value through dermal route for the children population were less than unity implying that there will be no adverse health effect through dermal route for children. The hazard index value through ingestion route for children was above unity which suggest that there will be a cumulative adverse health effect due to the presence of these heavy metals in the groundwater. There was no cumulative effect of the heavy metals in the ground water for children through dermal route.

The non-carcinogenic health risk for adult and children population in Ugep community shows that the individual metals Cd, Cr and Pb were above unity suggesting that an adverse health effect will occur due to the consumption of the groundwater through ingestion route. The hazard index which was above unity suggest a cumulative adverse health effect especially for the children population through ingestion route. Similar findings were reported by Aralu *et al.*, (2023), where the hazard index of children was higher than the adult population. The hazard quotient and hazard index for adult and children through dermal route were less than unity which implies that there will be no adverse health effect as a result of the presence of the individual heavy metals as well as cumulative presence of these heavy metals in the groundwater through dermal route. It was also shown from the non-carcinogenic risk assessment that adult and children population from Ugep community, are at higher risk of the adverse effect of the metals in the groundwater than those from Assiga community. This could be attributed to the fact that Ugep being an urban community tend to have more anthropogenic activity that may influence the concentrations of heavy metals in the environment which later finds its way into groundwater.

Table 8: Carcinogenic risk through ingestion of heavy metals in ground water from Assiga and Ugep communities

Metals	**Assiga community**		**Ugep community**	
	Adult	Children	Adult	Children
Cd	4.9×10^{-5}	1.9×10^{-4}	1.9×10^{-4}	7.6×10^{-4}
Cr	5.0×10^{-3}	1.9×10^{-2}	1.4×10^{-2}	5.2×10^{-2}
Pb	7.4×10^{-2}	2.8×10^{-1}	1.5×10^{-1}	5.3×10^{-1}

Carcinogenic risk, according to Edokpayi *et al.,* (2018), is the incremental probability that an individual will develop cancer over a life time period due to exposure under specific conditions. The carcinogenic risk associated with the borehole water via ingestion route was calculated for Cd, Cr and Pb. In most regulatory program, the carcinogenic risk value which exceeds between 10^{-6} to 10^{-4} could cause cancer over a life time period. The carcinogenic risk value for Cd in groundwater from both communities for adult and children population were within the safe range and as such, the presence Cd in the water would not cause cancer over a life time period but Cr and Pb metals in the groundwater from both communities exceeded the safe range limits hence, the consumption of the groundwater by adult and children population from these communities through ingestion route could cause cancer over a life time period. These findings agree with the work reported by Edokpayi *et al.*, (2018), where it was reported that the consumption of groundwater contaminated with Cr and Pb from Muledane area of Vhembe district, South Africa, may cause cancer in adult and children.

4.0 Conclusion

The two samples analysed exhibited the presence of heavy metals which included zinc (Zn), cadmium (Cd), lead (Pb), chromium (Cr) and copper (Cu), and their concentrations ranked as: Zn>Cr>Cu>Pb>Cd. Zinc had the highest concentration in both samples (4.02 mgL^{-1} and 0.88 mgL^{-1}), as opposed to the remaining heavy metals (Cu, Cd, Pb and Cr). Concentrations of Cd and Cr were found to be higher than WHO values for the two metals indicating influx of cadmium materials from sludge, batteries, PVC materials, coatings and motor oils, and application of pesticides and fertilizers that contain chromium, improper disposal of industrial waste, and the disposal of fossil fuels. However, the heavy metals at the two sampling locations were within the permissible limits of WHO except for Cr and Cd whose concentrations were higher than the WHO permissible limits. Zinc was considerably high in sample B and must be properly checked from time to time in order to forestall any further rise in concentration that may have adverse effect on the ecosystem. Result of the contamination factor index for sample A reveals that Zn, Cu and Pb had low contamination factor, while Cd and Cr had very high contamination factor index, indicating influx of cadmium and chromium containing waste at the site. Sample B also indicated low contamination factor for Zn, Cu and Pb, moderate CFI for chromium and very high CFI for Cd. The results generally reveal that groundwater from the two communities were mostly contaminated by Cd and Cr. The health risk assessment shows that the children population from both communities are more vulnerable to the toxic effect of the metals in the groundwater. The non-carcinogenic risk shows that the ingestion of Cd, Cr, Pb and Zn by children population from Assiga community will have an adverse effect on their health and the presence of all metals analysed will have a cumulative adverse health effect on the adult and children's health. The non-carcinogenic risk also shows that the ingestion of Cd, Cr and Pb by adult and children population from Ugep community will have adverse health effect on them and there will also be a cumulative adverse effect due to the ingestion of these metals present in the groundwater from the community. The carcinogenic risk shows that the ingestion of Cr and Pb in groundwater will cause cancer in adult and children over a life time period. There is therefore, the need for regular monitoring and awareness creation by the Environmental Protection Agency to ensure reduction/stoppage of activities around the area which might lead to increased levels of the contaminants (heavy metals) that may pose serious health risks to the inhabitants. Alternatively, remediation technologies (e.g., phytoremediation) could be introduced in the two communities to help reduce the levels of these heavy metals especially Cd and Cr.

4.1 Recommendations

i. The government should provide suitable landfills disposals for the treatment of highly concentrated water.

ii. Proper study needs to be carried out in Yakurr Local Government Area of Cross River State as well as any area in Nigerian to monitor the heavy metals in water.

iii. There is need for regular monitoring and awareness creation by the environmental protection agency to ensure segregation of waste before dumping into water to reduce increased levels of the concentration of heavy metals contaminants water which may affect the health of humans in rural areas.

References

Aralu, C, C., Okoye, P.A, C., Abugu, H.O., Eze, V.C. and Chukwuemeka-Okorie, H. (2023). Potentially toxic element contamination and risk assessment of borehole water with landfill in the Newi metropolis. *Health environment*, 4(1):186-197

Bakis R, Tuncan A (2011) An investigation of heavy metal and migration through groundwater from the landfill area of Eskisehir in Turkey. *Environ Monit Assess 176* (1):87-98.

Demirak, A., Yilmaz, F., Tuna, A.L. and Ozdemir, N. (2006) Heavy metals in water, sediment and tissues of Leuciscus cephalus from a stream in southwestern Turkey. Chemosphere, v.63, pp.1451-1458.

Edokpayi, J.N., Enitan, A.M., Mutileni, N and Odiyo, O. (2018). Evaluation of water quality and human risk assessment due to heavy metals in groundwater around Muledane Area of Vhembe District, Limpopo Province, South Africa. *Chemistry center Journal,* 12(2): 1-16

Ghose, S. (2003). Environmental chemistry (1st edn.). New Delhi: Dominant Publishers and Distributors.

Ihenetu, S.C., Njoku, V.O and Ibe, F.C (2021). Assessment of pollution status and health risk in Nwangele Local Government Area: Case study of Onuezuze River. *Journal of Material and Environmental Science,* 12(94): 616-630

Kumar, R, Tripathi, R.M, Gupta, A.K., (2014). Seasonal Variation of heavy metal concentration in water of River Yamuna, Allahabad, Uttar Pradesh, India. *International Journal of Current Microbiocidal Applies Science 3* (7): 945-949.

Lu Y, Tang C, Chen J, Yao H (2016) Assessment of major ions and heavy metals in groundwater: a case study from Guangzhou and Zhuhai of the Pearl River Delta, China, vol 10. *Frontiers of Earth Science,* pp 340-351.

Marcovecchio, J.E, Botte, SE, Freije, R.H., (2007). Heavy Metals, Major Metals, Trace Elements. In: Nollet LM (Ed.), Handbook of Water Analysis. (2nd edn), CRC Press, London, pp: 275-311. Adepoju-Bello AA, Alabi OM (2005) *Heavy metals:* A review. The Nig J

McMurry, J, Fay, R.C., (2004). Hydrogen, Oxygen and Water. In: McMurry Fay Chemistry, Hamann KP (Ed.). (4th edn), *New Jersey: Pearson Education*, pp: 575-599.

Mendie, U. (2005). The Nature of Water. In: The Theory and Practice of Clean Water Production for Domestic and Industrial Use. *Lacto-Medals Publishers, Lagos*, pp: 1-21.

Poorter, L., Bongers, F., Kouame, F.N., and Harthorme, W.D., (2004). Biodervisity of West African forest: An Ecological atlas of woody plants species, CABI Publishing, Singapore, 521p.

Purushotham, M. Rashid, M. Ahmad Lone, A. Narsing Rao, S. Ahmed, E. Nagaiah and F.A. Dar (2013). Environmental impact assessment of air and heavy metal concentration in groundwater of Maheshwaram Watershed, Ranga Reddy District, Andhra Pradesh. *Journal Geological Society of India*, Vol.81, pp.385-396.

Romic, M., and Romic, D. (2003). Heavy metal distribution in agricultural topsoils in urban area. *Environ. Geol.*, v .43, pp.795-805.

Schwartz, K. (1997) Clinical chemistry and chemical toxicology of metals. Environ. Geol., v.43, pp.795-805.

Singh, R., Chavan, S.L. and Sakale, P.H. (2006). Heavy metal concentration in water, sediments and body tissues of Red Worm (Tubifex SPP) collected from Natural Habitats in Mumbai, India. *Environmental Monitoring and Assessment*, v.129 (1-3), pp.471-481.

United State Environmental Protection Agency (USEPA) (2011). Exposure factor handbook 2011 edition (final report) U. S Environmental Protection Agency, Washington, DC, EPA/600/R-09/052F, 2011

Vanloon, G.W, Duffy S.J., (2005). The Hydrosphere. In: Environmental Chemistry: A Global Perspective. (2nd edn), Oxford University Press, New York, USA, pp: 197-211. 2.

Vodela JK, Renden, Lenz SD, Mchel Henney WH, Kemppainen BW (2001) Drinking water contaminants. *Poult Sci 76*: 1474-1492.