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HUMAN HEALTH RISK ASSESSMENT OF HEAVY METALS IN GROUNDWATER SOURCES PROXIMAL TO OPEN DUMPSITES IN BENIN CITY, SOUTHERN NIGERIA

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Abstract

In developing countries like Nigeria, waste management is a significant subject of the environment and public health concern due to the enormous volume of waste generated as a result of rapidly increasing human population. This study assessed the groundwater quality and the associated human health risk around dumpsites along an urban gradient in Benin City, a notable urbanised area in southern Nigeria. In accordance with the standard guidelines, groundwater samples were collected from three (3) locations close to solid waste disposal sites for physicochemical and heavy metals study. The results revealed that all measured parameters were within the permissible limits set by global regulatory standards for drinking water. Notably, metal levels like iron and zinc were elevated but still within acceptable limits. Human health risk assessment revealed that oral ingestion was the primary exposure pathway for heavy metals, and children were more vulnerable to the negative health impacts than adults. Among the metals analysed, chromium posed the highest cancer risk for both adults and children. However, there were no substantial non-carcinogenic health hazards indicated by the calculated Hazard Quotient (HQ) and Hazard Index (HI) values being below the permissible level (HQ, HI < 1). There is an urgent need for public health awareness to address the dangers of exposure to heavy metals from open dumping sites, particularly for the most vulnerable parts of the community, such as children.

Keywords: *Waste dumpsite, Heavy metals, Borehole, Cancer risk, Children*

Introduction

Human waste generation is an inevitable consequence of population growth and industrialisation (Ogbeibu *et al.,* 2013). With the exponential rise in global population, the volume of waste generated has surged, posing significant environmental and public health challenges worldwide (Amasuomo and Baird, 2017). Nigeria, with a population exceeding 200 million, generates nearly 32 million tonnes of waste annually, among the highest in Africa. However, the country continues to grapple with inefficient waste management systems, limited infrastructure, and outdated disposal methods. One of the most pressing challenges is the widespread use of open dumpsites, which typically lack waste segregation and treatment facilities (Ferronato and Torretta, 2019). These dumpsites contribute significantly to environmental degradation and increase the risk of groundwater contamination, especially in communities that depend on borehole water for domestic use.

In urban centres, such as Benin City, southern Nigeria boreholes serve as a primary source of drinking water. However, their quality is often compromised by anthropogenic activities, particularly when located in close proximity to unmanaged dumpsites (Ibe *et al.,* 2021). Reports of indiscriminate siting of dumpsites near residential areas in urban centres have been attributed to the rapid increase in waste generation, poor land use planning, and weak enforcement of environmental regulations (Aluko *et al*., 2022; Okoye *et al.,* 2023). These open dumpsites, which are prevalent across Nigeria, typically lack engineered containment systems such as impermeable liners and leachate collection units. Consequently, during precipitation events, percolating water interacts with decomposing waste materials to form leachate, a highly contaminated liquid that mobilises and transports hazardous substances, including heavy metals such as Pb, Cd, Cr, As, Cu and Zn (Ideriah *et al.,* 2024). These metals, known for their environmental persistence and toxicological significance, can migrate through soil profiles and eventually infiltrate groundwater aquifers tapped by boreholes (Oyem *et al*., 2015). The contamination of groundwater by heavy metals poses a serious public health concern, as these metals are non-biodegradable and can accumulate in human tissues over time, leading to chronic health effects.

Empirical evidence indicates that borehole water sources located near dumpsites often contain metal concentrations exceeding the permissible limits established by the World Health Organisation (WHO) and national regulatory agencies (Awomeso *et al.,* 2010; Edokpayi *et al.,* 2018). Chronic exposure to such contaminated water has been associated with a range of adverse health outcomes, including asthma, diarrhoea, cholera, developmental abnormalities, and increased carcinogenic risk among populations residing in close proximity to improperly managed waste disposal sites (Brender *et al.,* 2020). These health impacts are frequently attributed to sustained exposure to pathogenic organisms and hazardous substances, such as heavy metals, leaching into the groundwater (Zakir *et al.,* 2022; Aralu *et al.,* 2023). This study aims to assess the associated human health risk linked with heavy metal contaminated borehole water situated near dumpsites in Benin City, Edo State, Nigeria.

Study Area

The map of the study location is presented in Fig. 1. This study was carried out in Benin City, Edo State, Nigeria, which spans an area of approximately 748.35 km^2. The region is located in the tropical belt of southern Nigeria and experiences two distinct meteorological seasons: the rainy season (April–October) and the dry season (November–March). The area records an average annual rainfall of 2,500 mm, a mean temperature of 28°C, and an average relative humidity of 85%. Three sampling stations were selected based on their proximity and relationship to dumpsite activities: Site A: A passive (non-active) dumpsite at Asoro (6.308° N, 5.595° E), formerly managed by the Waste Management Board of the Ministry of Environment. It was originally a borrow pit for lateritic sand before being converted into a dumpsite. Site B: An active dumpsite (6.340°N, 5.615°E) adjacent to a farm plantation. Site C: Residential area (6.318°N,5.581° E) with active dumpsite activity.

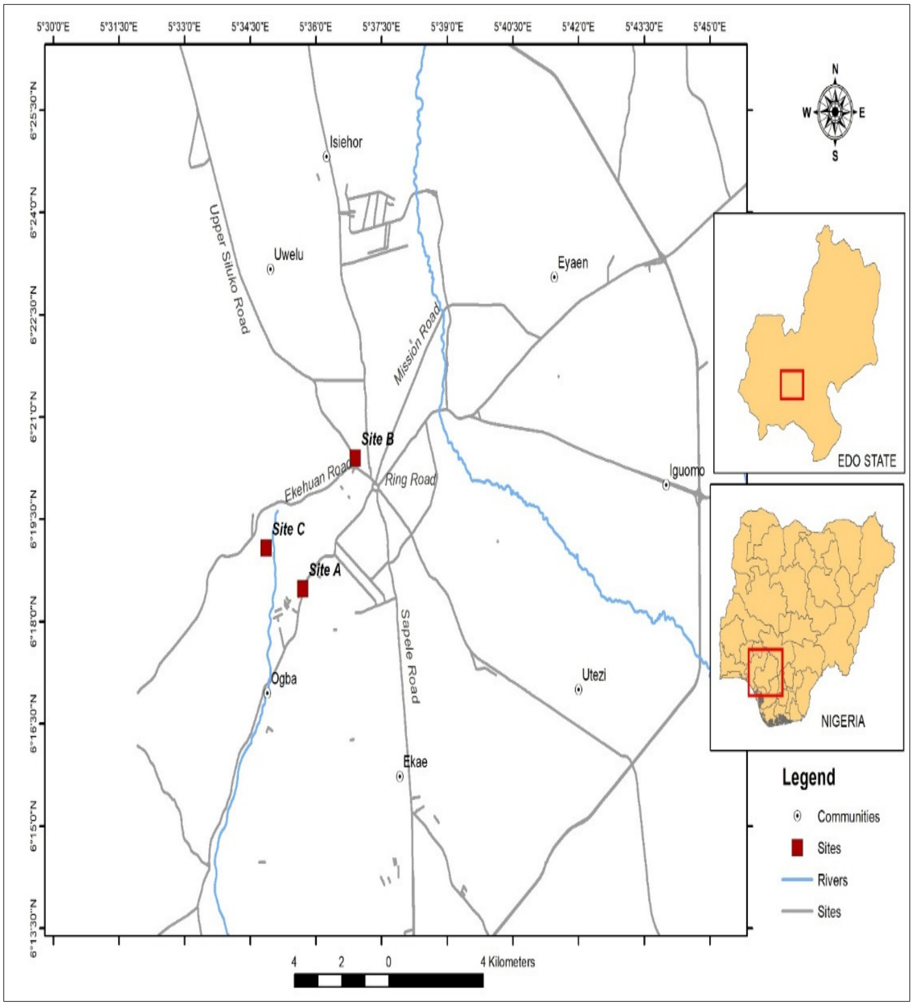

Fig. 1: Map of the Study Area

Materials and Methods

Sample Collection

Groundwater samples were collected monthly between April and June 2023 from boreholes in each study site. At each station, three samples were collected from boreholes in three separate residential buildings, using 75 cl pre-labelled bottles. Care was taken to prevent contamination, and sample containers did not come into contact with the discharge water line to avoid secondary contamination from storage tanks. All samples were stored in lightproof, insulated boxes containing ice packs and transported to the laboratory within 24 hours of collection.

Physicochemical and Heavy Metals analysis

An Electrochemistry Multimeter (Topac Instruments Inc., USA) with a digital CS-C933T was used to determine the physicochemical parameters in-situ, including temperature (^{o}C), hydrogen ion concentration (pH), and electrical conductivity (EC). The American Public Health Association's established procedures were employed for all other samples (APHA, 2017). The Atomic Absorption Spectrophotometer (AAS) 500 L model (England) was used to analyse the heavy metals iron (Fe), chromium (Cr), nickel (Ni), lead (Pb), copper (Cu), and zinc (Zn).

Human Health Risk Assessment

Non-Carcinogenic Risk

Chronic Daily Intake

The following formula was used to determine the Chronic Daily Intake (CDI) of heavy metals that people consume through ingestion and dermal adsorption of the borehole waters (USEPA, 2011).

CDI $_{oral}$ = C$_{hm}$ x D1 x ABS x EF x ED/BWx AT ----------------------(1)

CDI $_{dermal}$ = C$_{hm}$ x SA x K$_{p}$ x ABS x ET x EF x ED x CF/ BWx AT----------(2)

C$_{hm}$, heavy metal level in the fish muscle of the species (mg/L-^{1}), D1, daily average intake (L Day^{-1} 2.2 ingestion), ABS, Absorption factor (0.001for both ingestion and dermal), EF, Exposure frequency (365 ingestion, 350 dermal),BW, Body weight, AT, Average time (26207 ingestion, 10500 dermal), SA Skin surface area (18000 dermal), Kp, Permeability coefficient (Cd, Cr, Fe, Mn & Cu = 0.001;Pb = 0.0001 and Zn = 0.0006)

Hazard Quotient

The Hazard Quotient (HQ) of the heavy metal through oral and dermal adsorption were determined using the following (USEPA, 2011).

HQ $_{oral}$ =C DI $_{oral}$ /R$_{f}$D $_{oral}$ ------------(3)

HQ $_{dermal}$ = CDI $_{oral}$ /R$_{f}$D $_{oral}$ ----------(4)

CDI, Chronic daily intake of heavy metal, RfD, the oral reference dose of metals

Hazard Index

HI $_{oral}$ = ∑ HQ $_{oral}$=HQ $_{Fe}$ + HQ $_{Cr}$ +HQ $_{Ni}$ +HQ $_{Pb}$+ HQ $_{Cu}$ +HQ $_{Zn}$---------------------(5)

HI $_{dermal}$ = ∑ HQ $_{dermal}$ =HQ $_{Fe}$ + HQ $_{Cr}$ +HQ $_{Ni}$ +HQ $_{Pb}$+ HQ $_{Cu}$ +HQ $_{Zn}$------------------(6)

Carcinogenic Health Risk

Incremental Lifetime Cancer Risk

Using the following equation, the incremental lifetime cancer risk (ILCR) linked to exposure to one likely carcinogen (Cr) was determined.

ILCR=CSF x CD--------------------(7)

Data Analysis

To identify the significant variations in the various parameters, the data was subjected to descriptive analysis and inter-station comparisons using parametric one-way analysis of variance (ANOVA). The PAST (version 4.03) software for Windows was used to conduct correlation analysis. In order to ascertain the substantial correlation between heavy metals and the physico-chemical parameters, correlation coefficients were calculated. Blue colours in the visual output denote positive correlation while red colours denote negative correlation. Dark colours signify a greater level of correlation, the darker the colour the stronger the correlation. Quantitative evaluation of the risks to human health using Origin Pro 9.6.5 and Microsoft Excel 2010.

Results and Discussion

Physicochemical Properties of Water

Table 1 shows the findings of the borehole water sample analysis. The pH values in the water samples were between 4.93-5.57. The values recorded were below the acceptable levels, indicating mildly acidic groundwater. The low pH values observed in the majority of the water samples may be ascribed to the leaching of decaying waste materials from nearby dumpsites (Zakir *et al.,* 2022). Acidic water is of particular concern as it enhances the solubility and mobility of heavy metals, which can pose health risks upon chronic exposure (Aralu *et al.,* 2023). Groundwater temperature across the sites was relatively uniform, with values ranging from 28.07°C to 28.3°C. These temperatures are typical for tropical aquifers, affected by ambient climate conditions. Temperature impacts chemical and biological processes in aquifers, but it does not define potability on its own (Riedel, 2019). Electrical conductivity (EC) values recorded in this study range from 23.33-36.67µS/cm. The elevated EC values observed in the samples were all within the WHO permissible limit of 100 µS/cm for low mineralised drinking water. EC reflects the ionic strength and acts as a surrogate for total dissolved solids (TDS) in water.

The relatively low EC measured indicates that salinisation or mineral enrichment have had little influence on the groundwater, and it may still be deemed safe to drink. However, slightly greater EC at site A may indicate early-stage leachate percolation, which introduces ions like chloride and sulphate. Alkalinity values (5.00–7.50 mg/L) and total hardness (4.80–9.61 mg/L) were low across all sites, suggesting that the groundwater is soft and weakly buffered. Low alkalinity indicates a restricted ability to neutralise acids, making the aquifer more sensitive to pH swings and acidification from acidic leachates or acid rain. Soft water is not intrinsically dangerous; nonetheless, its corrosive properties can leach heavy metals from aquifer materials and pipelines, raising toxicological concerns (Jia *et al.,* 2022). This further supports the observed acidic pH values recorded in the various locations.

Table 1: Mean, standard error, p- values and recommended limits of heavy metals in borehole water samples

Parameters and units	A X±S. E	B X±S. E	C X±S. E	P-value	WHO 2005	USEPA 2018
pH	5.47±0.20	4.93±0.03	5.57±0.32	0.17	6.5-8.5	6.5-8.5
Temperature	28.3±30.33	28.1±0.00	28.07±0.03	0.59	30	-------
EC (µS cm^{-1})	36.67±6.77	35.00±0.5	23.33±10.35	0.41	100	-------
Alkalinity	7.50±1.4	5.83+0.83	5.00±2.50	0.61	-------	------
Turbidity	0.19±0.05	0.29±0.15	0.35±0.16	0.69	5.00	------
Hardness	7.47±2.82	4.80±0.00	9.61±6.41	0.72	-------	-------
Cl (mg L−1)	10.64±2.05	9.46±1.18	7.09±3.54	0.61	0.14	250
SO4 (mg L−1)	0.28±0.07	0.12+0.03	0.28±0.05	0.14	250	250
NO3 (mg L−1)	0.41±0.27	0.68±0.28	0.95±0.28	0.44	50	------
NH3 (mg L−1)	0.01±0.00	0.01±0.00	0.01±0.00	0.73	0.5	------
Ca (mg L−1)	1.50±0.57	0.85±0.21	2.35±1.71	0.62	0.035	-------
Fe (mg L−1)	0.02±0.00	0.01±0.00	0.03±0.01	0.07	0.3	0.30
Cr (mg L−1)	0.01±0.00	0.01±+0.00	0.01±0.00	0.26	0.005	0.10
Ni (mg L−1)	ND	ND	ND	0.27	0.10	-------
Pb (mg L−1)	ND	ND	ND	0.42	0.05	0.015
Cu (mg L−1)	0.01±0.01	0.01±+0.00	0.02±0.00	0.63	1.00	1.30
Zn (mg L−1)	0.03±+0.01	0.03±0.00	0.05±0.01	0.06	3.00	5.00

Turbidity values ranged from 0.19±0.35 NTU within the WHO guidelines. Low turbidity indicates low levels of suspended particles and generally correlates with aesthetically acceptable water. Chloride concentrations ranged from 7.09±10.64 mg/L were, below the USEPA maximum permissible limits of 250 mg/L, but above the WHO recommended limit. Since chloride is conservative in groundwater, it is frequently employed as a marker of sewage or landfill leachate pollution. The observed values point to the effect of either residential waste or saline intrusion during the study period. The greater concentration in site A, may indicate early stages of pollution or closeness to more active garbage zones. Sulfate values were low, ranging from 0.12±0.28 mg/L, below the recommended limit of 250 mg/L. Groundwater naturally contains sulphate because of mineral dissolution, but industrial effluents and landfill leachate can also contribute to high quantities (Abd-El Salam and Abu-Zuid, 2015). Long-term waste disposal may change this, although the low sulphate level indicates a limited geogenic or human influence.

Nitrate concentrations ranged between 0.41± 0.95 mg/L, indicating low levels relative to the WHO limit of 50 mg/L. Nitrate in groundwater is derived from the oxidation of ammonia, nitrification processes, or the leaching of fertilisers and decaying organic matter (Gutiérrez *et al.,* 2018). The current values suggest minimal influence from organic waste decomposition or agricultural runoff, although values should be monitored regularly due to potential cumulative effects from the nearby dumpsite. In comparison to the WHO standard of 50 mg/L, nitrate concentrations were low, ranging between 0.41±0.95 mg/L. According to Gutiérrez *et al. (*2018), nitrate in groundwater is produced via nitrification processes, fertiliser leaching, or the oxidation of ammonia. Chronic exposure to elevated nitrate levels can result in methemoglobinemia or "blue baby syndrome" in infants (Brender *et al.,* 2020). Although the current findings indicate no impact from agricultural runoff or the decomposition of organic waste, data should be routinely checked because of the possible cumulative impacts from the neighbouring dumpsite Ammonia concentrations were consistent and low (0.00 ± 0.01 mg/L) throughout the sites, remaining below the 0.5 mg/L WHO acceptable limit. The presence of ammonia suggests the decomposition of nitrogenous organic matter and might be an indication of sewage or solid waste leachate pollution. Even if the levels are currently low, the ongoing addition of organic waste may eventually alter the redox conditions and further impact the water chemistry in those sites.

Essential and Toxic Metal Content in Water

Essential and toxic metal content in water samples collected from site A, B, and C are presented in Tab. 1. Essential metals Ca, Fe, Cu, and Zn ranged (0.85-2.35 mg/L; 0.01-0.03 mg/L;0.01-0.02 mg/L and 0.03-0.05 mg/L. These metals concentrations fall within internationally acceptable limits. However, Cr and Mn elevated concentrations were above the WHO limits, underscore the need for routine monitoring and potential remediation. The non-detection of Pb and Ni, two of the most toxic heavy metals, further reinforces the relatively low risk posed by these water sources at the time of sampling. The box plot (Fig. 2) shows the concentrations of heavy metals (Fe, Cr, Ni, Pb, Cu, Zn) in borehole water samples. Zn exhibited the highest median concentration with a wide variability, followed by Fe and Cu. Pb showed the lowest concentration, nearly negligible, indicating minimal contamination. Ni and

Cr also recorded low levels. However, the elevated Zn and Fe levels, though within limits, may indicate localised geochemical influence or leaching from nearby dumpsites.

The Origin of Heavy Metals and their Relationship with Physicochemical Properties

A hierarchical cluster analysis of the six heavy metals (Fe, Pb, Cr, Zn, Cu, and Ni) found in water samples is displayed in the dendrogram (Fig 3). The clustering reveals distinct groupings based on similarity in their concentration patterns. Fe and Pb are closely related; they may have a shared source, most likely leaching from dumpsites. Similar human inputs are indicated by the formation of another cluster between Cr and Zn. The modest association between Cu and the Cr–Zn cluster suggests a common, albeit less obvious, source of contamination.

Pearson correlation analysis revealed significant interrelationships among the physicochemical parameters and heavy metal concentrations. Notably, EC exhibited strong positive correlations with Mg^{2+}, Ca^{2+}, Hardness, SO_4^{2-}, NO_3^-, and Fe. The dark blue hue of these ions suggests that they play a significant role in the conductivity levels and ionic composition of the water. As indicated given the concentrations of the divalent cations are the primary determinants of water hardness. Strong positive intercorrelations between the heavy metals Pb, Cr, Ni, and Fe may indicate shared origins, including leachate percolation from the adjacent dumpsite.

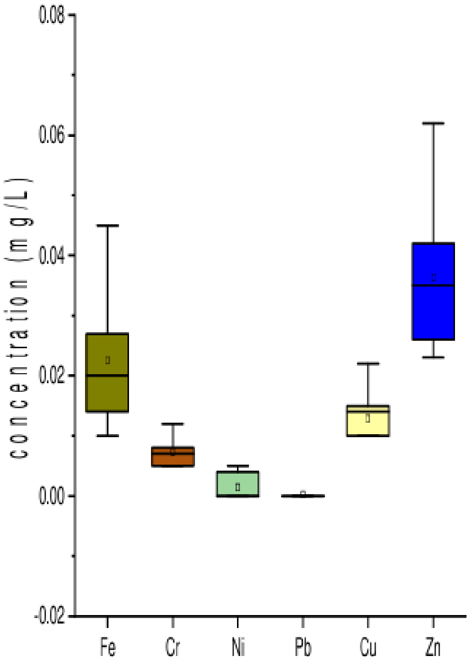

Fig. 2: Box plot of heavy metal concentration in borehole water samples

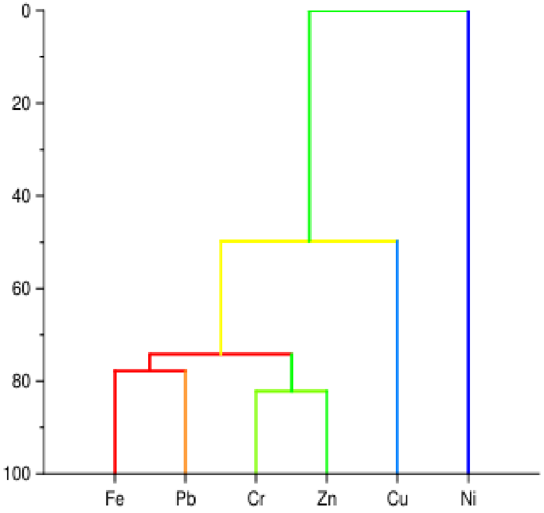

Fig. 3: Dendrogram showing cluster analysis of heavy metals in the groundwater samples from the dumpsite

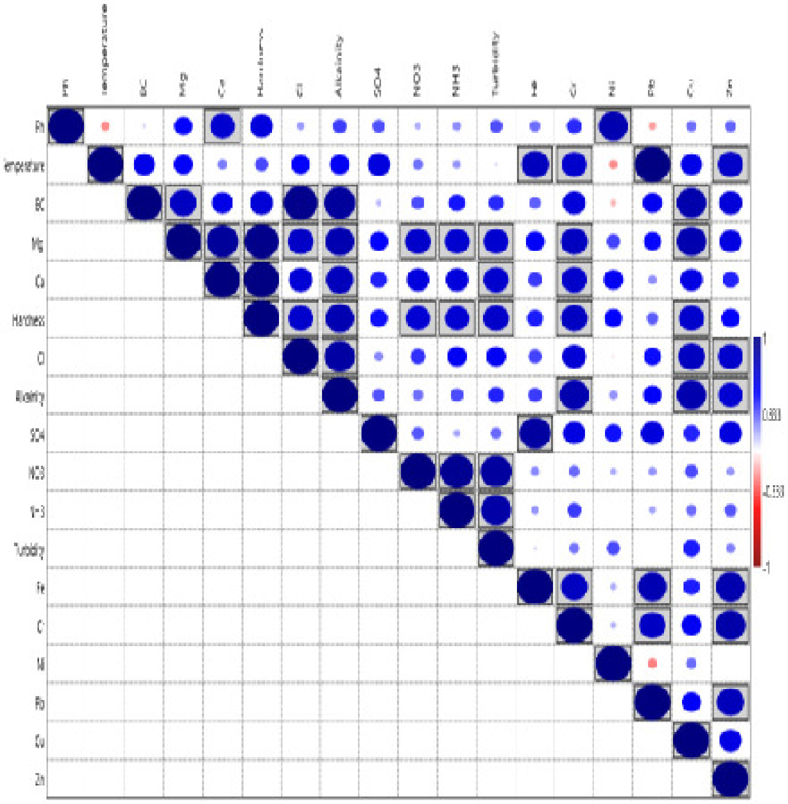

Fig. 4: Pearson's correlation coefficients among measured parameters

Human Health Risk Assessment

Non-carcinogenic risk was measured through ingestion and dermal exposure to heavy metals present in groundwater in the study area. The calculated CDI $_{\text{oral}}$ values for adult and children (Table. 2) ranged as follows: site1: 7.19×10^{-4}–1.63×10^{-3} (adults) and 1.09×10^{-3}–2.46×10^{-2} (children); site 2: 1.44×10^{-3}–5.83×10^{-4} (adults) and 1.14×10^{-3}–2.69×10^{-3} (children); Site 3: 1.78×10^{-3}–9.14×10^{-4} (adults) and 2.64×10^{-4}–4.34×10^{-3} (children) for Fe, Cr, Ni, Cu and Zn.. The calculated HQ$_{\text{oral}}$ values ranged as follows; Site 1: 1.03×10^{-3}–2.86×10^{-2}; Site 2: 2.05×10^{-3}–1.46×10^{-2}; Site 3: 2.15×10^{-3}–2.20×10^{-2}. HI $_{\text{oral}}$ calculated values ranged from site 1(2.65 E-02, 2.65 E-02) site 2 (3.29 E-02, 4.97E-02) site 3(4.06 E-02, 6.13 E-02). The estimated CDI $_{\text{dermal}}$ values (Table 3) for Fe, Cr, Ni, Cu and Zn ranged as follows: Site 1: 2.70×10^{-9}–2.01×10^{-8}; Site 2: 1.43×10^{-9}–2.97×10^{-8}; Site 3: 6.34×10^{-10}–3.69×10^{-8}. The calculated HQ $_{\text{dermal}}$ values ranged as follows: Site 1: 8.39×10^{-9}–3.92×10^{-7}; Site 2: 1.17×10^{-8}–3.01×10^{-7}; Site 3: 1.43×10^{-8}–4.72×10^{-7}. Additionally, the HI $_{\text{dermal}}$ value ranged from 1.99E-07 to 3.01E-07 for adults and 4.5E-07 to 6.8E-07 for children. Based on the risk estimate for metals in groundwater for adults and children via oral and dermal routes, all the HQ and HI values across the locations were below 1.0. This indicates that the oral and ingestion exposure to groundwater contaminated with metals poses a non-carcinogenic risk within the locations.

The findings of this study are consistent with the study of Zakir *et al.* (2020) and Bodrud -Dozaa *et al.* (2019) that reported the HQ and HI values for dermal and ingestion absorption in all the studied metals pose zero probability for non-cancer risk to the residents in the Jamalpur Sadar area of Bangladesh.

Table 2: Calculated average chronic daily metal intake (CDI) due to oral and dermal exposure of waters collected in close proximity to dumpsites

	SITE A				**SITE B**				**SITE C**			
	Adult		**Children**		**Adult**		**Children**		**Adult**		**Children**	
	HQ$_{oral}$	**HQ$_{dermal}$**	**HQ$_{oral}$**	**HQ$_{dermal}$**	**HQ$_{oral}$**	**HQ$_{dermal}$**	**HQ$_{oral}$**	**HQ$_{dermal}$**	**HQ$_{oral}$**	**HQ$_{dermal}$**	**HQ$_{oral}$**	**HQ$_{dermal}$**
Fe	1.03E-03	8.39E-09	1.55 E-03	2.12E-08	2.05E-03	1.68E-08	3.10 E-03	4.25E-08	2.56 E-03	2.09E-08	3.86 E-03	5.28E-08
Cr	1.10 E-03	9.01E-09	1.66 E-03	2.28E-08	1.43 E-03	1.17E-08	2.15 E-03	2.95E-08	1.75 E-03	1.43E-08	2.64 E-03	3.62E-08
Ni	-	8.75 E-03	-	3.92E-07	8.75 E-03	7.15E-08	1.32 E-02	-	3.88 E-03	3.17E-08	5.85 E-03	-
Cu	1.89E-02	1.55E-07	2.86 E-02	6.75E-08	1.46 E-02	1.19E-07	2.20 E-02	1.46 E-02	1.19E-07	2.20 E-02	3.45E-02	4.72E-07
Zn	5.44E-03	2.67E-08	8.21 E-03	4.25E-08	6.16 E-03	3.02E-08	9.29 E-03	7.64E-08	9.59E-03	4.70E-08	4.70E-08	1.19E-07
HI	2.65 E-02	1.99E-07	4.00 E-02	5.03E-07	3.29 E-02	2.49E-07	4.97E-02	4.5E-07	4.06 E-02	3.01E-07	6.13 E-02	6.8E-07

Table 3: Calculated hazard quotients (HQ) and hazard index (HI) values due to oral and dermal exposure of heavy metals from water samples

	Site A				**Site B**				**Site C**			
	Adult		**Children**		**Adult**		**Children**		**Adult**		**Children**	
	CDI $_{oral}$	**CDI $_{dermal}$**	**CDI $_{oral}$**	**CDI $_{dermal}$**	**CDI $_{oral}$**	**CDI $_{dermal}$**	**CDI $_{oral}$**	**CDI $_{dermal}$**	**CDI $_{oral}$**	**CDI $_{dermal}$**	**CDI $_{oral}$**	**CDI $_{dermal}$**
Fe	7.19E-04	5.88E-09	1.09 E-03	1.48E-08	1.44E-03	1.18E-08	1.14E-03	2.97E-08	1.78E-03	1.46E-08	2.64 E-04	3.69E-08
Cr	3.31E-04	2.70E-09	4.99 E-04	6.84E-09	4.28E-04	3.49E-09	6.45E-04	8.84E-09	5.25 E-04	4.29E-09	4.29E-09	1.09E-08
Ni	-	-	-	-	1.75E-04	1.43E-09	2.64E-04	-	7.76E-05	6.34E-10	1.17E-04	-
Cu	7.58E-04	6.19E-09	1.14 E-03	1.57E-08	5.83E-04	4.77E-09	8.80 E-04	1.20E-08	9.14E-04	7.47E-09	1.38E-03	1.89E-08
Zn	1.63 E-03	8.01E-09	2.46 E-02	2.01E-08	1.85 E-03	9.06E-09	2.69E-03	2.29E-08	2.87 E-03	1.41E-08	4.34 E-03	3.57E-08

Carcinogenic Human Health Risk

The incremental lifetime cancer risk (ILCR) associated with Cr through oral and dermal exposure among adults and children was calculated and presented in (Tab. 4). The results showed that the calculated ILCR values for Cr ranged 1.39E-04-3.33E-04 for ingestion and 1.14E-09-4.56E-09 for dermal exposure. This study reveals that oral ILCR values for both adult and children at the sites exceeded the 1 × 10^{-4} threshold, indicating a potential unacceptable lifetime cancer risk from exposure to Cr.

The finding of this study aligns with prior studies demonstrating that ingestion is often the dominant exposure route for heavy metals in contaminated environments due to higher intake rates and absorption efficiency into the gastrointestinal tract (USEPA, 2011; Wu *et al.,* 2015). Children exhibited higher ILCR values than adults across all sites exceeding the USEPA 2005 acceptable cancer risk threshold of 1.0 × 10^{-4} (USEPA, 2005). These elevated values in children can be attributed to physiological and behavioural factors, such as higher ingestion rates relative to body weight and increased vulnerability of developing organs to toxicants (Rahman *et al.*, 2016). Site 3 exhibited the highest ILCR values for both oral and dermal exposure across the age group.

Table 4: Calculated incremental lifetime cancer risk (ILCR) values due to oral and dermal exposure to heavy metals from water samples

	Site A				**Site B**				**Site C`**			
	Adult		**Children**		**Adult**		**Children**		**Adult**		**Children**	
ILCR	**oral**	**dermal**	**oral**	**dermal**	**oral**	**Dermal**	**oral**	**Dermal**	**oral**	**dermal**	**Oral**	**dermal**
Cr	1.81 E-04	1.47E-09	2.71 E-04	3.71E-09	1.39 E-04	1.14E-09	2.1 E-04	2.87E-09	2.21 E-04	1.8E-09	3.33 E-04	4.56E-09

This may indicate a higher local Cr contamination load, potentially due to leachate from waste sites or anthropogenic runoff, as suggested by previous studies (Tiwary *et al.,* 2005; Ibe *et al*., 2021). This is quite a source of concern as open dumpsite around residential areas should be discouraged due to the portend human health risk.

Conclusion

The current study emphasised the dangers to human health that may arise from ingest and dermal absorb of heavy metal-contaminated groundwater at open disposal sites in Benin City, Nigeria. Based on the selected areas, notable variations in the quantities of heavy metals in the groundwater quality were noted. The higher values for the majority of groundwater quality measures found at site 3 generally indicate that operating open dumps near residential areas poses a greater danger to public health. Although, no possible non-carcinogenic health hazards for the people living in the study region, according to the computed HI_{oral} and HI_{dermal} values for adults and children being less than 1.0. Regarding carcinogenic health risks, the study revealed that lifelong exposure to Cr from groundwater consumption in the study area, there is a chance that inhabitants, particularly children, may develop cancer.

In light of these findings, public health regulations that address the risks of exposure to heavy metals from open disposal sites are desperately needed, especially for the population's most vulnerable members, such as children.

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