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HUMAN HEALTH RISK ASSESSMENT OF SOME HEAVY METALS IN EME RIVER, UMUAHIA, ABIA STATE, NIGERIA

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ABSTRACT

This study evaluated the health risk of some heavy metals in Eme River, Umuahia. The study conducted in 6 stations was between December 2017 and November 2018. The non-carcinogenic method that involves determination of chronic daily intake (CDI), hazard quotient (HQ) and hazard index (HI) was applied in the assessment of ingestion, dermal and incidental ingestion exposures. Iron, lead and cadmium exceeded their limits and warranted risk assessment. The heavy metals' CDI values for the three routes were lower than their respective reference doses except for cadmium (ingestion route). Except for cadmium (ingestion), the hazard quotients also recorded values lower than the threshold value (1). The hazard indices (HI) values for dermal and incidental ingestion were well below the threshold value (1) while all the HI values (ingestion) recorded among the adult and children in all the stations were higher than the threshold value (1) except for adult in stations 2 and 3. This assessment showed that the risk of consuming the water was high and may be detrimental to the consumers. The children swimming in the river and sand miners were not at risk based on the outcome of the dermal and incidental ingestion routes assessment. Elevated concentrations of cadmium, iron, and lead above acceptable limits were responsible for the outcome while cadmium was the main metal that contributed to the adverse health risk observed.

Keywords: Health risk, heavy metal, incidental, ingestion, sand mining.

INTRODUCTION

Freshwaters in all its ramifications have always played a major role in the existence of mankind. They provide goods and services that are essential for human survival and well-being (Wantzen et al., 2016). Recreation (swimming) and sand are some of the benefits derivable from freshwater systems (Onwuka et al., 2013; Hanna et al., 2018). Assessment of metallic pollution in rivers is necessary because of the health risk they pose to humans (Zhang et al., 2021). Heavy metals enter into the river system through ever increasing human developmental activities including mining (Gao et al., 2020; Zeng et al., 2020). These metals threaten human health due to their toxic, persistent and bio-accumulative nature (Rajeshkumar et al., 2018; Zeng et al., 2019). The major ways through which humans are exposed to heavy metals in aquatic environments are direct ingestion and entry via the skin (Giri and Singh, 2014; Alidad et al., 2019) but incidental water ingestion during swimming could not be ruled out (Hoang et al., 2021; Jiménez-Oyola et al., 2021).

The non-carcinogenic method has been extensively applied in the evaluation of possible risks associated with metallic contamination of rivers (Zakir et al., 2020; Zhang et al., 2021; Anyanwu et al., 2022a, b, Jonah et al., 2023). Chronic daily intake, hazard quotient and hazard index are the commonly used parameters for risk assessment in humans (Onyele and Anyanwu, 2016; Alidad et al., 2019; Anyanwu et al., 2020; Zhang et al., 2021). Hence, health risks associated with some metallic elements in Eme River were evaluated using the parameters. Some children were involved in recreation, washing and extraction of drinking water during the dry season. Anyanwu and Onyele (2018) observed that surface waters in the region usually witness high human activities in the dry season because they are the most available and free source of water for most purposes. On the other hand, artisanal sand miners drink from the river as well as spend between 6 and 7 hours daily in the water while diving to extract sand from the river bottom. Sand mining can be of direct or indirect economic benefits in developing countries (Mattamana et al., 2013). It can have positive economic impact through job creation and employment. People earn their livelihood from the natural resources that are available and accessible to them (Onwuka et al., 2013). Consequently a lot of people (young and old) are involved in sand mining activities. Swimming and sand mining activities predisposes the people involved to heavy metal contamination via dermal exposure and incidental ingestion. Previous study has shown that Eme River water was not fit for consumption due to high heavy metal content (Anyanwu and Umeham, 2020) but the health risk was not assessed. The aim of this paper therefore, is to assess health risks associated with heavy metals in Eme River, Umuahia, through ingestion, incidental water ingestion and dermal exposures.

MATERIALS AND METHODS

Study Area

The source of Eme River was Uzoakoli in the northern part of Abia State; it transversed a number of towns to Onuimo where it joined Imo River. The studied section was roughly 3.25 km; from Ofeme to Umudiawa in Umuahia, Abia State (Figure 1). The study area was located on latitude 5°38’- 5°37’N and Longitude 7°25’ - 7°26’E. The reference station (Station 1) was upstream, situated within Mbato area of Ofeme. Some anthropogenic activities recorded in the dry season were laundry, recreation and fetching of water for drinking and other domestic purposes. The bottom sediment was muddy. The section of river where stations 2 – 6 were located was previously dredged. Station 2 was located downstream (approximately 1.84 km) of Station 1 at Eme - Ihite, Ofeme. Sand mining activities has stopped in this section of the river but other activities observed were limited laundry, recreation and fetching of water for drinking and other domestic purposes. The bottom sediment was sand combined with stones. Station 3 was approximately 419.67 m downstream of Station 2 and situated in Eme – Ihite area of Ofeme. The station was devoid of human presence throughout the study except a few boat movements. Large clayey boulders dominated the substrate. Station 4 was downstream; approximately 490.26 m after Station 3 in Umudiawa community. Between Stations 3 and 4 was an area of intense sand mining and landing. The bottom sediment was composed of sand. Station 5 was also downstream approximately 200.22 m after Station 4 in Umudiawa community. The bottom sediment was composed of sand and mining activities were observed around this station. Station 6 was also downstream and approximately 300.14 m after Station 5 in Umudiawa community. The station had sandy bottom sediment and mining was observed inside river channel and around the banks. Between stations 4 and 6, the sand miners extract water from the river for drinking and other purposes.

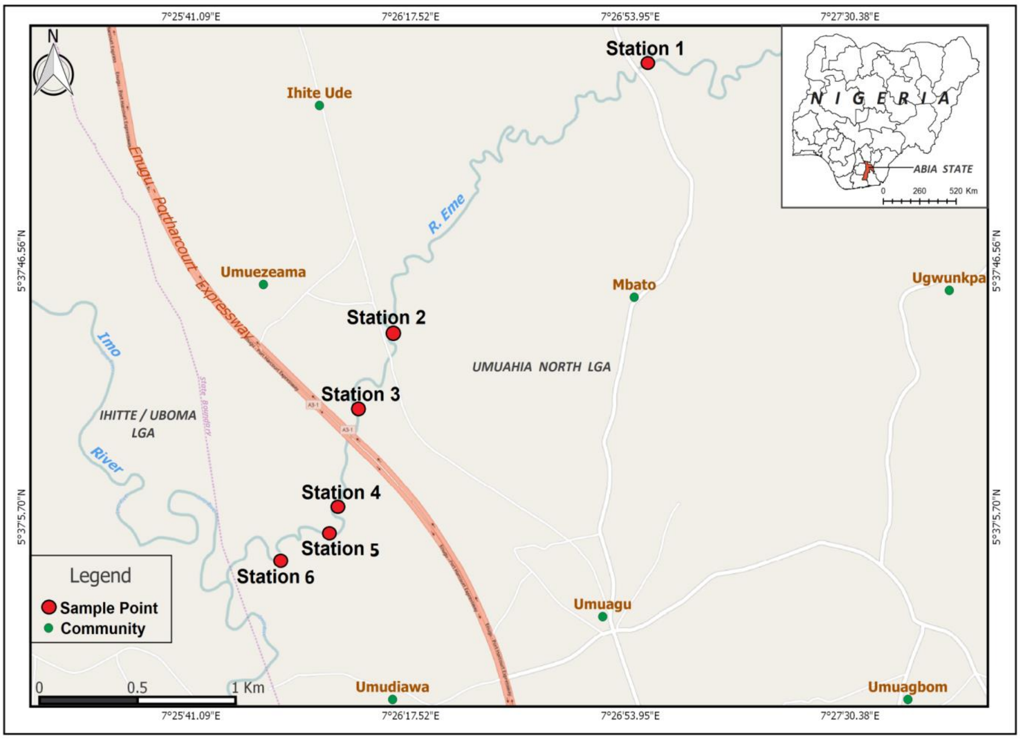

Figure 1: Map of Umuahia, Abia State, Nigeria showing the sampling Stations of Eme River.

Health Risk Assessment

The assessment of health risk was done for Fe, Pb and Cd that were higher than the permissible limits. Non-carcinogenic assessment method described by Muhammad et al. (2011) was used. Equations (1 – 3) were applied in the calculation of chronic daily intake (CDI) of the metals in Eme River water:

$$CDI_{Ing} = \frac{C_W x IR x EF x ED}{B_W x AT} \qquad \text{(Eq. 1)}$$

$$CDI_{Der} = \frac{C_W\ x\ SA\ x\ K_P\ x\ ET\ x\ EFx\ ED\ x\ 10^{-3}}{B_W x AT} \qquad \text{(Eq. 2)}$$

$$CDI_{IWI} = R\ x\ C_W \frac{ET\ x\ EF\ x\ ED}{B_W x\ AT} \qquad \text{(Eq. 3)}$$

where CDIing stands for the chronic daily intake (CDI) for direct ingestion (mg/kg/day); CDIder stands for the chronic daily intake (CDI) for skin penetration (mg/kg/day); *CDIiwi* stands for the chronic daily intake (CDI) for incidental water ingestion during swimming (mg/kg/day); Cw stands for the mean concentration of heavy metals in each water sample (mg/l); IR stands for the ingestion rate (Litre/day); EF stands for the exposure frequency (day/year); ED stands for the exposure duration (years); AT stands for the average time (days); BW stands for the average body weight for adults and children (Kg); ET stands for the daily exposure time (Hours/day); SA stands for the area of skin exposure (cm^2); R stands for the contact rate while swimming (Litre/hour) and Kp stands for the dermal permeability coefficient in water (cm/h) - (Iron = 0.001, lead = 0.0001 and cadmium = 0.001). The parameters applied in the calculation of CDI values are shown in Table 1.

Hazard Quotient

Equation 4 was applied in the calculation for the hazard quotient for risks that are not carcinogenic as described by USEPA (1999).

$$HQ = \frac{CDI}{RFD} \qquad \text{(Eq. 4)}$$

Table 1: The parameters applied in the calculation of CDI values

Factor/parameter	Symbol	Units	Adult	Children	Source
Oral Ingestion Exposure					
Exposure Duration	ED	Y	30	6	USEPA (2004)
Exposure Frequency	EF	Day/year	350	350	USEPA (2004)
Averaging Time	AT (ED x 365)	D	10,950	2,190	USEPA (2004)
Body Weight	BW	Kg	70.0	15.0	USEPA (2004)
Ingestion Rate	IR	Litre/day	2.0	1.0	USEPA (2004)
Dermal Exposure /Incidental Swimming Ingestion					
Exposure Frequency	EF	Day/year	15		Ma et al. (2007)
Exposure Time	ET	Hour/day	0.5		Ma et al. (2007)
Skin Area	SA	Cm^2	18,000	6,600	USEPA (2004)
Contact Rate	R	Litre/hour	0.044		Ma et al. (2007)

Where, CDI stands for the daily quantity of heavy metals that consumers may be exposed through ingestion, incidental ingestion and dermal routes while RfD is considered to be an estimated safe limit of daily intake for a pollutant or chemical. When, $HQ > 1$, it is an indication of adverse non-carcinogenic effect that need to be addressed but when $HQ < 1$, it indicates no adverse non-carcinogenic effect (within acceptable level).

Hazard Index (HI)

The combination of individual HQs to form the hazard index (HI) is required for the risk assessment of a mixture of pollutants (Wongsasuluk et al., 2014). Equation 5 was used in the calculation of HI:

$$HI = \sum_{i=1}^{n}(HQ)i \qquad \text{(Eq. 5)}$$

Where, HI, stands for the hazard index for the overall toxic risk and n stands for the total number of metals evaluated. When HI is less than 1.0, the potential non-carcinogenic adverse effect through ingestion, incidental ingestion and dermal routes is negligible (Zakir et al., 2020).

RESULT AND DISCUSSION

Heavy Metal Content

The heavy metals (iron, lead and cadmium) that exceeded limits in Eme River are shown in Table 2. Generally, higher values recorded in stations 1 – 2, 4 – 6 where some levels of human activities observed especially the downstream stations (4 – 6).

The values of iron were 0.36 - 6.28 mg/l. The acceptable limit was not lower than the concentrations and mean concentrations. Stations 1, 2, 3 and 5 had lower significant ($P < 0.05$) concentrations than Station 4. The values recorded for lead were 0.005 - 0.08 mg/l. The acceptable limit was also not lower than the concentrations of lead; though a few values in stations 1 – 3, 5 – 6 were lower than the limit. The mean concentrations equally exceeded limit except in station 3. Stations 1, 2, 3 and 5 also had lower significant ($P < 0.05$) concentrations than Station 4. Concentrations of cadmium were 0.003 - 0.05 mg/l. The acceptable limit was also not lower that recorded concentrations; though one in Station 3 was an exception. The mean concentrations were also above the limit except in Station 3. Stations 2 and 3 were also had lower significant ($P < 0.05$) concentrations than Station 4.

Table 2: The heavy metals that exceeded limits in Eme River, Umuahia, Southeast Nigeria

Parameter	Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 6	P-Value	SON (2015)
Iron	1.0 ± 0.13^{a} 0.57-2.41	1.0 ± 0.18^{a} 0.40-2.81	0.7 ± 0.07^{a} 0.36-1.14	2.6 ± 0.39^{c} 1.36-6.28	1.5 ± 0.31^{ab} 0.72-4.60	1.8 ± 0.32^{abc} 0.98-5.12	*	0.3
Lead	0.02 ± 0.003^{ab} 0.01-0.04	0.02 ± 0.003^{ab} 0.009-0.04	0.008 ± 0.001^{a} 0.005-0.02	0.05 ± 0.005^{c} 0.02-0.07	0.02 ± 0.007^{abd} 0.01-0.09	0.03 ± 0.004^{bcd} 0.01-0.06	*	0.01
Cadmium	0.02 ± 0.003^{bc} 0.009-0.04	0.01 ± 0.002^{ab} 0.007-0.02	0.007 ± 0.001^{a} 0.003-0.01	0.03 ± 0.004^{c} 0.01-0.05	0.02 ± 0.003^{bc} 0.009-0.05	0.02 ± 0.003^{bc} 0.01-0.05	*	0.003

*Source: Anyanwu and Umeham (2020); a, b, c, d = Means with different superscripts across the rows are significantly different at $p < 0.05$; SEM= Standard Error of Mean; SON (2015) = Nigerian standard for drinking water quality; * = $P < 0.05$*

The concentrations of iron (Fe), lead (Pb) and cadmium (Cd) exceeded their respective limits (Table 2) set by SON (2015) as reported by Anyanwu and Umeham (2020), hence the need for health risk assessment. The high concentrations were attributed to geology modified by season and human activities. In Nigerian rivers, high concentrations of iron, lead and cadmium have been previously reported (Obaroh et al., 2015; Anyanwu and Nwachukwu, 2020; Eze et al., 2021; Iwar et al., 2021; Anyanwu et al., 2022a; Digha et al., 2022; Sani et al., 2022). Okoye and Iteyere (2014) attributed the high iron levels in Nigerian rivers to high iron content of Nigerian soils while Iwar et al. (2021) and Sani et al., 2022 attributed the concentrations of Pb and Cd to anthropogenic sources. Orisakwe (2014) reported high public health significance of Lead and cadmium in Nigeria.

Chronic Daily Intake (CDI)

Table 3 shows the CDI values of the metals for ingestion, incidental ingestion and dermal routes as well as their respective reference doses. The health risk assessment revealed varied CDI values for adults, children and stations. Higher values were recorded among the children in relation to adults. Stations (1 – 2, 4 – 6) that witnessed some levels of human activities were also higher. The metals' CDI values for ingestion, incidental ingestion and dermal routes were lower than their respective reference doses except for cadmium (ingestion route).

Whenever the CDI value obtained for a particular pollutant exceed critical RfD value for that pollutant through any pathway of contact, the exposed individual will suffer adverse human health or non-carcinogenic effect from that pollutant concentration (Huang et al., 2014). The reference dose for Cd was higher than ingestion CDI values in stations 2 and 3 (adult) and station 3 (children) but lower in the other stations especially 4 – 6. The heavy metal concentrations and anthropogenic activities influenced the CDI values as a result; station 3 had the lowest value while station 4 had the highest. There was no human activity observed in station 3 while the downstream stations (4 – 6) witnessed various levels of sand mining activities. Station 4 witnessed the highest level human perturbation because it is downstream to major sand mining and landing sites.

Related studies have shown that human activities especially sand mining contribute to elevated levels of metallic elements in water bodies (Akankali et al., 2017; Lekomo et al., 2021; Rentier & Cammeraat, 2022; Sani et al., 2022). The CDI values were observed to be higher among the children. Children have higher age-dependent dose coefficients than adults which contribute to higher uptake; even though their mean water consumption volume is lower (WHO, 2017).This trend has also been reported in related studies (Zhang et al., 2021; Anyanwu et al., 2022a; Odo et al., 2022; Jonah et al., 2023).

Table 3: Chronic daily intakes of the heavy metals for ingestion, dermal and incidental ingestion routes

Parameter		Stn 1	Stn 2	Stn 3	Stn 4	Stn 5	Stn 6	RfD
Ingestion								
Iron	Adult	3.00E-02	3.00E-02	2.00E-02	7.00E-02	4.00E-02	5.00E-02	7.00E-01
	Children	6.00E-02	6.00E-02	5.00E-02	2.00E-01	1.00E-01	1.00E-01	
Lead	Adult	6.00E-04	6.00E-04	2.00E-04	1.00E-03	6.00E-04	8.00E-04	3.50E-03
	Children	1.00E-03	1.00E-03	5.00E-04	3.00E-03	1.00E-03	2.00E-03	
Cadmium	Adult	6.00E-04	3.00E-04	2.00E-04	8.00E-04	6.00E-04	6.00E-04	5.00E-04
	Children	1.00E-03	6.00E-04	5.00E-04	2.00E-03	1.00E-03	1.00E-03	
Dermal								
Iron	Adult	5.00E-06	5.00E-06	4.00E-06	1.40E-05	1.00E-05	1.00E-05	7.00E-01
	Children	9.00E-06	9.00E-06	6.00E-06	2.00E-05	1.00E-05	2.00E-05	
Lead	Adult	1.00E-08	1.00E-08	4.00E-09	3.00E-08	1.00E-08	2.00E-08	5.30E-04
	Children	2.00E-08	2.00E-08	7.00E-09	5.00E-07	2.00E-08	3.00E-08	
Cadmium	Adult	1.00E-07	5.00E-08	4.00E-08	2.00E-07	1.00E-07	1.00E-07	1.00E-03
	Children	2.00E-07	9.00E-08	6.00E-08	3.00E-07	2.00E-07	2.00E-07	
Incidental ingestion								
Iron	Adult	1.30E-05	1.30E-05	9.00E-06	3.00E-05	2.00E-05	2.00E-05	7.00E-01
	Children	6.00E-05	6.00E-05	4.00E-05	2.00E-04	9.00E-05	1.00E-04	
Lead	Adult	3.00E-07	3.00E-07	1.00E-07	6.00E-07	3.00E-07	4.00E-07	5.30E-04
	Children	1.00E-06	1.00E-06	5.00E-07	3.00E-06	1.00E-06	2.00E-06	
Cadmium	Adult	3.00E-07	1.00E-07	9.00E-08	4.00E-07	3.00E-07	3.00E-07	1.00E-03
	Children	1.00E-06	6.00E-07	4.00E-07	3.00E-06	1.00E-06	1.00E-06	

Hazard Quotients (HQs)

The hazard quotients (HQs) and hazard index (HI) ingestion, dermal and incidental ingestion routes are presented in Table 4. The values followed the same trend as CDI; higher values were recorded among the children and stations with some levels of human activities.

The hazard quotients (HQs) of the heavy metals for ingestion, incidental ingestion and dermal routes were lower than the threshold value (1) except for Cadmium (ingestion). The ingestion HQ values for Cd exceeded 1 except for adult and children in station 3. When HQs are high, the exposed individuals are more vulnerable (Sharma, 2020). As in the CDI values, the HQ values were higher among the children (Zhang et al., 2021; Anyanwu et al., 2022a; Odo et al., 2022; Jonah et al., 2023) and was also influenced by human activities. Station 3 had the lowest values because no activity was observed there while station 4 had the highest. Station 4 was downstream to a section of the river where intensive sand mining and landing was taking place.

Previous studies have shown that sand mining related activities contribute to elevated concentrations of organic and inorganic pollutants downstream of the mining site (Akankali et al., 2017; Lekomo et al., 2021; Rentier and Cammeraat, 2022; Sani et al., 2022). Station 1 witnessed more activities than station 2 during the dry season while sand mining activities also occurred in stations 5 and 6 during the wet season.

Table 4 Ingestion, dermal and incidental ingestions Hazard Quotients and Hazard Index for Adult and Children in the stations

Parameter/	**Station 1**		**Station 2**		**Station 3**		**Station 4**		**Station 5**		**Station 6**	
Stations	**AdHQ**	**ChHQ**	**Ad HQ**	**ChHQ**	**Ad HQ**	**ChHQ**	**AdHQ**	**ChHQ**	**AdHQ**	**ChHQ**	**AdHQ**	**ChHQ**
Ingestion												
Iron	4.00E-02	9.00E-02	4.00E-02	9.00E-02	3.00E-02	7.00E-02	1.00E-01	2.90E-01	6.00E-02	1.40E-01	7.00E-02	1.40E-01
Lead	1.70E-01	2.90E-01	1.70E-01	2.90E-01	5.70E-02	1.40E-01	2.90E-01	8.60E-01	1.70E-01	2.90E-01	2.30E-01	5.70E-01
Cadmium	1.20E+00	2.00E+00	6.00E-01	2.00E+00	4.00E-01	1.00E+00	1.60E+00	4.00E+00	1.20E+00	2.00E+00	1.20E+00	2.00E+00
HI	**1.41E+00**	**2.38E+00**	**8.10E-01**	**2.38E+00**	**4.87E-01**	**1.21E+00**	**1.99E+00**	**5.15E+00**	**1.43E+00**	**2.43E+00**	**1.50E+00**	**2.71E+00**
Dermal												
Iron	7.00E-06	1.00E-05	7.00E-06	1.00E-05	6.00E-06	9.00E-06	1.00E-05	3.00E-05	1.00E-05	1.00E-05	1.00E-05	3.00E-05
Lead	2.00E-05	4.00E-05	2.00E-05	4.00E-05	8.00E-06	1.00E-05	6.00E-05	9.00E-04	2.00E-05	4.00E-05	4.00E-05	6.00E-05
Cadmium	1.00E-04	2.00E-04	5.00E-05	9.00E-05	4.00E-05	6.00E-05	2.00E-04	3.00E-04	1.00E-04	2.00E-04	1.00E-04	2.00E-04
HI	**1.27E-04**	**2.50E-04**	**7.70E-05**	**1.40E-04**	**5.40E-05**	**7.90E-05**	**2.80E-04**	**1.23E-03**	**1.30E-04**	**2.50E-04**	**1.50E-04**	**2.90E-04**
Incidental Ingestion												
Iron	1.00E-05	9.00E-05	1.00E-05	9.00E-05	1.00E-05	6.00E-05	4.00E-05	3.00E-04	3.00E-05	1.00E-04	3.00E-05	1.00E-04
Lead	6.00E-04	2.00E-03	6.00E-04	2.00E-03	2.00E-04	9.00E-04	1.00E-03	5.00E-03	6.00E-04	2.00E-03	8.00E-04	4.00E-03
Cadmium	3.00E-04	1.00E-03	1.00E-04	6.00E-05	9.00E-05	4.00E-05	4.00E-04	3.00E-03	3.00E-04	1.00E-03	3.00E-04	1.00E-03
HI	**9.10E-04**	**3.09E-03**	**7.10E-04**	**2.15E-03**	**3.00E-04**	**1.00E-03**	**1.44E-03**	**8.30E-03**	**9.30E-04**	**3.10E-03**	**1.13E-03**	**5.10E-03**

Key: Ad = Adult; Ch = Children

Hazard Index (HI)

Multiple contaminants exposure may result in higher health risks and presents the need for the determination of cumulative risks - hazard indices (HI). HI gives an idea of the overall possible effects from multiple contaminants that are not carcinogenic via exposure routes (Sharma, 2020). The hazard indices (HI) for ingestion, dermal and incidental ingestion are also presented in Table 3. The HI values for dermal and incidental ingestion were well below the threshold value (1). On the other hand, all the HI values for ingestion recorded in the 6 stations in relation to adult and children were higher than the threshold value (1) except for adult in stations 2 and 3 (Figure 2).

HI greater than 1 is an indication of contamination level that may constitute adverse human health impact as well as a potential non-carcinogenic risk that should be remedied (Yi et al., 2011; Tripathee et al., 2016). The HI values for ingestion was influenced by cadmium concentration, CDIs and HQs. Long-term exposure to Cd in humans leads to cancer and organ system toxicity (Rahimzadeh et al., 2017) while Zhu et al. (2020) reported damages to the testis, DNA and male subfertility arising from Cd exposure. Kidney damage has been associated with exposure to Cd among others (Bot et al., 2020). The HI for the three exposure routes were also observed to be higher among the children; highlighting their vulnerability (Zhang et al., 2021; Anyanwu et al., 2022a; Odo et al., 2022; Jonah et al., 2023) and stations with more human activities (Sani et al., 2022).

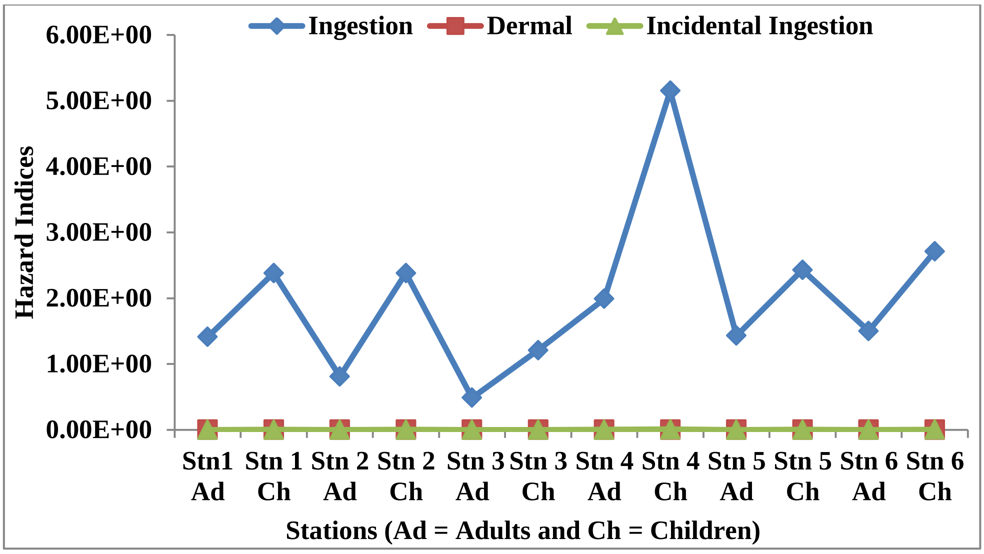

Figure 2: The distribution of Ingestion, Dermal and incidental Ingestion Hazard Indices (HIs) for Adult and Children among the stations.

CONCLUSION

The health risk assessment of Eme River has shown that risk of consuming the water was high and may be detrimental to the consumers. The children swimming in the river and sand miners were not at risk based on the outcome of the dermal and incidental ingestion routes assessment. Concentrations of the metals beyond acceptable limits contributed to the outcome while cadmium was the main metal that contributed the adverse health risk observed. Some of the adverse effects of cadmium pollution, toxicity and vulnerability of children were highlighted. Geology was the major source of the metals but was modified by season and anthropogenic activities (especially sand mining).

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

AUTHORS CONTRIBUTION

EDA, PEE and SNU designed the research. EDA and OGA conducted the field research, analyzed the data, and interpreted the results. All the authors contributed in writing the manuscript, reading and approving the final manuscript.

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