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Research Article **Araştırma Makalesi**

Heavy Metal Content of Water in Ikwu River (Umuahia, Nigeria): Pollution Indices and Health Risk Assessment Approach

Ikwu Nehri (Umuahia, Nijerya) Suyundaki Ağır Metal İçeriği: Kirlilik Endeksleri ve Sağlık Riski Değerlendirmesi

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Abstract: The heavy metal content of a local drinking water source in Southeast Nigeria was studied between January 2021 and June 2021 in 3 stations. Pollution indices (heavy metal pollution index and contamination index) and health risk assessment for non-carcinogenic were used to check the water's suitability for human consumption. Eight heavy metals were assessed with standard methods and compared with The Nigerian Drinking Water Quality Standard. Some metals (Mn, Pb, Fe, Cd, and Cr) exceeded acceptable limits. The heavy metal pollution index exceeded the threshold value (100), ranging between 503.56 and 746.80. The contamination index ranged between 10.74 and 17.12 indicating high contamination potential and all the hazard indices exceeded unity (1). The heavy metal content, pollution indices, and health risk assessment has shown that the water from the Ikwu River was not fit for human consumption. The main metals that influenced the results were Mn, Pb, Fe, Cd, and Cr, because they exceeded limits while Cd and Cr were responsible for the observed adverse health risk. The children were more vulnerable. The geogenic influence was a major factor exacerbated by season and anthropogenic activities in the river.

Keywords
- Limits
- Heavy metal
- Water quality
- Indices
- Drinking water

Özet: Güneydoğu Nijerya'da yerel bir içme suyu kaynağının ağır metal içeriği Ocak 2021 ile Haziran 2021 arasında 3 istasyonda incelenmiştir. Suyun insan tüketimine uygunluğunu kontrol etmek için kirlilik indeksleri (ağır metal kirlilik indeksi ve bulaşma indeksi) ve kanserojen olmayanlar için sağlık risk değerlendirmesi kullanıldı. Sekiz ağır metal, standart yöntemlerle değerlendirildi ve Nijerya İçme Suyu Kalite Standardı ile karşılaştırıldı. Bazı metaller (Mn, Pb, Fe, Cd ve Cr) kabul edilebilir sınırları aştı. Ağır metal kirlilik indeksi eşik değerini (100) aştı; 503,56 ile 746,80 arasında değişmektedir. Kirlilik indeksi 10.74 ile 17.12 arasında değişmekte olup, yüksek kontaminasyon potansiyeline işaret etmekte ve tüm tehlike indeksleri birden (1) aşmaktadır. Çocuklar daha savunmasızdı. Jeojenik etki, nehirdeki mevsim ve antropojenik faaliyetlerle şiddetlenen önemli bir faktördü.

Anahtar kelimeler
- Limitler
- Ağır metal
- Su kalitesi
- İndeksler
- İçme suyu

1. INTRODUCTION

The future of life on earth and sustainable development can only be guaranteed by the availability of good quality water in adequate quantity (Ertaş et al., 2021). Accessibility to potable water is the ease with which a greater majority of people get good quality and quantity of water for their basic needs (Lukman et al., 2016). Safe drinking water has also been described as a basic human right (Gebrekidan and Samuel, 2011, Li and Wu. 2019). Water quality degradation reduces its uses for different purposes coupled with the challenges of water scarcity (Ertaş et al., 2021).

Water pollutants majorly include heavy metals, fertilizers, other toxic inorganic, and organic compounds, etc. (Al-Jumaily, 2016). Considering the wide range of pollutants militating against safe drinking water supplies, heavy metals deserve the highest level of attention because they are toxic even at relatively low concentrations (Marcovecchio et al., 2007; Rehman et al., 2018). Heavy metals occur naturally on earth but can be influenced by human activities (Singh, 2007). In recent times, the quantity of heavy metals has increased tremendously in the environment as a result of human activities (Al-thahaibawi, 2021). Heavy metal concentrations in the environment and exposures worldwide have increased due to industrialization, urbanization, and agriculture, thereby increasing the deleterious human health effects associated with such exposures (Rusyniak et al., 2010). The consequences of such continuous exposure include an internal imbalance in the body and the accumulation and substitution of essential elements. Heavy metals also affect the activity of various hormones and essential enzyme functions (Mukke and Chinte, 2012).

Heavy metal pollution index (HPI) and contamination index are quality indices used in rating the composite influence of dissolved heavy metals in rivers (Addey et al., 2018; Anyanwu and Umeham, 2020b; Anyanwu et al., 2020; Hamidu et al., 2021). It is calculated from the viewpoint of the suitability of water for human consumption concerning metals contamination (Majhi and Biswal, 2016). Risk assessment for non-carcinogenic effects has also been used to evaluate the potential risk of heavy metal pollution in rivers (Muhammad et al., 2011; Wongsasuluk et al., 2013; Anyanwu et al., 2020; Anyanwu and Nwachukwu, 2020; Zakir et al., 2020). Heavy metal was not included in previous studies on the river (Anyanwu and Emeka, 2019; Anyanwu et al., 2022). Hence, this study aims to assess the heavy metal content in relation to drinking water suitability using pollution indices and health risk assessment**.**

2. MATERIAL and METHODS

2.1. Study Area

The study was carried out in Ikwu River, which is located in Umuire Community along Umuahia – Uzoakoli Road, Umuahia, South-east Nigeria within 53411988 – 53448000N and 72844400 – 72852764E (Figure 1).

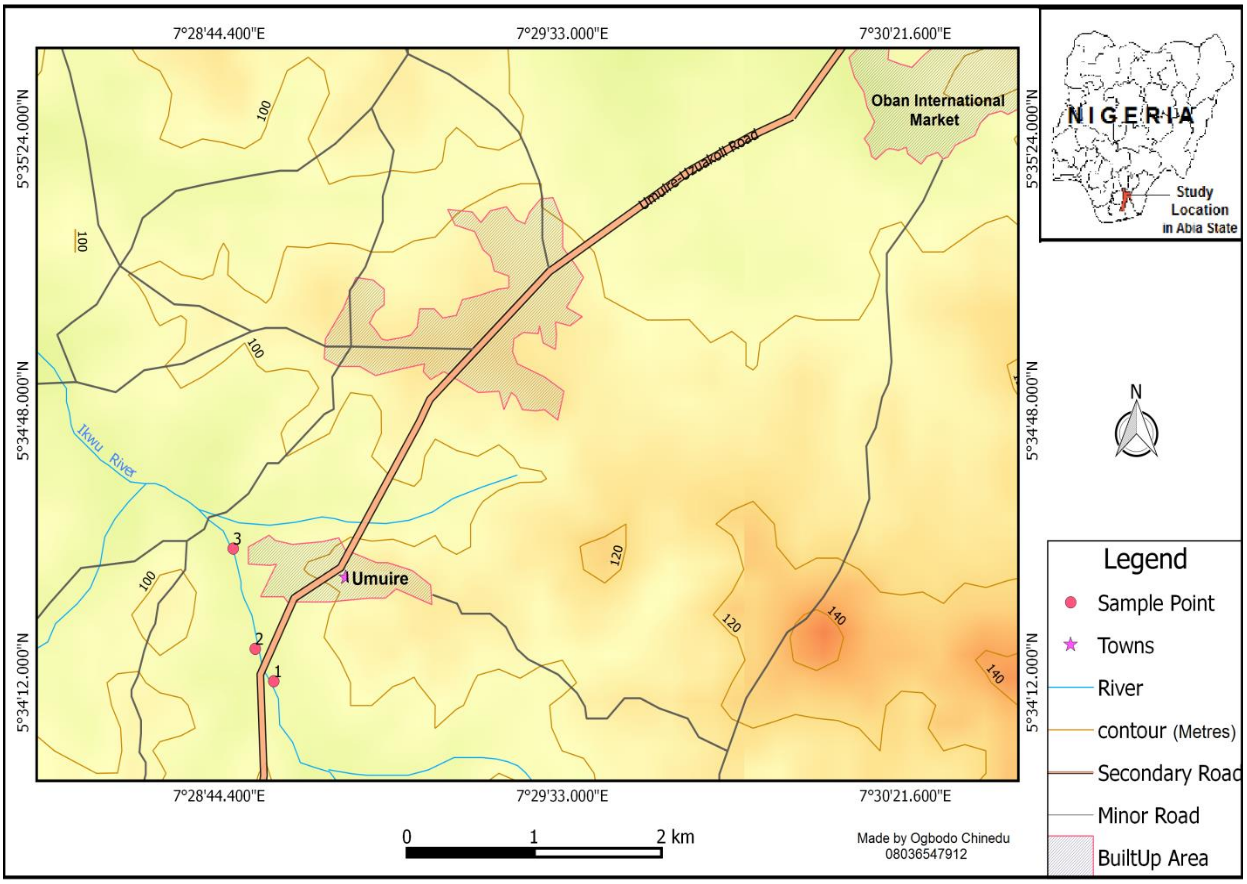

Figure 1: Map of Umuahia, Abia State, Nigeria showing the sampling stations of Ikwu River.

The popular Ubani market is in the watershed of the river. Ikwu River flows through Umuire and Umuegwu Okpula communities and discharges into the Imo River Basin. The three stations were selected based on accessibility and observed anthropogenic activities. Station 1 was the reference site, located upstream on the right along Umuahia – Uzoakoli Road. No activities were observed during the study except periodic signs of cattle watering. Previously, extraction of water for horticulture, agricultural, and drinking purposes was reported (Anyanwu and Emeka, 2019). Station 2 was located by the left side of Umuahia – Uzoakoli Road, 350 meters downstream of Station 1. Many activities were observed some distances upstream of Station 2 such as bathing, washing of cars, motorcycles, and tricycles, children swimming, abstraction of drinking water, and sand mining as the rains increased. Station 3, located within Umuire community is a major source of water for most domestic activities. It is about 430 meters downstream of Station 2. Observed human activities were abstraction of drinking water, washing of clothes, bathing, swimming, and sand mining as the rains increased. Stormwater from Umuire community is also discharging into this station after rainfall events.

2.2. Samples Collection and Analyses

Water samples were collected monthly with a one-liter water sampler from Ikwu River between January and June 2021 and transferred into a clean 250 ml plastic bottle. The samples were acidified to pH 2 with nitric acid (HNO_3) according to Sharma and Tyagi (2013). The digestion was with concentrated Analar nitric acid according to Zhang (2007) while the determination of heavy metals was carried out with UNICAM Solaar 969 atomic absorption spectrometer (AAS) which used acetylene-air flame. The data were summarized with Microsoft Excel while two-way ANOVA was used to test for significant differences in stations and months.

2.3. Pollution Assessment Indices

2.3.1. Heavy metal pollution index

The heavy metal pollution index (HPI), based on the weighted arithmetic mean method was developed by Prasad and Bose (2001). HPI indicates the total quality of water with respect to heavy metals (Horton, 1965; Mohan et al., 1996). HPI has been applied extensively (Addey et al., 2018; Anyanwu and Umeham, 2020b; Anyanwu et al., 2020; Hamidu et al., 2021). To compute HPI, unit weightage (W_i) was considered as a value inversely proportional to the recommended standard (S_i) for the relevant parameters (Prasad and Bose, 2001).

The formula for HPI was described by Mohan et al. (1996) and presented as:

$$\text{HPI} = \frac{\sum q_i \, x \, W_i}{\sum W_i} \qquad (1)$$

Where *qi* is the sub-index of ith parameter. *Wi* is the unit weightage of ith parameter and n is the number of parameters considered.

W_i = 1/Standard (S)

The sub-index (*qi*) of each parameter is defined by:

$$qi = 100 \, x \, \frac{C_i}{S_i} \qquad (2)$$

where *Ci* is the measured value of ith parameter while *Si* is the recommended standard value of ith parameter. The critical value of HPI for drinking purposes as proposed by Prasad and Bose (2001) is 100. Eight (8) heavy metals (Mn, Cu, Pb, Fe, Zn, Cd, Cr, and Ni) were evaluated and the weightage (*Wi*) was taken as the inverse of standard permissible limits by Nigerian Standard for Drinking Water Quality (SON, 2015).

2.3.2. Contamination index

The contamination index was developed by Backman et al. (1998) and it calculates the relative contamination of different metals separately and manifests the sum of generated components as a representative. The contamination index was calculated with the equation:

$$C_d = \sum_{i=0}^{n} C_{fi}$$

$$\text{Where } Cf_i = \left(\frac{CA_i}{CN_i}\right) - 1 \qquad (3)$$

Cf_i = contamination factor for *i*-th component,

CA_i = analytical value for *i*-th component and

CN_i = upper permissible concentration of *i*-th component. (N denotes the 'normative value'). The low, medium, and high contamination levels are referred to C_d values of less than 1, between 1 and 3, and greater than 3, respectively. CN_i is considered the standard permissible value (S_i) used in the calculation of HPI. This method has been widely used by various researchers (Biswas et al., 2017; Dibofori-Orji et al., 2019; Anyanwu et al., 2020; Anyanwu and Umeham, 2020b).

2.4. Health Risk Assessment

Health risk assessment was carried out for the metals that exceeded acceptable limits (Mn, Pb, Fe, Cd, and Cr). The non-carcinogenic method as described by Muhammad et al. (2011) was used for the human health risk assessment. The chronic daily intake (CDI) of heavy metals in Ikwu River water was evaluated by the equation (4):

$$CDI = \frac{C_W x IR x EF x ED}{B_W x AT} \qquad (4)$$

Where, CDI is the daily dose of heavy metals to which consumers might be exposed. C_W (mg/l) is the concentration of heavy metals in the river water, *IR* is the ingestion rate, *EF* is the exposure frequency, *ED* is the exposure duration, *BW* is the body weight, *AT* is the averaging time. The input parameters used in evaluating CDI values are presented in Table 1.

Table 1. Input parameters used in evaluating CDI values

Factor/parameter	Symbol	Units	Adult	Children
Exposure Duration	ED	Years	30	6
Exposure Frequency	EF	Days/year	350	350
Averaging Time	AT (ED x 365)	Days	10950	2190
Body Weight	BW	Kg	70.0	15.0
Ingestion Rate	IR	L/day	2.0	1.0

Source: (USEPA, 2004, 2006).

2.4.1. Hazard quotient

The hazard quotient (HQ) for non-carcinogenic risk was calculated using the equation by USEPA (1999):

$$\text{HQ}=\frac{CDI}{RFD} \qquad (5)$$

Where, *CDI* is the daily dose of heavy metals to which consumers might be exposed and *RfD* is the reference dose (mg/kg/day) which is the daily dosage that enables the individual to sustain this level of exposure over a long period of time without experiencing any harmful effects.

If, $\text{HQ} > 1$, it represents adverse non-carcinogenic effects of concern while $\text{HQ} < 1$ represents an acceptable level (no concern) (Maigari et al., 2016).

2.4.2. Hazard index

For the risk assessment of a mixture of pollutants, the individual HQs are combined to form the hazard index (HI) (Wongsasuluk et al., 2013).

$$HI = \sum_{i=1}^{n}(HQ)i \qquad (6)$$

Where, HI, is the hazard index for the overall toxic risk and n is the total number of metals under consideration. When HI is <1.0, non-carcinogenic adverse effect through ingestion is negligible (Zakir et al., 2020).

2.5. Statistical Analysis

The data were summarized using the Descriptive Statistic Package of Microsoft Excel while Two-way ANOVA without replicate was used to determine significant spatial and temporal variations.

3. RESULTS

3.1. Spatial and Temporal Variations

The summary of the heavy metal values is presented in Table 2. Iron, lead, and cadmium exceeded limits throughout the study and significantly higher values were recorded during the dry months (January - March 2021) while lower values were recorded during the onset of the wet season (April - June 2021). Iron values ranged between 0.43 and 3.11 mg/L. The lowest value was recorded in Station 1 (June 2021). The highest value was recorded in Station 2 (January 2021). Fe was significantly different ($p < 0.05$) in both stations and months. All the values were above the acceptable limit. Station 1 was significantly ($p < 0.05$) lower than Stations 2 and 3 while January was significantly ($p < 0.05$) higher than the rest of the months.

Table 2. Summary of heavy metals measured at Ikwu River (with a range in Parenthesis)

Parameter	**Station 1 X±S.E.M.**	**Station 2 X±S.E.M**	**Station 3 X±S.E.M**	**Station *P* – Value**	**Month *P* – Value**	**SON 2015****
Mn (mg/L) *****	0.22 ± 0.06^{a}	0.30 ± 0.09^{b}	0.30 ± 0.08^{b}	$p < 0.05$	$p < 0.05$	0.2
	(0.11 – 0.53)	(0.17 – 0.75)	(0.14 – 0.66)			
Cu (mg/L)	0.12±0.02	0.16±0.05	0.14±0.03	$p > 0.05$	$p < 0.05$	1.0
	(0.07 – 0.22)	(0.08 – 0.38)	(0.09 – 0.25)			
Pb (mg/L) *****	0.03 ± 0.001^{a}	0.04 ± 0.001^{b}	0.04 ± 0.01^{b}	$p < 0.05$	$p < 0.05$	0.01
	(0.01 – 0.06)	(0.02 – 0.07)	(0.01 – 0.09)			
Fe (mg/L) *****	0.83 ± 0.31^{a}	1.08 ± 0.41^{b}	1.02 ± 0.37^{b}	$p < 0.05$	$p < 0.05$	0.3
	(0.43 – 2.40)	(0.55 – 3.11)	(0.48 – 2.84)			
Zn (mg/L)	0.54±0.24	0.66±0.30	0.61±0.24	$p > 0.05$	$p < 0.05$	3
	(0.21 – 1.73)	(0.27 – 2.17)	(0.22 – 1.80)			
Cd (mg/L) *****	0.02±0.01	0.03±0.01	0.03±0.01	$p > 0.05$	$p > 0.05$	0.003
	(0.01 – 0.04)	(0.01 – 0.05)	(0.01 – 0.06)			
Cr (mg/L) *****	0.05 ± 0.01^{a}	0.07 ± 0.01^{b}	0.06 ± 0.06^{b}	$p < 0.05$	$p < 0.05$	0.05
	(0.02 – 0.09)	(0.03 – 0.11)	(0.02 – 0.11)			
Ni (mg/L)	0.01±0.00	0.02±0.00	0.01±0.00	$p > 0.05$	$p > 0.05$	0.02
	(0.01 – 0.03)	(0.01 – 0.02)	(0.01 – 0.02)			
HPI	503.56	746.80	738.46			
C_d	10.74	17.12	16.26			

*Mean Values exceeded acceptable limits; **Nigerian Standard for Drinking Water Quality (NSDWQ) (2015); SEM= Standard Error of Mean.

Lead values ranged between 0.01 and 0.09 mg/L. The lowest value was recorded in Stations 3 (April 2021) and 1 (June 2021) while the highest value was recorded in Station 3 (March 2021). All the values were above the acceptable limit. Station 1 was significantly ($p < 0.05$) different from Stations 2 and 3 while January to March 2021 was significantly ($p < 0.05$) higher than April to June 2021 values.

Cadmium values ranged between 0.01 and 0.06 mg/L. The lowest value was recorded in Station 1 (January and June 2021); Station 2 (June 2021) and Station 3 (April 2021). The highest value was recorded in Station 3 (March 2021). All the values were above the acceptable limit. Cadmium values were not significantly different ($p > 0.05$) in months and stations.

Manganese, chromium, and nickel had values that exceeded limits only during the dry months. The Manganese values ranged between 0.11 and 0.75 mg/L. The lowest and highest values were recorded in June and January 2021 in Stations 1 and 2, respectively. The values recorded from January to March 2021 were higher than the standard limits set by SON (2015) while April to June 2021 values were within the acceptable limits. Station 1 was significantly ($p < 0.05$) lower than Stations 2 and 3 while January to March 2021 was significantly ($p < 0.05$) higher than April to June 2021.

Chromium values ranged between 0.02 and 0.11 mg/L. The lowest value was recorded in Station 1 (June 2021) and Station 3 (April 2021). The highest value was recorded in Station 2 (March 2021) and Station 3 (March 2021). Chromium values were significantly different ($p < 0.05$) in the months and stations. Station 1 was significantly ($p < 0.05$) lower than Stations 2 and 3. Values from January to March 2021 were above the acceptable limit while March 2021 value was significantly ($p < 0.05$) higher than the rest of the months.

Nickel values ranged between 0.01 and 0.03 mg/L. The lowest value was recorded in Station 1 in all the months except in March 2021. The highest value was recorded in Station 1 (March 2021). The value obtained in Station 1 (March 2021) exceeded the acceptable limit. Nickel values were not significantly different ($p > 0.05$) in the months and stations.

Zinc and copper were all within their limits though higher values were recorded during the dry months. Zn values ranged between 0.21 and 2.17 mg/L. All the values were below the acceptable limit (3 mg/L). The lowest value was recorded in Station 1 (June 2021). The highest value was recorded in Station 2 (January 2021). Zn was highly significantly different ($p < 0.05$) in months but not significant ($p > 0.05$) in stations. January was significantly ($p < 0.05$) higher than the rest of the months. The copper values ranged between 0.07 and 0.38 mg/L. The lowest value was recorded in June 2021 in Station 1 and the highest value was recorded in January 2021 in Station 2. All the values were within the acceptable limit and there was no significant difference ($p > 0.05$) among the stations while January 2021 value was significantly ($p < 0.05$) higher than February to June 2021 values.

3.2. Pollution Indices

The heavy metal pollution index and contamination index showed the possible geogenic and anthropogenic impacts in the river. The HPI and C_d values are also presented in Table 2. The HPI values ranged from 503.56 (Station 1) to 746.80 (Stations 2) which exceeded the threshold value of 100. The high HPI was contributed by the high values recorded for manganese, lead, iron, cadmium, and nickel in all the stations. Stations 2 and 3 had higher HPI values.

The C_d ranged between 10.74 (Station 1) and 17.12 (Station 2) and all are greater than 3, indicating high pollution potential risk. Stations 2 and 3 also recorded the higher values.

3.3. Health Risk Assessment

3.3.1. Chronic daily intake

The chronic daily intake (CDI) of the heavy metals that exceeded limits and respective oral toxicity reference doses (RfD) values are presented in Table 3. The CDI values for Mn were 0.006 mg/kg/day (adult) and 0.007 mg/kg/day (children) in Station 1 and 0.0082 mg/kg/day (adult) and 0.019 mg/kg/day (children) in both Stations 2 and 3. CDI values for Mn recorded for adults and children in all the stations were lower than the RfD (0.14 mg/kg/day).

The CDI values for Pb were 0.0008 mg/kg/day (adult) and 0.0019 mg/kg/day (children) in Station 1 while values of 0.0011 mg/kg/day (adult) and 0.003 mg/kg/day (children) were recorded in Stations 2 and 3. Pb CDI values recorded in all the stations for adult and children were lower the RfD (0.0035 mg/kg/day).

Table 3. Chronic daily intakes of the heavy metals

Metal	**Station 1**		**Station 2**		**Station 3**		**RfD***
	Adult	**Children**	**Adult**	**Children**	**Adult**	**Children**	**(mg/kg/day)**
Mn	0.006	0.007	0.0082	0.019	0.0082	0.019	0.14
Pb	0.0008	0.0019	0.0011	0.003	0.0011	0.003	0.0035
Fe	0.227	0.053	0.296	0.069	0.279	0.065	0.7
Cd	0.0005	0.001	0.0008	0.0019	0.0008	0.0019	0.0005
Cr	0.0014	0.003	0.0019	0.005	0.0016	0.004	0.003

*(USEPA IRIS, 2011)

The CDI values for Fe were 0.22 mg/kg/day (adult) and 0.53 mg/kg/day (children) in Station 1, 0.296 mg/kg/day (adult) and 0.069 mg/kg/day (children) in Station 2 and 0.279 mg/kg/day (adult) and 0.065 mg/kg/day (children) in Station 3. CDI values for Fe recorded in all the stations for adult and children were lower than the RfD limit value (0.7 mg/kg/day).

The CDI values for Cd were 0.0005 mg/kg/day (adult) and 0.001 mg/kg/day (children) in Station 1 while the values of 0.0008 mg/kg/day (adult) and 0.019 mg/kg/day (children) were recorded in Stations 2 and 3. Cd CDI values recorded in all the stations (adult and children) exceeded the RfD (0.0005 mg/kg/day).

The Cr CDI values recorded for children in Stations 2 and 3 exceeded the RfD (0.003 mg/kg/day).

3.3.2. Hazard quotient

The Hazard Quotients (HQs) of the heavy metals that exceeded limits is presented in Table 4. All the HQs for Mn, Pb, and Fe were less than 1 for adults and children in all the stations. However, HQs for Cd were all greater than 1 in all the stations for both adults and children except for adults (station 1) while HQs for Cr were greater than 1 for only children in stations 2 and 3.

Table 4. Hazard Quotients and Total Hazard Index of the Heavy Metals

Metals	**Station 1**		**Station 2**		**Station 3**	
	Adult HQ	**Children HQ**	**Adult HQ**	**Children HQ**	**Adult HQ**	**Children HQ**
Mn	0.043	0.050	0.059	0.14	0.059	0.14
Pb	0.23	0.54	0.31	0.86	0.31	0.86
Fe	0.32	0.076	0.42	0.099	0.40	0.093
Cd	1.00	2.00	1.60	3.84	2.60	3.80
Cr	0.47	1.00	0.63	1.67	0.53	1.33
HI	2.063	3.666	3.019	6.609	3.899	6.223

3.3.3. Hazard index

Hazard indices (HI) recorded for both adult (2.06 – 3.90) and children (3.67 – 6.61) in all the stations were greater than threshold value (1).

4. DISCUSSION

Iron, lead, and cadmium exceeded limits throughout the study. Significantly higher values were recorded in the dry months while lower values were recorded from the onset of the wet season in April 2021. This observed trend could be attributed to geogenic sources influenced by season and anthropogenic activities. Grützmacher et al. (2013) and CGWB (2014) defined geogenic sources as levels that exceeded permissible limits without any direct or indirect link to anthropogenic activities and could have negative health effects. Little or no precipitation, low flow rate, higher air temperatures, and higher evaporation during the dry months contribute to the concentration and higher values of the metals (Etesin et al., 2013; Houssou et al., 2017; Haque et al., 2019). The dry periods or seasons are also associated with increased human visitations and activities because rivers and streams are major sources of water for drinking and most domestic activities in the region (Onyele and Anyanwu, 2018; Anyanwu and Umeham, 2020a, b). However, sand mining activities started and increased with the rains in the river as observed by Anyanwu et al. (2020) and Anyanwu and Umeham (2020a, b). These activities tend to impact negatively on the water quality as observed in Stations 2 and 3 (Anyanwu and Umeham, 2020a, b). On the other hand, the lower values recorded from the onset of the rains (April 2021) could be as a result of dilution (Griffin, 2017). More water is released into the river channel during the wet season. Ezekiel and Dikam (2020) also observed that iron, lead, cadmium and manganese exceeded limits in River Dilimi, Jos North, Plateau State, Nigeria and attributed it to anthropogenic impacts.

Manganese, chromium, and nickel had values that exceeded limits only during the dry months. This observed trend could also be attributed to season and anthropogenic influences as observed in iron, lead, and cadmium (Etesin et al., 2013; Houssou et al., 2017; Haque et al., 2019).

Zinc and copper were all within acceptable limits though higher values were recorded in the dry months. This could also be attributed to season and anthropogenic influences as observed in the other metals. Ezekiel and Dikam (2020) also observed that zinc and copper were within limits in River Dilimi, Jos North, Plateau State, Nigeria despite anthropogenic impacts.

All the HPI exceeded the threshold value (100) in all the stations. Stations 2 and 3 had higher HPI values attributable to geology, season, and human activities, especially sand mining activities. The contribution of sand mining to heavy metal contamination has been variously reported (Pillay et al., 2014; Anyanwu and Umeham, 2020b; Ijaola and Simon, 2021). The HPI values recorded in this study were lower than 1408.33 recorded in River Povpov, Itakpe, Kogi State, Nigeria (Ameh and Akpah, 2011) but higher than 619.8 recorded in Eme River, Umuahia (Anyanwu and Umeham (2020b) and 512.4 recorded in Iyiakwu River, Elemaga (Anyanwu et al., 2020). Both rivers were subjected to more intense sand mining activities.

The C_d values were all greater than 3, indicating high pollution potential risk. Stations 2 and 3 also recorded the higher C_d values; attributed to the factors influencing the HPI. The high C_d was also influenced by the high values recorded for manganese, lead, iron, cadmium, and nickel in all the stations. Herojeet et al. (2015) suggested that Fe and Cd were among the metals that contributed to the high C_d values recorded in the Sirsa River, Himachal Pradesh, India. The C_d values were lower than 18.87 recorded in Eme River, Umuahia (Anyanwu and Umeham, 2020b) and 3.32 recorded in Iyiakwu River, Elemaga (Anyanwu et al., 2020).

The health risk assessment showed the CDI was varied among the metals. CDI values for Mn recorded in all the stations for adults and children were lower than the reference dosage and therefore do not pose any health risk to people drinking water from the stations. The CDI values were slightly lower than the values recorded by Anyanwu et al. (2020) and the same as the only CDI recorded for Mn in Station 1 of Ossah River, Umuahia (Anyanwu and Nwachukwu, 2020). Health effects from Mn are not critical except at concentrations exceeding 5 mg/L (Dimirkou and Doula, 2008).

The CDI values of Pb recorded for adults and children in all the stations were lower than the reference dosage. Thus, lead does not pose any health risk for those exposed to drinking the water. The CDI values recorded by Anyanwu et al. (2020) were slightly lower.

The CDI values for Fe recorded in all the stations for adults and children were lower than the reference dosage. Consequently, Fe does not pose a health risk for those exposed to drinking the water. Though the CDI values were lower than the reference dosage, they could have been influenced by the high Fe content of the river. Related studies recorded high CDI values for Fe (Ekere et al., 2014; Maigari et al., 2016; Onyele and Anyanwu, 2018; Anyanwu et al., 2020; Anyanwu and Nwachukwu, 2020). Naturally, iron has high concentrations on earth and is more abundant in the Nigerian freshwater environment (Adefemi et al., 2004; Aiyesanmi, 2006; Kumar et al., 2010; Iwuoha et al., 2012). Iron in high concentrations is associated with higher risks for cancer, heart disease, and other ailments (arthritis, endocrine problems, diabetes, and liver disease (Elci et al., 2008).

The CDI values for Cd recorded in all the stations (adult and children) exceeded the reference dosage. As a result, Cd poses a health risk for those exposed to drinking the water. The high CDI values of Cd could be as a result of the high Cd content in the river. Cadmium CDI values were lower in Ekere et al. (2014) and higher in Anyanwu et al. (2020). Generally, Cadmium was considered as toxic trace element (Mandour, 2012). Cadmium toxicity is through ingestion and chronic exposure in humans affect the kidney as the critical target organ (Johri et al., 2010; Unisa et al., 2011).

The Cr CDI values recorded for children in Stations 2 and 3 exceeded the reference dosage. Thus pose a serious health risk for children exposed to drinking the water in the stations. The values were within the ranges recorded by Anyanwu et al. (2020) and Anyanwu and Nwachukwu (2020). Chromium is considered carcinogenic and genotoxic at higher concentrations (Paustenbach et al. 2003; Moffat et al., 2018).

Some HQ values for cadmium (adults and children) and chromium (children) exceeded 1 and were attributed to high CDI values. The high HQ values make exposed individuals vulnerable. Therefore, the metals pose long term health risks to the water users. Hazard indices (HI) for both adult and children in all the stations were higher than the threshold value (1). The long-term health risk is therefore high, and the non-carcinogenic adverse effect cannot be ignored.

5. CONCLUSION

The heavy metal content, pollution indices, and health risk assessment has shown that the water from Ikwu River was not fit for human consumption. The main metals that influenced the results were manganese, lead, iron, cadmium, and chromium, because they exceeded limits while cadmium and chromium were responsible for the observed adverse health risk. The children were more vulnerable. Geogenic influence was a major factor exacerbated by season and anthropogenic activities in the river.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

AUTHOR CONTRIBUTIONS

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

ETHICAL APPROVAL STATEMENTS

Not applicable

DATA AVAILABILITY STATEMENT

The data used in the present study are available upon request from the corresponding author. Data is not available to the public due to privacy or ethical restrictions.

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