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Application of Pollution Indices and Health Risk Assessment of Heavy Metals in the waters of a South-eastern Nigeria River

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ABSTRACT: This study on the heavy metal content of a local drinking water source in South-east Nigeria was carried out in 3 sampling stations between May 2019 and October 2019. Pollution indices and health risk assessment for non-carcinogenic were used to check the water's suitability for human consumption. The indices were heavy metal pollution index (HPI) and Contamination Index (C_d). Eight metals were evaluated with standard methods and compared with Nigerian and WHO drinking water standards. Some metals like iron, lead and cadmium exceeded the recommended limits. The stations Heavy Metal Pollution Index ranged between 511.4 and 512.4 while the monthly values ranged between 279.8 and 547.6; all exceeding the threshold value of 100. Contamination Index ranged between 3.12 and 3.32 (stations) and -0.80 to 4.80 (month) indicating high contamination potential and low to high contamination potentials respectively. All the hazard indices also exceeded one (1). Stations 1 and 2 were higher in all the indices. All the indices were linked the high values of iron, lead and cadmium, influenced by sand mining activities. The pollution indices and Health Risk Assessment converged to show that the waters of Iyiakwu River are not fit for human consumption. The children are more vulnerable since it the main source of drinking water in the area.

Keywords: Limits, HPI, Heavy metal, water quality, indices.

INTRODUCTION

Access to safe and good quality drinking water is a basic need of all humans, irrespective of their nationality and sociopolitical status (Li & Wu, 2019). Health of consumers is significantly affected by drinking water of poor quality. In rural areas, the situation is worsened by the increased demand of water and reduction of water quantity and quality due to population growth and economic development (Hoaghia et al., 2016; Li & Qian, 2018). Scheili et al. (2015) observed that the quality of a water source is a major determinant of the drinking water quality especially in the rural areas and small municipalities where water are obtained from different sources without any form of treatment. Scheili et al. (2016a, b) went further to report that the quality of a water source can be affected by meteorological and climatic factors while the variability of anthropogenic activities was the major factor that could explain the day to day variability of drinking water quality.

Chemical contaminants of drinking water are often overlooked compared biological contaminants, because the adverse health impacts of chemical

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contaminants usually manifest after a long time (Fatemeh et al., 2016). Monitoring of heavy metal contamination in rivers is important because they pose threat to aquatic life, human health and to the environment as a result of their tendency to biomagnify and their toxicity (Ahmed et al., 2015; Ali et al., 2016). The heavy metals in water could be derived from both geogenic and anthropogenic (Ahmet et al., 2006; Anyanwu & Onyele, 2018). Surface and ground waters can be polluted by heavy metals thereby affecting the quality for drinking and irrigation purposes (Krishna et al., 2009; Rahman et al., 2020). Some heavy metals are essential to humans but can result in deleterious health consequences when they exceed recommended levels in drinking water (Prasanna et al., 2011; Prasad et al., 2014).

A number of studies on heavy metal pollution of water resources have been carried out around the world (Muhammad et al., 2011; Kelepertzis, 2014; Ojekunle et al., 2016; Biswas et al., 2017; Rahman et al., 2020) and the study area (Ngah & Ekpebegh, 2016; Akachukwu et al., 2017; Anyanwu & Onyele, 2018; Anyanwu & Umeham, 2020b).

Measuring the concentrations in water is usually the method of monitoring heavy metals in aquatic ecosystem (Ebrahimpour & Mushrifah, 2008; Balakrishnan & Ramu, 2016) but quality indices are useful in getting the aggregate influence of all parameters on overall pollution. It also makes the assessments reproducible and compiling all the pollution parameters into an easy approach (Balakrishnan & Ramu, 2016).

Two indices (heavy metal pollution index and contamination index) and Health Risk Assessment for non-carcinogenic were used to evaluate the potential risk of metal pollution in Iyiakwu River. It is a rural river located at Elemaga Community, Ikwuano Local Government Area, Abia State, Southeast Nigeria and a major source of drinking water especially in the dry season. The objective of this study was to evaluate the suitability of Iyiakwu River for human consumption in respect to heavy metal content using pollution indices and health risk assessment.

MATERIALS AND METHODS

The study was carried out in Iyiakwu River, Elemaga, Ikwuano Local Government Area, Abia State, Nigeria (Fig. 1). The section of the river studied lies within Latitude 05^{o} 26’ 21” - 05° 26’ 40”N and Longitude 07° 37’ 3” - 07° 37’ 16”E (Fig. 2). Station 1 is upstream and the control station. It is downstream to a number of sand mining sites. The substrate is sandy. Human activities observed during the study include extraction of water for drinking, fermentation and processing of breadfruit and cassava in plastic containers. Station 2 was 2.15km downstream of station 1. The substrate was also sandy. Human activities observed during the study include extraction of water for drinking and nursery, sand mining activities, washing of clothes, fermentation and processing of cassava in plastic containers and swimming. Effluents from palm oil mill are discharged into the river in this station. Station 3 was 1.97km downstream of station 2. It was located within a large expanse of palm bush, cocoa farms and farmlands. Little or no activities were observed during the study but sand mining activities was observed in September and October 2019.

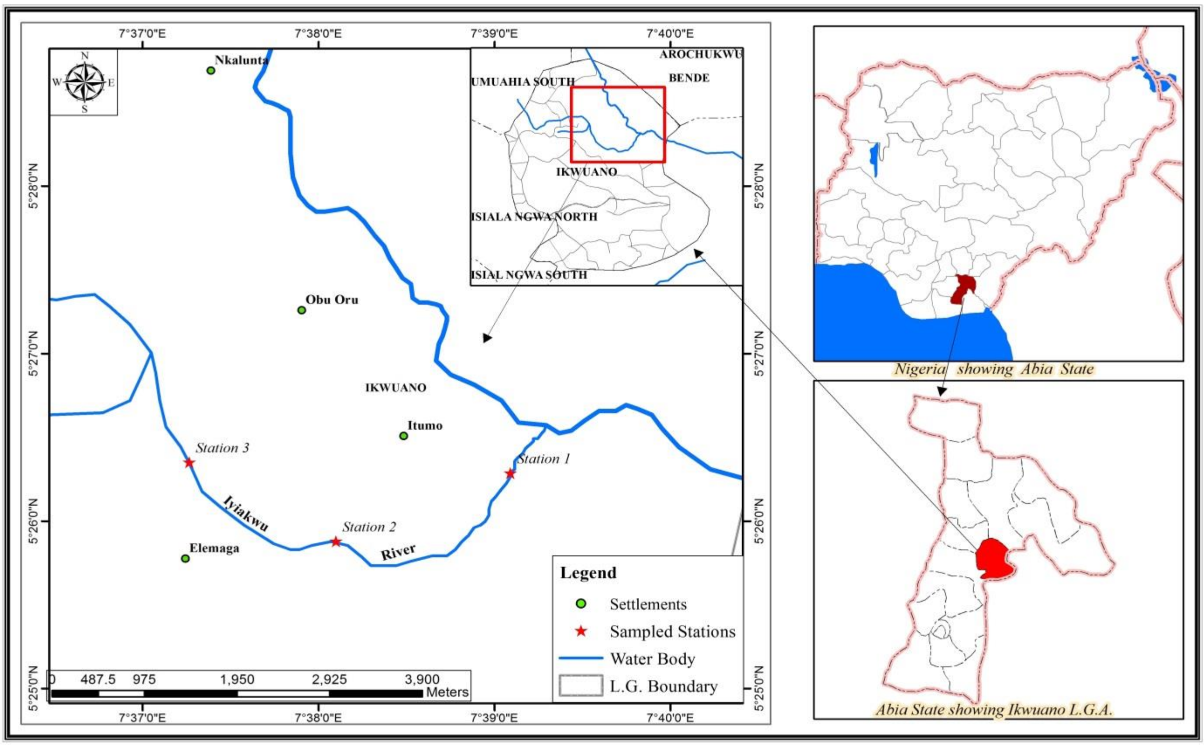

Fig. 1. Study Map showing the Sampling Stations of Iyiakwu River, Elemaga, Ikwuano Local Government Area, Abia State, Nigeria.

Water samples were collected monthly from Iyiakwu River between May and October 2019; in a one litre water sampler and transferred into a clean 250ml plastic bottle. The pH of the water samples reduced to pH 2 with Nitric acid (HNO_3) as described by Sharma & Tyagi (2013). The water samples were digested with concentrated analytical grade Nitric acid as described by 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 heavy metal pollution index (HPI) was developed by Prasad & Bose (2001) and it is based on weighted arithmetic mean method. HPI indicates the total quality of water with respect to heavy metals (Horton, 1965; Mohan et al., 1996). In order to compute HPI, unit weightage (Wi) is considered as a value inversely proportional to the recommended standard (Si) for the relevant parameter (Prasad & Bose, 2001).

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

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

where, *q*i is the sub-index of ith parameter. *W*i is the unit weightage of ith parameter and n is the number of parameters considered.

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

The sub-index (*q*i) of each parameter is defined by: where *Ci* is the measured value of ith parameter, while *S*i is the recommended standard value of ith parameter. The critical value of HPI for drinking purposes as given by Prasad & Bose (2001) is 100. In computing the HPI, eight heavy metals (Mn, Cu, Pb, Fe, Zn, Cd, Cr and Ni) were considered and the weightage (Wi) was taken as the inverse of standard permissible value which is the Nigerian Standard for Drinking Water Quality (SON, 2015) and WHO Drinking Water Standard (WHO, 2017).

Backman et al. (1997) developed the contamination index and it calculates the relative contamination of different metals separately and manifests the sum of generated components as a representative. Contamination index was calculated using the following equation:

$$C_d = \sum_{i=0}^{n} C_{fi} \quad (3)$$

where $Cf_i = \left(\frac{CA_i}{CN_i}\right) - 1$

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 as the standard permissible value (S_i) used in the calculation of HPI. These methods have been widely used by the various scientists (Nasrabadi, 2015; Biswas et al., 2017; Dibofori-Orji et al., 2019; Anyanwu & Umeham, 2020b).

Health risk assessment was carried out for all the metals evaluated. The Non-carcinogenic method as described by Muhammed et al. (2011) was used for the human health risk assessment. The Chronic Daily Intake (CDI) of heavy metals in Iyiakwu River water was evaluated by the equation:

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

where, CDI represent the daily dose of heavy metals in mg/L, which the consumers could be exposed to. CW (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. Parameters used to characterize 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).

The equation by USEPA (1999) was used calculate the Hazard Quotient (HQ) for non-carcinogenic risk:

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

where, CDI represent the daily dose of heavy metals in mg/L, which the consumers could be exposed to and RfD represent the reference dose, the daily dosage that is required by an individual to cope with this level of exposure over a long duration without experiencing any deleterious effects.

If, HQ> 1, it represents adverse non-carcinogenic effects of concern while HQ< 1 represents acceptable level (no concern).

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

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

where, HI, is the hazard index for the overall toxic risk and n is the total number of metals under consideration. The non-carcinogenic adverse effect due to ingestion can be considered to be negligible if HI<1.0 (Ayantobo et al., 2014).

The data was entered into Microsoft Excel, and one-way ANOVA was used for statistical analysis of the data for significant differences. Tukey Pairwise test was used to determine the source of significant differences between means. All statistical analysis was performed with PAST software package (Version 3.24) (Hammer et al., 2001).

RESULTS AND DISCUSSION

The summary of the heavy metal values are presented in Tables 2 and 3. The Manganese values ranged between 0.04 and 0.13 mg/L. The lowest and highest values were recorded in August and October 2019 respectively in station 3. All the manganese values were within the acceptable limit set by SON (2015). There was no significant difference ($p>0.05$) among the stations (Table 2) while October 2019 was significantly different ($p<0.05$) from May, June and August 2019 (Table 3).

The copper values ranged between 0.03 and 0.07 mg/L. The lowest values were recorded in all the stations except July 2019 while the highest was recorded in station 3 in October 2019. All the values were within the acceptable limits set by SON (2015) and WHO (2017); there was no significant difference ($p>0.05$) within the stations and months (Tables 2 and 3).

Lead, on the hand, ranged between 0.01 and 0.03 mg/L. The lowest values were recorded in stations 2 (September 2019) and 3 (August 2019) while the highest values were recorded in stations 1 and 2 (July 2019) and in station 3 (October 2019). All the values exceeded acceptable limit set by SON (2015) and WHO (2017) except in stations 2 (September 2019) and 3 (August 2019) (Table 2). There was no significant difference ($p>0.05$) within the stations and months (Tables 2 and 3).

The iron values ranged between 0.29 and 0.67 mg/L (Tables 2 and 3). The lowest values were recorded in August 2019 in station 3 while the highest value was recorded in station 1 in July 2019. All the values exceeded the acceptable limit set by SON (2015) except in station 3 in August 2019 and there was no significant difference ($P>0.05$) within the stations and months.

The zinc values ranged between 0.08 and 0.23 mg/L. The lowest and highest values were recorded in August and October 2019 respectively in station 3. All the values were within acceptable limit set by SON (2015). There was no significant difference ($P>0.05$) among the stations (Table 2) while September 2019 was significantly different ($P<0.05$) from May, June and August 2019. On the other hand, October 2019 was significantly different ($P<0.05$) from May to August 2019 (Table 3).

The cadmium values ranged between 0.01 and 0.03mg/L. The lowest values were recorded in station 1 (May, August and September 2019), station 2 (September and October 2019) and station 3 (May, June and August 2019). All the values highly exceeded the acceptable limit and there was no significant difference ($P>0.05$) in the stations and months (Tables 2 and 3).

The chromium values ranged between 0.02 and 0.04mg/L (Tables 2 and 3). All the values were within the acceptable limit set by SON (2015) and WHO (2017).The lowest values was recorded in stations 1 and 2 (September 2019) and station 3 (May, August and September 2019). The highest values were recorded in stations 1 (July 2019) and 3 (October 2019).

The nickel values ranged between 0.01 and 0.02 mg/L (Tables 2 and 3). The lowest values were recorded in stations 1 and 2 (September 2019) and station 3 (May and August 2019). The highest values were recorded in stations 1 (July 2019) and station 3 (October 2019). All the values of chromium and nickel were within the acceptable limit and there was no significant difference ($P>0.05$) in the stations and months (Tables 2 and 3).

All the metals generally increased with the rains attributed to increased runoff (Chiba et al., 2011; Offem et al., 2011; Ugwu & Wakama, 2012; Souza et al., 2016). Similar trend was observed in some metals in Woji Creek, Port Harcourt (Dibofori-Orji et al., 2019). Iron, cadmium and lead exceeded acceptable limits which could be geogenic influenced by anthropogenic and seasonal impacts (Pillay et al., 2014; Anyanwu & Onyele, 2018; Dibofori-Orji et al., 2019; Anyanwu & Umeham, 2020b). There was no significant difference in the stations probably due to the same anthropogenic impacts. Zinc and manganese, though, within acceptable limits were significantly different in September and October 2019 especially in station 3. This could be as a result seasonal influence enhanced by anthropogenic impact. Sand mining activities became high during that period in station 3. Anyanwu & Umeham (2020a & b) observed that sand mining activities are usually high during the peak of the rains. The concentrations of heavy metals recorded in this study were generally low compared to related studies in the region (Ekere et al., 2014; Anyanwu & Onyele, 2018).

Table 2. Summary of heavy metals measured at the stations of Iyiakwu River (with range in Parenthesis)

Parameter	Station 1 X±S.E.M	Station 2 X±S.E.M	Station 3 X±S.E.M	P – Value	Limits
Mn (mg/L)	0.08±0.01 (0.05 – 0.12)	0.09±0.01 (0.07 – 0.10)	0.07±0.02 (0.04 – 0.13)	P > 0.05	0.2*
Cu (mg/L)	0.04±0.01 (0.03 – 0.06)	0.04±0.01 (0.03 – 0.06)	0.04±0.07 (0.03 – 0.07)	P > 0.05	2.0**
Pb (mg/L)	0.02±0.003 (0.02 – 0.03)	0.02±0.002 (0.01 – 0.03)	0.02±0.002 (0.01 – 0.03)	P > 0.05	0.01***
Fe (mg/L)	0.43±0.05 (0.32 – 0.67)	0.42±0.04 (0.32 – 0.55)	0.39±0.04 (0.29 – 0.52)	P > 0.05	0.3*
Zn (mg/L)	0.15±0.02 (0.09 – 0.22)	0.13±0.01 (0.10 – 0.18)	(0.13±0.03 (0.08 – 0.23)	P > 0.05	3*
Cd (mg/L)	0.02±0.002 (0.01 – 0.03)	0.02±0.002 (0.01 – 0.02)	0.02±0.002 (0.01 – 0.02)	P > 0.05	0.003***
Cr (mg/L)	0.03±0.004 (0.02 – 0.04)	0.03±0.003 (0.02 – 0.03)	0.02±0.003 (0.02 – 0.04)	P > 0.05	0.05***
Ni (mg/L)	0.01±0.002 (0.01 – 0.02)	0.01±0.002 (0.01 – 0.02)	0.01±0.002 (0.01 – 0.02)	P > 0.05	0.07**
HPI	512.3	512.4	511.4		
C_d	3.31	3.32	3.12		

SEM= Standard Error of Mean; * = Nigerian Standard for Drinking Water Quality (NSDWQ) (SON, 2015); ** = WHO Drinking Water Guideline (WHO, 2017); *** = Same (SON, 2015; WHO, 2017).

Table 3. Summary of heavy metals measured monthly at Iyiakwu River (with range in Parenthesis)

Parameter	May 2019 X±S.E.M	Jun 2019 X±S.E.M	Jul 2019 X±S.E.M	Aug 2019 X±S.E.M	Sep 2019 X±S.E.M	Oct 2019 X±S.E.M	P – Value	Limits
Mn (mg/L)	0.06±0.01[a] (0.05 – 0.08)	0.06±0.01[a] (0.05 – 0.08)	0.08±0.02[ab] (0.05 – 0.11)	0.05±0.01[a] (0.04 – 0.07)	0.10±0.01[ab] (0.09 – 0.11)	0.12±0.01[b] (0.10 – 0.13)	P < 0.05	0.2*
Cu (mg/L)	0.04±0.01 (0.03 – 0.05)	0.04±0.01 (0.03 – 0.05)	0.05±0.01 (0.04 – 0.06)	0.04±0.01 (0.03 – 0.05)	0.03±0.00 (0.03 – 0.04)	0.05±0.01 (0.03 – 0.07)	P > 0.05	2.0**
Pb (mg/L)	0.02±0.00 (0.02)	0.02±0.00 (0.02)	0.03±0.00 (0.02 – 0.03)	0.02±0.00 (0.02)	0.02±0.00 (0.02)	0.02±0.00 (0.02 – 0.03	P > 0.05	0.01***
Fe (mg/L)	0.37±0.04 (0.31 – 0.45)	0.40±0.05 (0.34 – 0.50)	0.53±0.08 (0.38 – 0.67)	0.31±0.01 (0.29 – 0.32)	0.42±0.04 (0.37 – 0.50)	0.44±0.05 (0.32 – 0.52)	P > 0.05	0.3*
Zn (mg/L)	0.10±0.00[a] (0.09 – 0.10)	0.10±0.00[a] (0.10 – 0.11)	0.14±0.02[ab] (0.10 – 0.15)	0.09±0.00[a] (0.08 – 0.10)	0.18±0.00[bc] (0.18 – 0.19)	0.21±0.02[c] (0.17 – 0.23)	P < 0.05	3*
Cd (mg/L)	0.02±0.00 (0.01 – 0.02)	0.02±0.00 (0.01 – 0.02)	0.02±0.00 (0.02 – 0.03)	0.01±0.00 (0.01 – 0.02)	0.01±0.00 (0.01 – 0.02)	0.02±0.00 (0.01 – 0.03)	P > 0.05	0.003***
Cr (mg/L)	0.02±0.00 (0.02 – 0.03)	0.02±0.00 (0.02 – 0.03)	0.03±0.01 (0.02 – 0.04)	0.02±0.00 (0.02 – 0.03)	0.02±0.00 (0.02)	0.03±0.01 (0.02 – 0.04)	P > 0.05	0.05***
Ni (mg/L)	0.01±0.00 (0.01 – 0.02)	0.01±0.00 (0.01 – 0.02)	0.02±0.00 (0.01 – 0.02)	0.01±0.00 (0.01)	0.01±0.00 (0.01)	0.01±0.00 (0.01 – 0.02)	P > 0.05	0.07**
HPI	513.0	513.0	547.6	279.8	280.3	515.1		
C_d	2.79	2.89	4.80	-0.80	-0.16	3.57		

a, b, c = Means with different superscripts across the rows are significantly different at p<0.05; SEM= Standard Error of Mean; * = Nigerian Standard for Drinking Water Quality (NSDWQ) (SON, 2015); ** = WHO Drinking Water Guideline (WHO, 2017); *** = Same (SON, 2015; WHO, 2017).

The station and monthly results obtained for the HPI and C_d were also presented in Tables 2 and 3 respectively. The alignment of both indices (Heavy Metal Pollution Index and Contamination Index) showed an interesting trend and reflected the possible effects of geogenic influence exacerbated by season and human activities in the river. All the HPI results were all found to exceed the threshold value of 100(Prasad & Bose, 2001). Spatially, the values ranged from 511.4 (Station 3) to 512.4 (Station 2); reflecting the effects of geogenic and anthropogenic activities (Table 2). On monthly basis, the HPI values reflected the effect of season (rains); the lowest value (279.8) was recorded during the August break while the highest value (547.6) in July 2019, followed by 515.1 in October 2019. July and October are peaks of rain in the region. The high HPI was contributed by the high values recorded for iron, cadmium and lead in all the stations and months as observed in Anyanwu & Umeham (2020b). Stations 1 and 2 had the highest HPI values attributable to human activities especially intense sand mining activities in the stations. This trend was observed by Dibofori-Orji et al. (2019) and Anyanwu & Umeham (2020b) that recorded the highest HPI in stations 3 and 4 respectively; with the highest human impacts. Intense sand mining activities was only observed in September and October 2019 in station 3. Metal concentrations are generally higher downstream of mining operations sites with some minor variations (Pillay et al., 2014; Anyanwu & Umeham, 2020b). On monthly basis, the HPI values were generally influenced by season (rains) rather than anthropogenic activities. The high HPI values recorded in this study were lower than 1408.33 recorded in dry season in River Povpov, Itakpe, Kogi State, Nigeria (Ameh & Akpah, 2011) and 619.8 recorded in Eme River, Umuahia, Nigeria (Anyanwu & Umeham, 2020b) but higher than the highest value (361.8) recorded in September 2018 by Dibofori-Orji et al. (2019) in Woji Creek, Port Harcourt, Nigeria.

The C_d results followed the same trend as the HPI spatially and monthly; the lowest was recorded in Station 3 while the highest was recorded in Station 2. It varied from 3.12 to 3.32; also reflecting the effects of the geogenic and anthropogenic activities. The results indicated that all the stations had high pollution potential risk (Table 2). The months of July and October 2019 had values of 4.80 and 3.75 that are greater than 3 while August and September 2019 had values of -0.80 and -0.16 respectively that are less than 0 (Table 3). Values greater than 3 are of high pollution potential risk while values lower than 0 were of low pollution potential risk. The results indicated that all the stations had values greater than 3; indicating high pollution potential risk. Stations 1 and 2 also recorded the highest C_d values still indicating the influence of sand mining activities in the stations as observed in Anyanwu & Umeham (2020b). The months of July and October 2019 had values greater than 3 while rest were less than 3; with August and September 2019 being less than 0. This also indicates seasonal (rain) influence on the heavy metal concentrations. The high C_d was also influenced by the high values recorded for iron, cadmium and lead in all the stations and months. Herojeet et al. (2015) recorded C_d values of between 0.23 and 45.29 in the Sirsa River, Himachal Pradesh, India while Anyanwu & Umeham (2020b) recorded Cd values of between -1.69 and 18.87 in Eme River, Umuahia, Nigeria. Both studies observed that Fe, Pb and Cd were among the metals that contributed to the high contamination index (C_d).

The station and monthly chronic daily intake (CDI) of the metals and oral toxicity reference dose (RfD) values are presented in Tables 4 and 5. Health Risk Assessment showed that the station and monthly CDI values of manganese, copper, lead, zinc and nickel were lower than oral reference doses (RfD) for both adults and children; these metals were not considered to pose health risks.

The CDI values for Mn were between 0.002 and 0.003 mg/kg/day (adults) and 0.005 and 0.006 mg/kg/day (children). The highest values for adults and children were recorded in station 2. On monthly basis, the CDI values were between 0.001 and 0.003 mg/kg/day (adults) and 0.003 and 0.008 mg/kg/day (children). The highest values for adult were recorded in September and October 2019 while highest value for children was recorded in October 2019.

For Cu, the CDI values of 0.001 and 0.003 mg/kg/day were recorded for adults and children respectively in all the stations. Value of 0.001 mg/kg/day was recorded for adults throughout the study period while 0.003 mg/kg/day were recorded for children throughout the study period except 0.002 mg/kg/day recorded in September 2019.

The CDI value of 0.0005 mg/kg/day was recorded for Pb in adults and children (0.0003 mg/kg/day) in all the stations while 0.001 mg/kg/day was recorded for adults and children throughout the study period except 0.002 mg/kg/day recorded for children in July 2019.

The CDI values for Fe are 0.010 – 0.0117 mg/kg/day (adults) and 0.027 – 0.028 mg/kg/day (children). The highest values for adults and children were recorded in station 1. The values for the monthly variation ranged between 0.009 and 0.012 mg/kg/day (adults) and 0.019 – 0.034 mg/kg/day (children). The highest monthly value was recorded in July 2019. The CDI values of iron for adult and children were above oral reference dose (RfD) (0.007mg/kg/day) in the stations and months. Thus, iron pose health risk for those exposed to drinking water from the river. Ekere et al. (2014), Maigari et al. (2016) and Onyele & Anyanwu (2018) equally recorded high iron CDI values. The high iron CDI values are as a result of high iron content of the river; this could be geogenic exacerbated by anthropogenic influences in the station (Pillay et al., 2014; Anyanwu & Onyele, 2018) and season (rains) in the months. Fe is usually more abundant in freshwater environment than other metals in Nigeria, due to its high occurrence on Earth (Adefemi et al., 2004; Aiyesanmi, 2006; Kumar et al., 2010; Iwuoha et al., 2012). Iron is an essential micronutrient, however, it can cause undesirable physiological problems if its concentration in water is high (Kar et al., 2008; Nair et al., 2010). Mandour (2012) reported that cases of liver failures were related to iron-contaminated drinking water in polluted surface and ground waters of Dakahlyia Governorate, Egypt and high concentration of iron may produce neurological effects (Zheng et al., 2003).

The CDI values for Zn are 0.003 – 0.004 mg/kg/day (adult) and 0.008 – 0.009 mg/kg/day (children). The highest values for adults and children were recorded in station 1. The monthly CDI values for Zn are 0.003 – 0.006 mg/kg/day (adults) and 0.006 – 0.013 mg/kg/day (children). The highest values for both were recorded in October 2019.

The CDI values of Cd adults ranged between 0.0005 and 0.001 mg/kg/day the highest value recorded in station 2. The value for the children was 0.001 mg/kg/day in all the stations. The monthly values ranged from 0.00 – 0.001 mg/kg/day (adults) and 0.001 mg/kg/day (children) throughout the study period. No values were recorded for adults in August and September 2109. CDI values of Cd for children were higher than oral reference dose (RfD) (0.0005 mg/kg/day) in the stations. Thus, cadmium pose health risk for children exposed to drinking water from the river. The monthly values all exceeded RfD except for adults in August and September 2019. Ayantobo et al. (2014), Ekere et al. (2014), Maigari et al. (2016) and Onyele & Anyanwu (2018) recorded similar range of cadmium CDI values. The high cadmium CDI values in the stations could be as a result of anthropogenic impact (sand mining) on the cadmium concentration of the water while that of the months could be season (rains). Cadmium is generally classified as toxic trace element and geologic deposits of cadmium can serve as sources to groundwater and surface water, especially in soft, acidic waters (Mandour, 2012). The kidney is the critical target organ in humans affected by chronic Cd exposure and toxicity through ingestion (Johri et al., 2010; Unisa et al., 2011).

CDI Values of 0.0005 – 0.0008 mg/kg/day were recorded for Cr in adults. The highest values were recorded in stations 1 and 2. The value of 0.001 mg/kg/day was recorded for children in all the stations. On monthly basis, the CDI value of 0.001 mg/kg/day was recorded for adults throughout the study period while values of 0.001 – 0.002 mg/kg/day for children. The highest monthly values were recorded in July and October 2019. CDI values of Cr for adults and children were higher than oral reference dose (RfD) (0.0003 mg/kg/day) in the stations. Thus, chromium pose health risk for adults and children exposed to drinking water from the river. Stations 1 and 2 were higher for the adults, which could be attributed to sand mining. The monthly values all exceeded RfD. This could be attributed to season (rains) because higher values were recorded in July and October 2019, which are peaks of rain in the region. Ayantobo et al. (2014), Ekere et al. (2014) and Onyele & Anyanwu (2018) equally reported high CDI values in chromium. High concentrations of chromium could lead to liver and kidney toxicity and genotoxic carcinogen (Strachan, 2010; Zhitkovich, 2011).

The CDI values for Ni were 0.003 mg/kg/day (adults) and 0.0006 (children) in all the stations. No monthly values were recorded for adults except for 0.001 mg/kg/day in July 2019 while the value of 0.001 mg/kg/day was recorded for children throughout the study.

Table 4. CDI (mg/kg/day) recorded for Adult and Children in the stations.

Metal	Station 1		Station 2		Station 3		RfD*
	AD	CH	AD	CH	AD	CH	(mg/kg/day)
Mn	0.002	0.005	0.003	0.006	0.002	0.005	0.14
Cu	0.001	0.003	0.001	0.003	0.001	0.003	0.037
Pb	0.0005	0.0003	0.0005	0.0003	0.0005	0.0003	0.0035
Fe	0.0117	0.028	0.0115	0.027	0.010	0.027	0.007
Zn	0.004	0.009	0.003	0.008	0.003	0.008	0.3
Cd	0.0005	0.001	0.001	0.001	0.0005	0.001	0.0005
Cr	0.0008	0.001	0.0008	0.001	0.0005	0.001	0.0003
Ni	0.003	0.0006	0.003	0.0006	0.003	0.0006	0.2

*USEPA IRIS (2011); AD = Adult; CH= Children

Table 5. CDI (mg/kg/day) recorded for Adult and Children on monthly basis.

Metal	May 2019		Jun 2019		Jul 2019		Aug 2019		Sept 2019		Oct 2019		RfD*
	AD	CH	AD	CH	AD	CH	AD	CH	AD	CH	AD	CH	(mg/kg/day)
Mn	0.002	0.004	0.002	0.004	0.002	0.005	0.001	0.003	0.003	0.006	0.003	0.008	0.14
Cu	0.001	0.003	0.001	0.003	0.001	0.003	0.001	0.003	0.001	0.002	0.001	0.003	0.037
Pb	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.0035
Fe	0.010	0.023	0.011	0.025	0.010	0.034	0.009	0.019	0.011	0.027	0.012	0.028	0.007
Zn	0.003	0.006	0.003	0.006	0.004	0.009	0.003	0.006	0.005	0.012	0.006	0.013	0.3
Cd	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.001	0.000	0.001	0.001	0.001	0.0005
Cr	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.0003
Ni	0.000	0.001	0.000	0.001	0.001	0.001	0.000	0.001	0.000	0.001	0.000	0.001	0.2

*USEPA IRIS (2011); AD = Adult; CH= Children

The hazard quotient (HQ) values for Mn, Cu, Pb, Zn and Ni were all less than 1 in the stations and months as a result pose minimal risks and acceptable. The HQ values for iron, cadmium and chromium exceeded 1 for adults and children in all the stations and months. The station and monthly Hazard Quotients (HQ) of the heavy metals are presented in Tables 6 and 7. All the HQs of Fe, Cd and Cr for adults and children exceeded 1 in the stations and months except for Cd values recorded for adults in the stations.

The HQs of Fe in the stations were 1.43 – 1.67 (adults) and 3.86 – 4.00 (children). The highest values for both adults and children were recorded in station 1. The monthly HQs for Fe were 1.29 – 1.71 (adults) and 2.71 – 4.86 (children). The highest value for adults was recorded in October 2019 while the highest for children was recorded in July 2019.

The HQs of Cd in the stations were 1.00 (adults) and 2.00 (children) in all the stations. The values for adults were not greater than 1 but all the children values were greater than 1. The monthly HQs for Cd were 2.00 for adults and children throughout the study period.

The HQs of Cr in the stations were 1.67 – 2.67 (adults) and 3.33 (children). The highest values for adults were recorded in stations 1 and 2. The monthly HQs for Cd for adults and children were all 3.33 except for 6.67 recorded for children in July and October 2019.

The high HQ values recorded were as result of high CDI values of iron, cadmium and chromium; influenced by anthropogenic and seasonal effects. HQ values were generally high for children in all the stations thereby making them more vulnerable. This was also observed in Onyele & Anyanwu (2018) and Rahman et al. (2020). These metals pose long term health risks to the water users in all the stations and months concerned. This health risk could be reduced in the dry season when dependence on the river will be high. Pressure on waterbodies in the region is usually very high during the dry season (Anyanwu and Umeham, 2020a & b).

Table 6. Hazard Quotients (HQ) and Hazard Index (HI) recorded for Adults and Children in the stations.

Metals	Station 1		Station 2		Station 3	
	HQ_{AD}	HQ_{CH}	HQ_{AD}	HQ_{CH}	HQ_{AD}	HQ_{CH}
Mn	0.014	0.036	0.021	0.043	0.014	0.036
Cu	0.03	0.08	0.03	0.08	0.03	0.08
Pb	0.14	0.086	0.14	0.086	0.14	0.086
Fe	1.67	4.00	1.64	3.86	1.43	3.86
Zn	0.01	0.03	0.01	0.02	0.01	0.02
Cd	1.00	2.00	1.00	2.00	1.00	2.00
Cr	2.67	3.33	2.67	3.33	1.67	3.33
Ni	0.02	0.003	0.02	0.003	0.02	0.003
HI(∑HQ)	5.55	9.57	5.53	9.42	4.31	9.42

AD = Adult; CH= Children

Table 7. Hazard Quotients (HQ) and Hazard Index (HI) recorded for Adults and Children on monthly basis.

Metal	May 2019		Jun 2019		Jul 2019		Aug 2019		Sept 2019		Oct 2019	
	HQ_{AD}	HQ_{CH}	HQ_{AD}	HQ_{CH}	HQ_{AD}	HQ_{CH}	HQ_{AD}	HQ_{CH}	HQ_{AD}	HQ_{CH}	HQ_{AD}	HQ_{CH}
Mn	0.014	0.029	0.014	0.029	0.014	0.036	0.007	0.021	0.021	0.043	0.021	0.057
Cu	0.025	0.075	0.025	0.075	0.025	0.075	0.025	0.075	0.025	0.05	0.025	0.075
Pb	0.29	0.29	0.29	0.29	0.29	0.57	0.29	0.29	0.29	0.29	0.29	0.29
Fe	1.43	3.29	1.57	3.57	1.43	4.86	1.29	2.71	1.57	3.86	1.71	4.00
Zn	0.01	0.02	0.01	0.02	0.01	0.03	0.01	0.02	0.02	0.04	0.02	0.04
Cd	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Cr	3.33	3.33	3.33	3.33	3.33	6.67	3.33	3.33	3.33	3.33	3.33	6.67
Ni	0.00	0.005	0.00	0.005	0.005	0.005	0.00	0.005	0.00	0.005	0.00	0.005
HI(∑HQ)	7.10	9.04	7.24	9.32	7.10	14.25	6.95	8.45	7.26	9.58	7.40	13.14

AD = Adult; CH= Children

Hazard indices (HI) recorded for adults and children in the 3 stations were far greater than threshold value of 1; decreasing spatially from station 1 to 3. The highest values for both were recorded in station 1 (Table 6). The monthly HI values were 6.95 – 7.40 (adults) and 8.45 – 14.45 (children). The highest values for adults and children were recorded in August 2019 and October 2019 respectively (Table 7). The HQ and HI values for children were generally higher than adults in both the stations and months; thereby making the children more vulnerable. All the recorded hazard index (HI) values highly exceeded unity (1). It is in line with the findings of Ayantobo et al. (2014), Ekere et al. (2014), Maigari et al. (2016), Onyele & Anyanwu (2018) and Rahman et al. (2020). The long-term health risk is high; therefore the non-carcinogenic adverse effect can not be overlooked.

CONCLUSION

The convergence of pollution indices and Health Risk Assessment has shown that the waters of Iyiakwu River are not fit for human consumption. The main metals that influenced the results were iron, lead, cadmium and chromium. The children are more vulnerable since it is the main source of drinking water in the area especially in the dry season. Sand mining is a major economic activity in the river affecting the heavy metal concentrations though exacerbated by season (rains). Effort should be made to regulate it in order to save the river and the people.

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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.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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