Research Article

Ecological and human health exposure risks to heavy metals in Oji River sediments: effect of abattoir and power station

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Abstract

In this study, the ecological and human health exposure risks due to the effects of abattoir and power station on heavy metal input into the sediments of Oji River in Enugu State Nigeria were assessed. Heavy metals in the sediments were measured using atomic absorption spectrometry. Pollution of the sediments was assessed using: contamination factor (CF), *degree of contamination (CD)*, geochemical accumulation index (I_{geo}) and pollution load index (PLI), whereas the ecological risk was assessed using potential ecological risk index. Non-carcinogenic risks of exposure by humans to the heavy metals were assessed using hazard index. Obtained results indicate that the abattoir contributed to heavy metal input into the sediments significantly (unlike the power station) and most likely due to the use of waste tires at the abattoir as fuel. All pollution parameters (CF, CD, I_{geo} and PLI) reveal that pollution of the sediment with heavy metals around the abattoir is most profound and the ecological risk of heavy metals in the sediments is very high. Non-carcinogenic risk of exposure to heavy metals due to inadvertent ingestion and contact with sediments is insignificant.

Keywords Ecological risks · Heavy metals · River · Risk assessment · Sediment

1 Introduction

Rivers are one of the most common sources of fresh water and provide ecosystem services that are beneficial to man and other living organisms, especially aquatic organisms. For ecosystem functioning of rivers to operate sustainably, the dynamics of the biological and physico-chemical characteristics of the rivers must be within the resilience abilities of all the community structures of the river; otherwise, unacceptable changes could take place. For example, activities of man can alter the biological and physico-chemical properties of rivers in such a manner that could bring about changes in aquatic ecology and water use patterns by humans [35]. It has been reported that changes in the riverine processes and aquatic ecology may manifest in several ways such as reduced biodiversity and productivity, altered plant community structure and behavior, reduced resilience to invasive species and altering river vertebrates and invertebrates community structure [7, 15].

Heavy metals are common environmental pollutants arising mainly from increased anthropogenic activities and pollute rivers as they partition into water column and sediments [2, 9, 10]. Greater proportion of the heavy metals is partitioned onto the bed sediments with a little proportion remaining in the water phase [12]. Hence, it has been reported that under certain circumstances, over 90% of the heavy metals entering a water body enter sediment bound rather than freely in the water phase [31].

The ecological importance of sediments cannot be over-emphasized as they act as both sinks and reservoirs for environmental contaminants such as heavy metals. If

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heavy metals accumulate beyond a certain level in sediments, they could cause ecological mayhem. Monitoring ecological risks in sediments from heavy metals is therefore extremely important and could be achieved via the estimation of geoaccumulation index [25], pollution load index and ecological risk index [14].

Oji River itself as a water body is a tributary of Anambra River, the main tributary of the lower Niger River. Oji River which is the focus of this study is extremely important because of several anthropogenic activities around the river at several locations that could impact on the aquatic ecology of the river. Abattoir where waste tires are burnt as fuel used in the preparation of hide and skin from slaughtered cows is located very close to the Oji River. Also located close to the Oji River is a power station that distributes electricity to over 500,000 households within Enugu State.

The locals within the riverside use the water for bathing, washing and cooking and therefore could be exposed to the carcinogenic or non-carcinogenic health effects of some heavy metals. Heavy metals such as cadmium, lead and chromium are reported to have both carcinogenic and non-carcinogenic health effects, whereas others such as zinc, aluminum, copper have non-carcinogenic health effects [18, 24]. It is therefore extremely important to assess the seasonal exposure risks of the water users for the aforementioned purposes.

The release of heavy metals as environmental contaminants and consequent pollution of nearby rivers and soil arising from the operation of power generating plants is well reported [3, 11, 17]. However, there are hardly studies showing whether or not power distribution stations release heavy metals that could pollute a nearby river (that acts as a receptacle to the station's wastewater) to the extent of posing significant health and ecological risks.

Studies on the release of heavy metals into river sediments arising from the activities of power station and an abattoir (where waste tires are used as fuel for burning off cows' hairy skin as practiced in most developing countries such as Nigeria) are not well reported. It is therefore not known whether heavy metal input from an abattoir using waste tires as fuel poses any significant ecological and health risks.

This study shall assess pollution of Oji River sediments by heavy metals arising from abattoir and power plant activities using contamination factor, degree of contamination, geochemical accumulation index, pollution load index and potential ecological risk index. Contamination factor (CF) is a very useful tool in identifying the contamination level of sediments by the individual heavy metals. Because the degree of contamination (CD) considers all the measured heavy metals, it is useful in estimating the cumulative level of contamination. The geochemical

accumulation index (I_{geo}) provides a measure of the extent of the heavy metal contamination compared to background levels. It therefore provides evidence for anthropogenic releases of the heavy metals in the sediments. Pollution load index (PLI) is a good tool used in estimating the extent of pollution of the sediments. The potential ecological risk index (PERI) estimates risks posed to biota inhabiting the sediments from the heavy metal pollution of the sediments.

The objectives of this study therefore are to:

- Evaluate the concentration of heavy metals in the sediments of Oji River around the locations of an existing abattoir and Oji River Power Station
- Estimate ecological risks arising from the presence of the heavy metals in the sediments impacted by the activities of the abattoir and the Oji River Power Station
- Estimate non-carcinogenic risk of exposure to humans who make contact with the sediments

2 Materials and methods

2.1 Study area

The study area, shown in Fig. 1, is in Oji River Local Government Area (LGA). The Oji River LGA with a landmass of about 400 Km^2 and a population of 126,587 as at the 2006 population census is located geographically between latitude 6°14′N and 6°20′N and between longitude 7°17′E and 7°21′E. The geology of the area comprises 330-m-thick Ajali formation that is underlain by 400-m-thick Mamu and 200-m-thick Nkporo formations. These Ajali, Mamu and Nkporo formations are characterized by sandstone, sandy shale and mudstone, respectively [27, 30]. Rainy season (April–October) and dry season (November–March) are the two seasons in Nigeria especially the southern part of Nigeria where the study area is located. Rainfall at its peak can be quite heavy with several incidents of flooding that leave gully erosion in its trail [8]. The river is a fast-flowing one that receives waste discharges from several anthropogenic activities such as abattoir, power plants, agricultural runoff. The study area and sampling locations are as presented in Fig. 1.

2.2 Sampling

The sampling campaign for this study took place in October 2017 and January 2018 to cover both the wet and dry seasons. Samples were collected forthrightly each month in triplicate from locations shown in Fig. 1. The sampling locations were carefully selected to isolate effect of discharges from two major different activities, viz., abattoir
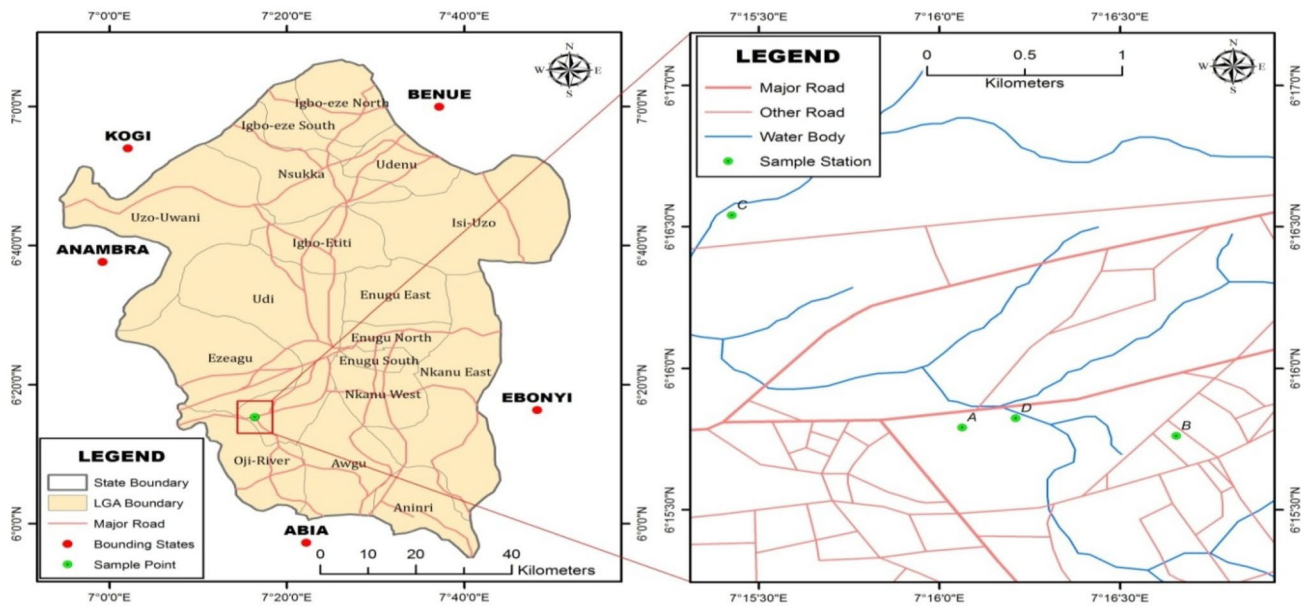
Fig. 1 Map of the study area showing sampling locations, *A*, *B*, *C* and *D*, covering a distance of about 0.75 km

and the power station. Sampling location *A* is about 250-m upstream the abattoir, while sampling location *B* is within the discharge point of wastewater from the abattoir. Sampling location *C* is about 250-m downstream the abattoir and about 100-m upstream the power station. Sampling location *D* is about 250-m downstream the thermal station. Surficial sediment samples were collected at a depth of 0–10 cm using stainless steel corer at three points (river bed periphery-2 samples and midriver bed-1 sample) from each of the sampling locations and composited. The sediment samples were collected into a polythene bag and sealed.

2.3 Laboratory analysis

The sediment samples were exposed to open air to dry and thereafter passed through a 2-mm mesh sieve to get rid of plant debris, stones and coarse materials. The sieved sediment samples were ground to powder using pestle and mortar and passed through a 3-mm mesh sieve to collect fine sediment samples required for analysis. The US EPA [42] prescribed method was adopted in acid digestion of the sediment samples. Succinctly, this method consists using 65% HNO_3/37% HCl at a ratio of 3:1 v/v to digest the sediment samples in a Teflon vessel held in a microwave oven using the appropriate sediment/acid mix ratio. In this study, 15 mL of acid mix was used in digesting 0.3 g of sediment sample. The microwave digester (Milestone s.r.l, Italy) was operated in three sequences at 120, 150 and 200 °C for 5, 10 and 15 min, respectively. After microwave digestion, deionized water

was added and the solution filtered using 0.45-µm filter membrane. Additional water was added to make up the volume to 50 mL and stored in the refrigerator below 4 °C until required for analysis. The heavy metals (Cu, Zn, Cr, Pb, Cd) were analyzed using SensAA GBC flame atomic absorption spectrometer.

2.4 Quality control

All the laboratory analysis was carried out in triplicate. Duplicate sample and blank analysis were carried out for the confirmation of method accuracy. The limit of detection (LOD), limit of quantification (LOQ) and recoveries were also determined. The LOD was determined as three times the standard deviation of 10 replicate blank measurements [29]. The LOQ was determined as three times the LOD value. The LOD varied from 0.2 to 0.5 µg/L; LOQ varied from 0.5 to 1.5 µg/L. The method accuracy and instrument precision were established by the measurement of recoveries using the spiking method for which the heavy metal concentration in spiked and unspiked triplicate sediment samples was determined using the relationship:

% Recovery = (concentration of heavy metals in spiked sediment sample − concentration of the heavy metals in unspiked sediment sample)/(concentration of the heavy metals in the spiking standard solution supplied by Sigma-Aldrich). The recoveries which varied from 81 to 104% are a reflection of the method accuracy, and the relative standard deviation (RSD) ranging from 5 to 11% is a reflection of the precision which is acceptable.

2.5 Pollution assessment and ecological risks due to heavy metals in the sediments

In this study, the ecological assessments of the sediments as contaminated by heavy metals were assessed using contamination factor (CF), degree of contamination (DC), geochemical accumulation index (I_{geo}), pollution load index (PLI) and potential ecological risk index (PERI).

2.5.1 Contamination factor

Contamination factor (CF) is a very useful tool used in identifying the contamination level of sediments by heavy metals [14].

$$CF = C_{sediment}/C_{background} \tag{1}$$

where $C_{sediment}$ = heavy metal mean concentration in the sediment; $C_{background}$ = heavy metal concentration in the background.

The background values used in this study are those reported by Hakanson [14].

2.5.2 Degree of contamination

The degree of contamination (DC) is estimated by adding the CF for all the heavy metals in the sample as described in Eq. 2.

$$DC = CF_1 + CF_2 + CF_3 + \cdots CF_n \tag{2}$$

2.5.3 Geochemical accumulation index (I_{geo})

The geoaccumulation index (I_{geo}) is computed as follows:

$$I_{geo} = \log_2\left(C_n/1.5B_n\right) \tag{3}$$

where C_n = concentration of heavy metals in the sediment; B_n = geochemical background value 1.5 is the matrix correction factor for minimizing lithogenic effects [50].

2.5.4 Pollution load index (PLI)

Pollution load index (PLI) is a veritable tool used in measuring the extent of pollution of the sediments and is expressed as [36]:

$$PLI = \left(CF_1 * CF_2 * CF_3 * \cdots CF_n\right)^{1/n} \tag{4}$$

where CF = contamination factor; n = number of heavy metals in the sediment sample.

2.5.5 Potential ecological risk index (PERI)

The potential ecological risk index (PERI) of the heavy metals in the sediments was derived from summing the potential ecological risk factor (PERF) of the individual heavy metals.

$$PERF = CF * TRC \tag{5}$$

where CF = contamination factor.

TRC = toxic response coefficient for a given heavy metal. This study adopted the TRC reported in Hakanson [14]. TRC is actually an indication of a heavy metal's toxicity and ecological sensitivity; hence, the higher the coefficient, the more toxic and ecological sensitivity [13].

$$PERI = PERF_1 + PARF_2 + PERF_3 + \cdots PERF_n \tag{6}$$

2.6 Human health risk exposure to heavy metals in the sediments

2.6.1 Non-carcinogenic risks of exposure to heavy metals as a result of ingestion of sediment and dermal contact

Hazard quotient (HQ) and hazard index (HI) were used in estimating the non-carcinogenic risks of exposure to heavy metals in the sediments according to Eqs. 7 and 8.

$$HQ = D/RfD \tag{7}$$

$$HI = HQ_1 + HQ_2 + HQ_3 + HQ_4 + HQ_5 \tag{8}$$

where D = exposure dose; RfD = reference dose for the heavy metals; HQ_1 to HQ_5 are the hazard quotients for each of the heavy metals.

The equations for computing the chronic exposure dose of the sediments via entry routes such as inadvertent oral ingestion and dermal contacts and definitions of the terms in the equations are as reported in Ugochukwu et al. [38].

The values of the parameters employed in determining exposure dose of the heavy metals in sediments for an adult considering chronic exposure duration of 35 years are as presented in Table 1.

2.7 Statistical method

Analysis of variance (ANOVA) was employed in data analysis using Minitab version 18 statistical software.

Table 1 Values of the parameters for determining exposure dose

Parameters	Values
IR$_S$ (soil ingestion rate)	0.02 g/day
EF (exposure frequency) 1 event per day	1
ET (exposure term)[a]	0.042
BW (body weight)	70 kg
Exposed skin surface area (hands) (SA$_H$)	430 cm^2
Exposed skin surface area (arms) (SA$_A$)	890 cm^2
Exposed skin surface area (legs) (SA$_L$)	1690 cm^2
Soil loading to skin hands (SL$_H$)	1×10^{-4} g/cm^2/event
Soil loading to skin arms and legs (SL$_A$ and SL$_L$)	1×10^{-5} g/cm^2/event
RAF$_{git}$	1
RAF$_{skin}$	0.1
CF (unit correction factor)	0.001 L/cm

[a]Exposure term is assumed to be 1 h a day, 7 days a week, 52 weeks a year, exposure period of 35 years [16]. ET = (1/24*7/7*52/52*35/35) = 0.125

Table 2 Concentration of the heavy metals in the various sampling locations of the Oji River sediments as sampled in October 2017 and January 2018

Heavy metals	Location			
	A	B	C	D
Concentration values (mg/Kg) for October 2017				
Pb	28.4	124	251	14.3
Cu	6.5	14.6	8.1	13.8
Cr	28.1	380	85.4	56.3
Zn	14	321	43.5	130.4
Cd	3.2	20.5	0.01	1.6
Concentration values (mg/Kg) for January 2018				
Pb	76	75	64.1	128.2
Cu	50.1	525	123.5	210
Cr	35.4	356	40.8	123.4
Zn	41.7	661	41	272.1
Cd	3.5	10.5	3.2	5.2

Values are presented as mean

3 Results and discussion

3.1 Concentration of the heavy metals in sediment and water column

The concentration of the heavy metals in the sediments of Oji River as monitored (within the period of October 2017 and January 2018) to ascertain the effects of the two major anthropogenic activities, namely abattoir and Oji River Power Station, is as presented in Table 2.

The concentration of the heavy metals in the sediments is highest around the abattoir (location *B*), especially for Zn, Cr, Cu and Cd (Table 4), indicating input of these metals into the sediments from the activities of the abattoir. The concentrations of these heavy metals for location *B* are not only just higher but also statistically significantly different from those of the other locations for both rainy and dry seasons. During our sampling campaign, it was observed that cow meat sellers who butcher cows at the abattoir make use of waste car tires to burn off the hairy portion of the cow skin in order to prepare the hide and skin for consumption by local residents. Piles of residue of the burnt tires are usually on site at the abattoir. Given that tires contain heavy metals including those covered in this study, these residues from burnt tires are veritable sources of the heavy metals [6, 22, 32]. Therefore, elevated concentration of Zn, Cr, Cu and Cd around the abattoir at location *B* is most likely to be due to the waste tires used as fuel for burning off the hairy skin of cows at the abattoir.

The concentration of lead in the sediments of Oji River around the abattoir is higher than the levels reported in the rivers of some regions of the world such as Awash River Basin in Ethiopia, Lijiang River in China, Dongting Lake in China, Korotoa River in Bangladesh and River Benue in Nigeria, whereas it is lower than the levels reported for Shur River in Iran, Gomti River in India, Axos River in Greece, Danube River in Germany and Tigris River in Turkey [1, 5, 19–21, 23, 34, 44, 46, 49]. The lead concentration in Oji River sediment of 99.5 mg/kg is higher than Canadian Council of Ministers of the Environment (CCME) probable effect level (PEL) of 91.3 mg/kg [4], indicating probable ecological risk. Also, the concentrations of chromium (368 mg/kg), copper (270 mg/kg), zinc (491 mg/kg) and cadmium (15.5 mg/kg) in the sediment of Oji River exceed the CCME PEL of 90, 197, 315 and 15.5 mg/kg, respectively, indicating possible ecological impairment due to these heavy metals.

3.2 Contamination factor, *degree of contamination*, geochemical accumulation index, pollution load index and potential ecological risk index

The contamination factor and degree, geochemical accumulation index, pollution load index and potential ecological risk index of the heavy metals in the sediment of Oji River are as presented in Table 3.

The contamination factor of the heavy metals in the sediments of Oji River at location *A* indicates that only cadmium poses considerable contamination with CF > 3.0 but < 6.0, whereas the rest of the other heavy metals with CF < 1.0 pose low contamination in the sediments [14]. In location *B*, during the wet season, Cu poses low contamination, whereas Pb and Zn pose moderate contamination.

Table 3 Sediment ecological risk values

Heavy metals	Location																			
	A					B					C					D				
	CF	CD	I_{geo}	PLI	PERI	CF	CD	I_{geo}	PLI	PERI	CF	CD	I_{geo}	PLI	PERI	CF	CD	I_{geo}	PLI	PERI
Values for wet season																				
Pb	0.4	4.1	−1.9	0.3	99	1.8	29	0.2	2.4	636	3.5	5	1.3	0.3	21.2	0.2	3.5	−2.9	0.5	52
Cu	0.1		−3.5			0.3		−2.4			0.2		−3.2			0.3		−2.4		
Cr	0.3		−2.3			4.2		1.5			0.9		−0.7			0.6		−1.3		
Zn	0.1		−4.2			1.8		0.3			0.2		−2.6			0.7		−1.0		
Cd	3.2		1.1			21		3.8			0.01		−7.2			1.6		0.1		
Values for dry season																				
Pb	1.1	6.2	−0.5	0.8	116	1.1	30	−0.5	4.5	385	0.9	7.3	−0.7	1.0	114	1.8	14	0.3	2.4	190
Cu	1.0		−0.6			11		2.8			2.5		0.7			4.2		1.5		
Cr	0.4		−1.9			4		1.4			0.5		−1.7			1.4		−0.1		
Zn	0.2		−2.7			3.8		1.3			0.2		−2.7			1.6		0.1		
Cd	3.5		1.2			11		2.8			3.2		1.1			5.2		1.8		

CF contamination factor; *CD* degree of contamination; I_{geo} geochemical accumulation index; *PLI* pollution load index; *PERI* potential ecological risk index

Table 4 Human health exposure using hazard index

Location	Sediments	
	Hazard index—wet season	Hazard index—dry season
A	0.005	0.006
B	0.05	0.04
C	0.009	0.007
D	0.006	0.02

However, Cr and Cd pose considerable and very high contamination to the sediments, respectively, at respective CF of 4.2 and 21 (Table 3). CF > 6.0 implies very high contamination [14]. It is therefore evident that the main heavy metal contaminants of the sediments in the wet season for location B are chromium and cadmium. During the dry season, only lead is of moderate contamination, whereas the rest are either of considerable or very high contamination. Cr and Zn are of considerable contamination, whereas Cu and Cd are of very high contamination. This study has revealed that Cr and Cd are of considerable and very high contamination in the sediments, respectively, for all seasons for location B of the Oji River sediments. For location C, only Pb poses considerable contamination in the wet season, whereas Cu and Cd pose moderate and considerable contamination, respectively. There is only moderate contamination of the sediments coming from Cd in the wet season for location D, whereas Pb, Cr and Zn pose moderate contamination in the dry season with Cd and Cu posing considerable contamination.

During the wet season, the degree of contamination (CD) for locations A, C and D in each case is < 7.0, indicating low degree of contamination, whereas for location B with CD = 29 which is > 28, the degree of contamination is very high [28]. However, during the dry season, location A with CD < 7 indicates low degree of contamination, whereas location C with CD 7.3 but < 14 indicates moderate degree of contamination [28]. Location D with CD = 14 is taken to be of considerable degree of contamination, whereas location B with CD = 30 is of very high degree of contamination. This study therefore reveals that during the wet and dry season, the degree of contamination is very high for location B. The degree of contamination for location A in all seasons is low, whereas locations C and D will have moderate and considerable degree of contamination only in dry season.

The geochemical accumulation index (I_{geo}) classification scheme proposed by Muller [25] and applied by other researchers such as Sharifi et al. [33] was used in interpreting the I_{geo} data in this work. The scheme is as follows:

Class 0 (uncontaminated): $I_{geo} \leq 0$; Class 1 (uncontaminated to moderately contaminated): $0 < I_{geo} < 1$; Class 2 (moderately contaminated): $1 < I_{geo} < 2$; Class 3 (moderately to heavily contaminated): $2 < I_{geo} < 3$; Class 4 (heavily contaminated): $3 < I_{geo} < 4$; Class 5 (heavily contaminated to extremely contaminated): $4 < I_{geo} < 5$; and Class 6 (extremely contaminated): $5 < I_{geo}$.

The I_{geo} for Pb, Cr, Cu and Zn in location A for the wet and dry seasons is less than 0, indicating that the sediment is not contaminated with these heavy metals, but the I_{geo} for cadmium in both wet and dry seasons is > 1 but < 2, indicating moderate contamination.

The I_{geo} for Pb in location B during the wet season indicates uncontaminated to moderately contaminated, whereas during the dry season, it becomes uncontaminated. I_{geo} for Cu in the same location indicates uncontaminated in wet season but moderately to heavily contaminated in dry season. There is moderate contamination coming from Cr for all seasons, whereas for Zn it is uncontaminated to moderately contaminated in wet season and moderately contaminated in dry season. In the wet season, the I_{geo} for cadmium indicates heavily contaminated, whereas during the dry season it is moderately to heavily contaminated.

The I_{geo} of Pb in location C in the wet season indicates moderately contaminated, whereas the I_{geo} for the rest of the other heavy metals in the same wet season indicates uncontaminated. For the dry season, the I_{geo} of Cu indicates uncontaminated to moderately contaminated, whereas it indicates moderately contaminated for Cd. There is no contamination coming from Cr, Zn and Pb in the dry season.

For location D, the I_{geo} for Pb, Cr, Zn and Cu in the wet season indicates uncontaminated, whereas for Cd, it is uncontaminated to moderately contaminated. In the dry season, there is no contamination coming from Cr, whereas it is uncontaminated to moderately contaminated for Pb and Zn and moderately contaminated for both Cu and Cd.

The utility of I_{geo} is derived from its ability to indicate possible anthropogenic input. As can be observed in location B where for all seasons, Cr occurred at a level of 'moderately contaminated' and cadmium at a level of either moderately to heavily contaminated or heavily contaminated, indicating that these two heavy metals are released into the aquatic environment from anthropogenic sources most probably the abattoir.

Pollution load index (PLI) data in this study were interpreted according to the scheme reported by Tomlinson et al. [36] and applied by Sharifi et al. [33] and Vu et al. [45] as follows:

PLI = O: not polluted; PLI < 1: unpolluted; PLI ≥ 1: polluted. The higher the PLI, the higher the pollution. It therefore follows that the sediments of location A for all seasons are unpolluted with the heavy metals, whereas locations C and D are unpolluted during the wet season but polluted during the dry season with location D being more polluted than location C. Location B is polluted in all the seasons but more polluted in the dry season. Using PLI, this study demonstrates that location B is the most polluted location.

The potential ecological risk index (PERI) in this study was interpreted using the scheme reported by Hakanson [14] as follows:

PERI < 110: low risk; 110 ≤ PERI < 200: moderate risk; 200 ≤ PERI < 400: considerable risk; and 400 ≤ PERI: very high risk.

PERI for the sediments at locations A, C and D during the wet season is < 110, indicating low ecological risk, but during the dry season, the ecological risk becomes moderate as PERI is > 110 but < 200. For location B during the dry season, the ecological risk is considerable at PERI of 385, whereas the ecological risk is very high during the wet season as the PERI = 636. This study therefore demonstrates that the aquatic biota within this location B is at a risk of biological impairment arising from the toxic effect of the heavy metals.

3.3 Non-carcinogenic risk exposure to heavy metals in sediments

The human exposure to the heavy metals as assessed using hazard index is presented in Table 4.

The human exposure to heavy metals via inadvertent ingestion of the sediment and dermal contact as assessed employing hazard index (HI) indicates that the non-carcinogenic health risk is very low for all locations and all seasons as the HI ≪ 1 in all cases. This implies that the non-carcinogenic risks associated with contact and ingestion of the sediment as the locals use the water are insignificant.

4 Conclusion

This study having assessed the heavy metal contamination of Oji River sediment in addition to the ecological and human health risk exposure found that cadmium contamination of the sediment is most profound followed by chromium and lead. The most polluted location is that within the location of the abattoir, the abattoir was found to contribute to the heavy metal input to the sediment due to the burning of waste tires. The geochemical accumulation index, contamination degree, pollution load index and potential ecological risk index all point to the fact that the location within the abattoir has the sediments highly polluted with heavy metals. There is insignificant non-carcinogenic risk of exposure by humans to the heavy metals in all the locations of as the HI is far less than unity. The heavy metal pollution of the sediments poses a great risk to the survival of benthic organisms and other biota that inhabits the water column.

The use of waste tires as fuel for burning off cows' hairy parts in preparation of the hide and skin for consumption should be discontinued as these appears to be the major source of heavy metal input into the river.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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