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Health Risk Assessment of Some Selected Heavy Metals in Water and Sediment Samples from Kwanar are Dam, Katsina State, North-Western Nigeria

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Abstract: This work contributes to the monitoring of water and sediment heavy metal pollution of Are dam Rimi Local Government Area, Katsina State Nigeria, using Atomic Absorption Spectrophotometry. From the results, Pb, Ni, and Cd level in the water sample are above the safety limit. The water Pollution index (PI) and Metal index (MI) indicate a threshold threat to human and aquatic life's utilizing the water, the Geo accumulation index (I-geo), Enrichment factor (EF), Contamination factor (CF), and Potential ecological risk index (PERI) values in sediment sample indicate unpolluted (class 0) with minimal enrichment, low contamination level, and low ecological risk respectively. The target hazard quotient (THQ) and Health risk index (HI) values for adults and children of the heavy metals in the water sample were below 1 suggestive of no non-carcinogenic adverse health hazards to the population. The Incremental lifetime cancer risk (ILCR) values were at the threshold level of $1.0 \times 10{-}4$ for Pb in children and Cd in adult and above the threshold for Cd in children and Ni in adult and children in the water sample, pointing to potential cancer risk to both adults and children from drinking the water sample.

Keywords: Pollution, water, sediment, contamination, health hazard

Introduction

Heavy metals pollution in water bodies is worrisome due to their known harmful effects and ability to accumulate with time and to be biotransformed along food chains (Rezaei and Sayadi, 2015). In water bodies, heavy metals may find their way due to physical, chemical, or biological processes into sediments (Yuan et al., 2012; Zhan et al., 2010). Due to their high physical-chemical stability, researchers have used sediment as environmental indicators, where, analysis of sediment has provided vital data used in the assessment of anthropogenic processes in aquatic systems (Malhotra et al., 2014). The potential health risk to the population and ecological impact of heavy metals pollution in water bodies and sediments has been widely documented (Hounkpe et al., 2017; Junianto and Izza, 2017; Yusuf et al., 2018; Yaradua et al., 2018a, b; Do'amekpor et al., 2018; Otene and Alfred-Ockiya, 2019). But to date, no study on the heavy metal burden of the area of study has been documented.

This study is aimed at evaluating the heavy metal burden of water and sediment samples from Kwanar-Are dam located in Rimi Local Government area Katsina State Northwestern Nigeria. The water body has multiple likely possible sources of heavy metal contamination, being located along the Katsina-Kano highway, adjoining a quarry site, and being used as a site for washing the tanks of trailers used for conveying petroleum products. Findings from the study will shed more light on heavy metal pollution if it exists, and may serve as a guide for environmental policy formulation or implementation.

Materials and Method

Study Area

The study was conducted at Kwanar Are dam located in Rimi LGA of Katsina State, Nigeria. Rimi LGA is located on Latitude 12o46'N and Longitude 7o41'E, covering an area of 452 km^2 (175sq miles) with a total population of 212,819 inhabitants. The adjoining human settlements are Tudun-Kadir, Faduma, Ci-ka-Koshi, and Are villages. The inhabitants of these villages are engaged in fishing, rain-fed and dry season farming and use the water for drinking and other domestic uses.

Water Sampling

8 samples were collected randomly on each extremity and median parts of the water at approximately 30cm below the water surface. For preservation, the water samples were acidified with nitric acid to a pH of 2 (Caerio et al., 2005) and analyzed within two weeks.

Sediment Sampling

Sediment samples were taken from the dam in September 2019. After being air-dried, homogenized, and large debris, stone, and pebbles removed the sample was disaggregated and digested using mixed acid (HCl-HNO3).

Heavy Metal Analysis in Water and Sediment Samples

Metal concentrations in samples (Zn, Pb, Cd, Ni, and Cu) were evaluated by the use of an atomic absorption spectrometer (AA210RAP BUCK flame emission spectrometer filter GLA-4B Graphite furnace, East Norwalk USA) using standard methods (AOAC, 1995).

Water Quality Assessment

Pollution Index (PI): The pollution index (PI) of each metal in the water sample was calculated using the below equation (Caerio et al., 2005).

$$\frac{PI = \sqrt{\left(\frac{Ci}{Si}\right) max^2 + \left(\frac{Ci}{Si}\right) min^2}}{2}$$

Where Ci = the concentration of each element; Si = metal level according to national water quality criteria. The water quality criteria used in this study were the USEPA's permissible limits of Ni, Pb, Cu, and Zn, and WHO allowable limits of Cd (Mohod and Dhote, 2013). Standard classifications were used to interpret the calculated pollution indices (Goher et al., 2014).

Metal Index (MI):

The relative importance of individual metal influence on the sample water quality consideration was calculated using the MI (Tamasi and Cini, 2004), which is rated between zero and one, with values that are above one being considered as a threshold of warning(Bakan et al., 2010).

$$\sum_{i=1}^{n} \frac{Ci}{(MAC)i}$$

Where Ci is the concentration of each element and MAC is the maximum allowable concentration of the element.

Daily Intake of Metals (DIM) in Samples

The chronic daily intake of metals from drinking the water sample was calculated using the following equation

CDI = D x Ci/BW

Where D (L d1) represents average daily drinking water intake and has a value of 1.488 person−1 d−1 (Zhang et al., 2011), Ci represents the concentration of metal in a sample and the average body weight for the adult and children population was taken as 60 kg **(Orisakwe et al., 2015)** and 24 kg (Ekhator et al., 2017) respectively.

Non-cancer Risks

Non-carcinogenic risks for individual heavy metals of the sample were evaluated by computing the target hazard quotient (THQ) using the following equation (Micheal et al., 2015).

$THQ = CDI/R_fD$

CDI is the chronic daily heavy metal intake (mg/kg/day) as obtained previously and RfD is the oral reference dose (mg/kg/day). The following reference doses from literature were used (Pb = 0.6, Cd = 0.5, Zn = 0.3, Cu = 0.04, Ni = 0.4) (Li et al., 2013; US-EPA, 2002).To evaluate the potential risk to human health through more than one heavy metal, chronic hazard index (HI) is obtained as the sum of all THQ calculated for individual heavy metals for a particular exposure pathway (NFPCSP Nutrition Fact Sheet, 2011). It is calculated as follows:

$$HI=THQ_1+THQ_2+\cdots+THQ_n$$

Where 1, 2 …. n is the individual heavy metals in samples.

When HI < 1 the population is assumed to be safe, and when 1 < HI < 5 is a level of concern (Guerra et al., 2012).

Cancer Risks

The possibility of cancer risks in the studied sample through intake of carcinogenic heavy metals was estimated using the Incremental Lifetime Cancer Risk (ILCR) (Liu et al., 2013).

$$ILCR= CDI\times CSF/60$$

Where, CDI is the chronic daily intake of the carcinogenic heavy metal, mg/kg BW/day which represents the lifetime average daily dose of exposure to the metal, and CSF is the cancer slope factor which is heavy metal-specific and is the risk arising due to a lifetime average dose of 1 mg/kg BW/day (Micheal et al., 2015). The following cancer slope factor for specific heavy metals were used; Pb = 0.0085 mg/kg/day (Kamunda et al., 2016), Cd = 0.38 mg/kg/day (Yang et al., 2018), Ni = 1.7 mg/kg/day (Javed et al., 2016). ICR value in the sample represents the probability of an individual's lifetime health risks from carcinogenic heavy metals exposure (Pepper et al., 2012). The level of acceptable cancer risk (ILCR) for regulatory purposes is considered within the range of 10−6 to 10−4 (Li and Zhang, 2010). The CDI value was calculated based on the following equation.

$$CDI = (EDI \times EFr \times ED_{tot})/AT$$

Where EDI is the estimated daily intake of metal from ingestion of the sample; EFr is the exposure frequency (365 days/year); EDtot is the exposure duration of 60 years, average lifetime for Nigerians; AT is the period of exposure for non-carcinogenic effects (EFr × EDtot), and 60 years lifetime for carcinogenic effect (Micheal et al., 2015). The cumulative cancer risk as a result of exposure to multiple carcinogenic heavy metals is calculated by the following equation (Liu et al., 2013).

$$\sum 1_n = ILCR_1 + ILCR_2 + \cdots + ILCR_n$$

Where, n = 1, 2 …, n is the individual carcinogenic heavy metal.

Assessment of Metal Contamination Levels in Sediment

Geo-accumulation Index (I-geo)

Heavy metals pollution in sediment sample was evaluated using I-geo (Muller, 1969):

$$\text{I-geo} = \log_2 / (C_n / 1.5B_n)$$

Where Cn is the measured content of the metal in the sample and Bn is the geochemical background content of the same metal. To reduce the effect of likely differences in the background values due to anthropogenic influences, the constant 1.5 is used. The index of geo-accumulation (Igeo) is characterized as follows: Igeo is ≤0 (unpolluted), class 0; if Igeo is 0 – 1 (unpolluted to moderately polluted), class 1; if Igeo is 1 – 2 (moderately polluted), class 2; if Igeo is 2 – 3 (moderately to strongly polluted), class 3; if Igeo is 3 – 4 (strongly polluted), class 4; if Igeo is 4 – 5 (strongly-extremely polluted), class 5; if Igeo is >6 (extremely polluted), class 6 (Muller, 1969).

Enrichment Factor (EF)

Enrichment Factor (EF) is considered to estimate the abundance of metals in the sediment samples. EF was calculated by a comparison of each tested metal concentration with that of a reference metal (Muller, 1981). In the present study, Fe was used as a conservative tracer (Tippie, 1984). The EF was calculated using the below equation (Rubio et al., 2000):

$$EF = (M/Fe)_{sample}/(M/Fe)_{Background}$$

Where EF is the enrichment factor, (M/Fe)sample is the ratio of metal and Fe concentration of the sample, and (M/Fe)background is the ratio of metals and Fe concentration of a background. Five contamination categories are reported based on the enrichment factor. EF <2 deficiency to minimal enrichment, EF = 2-5 moderate enrichment, EF = 5-20 significant enrichment, EF = 20-40 very high enrichment, EF>40 extremely high enrichment (Sutherland, 2000).

Contamination Factor (CF)

CF was calculated according to the equation described below (Pekey et al., 2004):

$$C = M_c/B_c$$

Where Mc is the concentration of the metal and Bc is the background concentration of the same metal. Four categories are documented based on the contamination: CF<1 low contamination; 1≤CF≥3 moderate contamination; 3≤CF<6 considerable contamination; CF>6 very high contamination (Hakanson, 1980).

Degree of Contamination (Cd) and Pollution Load Index (PLI)

The degree of contamination (Cd) depicts the sum of all contamination factors. The following terms were adopted to illustrate the degree of contamination: Cd<6: low degree of contamination; 6≤Cd<12: a moderate degree of contamination; 12≤Cd<24: the considerable degree of contamination; Cd>24: a very high degree of contamination indicating serious anthropogenic pollution. Pollution Load Index (PLI) was used to evaluate the extent of pollution by heavy metals in the environment. The range and class are the same as Igeo (Tomlinson et al., 1980):

$$PLI = (CF_I+CF_2+CF_3 \ldots\ldots\ldots CF_n) \wedge (1/n)$$

Potential Ecological Risk Index (PERI)

To evaluate the Potential Ecological Risk Index (PERI) proposed by Hakanson (1980), a method that considers the synergy, toxic level, concentration of the heavy metals, and ecological sensitivity of heavy metals (Nabholz, 1991; Singh et al., 2010; Douay et al., 2013), the following Equation was used;

$$Eri = Tri \times Cfi$$

Where, Tri is the toxicity coefficient of each metal whose standard values are Cd = 30, Ni = 5, Pb = 5, Cu = 5, and Zn = 1 (Hakanson, 1980; Xu, 2008) and Cfi is the contamination factor. To describe the ecological risk index the following order: $Er < 40$, low; $40 \leq Er < 80$, moderate; $80 \leq Er < 160$, considerable; $160 \leq Er < 320$, high; and $Er \geq 320$, very high.

Results and Discussion

The results of the heavy metals concentration in the water and sediment samples are shown in table 1. From the table, the heavy metal Ni has the highest concentration in both water and sediment samples, while Cd recorded the lowest concentration in both samples. The concentration values for the heavy metals evaluated is in the decreasing order Ni > Pb > Cu > Zn > Cd. From the results, except Pb, Ni, and Cd level in water sample which is above the safety limit, the concentrations of the heavy metals Zn and Cu in the water sample and all the evaluated metals in the sediment sample were lower than the recommended levels proposed by WHO/USEPA. The mean Ni, Pb, and Cd concentrations in the present study that is above the safe limit (0.05; 0.05; 0.01 mg/l respectively) proposed by the WHO (2011) can be linked to the likely multiple pollution sources of the Dam.

Compared to values reported in the literature, the mean heavy metal concentrations in water and sediment samples are similar to what was observed in some previous studies conducted in Katsina and Jigawa States, all in Nigeria (Yaradua et al., 2018a and b; Ringim et al., 2016). But the values are lower to values reported for Jare River Katsina State, Nigeria (Yusuf et al., 2018), Bangalore dam, India (Aboud et al., 2010), Sakumo II lagoon, Ghana (Do'amekpor et al., 2018), Red Sea Coast of Jizan, Saudi Arabia (Mortuza and Misned, 2017) and in a mining community of Abakaliki, southern Nigeria (Obasi and Akudinobi, 2020). Likewise, the values are higher when compared to mean concentrations values reported for Mada River Nassarawa State, Nigeria (Tukura et al., 2015) and Elechi Creek Port Harcourt State, Nigeria (Otene et al., 2019). The similarity and differences may be due to the location and pollution sources of the various sites as compared to the present study.

Table 1 Heavy metal concentrations of water (mg/l) and sediment (mg/kg) samples

Samples	**Heavy metals**					
	Fe	Pb	Cu	Zn	Ni	Cd
Water	1.2729± 0.0321	0.0632± 0.0037	0.0379± 0.0013	0.0277± 0.0050	0.0825± 0.0048	0.0154± 0.0031
Sediment	15.5669± 0.0785	0.0818± 0.0014	0.0686± 0.0024	0.0310± 0.0056	0.0962± 0.0025	0.0288± 0.0007

Values are presented as mean ± standard deviation

Metal Index (MI)

The MPI for the heavy metals Pb and Cd indicate a moderate effect on the water quality, while the MI for the heavy metals Pb, Ni, and Cd indicate a threshold threat to human and aquatic life's utilizing the water (table 2). The calculated values were also higher than values reported in a study conducted in Katsina State, Nigeria (Yaradua et al., 2018a) and Ismailia Canal of Nile river Egypt (Goher et al., 2014).

Table 2 Heavy Metal Pollution and Metal Indices for Water sample from Kwanar Are Dam Katsina State, Nigeria

Metal	Metal Pollution Index	Metal Index
Pb	2.9793	4.2133
Cu	0.0134	0.0189
Zn	3.8184E-03	0.0054
Ni	0.8334	1.1786
Cd	2.1779	3.0800

Key = Metal Pollution Index= Class 1 (< 1) No Effect on Water Quality; Class 2 (1-2) Water Quality Slightly Affected; Class 3 (2-3) Water Quality Moderately Affected; Class 4 (3-5) Water Quality Strongly Affected; Class 5 (> 5) Water Quality Seriously Affected. Metal Index < 1 Represent no threat to human health and aquatic life; Metal Index > 1 Represent threshold level of threat to human health and aquatic life

The results for the CDI in adults and children were lower than the tolerable daily intake limit set by the USEPA (table 3). The order of sequence of CDI in both adults and children is as follows: Ni > Pb > Cu > Zn > Cd. The result is similar to what was reported for Dadinkowa dam and Gombe Abba river in northern Nigeria (Maigari et al., 2016) and CDI for heavy metals of some rural areas of southeast Nigeria (Nwachukwu et al., 2014).

Table 3 Chronic Daily Intakes of Heavy Metals in Adult and Children from Drinking Water from Are Dam, Katsina State, Nigeria

Population			Heavy Metal		
	Pb	Cu	Zn	Ni	Cd
Adult	1.5674E-03	9.3992E-04	6.8696E-04	2.0460E-03	3.8192E-04
Children	3.9184E-03	2.3498E-03	1.7174E-03	5.1150E-03	9.5480E-04

Table 4 represents the calculated THQ and HRIs in the children and adult population from consumption of the water sample. From the results, the THQ and HRI are all below 1, with children having a higher value compared to the adult population. The order of THQ sequence for individual heavy metals is as follows: Cu > Ni > Pb > Zn > Cd, a trend similar for both the adult and children population. A THQ and HRI value of below 1 has been reported in previous studies conducted in Nigeria (Maigari et al., 2016; Nwachukwu et al., 2014).

Table 4 Target Hazard Quotient (THQ) and Health Risk Index (HRI) in Adult and Children from Drinking Water from Are Dam, Katsina State, Nigeria

Population	THQ					HRI
	Heavy Metal					
	Pb	Cu	Zn	Ni	Cd	
Adult	2.6123E-03	2.3500E-02	2.2899E-03	5.1150E-03	7.6384E-04	3.4281E-02
Children	6.5307E-03	5.8800E-02	5.7247E-03	1.2800E-02	1.9096E-03	8.5765E-02

The Incremental lifetime cancer risks (ILCR) and the cumulative incremental lifetime cancer risks (∑ILCR) are presented in table 5. From the table, the ILCR values were at the threshold level of 1.0 × 10−4 for Pb in children and Cd in adult and above the threshold for Cd in children and Ni in adult and children, while the ∑ILCR is above the threshold in both adult and children in the water sample. The highest contributor to cancer risk is Ni. Similar to the results in this study, heavy metals have been reported to contribute to the cancer burden in a study conducted in Linshui River, south China (He et al., 2018).

Table 5 Incremental Lifetime Cancer Risk (ILCR) and Cumulative Incremental Lifetime Cancer Risk (∑ILCR) in Adult and Children from Drinking Water from Are Dam, Katsina State, Nigeria

Population	ILCR			∑ILCR
	Heavy Metal			
	Pb	Cd	Ni	
Adult	8.1046E-05	8.8287E-04	2.1160E-02	2.1256E-02
Children	2.0262E-04	2.2072E-03	5.2898E-02	5.3139E-02

Table 6 displays the I-geo, CF, EF, CD, MCD, and PERI of the Evaluated Heavy Metals in the Sediment sample; from the table the I-geo values indicate unpolluted (class 0). The Igeo values in this study are similar to the Igeo values for heavy metals in sediment conducted by Saikia et al., (2016) in Brahmaputra River and the results of Abuduwaili et al., (2015) in the study conducted on heavy metals in sediments samples from Aibi lake Northwest China. But the results are lower than the values reported in a study conducted on heavy metal pollution in sediment samples from Tigris River (Abdulhameed et al., 2014) and the results reported by Sayadi et al., (2017).

The relative distributions of the contamination factor in the sediment sample are: Cd > Ni > Cu > Pb > Zn, with all the heavy metals, exhibiting low contamination. The observed CF values in this study are below the CF values reported for river Tigris (Abdulhameed et al., 2014) and the Red Sea coast of Jizan Saudi Arabia (Mortuza and Musnad, 2017), but are comparable to the report of a study conducted in Katsina State (Yaradua et al., 2018b) and values reported for river Turaq (Banu et al., 2013).

The range of Sediment EF values of the heavy metals Indicates deficiency to minimal enrichment. This in contrast to the report of Abdulhameed et al., (2014) that reported significant enrichment for the heavy metals Cd, Cr, and Pb in sediment sample from the Tigris river and the results of Sayadi et al., (2017) and Mihaileanu et al., (2019) for soil samples.

The value of PERI for all the heavy metals ranges from 8.6400 E-01 to 1.7714 E-03, indicating that the sediment sample is unpolluted by the studied heavy metals. The PERI values recorded in the present study are lower than the value reported for Tigris river and river Turaq (Abdulhameed et al., 2014; Banu et al., 2013), and in soil samples of river Niger flood plain at Jebba, Northcentral Nigeria (Omotoso et al., 2015), but similar to PERI values reported for sediment samples from Subansiri river and Brahmaputra river (Saikia et al., 2016) and the report of Mortuza and Musnad (2017) of PLI values of a sediment sample from the Red Sea, Jizan, Saudi Arabia.

Table 6 Geo-accumulation Index (I-geo), Contamination Factor (CF), Enrichment Factor (EF), Degree of Contamination (CD), Modified Degree of Contamination (MCD) and Potential Ecological Risk Index (PERI) of the Evaluated Heavy Metals in the Sediment Samples

Heavy metal	I-geo	CF	EF	PERI
Pb	-2.6882	1.1686E-03	1.06121E-03	5.8429E-03
Cu	-2.9930	1.3720E-03	1.06124 E-03	6.8600E-03
Zn	-2.9725	1.7714E-04	1.06123 E-03	1.7714E-03
Ni	-2.6194	1.4147E-03	1.06122 E-03	7.0735E-03
Cd	-1.1938	2.8800E-02	1.06126 E-03	8.6400E-01
CD		7.0124E-02		
MCD		1.4025E-02		

Conclusion

Evaluation of heavy metal concentrations with the potential health risk and ecological impact in water and sediment samples of a water body with possible multiple sources of pollution was carried out. Pb, Ni, and Cd level in the water sample were above the safety limit. Pollution index (PI) and Metal index (MI) indicate a threshold threat to human and aquatic life's utilizing the water. Pollution indices in sediment samples indicate unpolluted (class 0) with minimal enrichment, low contamination level, and low ecological risk respectively. The target hazard quotient (THQ) and Health risk index (HI) values suggest a no non-carcinogenic adverse health hazard to the population. The Incremental lifetime cancer risk (ILCR) values were at the threshold level for Pb in children and Cd in adults and above the threshold for Cd in children and Ni in adults and children in the water sample, pointing to potential cancer risk.

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