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ECOLOGICAL RISK ASSESSMENT OF HEAVY METALS IN SEDIMENT OF IBI RIVER NIGERIA AFFECTED BY VARIOUS ANTHROPOGENIC ACTIVITIES

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Abstract: *Ecological risk assessment of Heavy Metals in Sediment of Ibi River Nigeria affected by various anthropogenic activities was studied in August 2024. The objectives were to; characterize the occurrence and distribution of heavy metals in the sediments of the river, assess the pollution status and the ecological risk, and identify possible sources of heavy metal pollution in the river. Four (4) sampling stations were selected. Sediment samples were taken from each sampling location using Van Veen grab. Physico-chemical parameters of each sampling station was also taken. Analysis of Variance (ANOVA) was used to test for significant differences in heavy metal content of the sample types. One-way ANOVA was used for mean metal level comparisons at 95% level of significance. The results showed that the degree of contamination for the individual metal is within the range of 0.9863 - 1.5650. The degree of contamination data signifies anthropogenic impact in all the sampling stations. Heavy Metals (Pb, Cd, Cu, Cr, Fe, Zn, Ni and Mn) in the river have low risk index. The mean concentration of the measured elements in the river was Fe>Ni>Pb>Zn>Mn>Cu>Cr>Cd, with mean values in descending order of 21.20 $mgkg^{-1}$, 1.50 $mgkg^{-1}$, 1.42 $mgkg^{-1}$, 1.20 $mgkg^{-1}$, 0.75 $mgkg^{-1}$, 0.32 $mgkg^{-1}$, 0.27 $mgkg^{-1}$ and 0.03 $mgkg^{-1}$ respectively. Among the selected heavy metals, Fe presents very high ecological risk and should be carefully monitored and remediated. Other heavy metals incur limited, if any, pollution according to the risk assessment. The study therefore recommends that the framework for mandatory action should be initiated for regular assessment of River Benue at Ibi to ensure conservation of the biota therein. There should be strict regulations to control the dumping of chemical contaminants into the river with enforcement of penalties imposed on defaulters, and enlightenment programs for the public on the dangers of Ibi river pollution are very necessary.*

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1.0 Introduction

Rivers play an important role in conserving water, providing drinking water for humans, and providing and managing water resources for various ecosystems (Cosgrove and Loucks, 2015). However, with the accelerated urbanization, and the improvement of industrial and agricultural production, more and more pollutants are discharged into river waters (Luo *et al.,* 2019). Therefore, the river water environment is under great threat. Heavy metals are common pollutants in the rivers around the world. Most of them will be enriched in the sediment through flocculation or precipitation after entering the water body (Brady *et al.,* 2015). When the external redox conditions, PH value, and hydrodynamic conditions change, the heavy metals adsorbed in the sediment will be released back to the surface water, leading to secondary pollution (Jia *et al.,* 2021). Because heavy metals are difficult to degrade, highly toxic, and easily enriched, the released heavy metals will pollute water and pose potential threats to aquatic organisms and human health. Therefore, it is of great significance to investigate the risk and potential sources of sediment heavy metal pollution in rivers to protect the ecological safety in the watershed. Many rivers have suffered heavy metal pollution, e.g., the Volga (Lychagin *et al.,* 2015), and the Danube River (Calmuc *et al.,* 2021). In general, the concentration of heavy metals is relatively low in water and soil (Wang *et al.,* 2020). However, large amounts of heavy metals were released into the aquatic environment from anthropogenic activities such as mineral development, metallurgical engineering, pesticide spraying, and transportation (Briffa *et al.*, 2020). In particular, the ecological risk of rivers and lakes as the drinking water sources has attracted increasing attention worldwide (Kumar *et al.,* 2020).

Heavy metals are the most important forms of aquatic pollutants and may accumulate in the tissues of fish, which are often at the top of the aquatic food chain (Dirican *et al.,* 2013). The progressive and irreversible accumulation of metals in various organs of aquatic creatures ultimately leads to metal-related diseases in the long run because of the toxicity of the metals, thereby endangering the aquatic biota and other organisms (Mallampati *et al.,* 2007). Their toxicity has been demonstrated long ago; Greek and Roman physicians diagnosed symptoms of acute lead poisoning long before toxicology became a science. Exposure to heavy metals has been linked to developmental retardation, various cancers, kidney damage and even death.

Nowadays, heavy metal pollution is becoming a global concern with worries expressed in many different countries due to the toxicity, extensive sources, non-biodegradable properties and accumulative behaviors of heavy metals (Hui-na *et al.,* 2012; Dou *et al.,* 2013). Heavy metals in marine and coastal sediments represent a potential source of contaminants to the overlying water and hence can influence water

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quality. This is the result of waste disposal and waste water discharged into the sea, which causes serious impacts on the marine environment (Dou *et al.,* 2013). Heavy metals in the environment have two main sources: lithogenic and anthropogenic.

Lithogenic include natural processes, for example the weathering of rocks and volcanic activities. Anthropogenic sources are caused by human activities from mining, industry, agriculture, and construction of urban developments, all of which transfer contaminants to the marine environment (Sany *et al.,* 2011).

Despite the critical importance of the Ibi River to the surrounding communities and ecosystems, there is a growing concern about the rising levels of heavy metal contamination. Industrial activities, agricultural runoff, improper waste disposal, and other anthropogenic sources are contributing to the influx of these hazardous substances into the river. The presence of heavy metals poses a substantial risk to aquatic life, human health, and the overall ecological balance of the riverine environment. Therefore, the aim of the study is to assess the ecological risk of heavy metals concentration of Ibi river.

2.0 Materials and methods

2.1 Study Area

Ibi Local Government Area is one of the 16 Local Governments in Taraba State, with Ibi town as its headquarters. It is located at the southern part of Taraba State and lies within latitude 7° 00' - 8° 10' North of the Equator and longitude 11° 10' – 12° 10' East of the Greenwich Meridian Time (GMT) (Akoga 2012). Ibi has a landmass of 2,728.872 km2 with a population of 84, 407 based on 2006 National Population Census. The area shares boundary with Plateau State to the North and Nasarawa State to the West. The southern part bordered to Wukari Local Government Area, while Gassol and Karim-Lamido Local Government Areas had it boarder to the North-East axis. It is located in about 350 meters below sea level and has a plain land all over with fairly undulating and many swampy plain areas of fertile land good for the cultivation of rice, sugar-cane, etc (Akoga 2012). Ibi Local Government Area has a fertile soil. It has River Benue as major river passing through it and its tributaries; rivers Shimakar, Gishiri, Wase and some natural ponds and lakes such as Nwonyo, Isini, Awo, Sai, Aku, Tapga, Baruwana, Akoku, etc. Generally speaking, Ibi Local Government Area can best be described as an agrarian and aquatic environment. Akoga (2012) noted that this description is not an exaggeration considering the enormous farming and fishing activities going on in all the three districts of the Local Government. The main occupation of the people of Ibi today is fishing, farming and trading. Fishing is the predominant occupation carried out by two major Jukun clans in the town (Wanu and Wurbo). The Hausa are mostly traders. Types of crops cultivated include rice, maize, millet, guinea corn, cassava, yam,

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groundnut, bambara nut, benniseed, soya beans, melon, sugar-cane, and among others. The climate is tropical in Ibi, marked by wet and dry seasons. The climate here is classified as Aw by the Koppen-Geiger system. The average annual temperature in Ibi is 27.2 °C. About 1087 mm of precipitation falls annually. The rainy season spans between early May and late October, while the dry season starts from November to March. The rainy season reaches its peak in August and start retreating from late September.

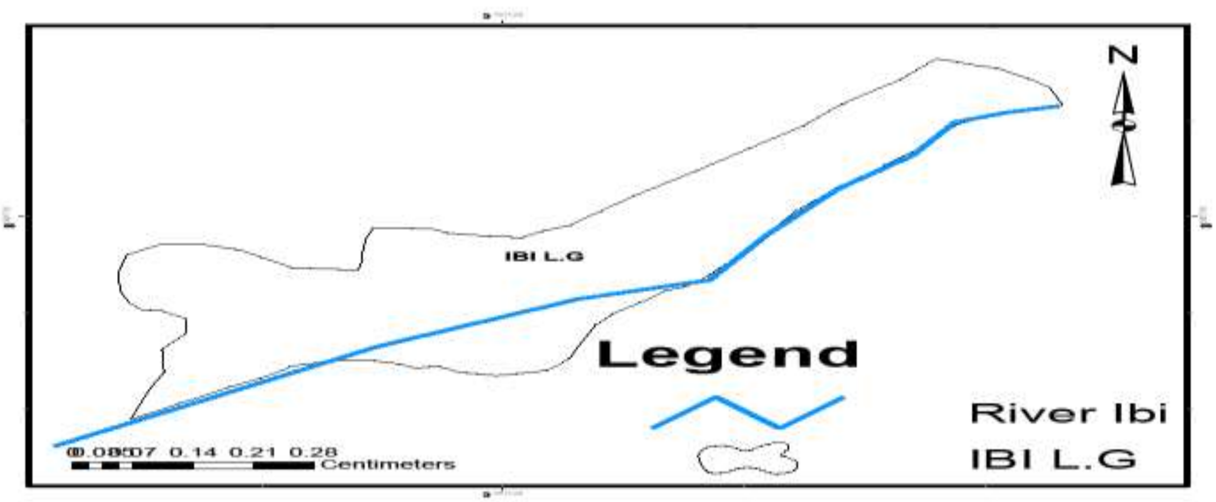

Fig. 1: Map of Ibi Local Government Area
Source: Ministry of Land and Survey, Jalingo

2.2 Collection of samples

Four (4) sampling locations were chosen along the course of the water body. A sampling location was located upstream, midstream and downstream where collection of sediment was done. Sampling was done Once for all the stations. Samples were obtained between 07.00 and 10.00 hours during the designated days. Physico-chemical parameters of water, such as Temperature, pH, Conductivity and Dissolved Oxygen (DO) were measured in addition to determining the concentration of heavy metals in sediment obtained from each sampling location. Surface water temperature was measured with mercury bulb field thermometer at the points of sample collection.

Sediment samples was collected from each of the four sampling locations with a Van Veen Grab (0.1 m^2). Composite sediment samples were obtained from each location and

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transported in labeled polyethylene bags, previously cleaned and treated with 5% nitric acid and rinsed with distilled water (Achionye-Nzeh and Isimaikaiye, 2010). The polythene bags were rinsed with water samples at the point of sediment collection before the sediment samples were put into it.

2.3 Water Quality Assessment

Temperature was measured using a mercury-in-glass thermometer (calibrated in degree Celsius), which was dipped into the water for two minutes; readings were taken when the mercury level was steady. Dissolved oxygen was measured using DO meter (model-AD 630 DO meter manufactured by Adwa®). After calibration according to the manufacturer's directions, the probe was inserted into the water sample and reading were taken when the digital meter reading was steady. The pH was measured as described by APHA (2012) and conductivity was measured using a conductivity metre (CDH-222 manufactured by Omega, United Kingdom) as described by the manufacturer.

2.4 Pollution assessment of heavy metals

2.4.1. Contamination Factor

The extent of contamination of sediment by a metal is often expressed mathematically in terms of a contamination factor calculated by: $CF = \frac{\text{metal content in the sediment}}{\text{Background level of metal}}$ or $\frac{C_{sample}}{C_{background}}$

Where CF < 1 refers to low contamination, 1 ≥ CF ≥ 3 means moderate contamination, 3 ≥ CF ≥ 6 indicates considerable contamination, and CF > 6 indicates very high contamination.

Background concentration (Earth Crust) of Cu, Zn, Mn and Pb of 45, 95, 850 and 20 mg/kg respectively in the reference Earth's crust were the average composition of shale value (NLNG, 2005) were used for this investigation. Iron was selected as the reference value being 4.72 mg/kg as the reference element. Cr and Cd with 71 and 0.2 mg/kg (Adamo, *et al.*, 2005, lastly Ni having 2.77 mg/kg or ppm (Amadi, *et al.*, 2018).

2.4.2 Degree of Contamination (Cd)

This is used to evaluate the extreme values of monitored elements in soil sediment samples. It is express mathematically as given below. CiF is the contamination factor for the i-th elements.

$$Cd = \sum CiF$$

Where (Cd)<6 refer to Low degree of contamination, 6≥Cd ≥12 mean moderate degree of contamination, 12≥Cd≥24 refer to high degree of contamination and Cd>24 refer to very high degree of contamination.

2.4.3 Pollution Load Index (PLI)

This is used to evaluate specific sampling site, according to the method proposed by Tomilson, *et al.*, (1980) and it is expressed as:

$$PLI = [CF1 \; x \; CF2 \; x \ldots\ldots\ldots\ldots\ldots\ldots\ldots . x \; CFn\,]^{1/n}$$

Where, n is the number of metals in the present study and CF is the contamination factor.

The values of the PLI vary from zero (non-contaminated) to 10 (highly contaminated). Typically, values <1 indicate non contamination, and values >1 indicate contamination with heavy metals

2.4.4 Assessment of potential ecological risk

The potential ecological Risk Index (RI) formulated by Hakanson in 1980 was used here to quantify the level of ecological risk of heavy

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metals in sediment (Hakanson, 1980). The RI assesses the combined ecological and environmental toxicity to provide an overall evaluation of the potential risks of heavy metal pollution, and is calculated as follows:

$$E_r^i = T_r^i \frac{Csample}{Cbackground}$$

$$RI = \sum E_r^i$$

Where E^i_r and T^i_r are the potential ecological risk factor and the toxic response factor of the heavy metal, respectively, and C_{sample} and $C_{background}$ are the measured and background concentration. The T^i_r values for Pb, Cd, Cr, Fe, Zn, Cu, Ni and Mn all taken from literature.

where T_f is the toxic response for a given element, T_f values for Fe, Mn, Cr, Zn, Co, Cu, Cd, Pb, and Ni are 1, 1, 2, 1, 5, 5, 30, 5 and 5 respectively (Zhang & Liu, 2014).

2.5 Laboratory Analysis

The pH, conductivity, total dissolved oxygen (TDO) and temperature of the water were measured using probe meter (Hana portable pH/EC/TDO/temperature meter, HI 98129 model), dissolved oxygen (DO) was measured using Winkler's method.

An OHAUS model of weighing balance was used for determining both fresh and dried weights prior to oven drying. Dried samples were grounded into powdery form, digested and tested for heavy metal contents using Atomic Absorption Spectrophotometer (Buck scientific 210/211 VGP model). The concentration (mg /kg) of the metals were calculated, with reference to Peer and Rosen (1977).

2.5 Statistical analysis

The data obtained were subjected to descriptive and inferential statistics. Descriptive statistics mainly mean and standard deviation were used to describe each of the water quality parameters as well as concentrations of metals in the sediment samples. Analysis of Variance (ANOVA) were used to test for significant differences in heavy metal content of the sample types. One-way ANOVA was used for mean metal level comparisons at 95% level of significance.

3.0 RESULTS

3.1 Physico-chemical Parameters of River Benue at Ibi.

The table below presents the physico-chemical parameters of the sampling stations. Station A, which is the Refuse dump site has the least Temperature of 29°C while Station D, the Agrochemical site has the highest Temperature of 33°C. For Conductivity, Station D has the least with 60.7 while Station B has the highest with 74.00. There are no much differences in the Dissolved Oxygen and pH with an average of 5.6mg/l and 5.74 respectively.

Table 1: Physico-chemical Parameters of River Benue at Ibi.

S/N	Temperature	Dissolved Oxygen	Conductivity	pH
A	29°C	5.6mg/l	61.95	5.95
B	32°C	5.4mg/l	74.00	5.67
C	31°C	5.8mg/l	65.7	5.74
D	33°C	5.6mg/l	60.7	5.60

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3.2 Ecological risk index standards for Heavy Metals

The table below is the Potential ecological risk index for heavy metals classified into 4 classes (Riyad, *et al.,* 2015).

Table 2: Levels of potential ecological risk for Heavy Metal in sediments

Range of E_r^i Value	Level of single metal ecological risk	Range of RI value	Level of comprehensive potential ecological risk
Er < 40	Low ecological risk	<150	low ecological pollution level
40≤Eri< 80	Moderate ecological risk	150 < RI < 300	low ecological pollution level
80≤Eri < 160	Considerable ecological risk	300 < RI < 600	severe ecological pollution level
160≤Eri < 320	High ecological risk	RI > 600	serious ecological pollution level
320≤Er	Very High ecological risk		Very high risk

3.3 Occurrence and abundance of the heavy metals in the sediments

Table 3 presents the Concentration of heavy metals (mgkg-1) in the sediment of Ibi River, eight heavy metals were discovered in the sediment samples, it summarizes the minimum, maximum, and average concentrations of the heavy metals detected in all the sediment samples, the concentration of Pb, Cd, Cr, Fe, Zn, Cu, Ni and Mn ranged in 0.178 - 0.473, 0.0037 – 0.0128, 0.011 – 0.016, 3.900 – 6.300, 0.200 – 0.400, 0.096 – 0.141, 0.300 – 0.500 and 0.110 – 0.330 $mgkg^{-1}$ respectively.

The average concentration ranked in the order of Fe (21.200 mgkg-1), Ni (1.500 mgkg-1), Pb (1.420 $mgkg^{-1}$), Zn (1.200 $mgkg^{-1}$), Mn (0.750 $mgkg^{-1}$), Cu (0.319 $mgkg^{-1}$), Cr (0.271 $mgkg^{-1}$) and Cd (0.0330 $mgkg^{-1}$). Hence, the element with highest concentration is Fe having 21.200 $mgkg^{-1}$ and the least concentration is Cd containing 0.033 $mgkg^{-1}$.

Therefore, the distribution of heavy metals is clearly different among different sample sites, including the refuse (sample A), Washing sites (sample B), packing boats (sample C) and farming sites (sample D). In sample all the samples the maximum concentration is contained by Fe and the Minimum concentration is contained by Cd.

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Table 3: Concentration of heavy metals (mg kg-1) in the sediment of Ibi River

SAMPLES.	Pb	Cd	Cr	Fe	Zn	Cu	Ni	Mn	Pollution Sources
A	0.178	0.0128	0.013	6.300	0.300	0.119	0.300	0.200	Refuse (Dirt)
B	0.355	0.0037	0.011	4.900	0.400	0.141	0.400	0.110	Laundry Site
C	0.414	0.0128	0.015	6.100	0.200	0.096	0.500	0.330	Boats Park
D	0.473	0.0037	0.016	3.900	0.300	0.119	0.300	0.110	Agrochemicals.
TOTAL	1.420	0.033	0.271	21.200	1.200	0.319	1.500	0.7500	

Table 4 shows the Mean ± Standard Deviation of the actual concentration ($mgkg^{-1}$) of each element. It also shows the F-statistic value with its corresponding p-value. Testing for significant mean difference among the eight elements, the F-statistics is 80.517 and its corresponding p-value is 0.000. Since the p-value is less than 0.05 level of significance, there is significant mean difference in actual concentration among the elements. Duncan multiple tests is used to determine where the significant mean difference exist, and this is denoted by the small letters' superscript in Table 4 The mean actual concentration of Iron is significantly greater than each of the means actual concentration of Lead, Cadmium, Chromium, Zinc, Copper, Nickel and Manganese. There is no significant mean difference in actual concentration of Lead, Cadmium, Chromium, Zinc, Copper, Nickel and Manganese.

Table 4: Mean Actual Concentration ($mgkg^{-1}$) of Elements

S/N	Element	Mean ± Standard Deviation
1	Lead	0.3550 ± 0.12745
2	Cadmium	0.0083 ± 0.00525
3	Chromium	0.0138 ± 0.00222
4	Iron	5.3000 ± 1.11952
5	Zinc	0.3000 ± 0.08165
6	Copper	0.1188 ± 0.01837
7	Nickel	0.3000 ± 0.14142
8	Manganese	0.1875 ± 0.10404

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F-Statistic value = 80.517 P-value = 0.000

3.4 Contamination Factor of Heavy Metals of River Benue at Ibi.

The values of the studied metals from all four sampling stations are shown in Table 5. This present study, the highest CF value was obtained for Fe (4.4915) and therefore give a very high contamination factor while low contamination factors are being registered for Cr and Mn (0.008). The values of Pollution Load Index or status was found to be higher than (>1), this confirmed that Ibi river is currently undergoing possible environmental contamination.

Table 5: Contamination Factor (CF) and Degree of Contamination (CD) values for sediments in Ibi River

SAMPLES	Pb	Cd	Cr	Fe	Zn	Cu	Ni	Mn	CD
A	0.0090	0.0650	0.0020	1.3347	0.0032	0.0026	0.0722	0.0002	1.4889
B	0.0180	0.0200	0.0020	1.0381	0.0042	0.0031	0.0722	0.0001	1.1577
C	0.0210	0.0650	0.0020	1.2924	0.0021	0.0021	0.1800	0.0004	1.5650
D	0.0240	0.0200	0.0020	0.8263	0.0032	0.0026	0.1080	0.0001	0.9863
TOTAL	0.0720	0.5300	0.0080	4.4915	0.0127	0.0104	0.4324	0.0008	5.1979

All units are in mg/kg

Therefore:

$$PLI = \sqrt[n]{CFn1 \times CFn2 \times \ldots\ldots \times CFni}$$

$$PLI = \sqrt[8]{\mathbf{10.7557}}$$

$$PLI = 1.3457$$

Approximately, PLI = 1.35

3.5 Potential Ecological Risk Assessment of Heavy Metals of River Benue at Ibi.

The Ecological risk index (Er) shows the risk index in the river sediment. From Table 7, the pollution level in the Ibi river is a low risk of heavy metals. From the samples, 100% were identified as low risk, particularly for Pb, Cd, Cu, Cr, Zn, Ni and Mn (Er < 40), only Fe tends high but still Er < 40. To some extent, the Er value for all sampling sites indicates a high potential ecological risk for Fe, metals, the

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potential ecological risk may be expressed as low pollution.

Table 6: Potential Ecological Risk Assessment of heavy metals in River Benue at Ibi.

SAMPLES	Pb	Cd	Cr	Fe	Zn	Cu	Ni	Mn	RI (Risk Index)
A	0.0450	1.950	0.0004	1.3347	0.0032	0.0130	0.3610	0.0002	3.7075
B	0.0900	0.600	0.0004	1.0381	0.0042	0.0155	0.3610	0.0001	2.1093
C	0.1050	1.950	0.0004	1.2924	0.0021	0.0105	0.9000	0.0004	4.2608
D	0.1200	0.600	0.0004	0.8263	0.0032	0.0130	0.5400	0.0001	2.103

4.0 Discussion

Heavy metals contamination in sediment is of major concern particularly in many modern countries due to their toxicity, persistence and bioaccumulative nature (Yaron, *et al.*, 1996). The level of metal concentration observed in all the stations may be due to influx of waste which influences their concentration and metals mobility which depends directly on the environment and some metals properties such as pH, organic matter concentration, silt and clay concentration, salinity, dissolved oxygen concentration. However, it has been reported that mobility of heavy metals depends not only on the total concentration in the soil and sediment but also on the sediment properties, metal properties and environmental factors.

The occurrence and distribution patterns of Pb, Cd, Cr, Fe, Zn, Cu, Ni and Mn in Ibi River were illustrated in table 4. The results indicate that urbanization has contributed to the elevation of Pb content in the sediment. Domestic and industrial effluents, municipal runoffs and atmospheric deposition may be the major sources. The contribution of Pb from the use of leaded petrol in ship and speed boat operator is possibly significant. This is in line with the study of Sadip *et al.,* (2003) who reported that low concentrations of Pb still might pose a threat to life in a marine environment in comparison with other heavy metals.

The high concentration of Fe could be attributed to the refuse dump in the river, this is consistent to the study of Lintang (2023) who suggested that heavy metals may come from other environmental factors, such as soil and waste on the riverbank. The relatively low concentration detected in Cadmium, chromium and zinc in the sediment reflects their natural background levels in the sediment, this concurred to Lintang (2023) who reported the low loading of Cr which indicates a small enrichment of the metal, results for some heavy metals (Pb, Cu, Cr, and Cd) suggest low-risk sediment in Winongo

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River. However, heavy metals in the water and sediment should still be continuously monitored in the Ibi River because it is used for agriculture, domestic purposes, and fisheries. Moreover, land use changes in the future may lead to an increase in heavy metals in the river water and sediment. Hence, to manage the pollution from agriculture, artifcial fertilizer should be reduced

Hall *et al*., (1997) reported that Zn is a micronutrient for aquatic life in all-natural water and sediments, even at low concentration Zn can become toxic to aquatic organisms at higher concentration level than the threshold required contents.

Generally, the pollution load index value significant increased as anthropogenic activities increased as well as dispersion of metal content with increasing distance from point of discharged. The relative low value of pollution load index indicates no much input from anthropogenic sources. Table 5 shows the contamination factor of each element and the degree of contamination in each of the sampling stations. The degree of contamination for the individual metal are within the range of 0.9863 - 1.565. The degree of contamination data signifies anthropogenic impact in all the sampling stations.

Pollution load index can increase to domestic and industrial effluents such as sewage discharges, cement bags washing and influx from the nearby rivers loaded with various wastes that are subsequently deposited into Rivers.

The pollution level in the Ibi river is at low risk of heavy metals. From the samples, 100% were identified as low risk, particularly for Pb, Cd, Cu, Cr, Zn, Ni and Mn (Er < 40), only Fe tends high but still Er < 40. To some extent, the Er value for all sampling sites indicates a high potential ecological risk for Fe, metals, the potential ecological risk may be expressed as low pollution.

4.1 Conclusion

Heavy metal pollutants in river sediment have been a serious environmental concern in aquatic ecosystems. In this study, heavy metal pollution in the water and sediment of the Ibi River was analyzed using Contamination factor (CF), degree of contamination (Cd), Pollution load Index (PLI) and ecological risk Index (RI). The results showed that heavy metals (Pb, Cd, Cu, Cr, Fe, Zn, Ni and Mn) in the river water have low risk index. The mean concentration of the measured elements in the water were Fe>Ni>Pb>Zn>Mn>Cu>Cr>Cd, with mean values in descending order of 21.20 $mgkg^{-1}$, 1.5 $mgkg^{-1}$, 1.420 $mgkg^{-1}$, 1.2 $mgkg^{-1}$, 0.750 $mgkg^{-1}$, 0.319 $mgkg^{-1}$, 0.271 $mgkg^{-1}$ and 0.0331 $mgkg^{-1}$ respectively. Among the selected heavy metals, Fe presents very high ecological risk and should be carefully monitored and remediated. Most other heavy metals incur limited, if any, pollution according to the risk assessment.

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