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Temporal Pollution Load Index and Ecological Risks Evaluation of Some Heavy Metals in the Sediment of Elechi Creek, Port Harcourt, Nigeria

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ABSTRACT

Heavy metals in aquatic sediment have become public concern as a result of accumulation, bioaccumulation, bioconcentration, biotransformation in the food web with regards to anthropogenic activities. The study was conducted to rate pollution load index and ecological risk appraisal of some heavy metals in the sediment of Elechi Creek, Port Harcourt, Nigeria. Sediment representatives were retrieved from three sites between January and December 2021. The exact levels of heavy metals [Cadmium (Cd), Copper (Cu), Iron (Fe), Zinc (Zn), Lead (Pb), and Chromium (Cr)] concentrations were measured by atomic absorption spectrophotometer. Pollution Index models were employed, such as geo-accumulation index (I-geo), Enrichment factor (EF), and Pollution load index (PLI) were used for pollution assessment of sea bed sediment. The results demonstrated contamination factor (Cf) ranged between (0.027 mg/Kg) and Cd (0.31 mg/Kg) indicated moderate contamination (<3), I-geo ranged between Cd (0.000213 mg/Kg) and Fe (297142.8 mg/Kg) indicated exceedingly pollution (>5), EF ranged between Fe (96.86) and Cr (99.96) indicated enrichment (>1), PLI ranged between Cu (0.0023 mg/Kg) and Fe (0.69 mg/Kg) indicated no pollution (0) while ERI ranged between Cr (0.12 mg/Kg) and Cd (135.97 mg/Kg) indicated high ecological risk (<320). The study showed that I-geo, EF and ERI have a significant high toxic level of heavy metals from illegal oil operations. The need for urgent monitoring and regulation by government agencies to protect the environment to avoid further pollution is recommended.

Keywords: Sediment Pollution, Heavy Metals, Pollution Indices, Elechi Creek, Port Harcourt

INTRODUCTION

Sediments play a crucial role as sensitive indicators for contaminants monitoring in aquatic ecosystems. They serve as an important archive for a variety of pollutants, including heavy metals, microplastics, pesticides, metal scraps, and Polychlorinated biphenyls (PCBs). Sediment contamination arises from the expulsion of heavy metals due to man-made activities like mining, transportation, chemical sector, power output and consumption, scrapping soil, fisheries, agriculture, oil discovery, facilities expansion, and the deposition of particulate matter from the surrounding environment (Tunde and Oluwagbenga, 2020). A body of water's bottom is home to lose sand, clay, silt, and other soil particles known as sediment (Davies and Tawari, 2010; Davies and Tawari, 2013). Essential environmental data on impurity status is provided by sediment (Al-Mur, 2019), and are becoming more widely acknowledged the origin and end locations of inorganic and biological substances in an ecosystem (Davies and Abowei, 2009; Morelli and Gasparon, 2014) and can aid the development of aquatic fauna and flora. For as long as aquatic life exists, they serve as floor covering (Kpikpi, 2023), and influence by the dynamics of

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physico-chemical parameters build up, vary based on location (Kpikpi and Bubu-Davies, 2021; Davies and Kpikpi, 2024).

Heavy metals toxicity, longevity, bioaccumulation and poisoning in aquatic settings garnered a lot of attention (Gao *et al.*, 2019). Five distinct categories of heavy metals can be found in the sediment and their diversity is attributed to resettlement circumstances in a changing environment (Al-Mur, 2019). One helpful means to effectively consider environmental pollution such as heavy metals pertain to sedimentation (Goorzadi *et al*., 2009). The food chain and the food web are affected through direct interaction makes a variety of problems likely, from chemical changes to death of aquatic life that depend on contaminated sediment.

Pollution load index (PLI) is a model developed to quantify the extent of the overall contamination of heavy metals in aquatic sediment sample. According to Chris and Anyanwo (2023) mention that PLI is the nth up residence concentration arithmetic via the overall metal degree greater than the background concentration of the natural elements. Simeon and Friday (2017) explained contamination factor (Cf) as the proportion of metal load to the background value usually classified in 6 rank levels (Otene and Nnadi, 2020). Enrichment factor (EF) is a reasonably user-friendly tax for passing judgement on contamination stages and determining the degree of enrichment character in the environment (Benhaddya and Hadjel, 2013). EF and I-geo indices are often recognized to differentiate the interval of silt that has been naturally or artificially enriched (Praveena *et al.,* 2008).

Elechi Creek is one of the economic importance regions in Port Harcourt city local government area embracing financiers from different parts of the country. The creek provides businesses for all including marketing, fishing, healthcare, industries, badges and shipping transport, dredging among other operations of the area. Studies on heavy metals document in sediment (Davies *et al.* 2006), in crab (Abolude *et al.* 2009) but few to be mentioned. Based on literature search, there are few or no reports on the use of developed model, indices, pollution load and ecological indices in Elechi Creek. To breach the opening in knowledge, the study aimed to appraise pollution load index and ecological risks evaluation of some heavy metals in the sediment of Elechi Creek, Port Harcourt, Nigeria.

MATERIALS AND METHODS

Study Area

Elechi Creek is located in the Niger Delta, South-west Port Harcourt and South-south Nigeria. The creek bears longitude 6°973'62'N and 6°973'33'E, latitude 4°783'53'N and 4°789'44'E. In both the wet and dry seasons, the water features intermittent mud plains and a brackish mangrove habitat that is susceptible to twice a day flooding cycle. The creek is a prime economic hydro-mapping feature in the vicinity, consisting of a vast meshwork of rivers, estuaries and thus, empty into the lower Bonny Estuary. The section's greenery encompasses species of Nypa palms, *Acicennia*, and *Rhizophora*. The research region is prone to noteworthy human deeds, particularly illegal crude oil exploration and vendors, foul sewage, saw milling of timber, abattoir and greywaters from factories and laboratories. Additional modest domestic used water is toss away as well from the university residential building and hotels into the shallow marginal estuarine reaches within the catchment district.

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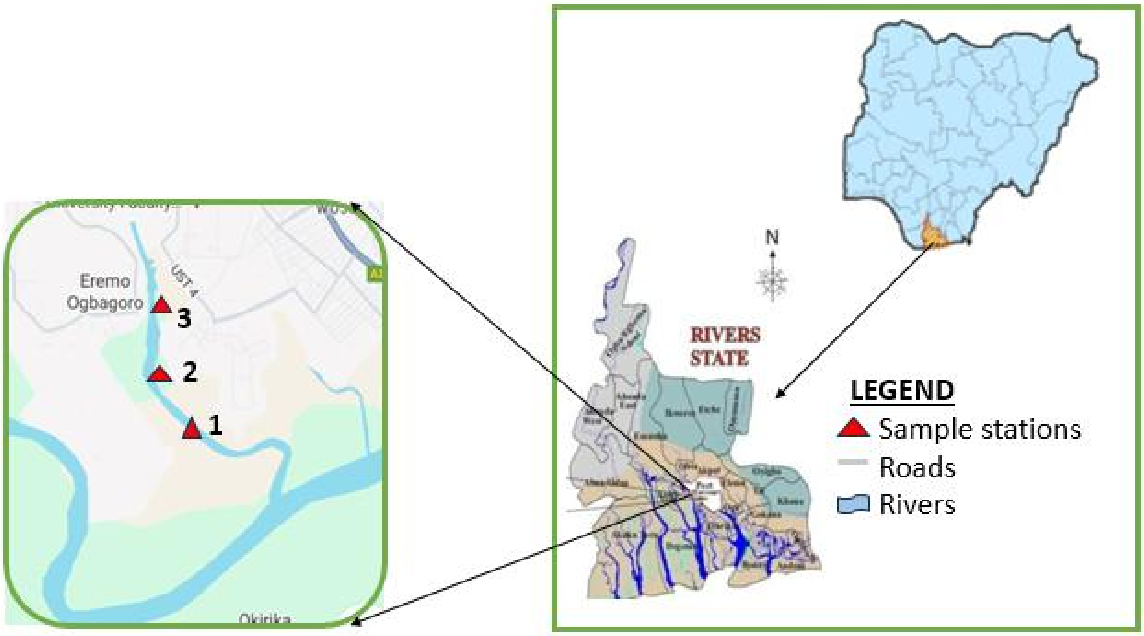

Figure 1: Map of the study area

Field Sample Collections

Subsets settling were gathered from three stations between January and December 2021 along the Elechi Creek in a motorized fibre boat that is open at low tide. The subset settling were parcel in an ice chest case and transit to the Laboratory for further analysis.

Heavy Metals Analysis

Sediment subset was broken down using a strong Nitric acid (HNO_3) solution and concentrated Perchloric acid ($HCLO_4$) acid (Davies and Tawari, 2013). The digested matter was scrutinized with an Atomic Absorption Spectrophotometer (AAS) model AA-7000, (Shimadzu).

Sediment Ecological Assessment

Some build indices uncovered in articles were used to unravel the degree of heavy metal contamination in sediments. Calculations for these indices were tied to background worth of the heavy metal building blocks.

Contamination Factor (CF)

A contamination factor (C_f^i) outlines the proportion concentration of a single metal, the dispersion of a certain unsafe substance in the sediment. It expressed by the equation (1).

$$CF = \frac{Cn}{Bn} \quad \text{..........Equation 1}$$

Enrichment factor (EF)

The EF was leveraged to inspect the level of human-driven compromise metalloid and metal elements heights of the sediment applying equation (2);

$$EF = \left(\frac{Cn}{Bn} - 1\right) * 100 \quad \text{..........Equation 2}$$

Where Cn is the metal concentrations in the sample, and Bn the background world average shale of the metals. Thus, the background concentrations of Cd, Cu, Fe, Zn, Pb, and Cr in the average shale were obtained from (Wan *et al.*, 2016).

Geo-Accumulation Index (I-geo)

The geo-accumulation (I-geo) index was employed to rate sediment pollution levels by contrasting the active concentrations of each metal with those from untainted or early age. Owing to the absence of data from early age, the international average shale was used as the standard in order to determine the level of contamination in sediments by employing the calculation adopted by (Muller, 1969).

$$Igeo = \log 2 \frac{Cn}{1.5 * Bn} \quad \text{.........Equation 3}$$

Where: Cn = Concentration of element measured in the sediments

Bn = Geochemical background value for the element

Pollution Load Index (PLI)

To evaluate the extent of heavy metal contamination in the sediment, the Pollution Load Index (PLI) was adopted using the procedure by (Ogbeibu, 2014).

$$PLI = (Cf1 * Cf2 * Cf3 \dots \dots \dots Cfn)^{1/n} \quad \text{.........Equation 4}$$

Ecological Risk Factor (ERI)

An ecological risk factor (Er^i) was applied to precisely press out the inherent capacity of ecological risk of a given contaminant as suggested by (Hakanson, 1980).

$$Er^i = Tr^i \, . \, C^i f \qquad \text{Equation 5}$$

Where Tr^i:- Toxic-response factor for a given substance, and

C^i_f - The contamination factor.

Degree of Contamination

The degree of contamination (C_d). was described as the sum aggregate of all the contamination factors in the sample. It gives a sense of the general levels of contamination in the sediments from the site.

$$DC = \sum C^i{}_f(Cd) + \sum C^i{}_f(Fe) + \sum C^i{}_f(Cu) + \dots\dots\dots + \sum n \qquad \text{Equation 6}$$

Where C^i_f is the element contamination factor.

Statistical Analysis of Results

Analysis of variance (ANOVA) for samples were performed at ($p < 0.05$) with Statistical Package for the Social Sciences (SPSS Version 26).

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Table 1: Contamination level base on Contamination factor (CF), Geo-accumulation index (Igeo) and pollution load index (PLI)

S/N	Contamination Factor (CF)		Geo-accumulation Index (Igeo)		Pollution load index (PLI)	
	Level	**Value**	**Level**	**Value**	**Level**	**Value**
1.	Low	<1	Unpolluted	≤ 0	No pollution	0
2.	Moderate	<3	Unpolluted to moderately polluted	≤ 1	BacKground pollution	1
3.	Considerable	<6	Moderately polluted	<2	Elevated pollution	>1
4.	Very high	>6	Moderately to heavily polluted	<3		
5.			Heavily polluted	<4		
6.			Heavily to extremely polluted	<5		
7.			Extremely polluted	>5		

Ogbeibu (2014)

Table 2: Enrichment factor (EF) and ecological risk index (ERI)

S/N	Enrichment factor (EF)		Ecological risk index	
	EF Level	EF Value	ERI Level	ERI value
1.	Lack enrichment	<2	Low	<40
	Mild enrichment	<5	Moderate	<80
2.	Meaningful enrichment	<20	Appreciable	<160
3.	Very high enrichment	<40	High	<320
4.	No enrichment	< 1	Serious	>320
5.	Enrichment	>1		

Wan *et al.* (2016)

RESULTS

The concentration of the heavy metals in the sediment for contamination factor of all months were presented in Table 3. The highest overall mean concentration 3.13±0.13 mg/Kg was observed in Fe (Iron) and the lowest 0.027±0.0010 mg/Kg was observed in Cu (copper) (Table 3). The I-geo value recorded in this study are presented in Table 4. Cd showed rank of unpolluted while Zn and Pb showed the rank of moderately polluted, Cu, Fe and Cr revealed rank of extremely polluted (Table 4).

Enrichment factor (EF) was used to estimate the influence of anthropogenic participation of a single metal(s) in aquatic sediment. The present study observed EF values of Cd, Cu, Fe, Zn, Pb and Cr were less than one between January and December 2021 indicating the rank of no enrichment (Table 5).

The pollution load index (PLI) of Cu, Zn, Pb and Cr recorded higher concentration between June and December indicating the rank of elevated pollution; whereas Cd showed less than one (<1) from January to December 2021 which indicated rank of no pollution or background pollution (Table 6). Thus, the overall mean values showed that the heavy metal of pollution load index (PLI) ascribed the rank of no pollution in the study.

The ecological risk index (ERI) showed concentrations of the heavy metal Cd from January to December were less than (<160) except June and October were greater than (>320). While Cu, Fe, Zn, Pb and Cr were less than (< 40) from January to December 2021 (Table 7). Though, the overall mean value showed that Cu, Fe, Zn, Pb and Cr were (< 40) indicating low ecological risk whereas Cd (< 160) indicated appreciable ecological risk (Table 7).

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Table 3: Monthly contamination factor (CF) of heavy metals in Elechi Creek, Port Harcourt with their shale values, Probable effect limit and toxicity response factors

MONTH	HEAVY METAL					
	Cd	Cu	Fe	Zn	Pb	Cr
Jan-21	3.33	0.028	3.03	0.11	0.09	0.04
Feb	3.63	0.028	3.08	0.11	0.09	0.04
March	3.6	0.028	3.08	0.11	0.09	0.04
April	3.63	0.026	3.09	0.11	0.09	0.03
May	0.0033	0.026	3.29	0.11	0.09	0.02
June	3.33	0.026	3.30	0.11	0.09	0.02
July	0.0033	0.026	3.29	0.11	0.09	0.02
August	3	0.026	3.36	0.11	0.10	0.02
September	0.3	0.026	2.98	0.11	0.10	0.04
October	3.33	0.026	3.01	0.12	0.10	0.04
Nov	0.0033	0.028	3.02	0.12	0.07	0.04
Dec-21	3.63	0.028	3.02	0.12	0.09	0.03
Overall mean	**2.31±1.61**	**0.027±0.0010**	**3.13±0.13**	**0.11±0.0048**	**0.097±0.0067**	**0.037±0.0011**
Bn	**0.3**	**45**	**4.72**	**95**	**20**	**90**
TRF	**30**	**5**	**5**	**1**	**5**	**1**
PEL	**3.53**	**197**	**N/A**	**N/A**	**91.3**	**90**
Cd	**27**	**0.32**	**37.61**	**1.40**	**1.16**	**0.44**

Bn – Background value (shale value), TRF – Toxicity response factor and PEL - Probable effect limit, Cd – Degree of contamination and N/A – Not Available

Table 4: Monthly Geo-accumulation index (I-geo) load index of heavy metals in Elechi Creek, Port Harcourt

Month	Heavy metal					
	Cd	Cu	Fe	Zn	Pb	Cr
Jan	-2.32	5.27	5.49	9.45	4.72	8.05
Feb	-2.19	5.27	5.51	9.44	4.71	8.06
March	-2.21	5.26	5.51	9.44	4.68	7.88
April	-2.19	0	5.52	9.44	4.71	7.58
May	-12.28	5.15	5.61	9.39	4.71	6.85
June	-2.32	5.13	5.61	9.37	4.72	6.89
July	-12.28	5.14	5.61	9.42	4.72	6.85
August	-2.47	5.16	5.64	9.42	4.77	6.82
September	-5.79	5.16	5.47	9.42	4.77	8.00
October	-2.32	5.18	5.48	9.56	4.77	8.01
Nov	-2.19	5.24	5.48	9.56	4.35	8.01
Dec	-2.19	5.27	5.48	9.50	4.65	7.72
PLI	**0.000213**	**8.62**	**297142.8**	**1.6**	**1.42**	**5.72**

I-geo index

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Table 5: Monthly enrichment factor (EF) of heavy metals in Elechi Creek, Port Harcourt.

Month	Heavy metal					
	Cd	Cu	Fe	Zn	Pb	Cr
Jan	-96.67	-99.97	-96.96	-99.88	-99.90	-99.95
Feb	-96.37	-99.97	-96.91	-99.88	-99.90	-99.95
March	-96.40	-99.97	-96.91	-99.88	-99.90	-99.96
April	-96.37	-99.97	-96.91	-99.88	-99.90	-99.96
May	-100.00	-99.97	-96.70	-99.89	-99.90	-99.98
June	-96.67	-99.97	-96.70	-99.89	-99.90	-99.98
July	-100.00	-99.97	-96.70	-99.89	-99.90	-99.98
August	-97.00	-99.97	-96.63	-99.89	-99.90	-99.98
September	-99.70	-99.97	-97.01	-99.89	-99.90	-99.95
October	-96.67	-99.97	-96.98	-99.87	-99.90	-99.95
Nov	-100.00	-99.97	-96.97	-99.87	-99.92	-99.95
Dec	-96.37	-99.97	-96.97	-99.88	-99.91	-99.96
Mean	**-97.68±0.40**	**-99.97±0.00**	**-96.86±0.13**	**-99.88±0.00**	**-99.90±0.01**	**-99.96±0.01**

Table 6: Monthly pollution load index (PLI) of heavy metals in Elechi Creek, Port Harcourt.

Month	Heavy metal					
	Cd	Cu	Fe	Zn	Pb	Cr
Jan	0.55	0.0095	1.51	0.077	0.082	0.049
Feb	0.60	0.0095	1.54	0.077	0.082	0.049
March	0.6	0.0094	1.54	0.077	0.080	0.043
April	0.60	4.21	0.79	0.0014	0.0013	0.00026
May	0.00055	4.17	0.84	0.0014	0.0013	0.00026
June	0.55	1.81	0.46	2.65	2.18	9.56
July	0.00055	1.82	0.46	2.74	2.18	9.56
August	0.5	1.85	0.47	2.74	2.25	9.13
September	0.05	8.25	0.23	5.24	3.85	7.23
October	0.56	8.32	0.23	5.77	3.87	7.23
Nov	0.00056	3.88	0.12	1.21	4.96	5.76
Dec	0.60	3.97	0.12	1.16	6.09	5.76
AVERAGE PLI	0.38±0.080	0.0023±0.0012	0.69±0.16	0.019±0.10	0.020±0.10	0.011±0.006

KEY: PLI - pollution load index

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Table 7: Monthly Ecological risk index (ERI) of heavy metals in Elechi creek, Port Harcourt.

Month	**Heavy metal**					
	Cd	Cu	Fe	Zn	Pb	Cr
Jan	100	16.66	15.19	0.11	0.49	0.049
Feb	109	18.16	15.43	0.11	0.49	0.049
March	108	18	15.43	0.11	0.48	0.043
April	109	18.16	15.45	0.013	0.048	0.0017
May	0.1	0.06	16.49	0.012	0.048	0.0010
June	363.33	60	16.50	0.012	0.049	0.0010
July	0.36	0.06	16.48	0.0014	0.0048	2.27
August	327	54	16.83	0.0014	0.0049	2.23
September	32.7	0.01	14.92	0.00148	0.0049	5.04
October	363.33	0.2	15.08	0.00018	0.00051	1.06
Nov	0.10	0.0002	15.12	0.00018	0.00038	1.06
Dec	118.81	0.21	15.12	0.00017	0.00047	8.71
Overall Mean	135.97±39.85	15.46±6.09	15.67±0.19	0.32±0.14	0.13±0.06	0.12±0.00
TRF	**30**	**5**	**5**	**1**	**5**	**1**

TRF – Toxic response factor

DISCUSSION

The contamination factors for Cu, Zn, Pb, and Cr were lower and inferior to <1 whereas Cd (<3) and Fe (<6) showed little high deviation. The present study conformed with previous studies by Otene and Alfred-Ockiya (2020) who reported highest mean value 0.075 mg/Kg contamination factor in Cd (cadmium) from Elele Stream, and highest mean value 3.2980 mg/Kg was recorded for Fe from Minichinda Stream Port Harcourt (Otene and Nnadi, 2020). The I-geo has been habitually employed to determine pollution status in the aquatic sediment. It typically features seven ranks ranging from unpolluted to very extremely polluted. Marcus and Edori (2016) reported the rank of unpolluted to moderately polluted river sediment in all studied heavy metals from Bomu and Oginigba Rivers, Port Harcourt. Chris and Anyanwu (2023), recorded rank of extremely polluted concentration for Cu, Cd, and Zn from the Bonny Estuary, Port Harcourt. Consequently, the ranking of moderately polluted sediment was recorded against Cd while Fe, Zn, Mn, Ni, Pb, Cr and Cd were noted for unpolluted rank Okorondu *et al.* (2021) in the Bight of Bonny Atlantic Coast, Port Harcourt, Nigeria.

The present study suggested that Cd proportion maintained the background value in Elechi Creek from January to December 2021. Perhaps the element has not received any anthropogenic influence to trigger its alteration while Zn, Pb, Cu, Fe and Cr revealed rank of pollution status in the creek between January and December 2021. This might be attributed to anthropogenic sources into the sediment of Elechi Creek from illegal artisanal oil vendors, oil industries, commercial ship, flying boats and badge transportation could be responsible for the release of these contaminants into the sediment. The study concurred with the report by Otene and Nnadi (2020) who documented that any location with higher I-geo rank could be traced to the influence of anthropogenic activities around the area. The enrichment factor (EF) in the study conformed to the rank of "no enrichment" as previous reported from the Great Kwa River and Minichinda Stream, Nigeria (Bassey and Ifedayo, 2014; Otene and Nnadi, 2020). The study disagrees with the report by Nowrouzi and Pourkhabbaz (2014) who documented high enrichment factor from the silt of Hara Eco-Reserve, Iran. The low enrichment could be attributed to lithogeny and the partitioning of these metals from the environment by aquatic macroinvertebrates.

Pollution load index (PLI) in the present study affirmed with the report by Andem *et al.* (2015) indicated that the sediment of Okporku River, Nigeria, does not incorporate any heavy metals. Also, supported by Aki and Isong (2019) who documented unpollution of heavy metals in the sediment along coastal area in Anantigha, Calabar, Nigeria. Thus, in the findings by (Okorondu *et al.* 2021), opined the rank of no pollution in the Bight of Bonny Atlantic Coast, Port Harcourt, Nigeria. The study differed from the updates by Islam *et al.* (2018) whose findings called attention to polluted sites and undergoing progressive deterioration in urban river in Bangladesh. Barakat *et al.* (2012) reported values ranging from 1.57 to 2.20, suggesting a specific degree of contamination exceeded the background values of the studied metals in the Day River, Morocco. However, the differences could be tied to the degree of human activities and input with regards to months, demand and production frame of oil related products. It could also be densities of aquatic life that might have sequestered these metals in the environment over time. The implication of this is that these heavy metals pose risk of contamination or pollution of the sediments and covering surface water. The assessment of PLI revealed that the sediment of the Elechi Creek is unpolluted by heavy metals even though there is high degree of contamination of Cu, Fe, Zn, Pb and Cr in some months.

The ERI in the study, corresponded with the current report by Otene and Nnadi (2020) in the sediment of Minichinda Stream, Port Harcourt, Nigeria and was classified low ecological risk. The finding was also consistent with the investigation by Gurumoorthi and Venkatachalapathy (2016), who reported a rank of moderate to applicable Environmental Risk Index 'ERI' in the coastal sediments of Kanyakumari, Southern India. Thus, additional evidence in favour of the low 'ERI' found in the sediments of the Lagos Lagoon in Southwest Nigeria and the Ohii Miri River in Abia State, Nigeria, by Jonah *et al.* (2014) and Ekaete *et al.* (2015). In the present study, the ERI showed values less than <160 and alluded to the rank appreciable according to Wan *et al.* (2016). However, the study showed variances of heavy metal concentrations compared to the value 0.088 mg/Kg reported in the sediment of Anantigha coastal marine area, Calabar, Nigeria (Aki and Isong, 2019). In the study area, boating activities, mechanic workshop, industrial discharge, illegal oil exploration vendors, commercial shipping transports were the major anthropogenic activities. This could be the reason for the elevation of these metals.

CONCLUSION AND RECOMMENDATION

The study showed that I-geo, EF, and ERI indices have a significant high toxic level of heavy metal pollution status in the sediment of Elechi Creek, Port Harcourt, Nigeria. Despite this status, there is possibility of increase or decrease in heavy metals loading in the sediment overtime if proper measures are put in place. For the purpose of protection of sediment-dwelling organisms, fish conservation, and preservation of other aquatic life, continuous monitoring of heavy metals in the sediment along the stretch of the creek should be checked from time to time.

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