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Determination of Heavy Metal Concentrations in Sediment of Bonny River, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author AB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors CPO and GOA managed the analyses of the study. Author AB managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Contamination of sediment by heavy metals is one of the global issues mostly in developing nations like Nigeria. Five heavy metal such Lead (Pb), Copper (Cu), Manganese (Mn), Zinc (Zn) and iron (Fe) in sediments from Bonny River in Rivers State were investigated. The increasing trend of metals was observed in sediments Cu < Pb < Zn < Fe < Mn. The mean concentration of the metals were 1.31, 3.95, 9.11, 15.07 and 31.54 mg/kg for Cu, Pb, Zn, Fe and Mn respectively. The concentration levels of all the heavy metals in sediment studied were lower than the safe values. The contamination factor calculated confirmed that the studied sediment were not polluted by these heavy metals. The Pollution load index (PLI) values were lower than one (< 1) in all the samples indicating good sediment quality. Geo-accumulation Index (Igeo) calculated was less than 0, likewise the enrichment factor values were less than 2 which implies deficiency to minimal enrichment. From the results obtained, the Bonny River sediments have low contamination level and are said to be unpolluted by all heavy metals. Therefore sediment from Bonny River is safe and can be used as a building material.

Keywords: Heavy metals; Bonny River; pollution; contamination factor; geo-accumulation.

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1. INTRODUCTION

Atomic absorption spectroscopy is a common technique used in many chemical measurements requiring a high degree of precision and accuracy, such as food and drug safety, clinical diagnostics and environmental sampling [1]. Atomic absorption spectrometers may be used to analyze the concentration of over 70 different elements in a given sample solution, making them a very valuable instrument in any laboratory.

Contamination of heavy metals in the aquatic environment has attracted global attention owing to its abundance, persistence and environmental toxicity [2,3]. Both natural and anthropogenic activities are responsible for the abundance of heavy metals in the environment [4,5]. However, anthropogenic activities can effortlessly generate heavy metals in sediment and water that pollute the aquatic environment [6]. The increasing pollution by heavy metals have a significant adverse health effects for invertebrates, fish and humans [7,8,9,10]. The metal pollution of aquatic ecosystems is increasing due to the effects from urbanization and industrialization [9,6,11]. Metal distribution in River sediments are mainly influenced by industrial wastes [12-14].

In the aquatic environment, sediments have been widely used as environmental indicators for the assessment of metal pollution in the natural water [15]. The principal comportment of metals is a function of the suspended sediment composition and water chemistry in the natural water body [16]. During transportation of heavy metals in the riverine system, it may undergo frequent changes due to dissolution, precipitation and sorption phenomena [1,14], which affect their performance and bioavailability [15]. Sediment is an essential and dynamic part of the river basin, with the variation of habitats and environments. The investigation of heavy metals in water and sediments could be used to assess the anthropogenic and industrial impacts and risks posed by waste discharges on the riverine ecosystems [7,17]. Therefore, it is important to measure the concentrations of heavy metals in water and sediments of any contaminated riverine ecosystem. Nowadays heavy metal pollution is a main problem in many developing countries like Bangladesh [18]. The unplanned urbanization and industrialization of Bangladesh have detrimental effects on the quality of water and sediment as well as other aquatic fauna.

The disposal of urban wastes, untreated effluents from various industries and agrochemicals in the open water bodies and rivers has reached alarming situation in Rivers state, which are continually increasing the metals level and deteriorating water quality [19,2,20]. In Rivers state, Bonny River is the largest and important river in the Port Harcourt City and sea port area. Because of the industrial activities in the area, the heavy metal pollution of the Bonny River is increasing day by day. The studied river receives huge amount of untreated effluents from industries such as Nigerian Liquefied Natural Gas, steel mills, oil refineries and others. To date, no scientific research regarding heavy metal pollution in water and sediment of the study river has been conducted so far. Therefore, the objectives of this study were to determine the levels of heavy metals in sediments and its associated health parameters.

2. MATERIALS AND METHODS

2.1 Study Area and Sampling

This study was conducted on the coastal communities around Bonny River which passes through Ocean terminal (Fig. 1 and Table 1). The samples were collected in May, 2017 at various sampling sites as presented in Table 1. Bonny River is one of the major and most important rivers in Rivers State. Bonny Island is approximately 40 km South of Port Harcourt in Rivers State of Nigeria and on the eastward side of the Cameroon Mountain. The Island lies on the E7^{o}10' N4^{o}27' with an estimated population of 270,000 [21] and plays host to multinational oil and gas companies such as Shell Petroleum Development Company (SPDC) Export terminal, Mobil Producing Unlimited, Chevron Nigeria Limited and Nigerian Liquefied Natural Gas Company (NLNG) . Other cottage industries exist but on a small scale. These include bakeries, block molding, tile manufacturing as well as gas and welding industries [22]. The region produces a type of crude oil as Bonny light oil. Much of the oil extracted on shore in Rivers State is piped to Bonny for export. The Island has a relatively flat topography on an elevation of 3.05 atmospheric mean sea level with a total land area of 214.52 m^2 [8] with about 70% of its size suffering from tidal flooding and land subsidence. The geology of the area comprises basically of alluvial sedimentary basin and basement complex. The sub strata of the island consist mainly of fine sands, down to about 10 m with occasional clay layers.

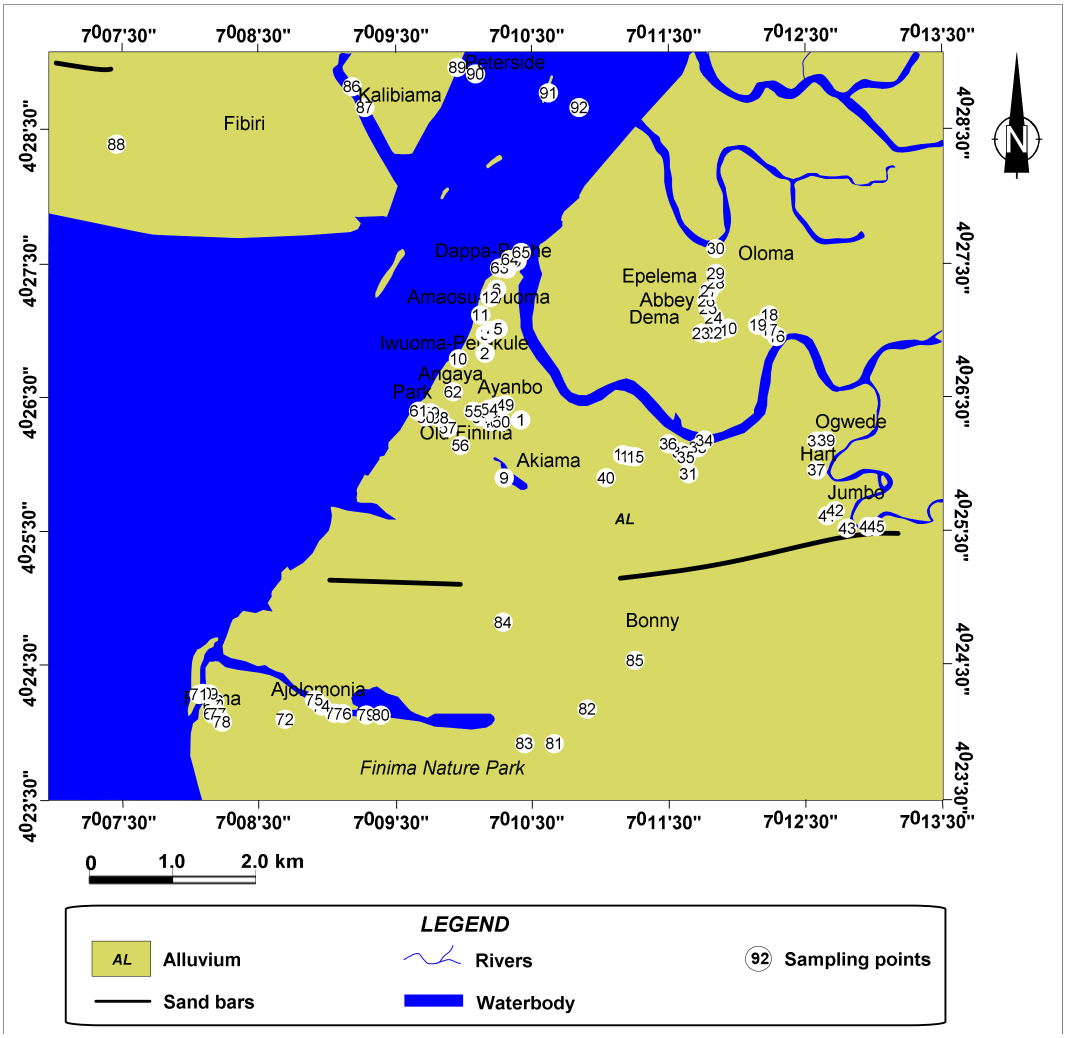

Fig. 1. Map of the study area

Economically, the main occupations of people of Bonny Island are farming, fishing and trading.

Farming takes place on the dry land ridges within the galloping swamp forest. Fishing is a very important economic activity at Bonny Island. It has been estimated that fish may account for as much as 80% of protein consumption in such coastal areas of Nigeria. The catches are partly retained for consumption and partly sold at markets [22].

Twenty sediment samples were collected in May 2017 and placed in black polyethylene bags and transported to the laboratory. Laboratory apparatus were soaked in nitric acid and washed with tap and distilled water to remove any traces of cleaning agent. They were then dried and kept in a clean place. Samples were air dried and after homogenization using pestle and mortar, they are passed through a 2 mm mesh screen and stored in polyethylene bags.

2.2 Chemical and Sample Digestion

About 2.0 g portion of dried sediment were digested in 15 cm^3 of tri- acid mixture (HNO_3, $HClo_4$ and H_2SO_4, as 5:1:1 ratio) at 80°C until the transparent solution appeared [22]. After cooling, the digested sample was filtered using Whatman No. 41 filter paper and the filtrate was finally maintained at 50 cm^3 distilled water. The clear solution was then poured into sample bottles for reading in the Atomic Absorption Spectrometer [9].

2.3 Quality Control Analysis

All the matrixes were analyzed for Pb, Zn, Cu, Mn and Fe by atomic absorption spectrophotometer. Chemicals were purchased from MERCK chemicals Germany and used for the samples preparation without further purification. Distilled water was used for the solution preparation and glassware was washed with 10% HNO_3. The standards were prepared for each metal from their stock solution to calibrate the instrument. Precision and accuracy of analysis were checked through repeated analysis against NIST standard reference material SRM 2709 for sediment [19,23].

2.4 Assessment of Heavy Metals in Sediment

Heavy metals (Fe, Pb, Zn, Mn, and Cu) concentration in the filtrate of the digested samples were determined using Unicam 939.959 Atomic Absorption Spectrophotometer (AAS). In the interpretation of geochemical data, choice of background values plays a significant contribution. Several researchers have used the average shale values or the average crustal abundance data as reference baselines [24,25, 12, and 2]. The degree of contamination from heavy metals could be evaluated by determining the contamination factor (CF), pollution load index (PLI), enrichment factor and geoaccumulation index (Igeo).

2.4.1 Pollution load index (PLI) and contamination factor (CF)

To evaluate the sediment quality, combined approaches of pollution load index of the four metals were calculated according to [2]. The PLI is defined as the nth root of the multiplications of the contamination factor of metals (CF).

PLI = $$PLI = (CF_1\ x\ CF_2\ x\ CF_3\ x - - - - - x\ CF_n)^{\frac{1}{n}} \quad (1)$$

Where CF is the contamination factor and n is the number of parameters.

Where CF metals is the ratio between the content of each metal to the background values (background value from the average shale value) in sediment...

This is the level of contamination of sediment by metals which is expressed in terms of a contamination factor (CF) calculated a [26]:

$$CF = \frac{C_m\text{Sample}}{C_m\text{Background}} \quad (2)$$

Where Cm sample is the concentration of a particular metal in sediment and Cm Background is the value of the world surface rock average.

Therefore, PLI value of zero indicates excellence, a value of one indicates the presence of only baseline level of pollutants and values above one indicate progressive deterioration of the site and estuarine quality [21]. The PLI gave an evaluation of the overall toxicity status of the sample and also it is a consequence of the contribution of the studied four metals. The ratio of the measured concentration to natural abundance of a given metal had been proposed as the contamination factor (CF) being classified into four grades for monitoring the pollution of one single metal over a period of time [15, 9]: low degree ($CF < 1$), moderate degree ($1 \leq CF < 3$), considerable degree ($3 \leq CF < 6$), and very high degree ($CF \geq 6$). Thus, the CF values can monitor the enrichment of one given metal in sediments over a period of time.

2.4.2 Geo-accumulation index (Igeo)

The degree of contamination from the heavy metals could be assessed by measuring the geo-accumulation index (Igeo). The index of geoaccumulation has been widely used to the assessment of sediment contamination [27, 28, and 22]. In order to characterize the level of pollution in the sediment, geo-accumulation index (Igeo) values were calculated using the equation, (2)

$$\text{Igeo} = \text{Log2}\left[\frac{C_n}{1.5\text{Bn}}\right] \quad (3)$$

Where Cn is the measured concentration of metal n in the sediment and Bn is the geochemical background value of element n in the background sample [29, 30, and 2]. The factor 1.5 is introduced to minimize the possible variations in the background values which may be qualified to lithogenic effects.

2.4.3 Enrichment factor (EF)

The enrichment factor (EF) is based on the standardization of the analyzed element against a reference element. The EF assesses the degree of contamination and points to possible anthropogenic impact in shore sediments. The element which has low occurrence variability was considered suitable for use as a reference element. This present study has used Fe as the reference element of normalization. The EF is defined by equation [14,15, and 31].

Table 1. Details of sampling locations of Bonny River

Site Code	Community
SEF 2	Fibiri
SEP 1	Peterside
SELH 1	Light House
SEPC 1	Park Community 1
SEPC 2	Park Community 2
SEAG	Agaya
SEO 1	Oloma
SEL 1	Hart/LongJohn
SEMB 1	Main Bonny Town
SEM 1	Minima
SEAB 1	Abalamabie
SEAK 1	Akiama
SEAJ 1	Ajolomonia
SEOG 1	Iwuoma
SEAY 1	Ayanbo 1
SEE 1	Epelema
SEK	Kalabiama
SEAD-P	Dappa-Poshe
SEAY 2	Ayanbo 2
SEFM 2	New Finima

$$EF = (C_M/C_{afe})_{sample} / (C_M/C_{Fe})_{earth's\ crust} \quad (4)$$

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 [18] where used for this investigation. Iron was selected as the reference value being 4.72 mg/kg as the reference element. The contamination criteria based on EF indicates that if EF < 2 (Deficiency to minimal enrichment), 2 ≤ EF < 5 (Moderate enrichment), 5 ≤ EF < 20 (Significant enrichment), 20 ≤ EF < 40 (Very high enrichment), EF ≥ 40 (Extremely high enrichment).

3. RESULTS AND DISCUSSION

The concentration of heavy metals (Zn, Pb, Cu, Mn and Fe) in sediment samples are presented in Table 2 while Table 3 represent the comparison of heavy metals concentration studied with results of other works. The contamination factor (CF), geo-accumulation indices (Igeo), Enrichment factor (EF) and pollution load index (PLI) calculated in each of the heavy metals are presented in Table 4, 5 and 6 respectively.

Table 2. Concentration of heavy metal in the sediments samples of Bonny River

S/N	Sample	Zn mg/kg	Pb mg/kg	Cu mg/kg	Mn mg/kg	Fe mg/kg
1	SEF 2	8.61	3.45	1.011	20.77	8.88
2	SEP 1	8.33	3.22	0.998	20.63	8.60
3	SELH 1	8.41	3.25	1.000	20.70	8.81
4	SEPC 1	8.44	3.41	1.021	20.76	8.86
5	SEPC 2	8.28	3.17	0.900	19.99	7.55
6	SEAG	8.20	3.09	0.891	17.86	7.50
7	SEO 1	7.56	2.22	0.861	17.69	7.53
8	SEL 1	7.59	2.41	1.861	17.55	7.29
9	SEMB 1	9.11	5.11	1.589	28.72	18.44
10	SEM 1	9.27	5.20	1.669	32.22	18.68
11	SEAB 1	10.61	4.88	1.501	45.05	22.88
12	SEAK 1	10.89	5.05	1.560	44.63	20.46
13	SEAJ 1	10.33	5.15	1.643	43.91	21.53
14	SEOG 1	9.68	4.93	1.489	40.88	19.43
15	SEAY 1	9.56	4.42	1.402	40.48	19.20
16	SEE 1	9.01	3.77	1.281	30.41	18.51
17	SEK	9.44	4.05	1.338	35.49	18.91
18	SEAD-P	9.29	3.59	1.243	35.21	18.89
19	SEAY 2	9.50	3.61	1.300	35.63	19.11
20	SEFM 2	10.17	4.98	1.630	44.30	20.33
	TOTAL	**182.28**	**78.96**	**26.188**	**630.82**	**301.39**
	AVERAGE	**9.11±0.94**	**3.95±0.95**	**1.31±0.31**	**31.54±9.97**	**15.07±5.93**

Table 3. Comparison of the heavy metal concentration in Bonny Sediment with results of other works

River/Date of Sampling/Location	Zn	Pb	Cu	Mn	Fe	Reference
This Study	**9.11**	**3.95**	**1.31**	**31.54**	**15.07**	
Ase River	12.46	-	3.32	24.72	110.52	[21]
Abonnema Shoreline	1.0535 - 7.0965	0.0075 - 0.0520	0.1332 - 0.6229	-	-	[32]
Asejire Lake	-	0.0740	-	-	2.392	[23]
Ibeno Coastal	0.05	0.05	-	9.67	22.18	[33]
Calabar River	115.58	16.58	21.13	-	6.00	[34]
Oil Exploration Zone of Nigeria	-	0.045	-	-	-	[34]
Euphrates River, Iraq	48.00	22.56	18.91	228.18	2249.47	[30]
World Average	303	230.75	122.9	975.3	57405.9	[35]

Table 4. Contamination Factor (CF) and Pollution Load Index (PLI) for metals of Bonny River sediments

Location	Zn	Pb	Cu	Mn	Fe	PLI
SEF 2	0.068	0.22	0.031	0.028	< 0.01	0.020
SEP 1	0.066	0.20	0.031	0.028	< 0.01	0.019
SELH 1	0.066	0.20	0.031	0.028	< 0.01	0.019
SEPC 1	0.066	0.21	0.032	0.028	< 0.01	0.020
SEPC 2	0.065	0.20	0.028	0.027	< 0.01	0.018
SEAG	0.065	0.19	0.027	0.024	< 0.01	0.018
SEO 1	0.060	0.12	0.027	0.024	< 0.01	0.016
SEL 1	0.060	0.15	0.058	0.023	< 0.01	0.019
SEMB 1	0.072	0.32	0.050	0.038	< 0.01	0.030
SEM 1	0.073	0.33	0.052	0.043	< 0.01	0.031
SEAB 1	0.084	0.31	0.047	0.060	< 0.01	0.034
SEAK 1	0.086	0.32	0.049	0.060	< 0.01	0.034
SEAJ 1	0.081	0.32	0.051	0.059	< 0.01	0.034
SEOG 1	0.076	0.31	0.047	0.055	< 0.01	0.032
SEAY 1	0.075	0.28	0.044	0.054	< 0.01	0.031
SEE 1	0.071	0.24	0.040	0.041	< 0.01	0.027
SEK	0.074	0.25	0.042	0.047	< 0.01	0.029
SEAD-P	0.073	0.22	0.039	0.047	< 0.01	0.020
SEAY 2	0.075	0.23	0.040	0.048	< 0.01	0.019
SEFM 2	0.080	0.31	0.052	0.059	< 0.01	0.019

3.1 Metal Concentration in Sediment

The mean concentrations (mg/kg) of heavy metals (Cu, Pb, Zn, Fe and Mn) in sediments are presented in Table 2. It is clear from the Table that concentrations of heavy metals at sites SEAB1 –SEAJ1 were much higher than others sites because of the fact that these sites are located at the sea port area of the river and extensive discharging of untreated effluents from the port and NLNG. Metals concentrations in sediment were higher in dry season than rainy season due to the lower water flow during dry season which could lead to accumulation of the heavy metals in sediment [10] but this study was conducted during the rainy season which might have accounted for low values recorded. The average concentration of heavy metals in sediments were in the increasing order of: Cu < Pb < Zn < Fe < Mn. Manganese (Mn) concentration in sediment was higher than other metals as a consequence of direct discharging untreated wastes from petroleum, fertilizers and liquefied gas products [2]. However, high level of Mn for site SEAK1 and SEAB J (45.05 and 44.6 mg/kg) indicates its higher input, which might be originated from the urban and industrial wastes [16].

The concentration of Copper (Cu) in sediment ranged between 0.861 to 1.861 mg/kg with an average value of 1.31±0.31 mg/kg. When compared with the world surface rock average (32 mg/kg) and mean shale concentration (11 mg/kg), it was found to be lesser than the values. In comparison with WHO (25 mg/kg) [36], USEPA (16 mg/kg) [37] and CCME (35.7 mg/kg), Cu mean value did not exceed the limit. In comparison with previous studies, Cu concentration is greater Abonnement shoreline (0.133 – 0.623 mg/kg) but lesser than Calabar River (21.13 mg/kg), Euphrate River (18.91 mg/kg) and World average (122.9 mg/kg). The contamination factor (CF) values of Cu ranged from 0.027 to 0.058. These values for Cu are lesser than 1 in all sampling sites, this suggest that these sites are low in contamination. The Igeo values of Cu ranged from -10.60 to -9.69 which is less than 0. This suggest that sediment quality of Bonny River is unpolluted in all sampling sites by Cu.

The concentration of Lead (Pb) varies from 2.22 to 5.15 mg/kg with an average value of 3.95±0.95 mg/kg. When compared with the world surface rock average (16 mg/kg) and mean shale concentration (20 mg/kg), it was found to be lesser than the values. In comparison with USEPA (40 mg/kg) and CCME (35 mg/kg), Pb mean value did not exceed the limit. In comparison with previous studies, Pb concentration is greater in Abonnema (0.0075-0.0520), Asejire Lake (0.0740 mg/kg), Ibeno coastal (0.05 mg/kg) and Oil exploration zone (0.045 mg/kg) but lesser than Calabar River (16.58 mg/kg), Euphrate (22.56 mg/kg) and World Average (230.75 mg/kg). The contamination factor (CF) values of Pb ranged from 0.12 to 0.33. These values for Pb are lesser than 1 in all sampling sites, this suggest that these sites are low in contamination. The Igeo values of Pb ranged from -6.91 to -6.18 which is less than 0. This suggest that sediment quality of Bonny River is unpolluted in all sampling sites by Pb.

The concentration of Zinc (Zn) varies from 7.56 to 10.89 mg/kg with a mean value of 9.11±0.94 mg/kg. When compared with the world surface rock average (127 mg/kg), mean shale concentration (95 mg/kg), the value did not exceed the limits. In comparison with WHO (123 mg/kg), USEPA (110 mg/kg) and CCME (123 mg/kg), Zn mean value was found to be lesser than these values. In comparison with previous studies, Zn concentration was greater than Abonnema (1.0535 – 7.0965 mg/kg) and Ibeno (0.05 mg/kg) but lesser than Ase River 12.46(mg/kg), Calabar River (115.58 mg/kg), Euphrate River (48.00 mg/kg) and world average (303 mg/kg). The CF values of Zn ranged from 0.060 – 0.086. These values for Zn where lesser than 1 in all sampling sites, this suggest that these sites are low in contamination. The Igeo values of Zn ranged from -11.63 to -11.11 which is less than 0. This suggest that sediment quality of Bonny River is unpolluted in all sample sites by Zn.

Table 5. Geo- accumulation indices (Igeo) of heavy metal in Bonny River sediments

Location	Zn	Pb	Cu	Mn	Fe	I_{tot}
SEF 2	-11.45	-6.77	-10.60	-15.29	-27.70	-71.81
SEP 1	-11.50	-6.91	-10.60	-15.29	-27.74	-72.01
SELH 1	-11.50	-6.91	-10.60	-15.29	-27.71	-72.01
SEPC 1	-11.50	-63.84	-10.55	-15.29	-27.70	-71.88
SEPC 2	-11.52	-6.91	-10.74	-15.35	-27.93	-72.45
SEAG	-11.52	-6.98	-10.80	-15.52	-27.94	-72.76
SEO 1	-11.63	-7.64	-10.80	-15.52	-27.93	-58.24
SEL 1	-11.63	-7.32	-9.69	-15.58	-27.98	-72.20
SEMB 1	-11.37	-6.23	-9.91	-14.85	-26.64	-69.00
SEM 1	-11.35	-6.18	-9.85	-14.68	-26.63	-68.69
SEAB 1	-11.15	-6.27	-10.00	-14.19	-26.33	-67.94
SEAK 1	-11.11	-6.23	-9.94	-14.19	-26.49	-67.90
SEAJ 1	-11.20	-6.23	-9.88	-14.22	-26.42	-67.95
SEOG 1	-11.29	-6.27	-10.00	-14.32	-26.57	-68.45
SEAY 1	-11.31	-6.42	-10.09	-14.35	-26.58	-69.75
SEE 1	-11.39	-6.64	-10.23	-14.74	-26.64	-69.64
SEK	-11.33	-6.58	-10.16	-14.55	-26.61	-69.23
SEAD-P	-11.35	-6.77	-10.27	-14.55	-26.61	-69.55
SEAY 2	-11.31	-6.71	-10.23	-14.52	-26.59	-69.36
SEFM 2	-11.22	-6.27	-9.85	-14.22	-26.50	-68.06

Table 6. Enrichment Factor (EF) for heavy metals in Bonny River sediments

Sample	Zn EF	Pb EF	Cu EF	Mn EF
SEF 2	0.048	0.092	0.012	0.013
SEP 1	0.048	0.088	0.012	0.013
SELH 1	0.047	0.087	0.012	0.013
SEPC 1	0.047	0.091	0.012	0.013
SEPC 2	0.054	0.099	0.013	0.015
SEAG	0.054	0.097	0.012	0.013
SEO 1	0.050	0.070	0.012	0.013
SEL 1	0.052	0.078	0.012	0.013
SEMB 1	0.025	0.065	0.009	0.009
SEM 1	0.025	0.066	0.009	0.010
SEAB 1	0.023	0.050	0.007	0.011
SEAK 1	0.026	0.058	0.008	0.012
SEAJ 1	0.024	0.056	0.008	0.011
SEOG 1	0.025	0.060	0.008	0.012
SEAY 1	0.025	0.054	0.008	0.012
SEE 1	0.024	0.048	0.007	0.009
SEK	0.025	0.051	0.007	0.010
SEAD-P	0.024	0.045	0.007	0.010
SEAY 2	0.025	0.045	0.007	0.010
SEFM 2	0.025	0.058	0.009	0.012

The concentration of Iron (Fe) varies from 7.29 to 22.88 mg/kg with an average value of 15.07±5.92 mg/kg. When compared with the world surface rock average (35900 mg/kg) and mean shale concentration (46700), it was found to be lesser than the values. In comparison with USEPA (30 mg/kg), Fe mean value did not exceed the limit. In comparison with previous studies, Fe concentration is greater Asejire Lake (2.392 mg/kg) and Calabar River 6.00 mg/kg) but lesser than Ase River (2.392 mg/kg), Ibeno coastal (22.18 mg/kg), Euphrate River (2249.47 mg/kg) and World average (57405.9 mg/kg). The CF values of Fe are < 0.01 in all sampling sites, this suggest that these sites are low in contamination. The Igeo values of Fe ranged from -27.98 to -26.33 which is less than 0. This suggest that sediment quality of Bonny River is unpolluted in all sampling sites by Fe.

The concentration of Maganese (Mn) varies from 17.55 to 45.05 mg/kg with an average value of 31.54±9.97 mg/kg. When compared with the world surface rock average (750 mg/kg) and mean shale concentration (850 mg/kg), it was found to be lesser than the values. In comparison with USEPA (30 mg/kg), Mn mean value is a little greater with 0.64 mg/kg which shows that Bonny River is not polluted by Mn. In comparison with previous studies, Mn concentration is greater than Ase River (24.72 mg/kg) and Ibeno coastal (9.67 mg/kg) but lesser than Euphrate River (228.18 mg/kg) and World average (975.3 mg/kg). The CF values of Mn ranged from 0.023 to 0.060. These values for Mn are lesser than 1 in all sampling sites (Table 4), this suggest that these sites are low in contamination. The Igeo values of Mn as shown in Table 5, ranged from -15.58 to -14.19 which is less than 0. This suggest that sediment quality of Bonny River is unpolluted in all sampling sites by Mn.

3.2 Assessment of Metal Pollution

The calculated pollution load index (PLI) values of metals in sediments are summarized in Table 6. The PLI values were ranged from 0.016 to 0.034 confirming that the sediment of the studied river was not contaminated (PLI < 1). The PLI can provide some understanding to the populations about the quality of the sediment. In addition, it also delivers essential information to the decision makers on the pollution status of the study area [38]. The Enrichment Factors of the trace metals in the Bonny River sediments at the 20 locations (Table 6) revealed that they were poorly enriched in all metals. The EF's varied in the ranged 0.045 – 0.099 for Pb, 0.025 – 0.05` for Zn, 0.009 – 0.013 for Cu and 0.009 – 0.015 for Mn. In general, the highest enrichment factor for all trace metals in the sediment samples were recorded at location SEPC 2. This could be due to the type of effluents that enters the region from the industrial sites.

4. CONCLUSIONS

Heavy metals (Zn, Cu, Mn, Pb and Fe) from the twenty selected locations of Bonny River were measured using AAS. The mean concentration values of all the heavy metals were below the world surface rock average, mean shale concentration, sediment quality guideline respectively. Heavy metal pollution is a major problem for the Riverine areas but was not the case for the study area in this work. In the present study concentrations of all the heavy metals were lower than the safe values which indicated that the Bonny River is not polluted by studied heavy metals. The overall pollution load was remarkably low. The contamination factor (CF), pollution load index (PLI) and geo-accumulation index (Igeo) calculated show that sediments were unpolluted by heavy metals.

This implies that it is safe to use sediments from Bonny river as building materials.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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