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Selected Physicochemical Evaluation of Sediments from a Mangrove Swamp in Warri, Southern Nigeria

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Abstract

Sediments were sourced once monthly within the months, February 2013 to July 2014, from several points on the Falcorp mangrove swamp, Ijala, Warri. The sediments were subjected to selected physicochemical analysis such as; total organic carbon, were conducted in accordance with standard procedures. Several indices which included; pollution load index (PLI) and potential ecological risk index (PERI) were utilized in the ecological risk assessment of the sediment associated heavy metals. Several statistical and multivariate analysis such as; Microsoft excel, SPSS version 16.0 and PAST were utilized in evaluation of the results. There was no significant difference (P>0.05) for TOC, Fe, Cr and Total nitrogen across the study stations. The observed differences between the total phosphorus, Cu, Pb, Zn and Cd across the smapled stations was significantly different (P<0.05). A positive correlation existed between TOC, Fe, Zn, Cu, Cd, Pb and Cr, whilst between total nitrogen and total phosphorus, a negative relationship was observed. The CF values for Zn, Cu, Cd, Pb and Cr fluctuated across the stations and were far lesser than 1. The potential ecological risk arising from the heavy metal profiles of the sediments was very minimal or non-existent.

1. Introduction

Statistically, it has been documented that the bottom sediment is known to harbour more than 99% of heavy metals present in the aquatic system [1]. Aquatic sediments have been described as critical repositories, sinks, and carriers for trace metals [2] [3]. Amongst sediment linked pollutants, trace metals are known to possess the potential to cause direct negative effects on sediment-dwelling organisms and at higher trophic levels, these metal tainted bottom dwellers can indirectly adversely affect man and other animals.

Pollution index has been described as an analytical tool for evaluating, analyzing, and transmitting of raw environmental data to decision makers, managers, technicians, and the general public [4]. The index can also be utilized for the assessment and quantification of the magnitude of sediment linked heavy metal pollution/deposition [4]. Pollution indices can either be utilized as either a single or integrated factor. Single index factors include Enrichment factor, Contamination factor, Geoaccumulation index and Ecological Risk Factors while integrated factors include; Pollution load index, Potential Ecological Risk index and Nemerow Pollution Index [5]. For sediment studies, enrichment factor value can be indicative of the potential of the examined sediments to exhibit toxic effects to biota under favourable conditions as the actual metal toxicity to biota is reliant on the physical, chemical and biological conditions under which organisms get in contact with metal polluted sediments [6]. Pollution Load Index (PLI) has been described as an integrated tool for the determination and comparison of the extent of pollution on different sites/at the same site on temporal scale [4]. It is usually derived as concentration factor (CF) which is the quotient obtained by the division of the respective metal concentration whilst Ecological Risk factor (ER) and Potential Ecological Risk Index are utilized for the evaluation of trace metal pollution and related ecological and environmental effect with the toxic response factor [4]. All these indices can be used together to evaluate the magnitude of environmental contamination.

The Falcorp mangrove swamp water channel has an interphase with other nearby water bodies. The swamp has/is been impacted directly by several anthropogenic activities which include farming, fishing activities and most importantly illegal oil bunkering /pipeline vandalization which poses a great danger to the environmental integrity of both the aquatic flora and fauna inhabiting the water and those depending on it for survival.

This study investigates selected physicochemical parameters and the derived ecological risk assessment of the respective trace metal content associated with aquatic sediments collected from Falcorp fresh water mangrove, Delta State.

2. Methodology

2.1. Description of Study Area and Sampling Stations

Falcorp mangrove swamp is sited in Warri South Local Government Area, Delta State, Southern Nigeria. It is located off the Warri refinery and petrochemical company jetty road, just behind the refinery. It falls within the mangrove swamp ecological zone but also has a direct interphase with the rainforest ecological zone. It lies on longitude (005^0 41.1E, 005^0 57.4E) and latitudes ($05^0$18.3N, $05^0$84.5N). The water channel within the mangrove swamp is fed by water from surrounding creeks, rivers and surface runoffs from neighboring communities within the Ijala area.

Five stations were designated for this study. Each of this station was approximately 600 meters apart from each other. Station 1(Longitude 005°42.213'E and Latitude 05°18.506' N), Station 2 (Longitude 005°41.4'E and Latitude 05°18.61' N), and Station 3 (Longitude 005°42.65° E and Latitude 05°.33.50°N) where located within the protected area of the Falcorp mangrove along the water channel, while Station 4 (Longitude 005°55.27'E and Latitude 05°66.202' N) and Station 5 (Longitude 005°48.94'E and Latitude 05°69.715' N) were located in Ifie creek which is linked to the water channel of the Falcorp mangrove. Sediments were collected from the five sampling points, once a month in the course of an eighteen (18) month period; February 2013- July 2014, with the aid of grab dipped into the water using a rope.

2.2. Physicochemical Analysis of the Respective Sediments

The sediments were subjected to air drying to remove moisture and air dried sediments were then grounded into very fine millimetre sized particles with the aid of a porcelain mortar to achieve homogenous samples. Macro nutritional parameters which included; Total organic carbon, total nitrogen and phosphorus of the dried sediments were evaluated according to procedures detailed by Radojevic and Bashkin [7]. In determining the trace metal content of the respective sediments, the respective samples were subjected to perchloric-Nitric acid-Sulphuric digestion with the aid of aluminium block digester 110pH. The resultant filterate was subjected to atomic absorbance spectrophotometery using Solaar 969 Unicam Series Atomic Absorption Spectrometer (AAS) in order to ascertain the respective trace metal; Iron, Zinc, Copper, Chromium, Cadmium and Lead of the sediment filtrate.

2.3. Determination of the Trace Metal Pollution Indices

The Degree of Contamination (DC), Contamination factor (CF), Pollution load index (PLI) were evaluated using a formula described by [8] and [9]. The Geo accumulation index (*Igeo*) was derived for the respective metals using formula as provided by [10] and [11]. The potential ecological risk index (PERI) for the trace metals was derived with the aid of a formula provided by [12].

2.4. Statistical Analysis

Statistical analysis was carried out on the data generated from each sampling station using general descriptive statistics. The student T – test and Kruskel Wallis Test was also used to test for significance at the 0.05 level of probability for the seasons and across the respective sampling stations. Multivariate analysis of the available data was done using the Statistical tool Pack for the Social Scientist (SPSS 16.0) and Duncan's Multiple Range test (DMR) was utilized to locate any significant difference(s) at 95% confidence Interval where one exist.

3. Results and Discussion

Table 1: Summary results of physicochemical analysis of the aquatic sediments

Parameter	Station 1	Station 2	Station 3	Station 4	Station 5	P-value	Significant-Level
	$\bar{X}$±S.E	$\bar{X}$±S.E	$\bar{X}$±S.E	$\bar{X}$±S.E	$\bar{X}$±S.E		
Total Organic Carbon (%) (Min-Max)	1.35±0.19^a (0.14-2.39)	1.33±0.18^a (0.08-2.13)	1.13±0.13^a (0.10-1.97)	1.09±0.13^a (0.08-1.94)	1.46±0.15^a (0.07-2.56)	0.414	*P>0.05*
Total Nitrogen (%) (Min-Max)	0.06±0.01^a (0.01-0.09)	0.06±0.01^a (0.01-0.12)	0.05±0.01^a (0.02-0.08)	0.06±0.01^a (0.02-0.10)	0.07±0.01^a (0.04-0.14)	0.421	*P>0.05*
Total Phosphorus (%) (Min-Max)	0.024±0.003^b (0.01-0.05)	0.03±0.01^b (0.01-0.07)	0.03±0.01^b (0.01-0.09)	0.032±0.004^b (0.01-0.07)	0.05±0.01^a (0.01-0.10)	0.003	*P<0.01***
Iron (µg/g, dried wt) (Min-Max)	426.99±26.05^a (222.40-617.89)	425.86±19.35^a (279.81-512.47)	399.11±30.16^a (184.41-609.28)	398.81±12.80^a (298.10-518.67)	454.19±18.34^a (293.11-611.82)	0.370	*P>0.05*
Zinc (µg/g, dried wt) (Min-Max)	27.64±2.09^a (14.52-47.29)	23.54±1.82^b (10.19-32.12)	23.09±1.76^b (12.25-35.10)	19.11±1.53^c (8.19-30.18)	24.04±1.54^b (12.13-35.33)	0.024	*P<0.05**
Copper (µg/g, dried wt) (Min-Max)	1.25±0.27^a (0.02-3.33)	0.61±0.10^b (0.01-1.18)	0.55±0.09^b (0.02-1.21)	0.71±0.16^b (0.02-2.19)	1.21±0.15^a (0.05-2.08)	0.004	*P<0.01***
Cadmium (µg/g, dried wt) (Min-Max)	0.01±0.003^a (0.001-0.02)	0.01±0.002^b (0.001-0.02)	0.01±0.001^b (0.001-0.02)	0.01±0.002^c (0.001-0.03)	0.004±0.001^c (0.001-0.02)	0.029	*P<0.05**
Lead (µg/g, dried wt) (Min-Max)	0.05±0.01^b (0.001-0.14)	0.06±0.02^a (0.001-0.17)	0.02±0.01^c (0.001-0.08)	0.02±0.01^c (0.001-0.09)	0.02±0.01^c (0.001-0.09)	0.008	*P<0.01***
Chromium (µg/g, dried wt) (Min-Max)	0.012±0.01^a (0.001-0.05)	0.01±0.002^a (0.001-0.02)	0.02±0.004^a (0.001-0.04)	0.02±0.003^a (0.001-0.04)	0.02±0.004^a (0.001-0.05)	0.480	*P>0.05*

Note: All similar alphabets with superscript in the same row indicated that the means were insignificantly different, *P>0.05* -There is no significant difference, *P<0.01*-There is highly significant difference**, *P<0.001*- There is very highly significant difference***, *P<0.05*- There is significant difference*

Table 2: Summary results of the physicochemical values of the sediments

Parameter	Dry season	Wet season	P-value	Significance Level
	$\bar{X}$±S.E	$\bar{X}$±S.E		
Total Organic Carbon (%)	1.76±0.06	0.96±0.06	0.000	*P<0.001**
Total Nitrogen (%)	0.06±0.01	0.06±0.004	0.813	*P>0.05*
Total Phosphorus (%)	0.03±0.003	0.04±0.003	0.196	*P>0.05*
Iron (µg/g, dried wt)	474.81±13.38	386.75±11.79	0.000	*P<0.001**
Zinc (µg/g, dried wt)	26.84±1.39	21.34±0.91	0.001	*P<0.001**
Copper (µg/g, dried wt)	1.26±0.14	45.84±31.69	0.266	*P>0.05*
Cadmium (µg/g, dried wt)	0.01±0.002	0.004±0.001	0.000	*P<0.001**
Lead (µg/g, dried wt)	0.06±0.01	0.014±0.005	0.000	*P<0.001**
Chromium (µg/g, dried wt)	0.02±0.002	0.009±0.002	0.000	*P<0.001**

Note: *P<0.001* - indicated very highly significant difference* *P>0.05* - indicated no significant difference

Table 3: Eigenvectors and Eigenvalues of the different physicochemical components

Parameters	**PC 1**	**PC 2**	**PC 3**	**PC 4**	**PC 5**	**PC 6**	**PC 7**	**PC 8**	**PC 9**
Total Organic Carbon	0.00	0.03	**0.73**	-0.68	-0.02	-0.01	0.00	-0.01	0.00
Total Nitrogen	0.00	0.00	0.00	0.01	-0.51	**0.71**	-0.48	-0.06	-0.03
Total Phosphorus	0.00	0.00	0.00	0.00	-0.22	**0.43**	**0.84**	0.22	0.08
Iron	**1.00**	-0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zinc	0.06	**1.00**	-0.06	-0.02	0.00	0.00	0.00	0.00	0.00
Copper	0.01	0.05	**0.68**	**0.73**	0.00	-0.01	0.01	-0.01	0.00
Cadmium	0.00	0.00	0.00	0.00	0.08	0.04	-0.10	0.06	**0.99**
Lead	0.00	0.00	0.02	-0.01	**0.82**	**0.56**	-0.05	-0.05	-0.09
Chromium	0.00	0.00	0.01	0.00	0.06	-0.03	-0.22	**0.97**	-0.08
Eigenvalue	**8926.39**	**33.37**	**0.38**	**0.13**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
% variance	**99.62**	**0.37**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

NB: Bolded values exceeded standards. Loadings > 0.71 are typically regarded as excellent, and loadings < 0.32 very poor [13]. However, the component with the maximal Eigenvalue is taken to be the most significant and should be one or greater for proper considerations during PCA [14]. Factor loadings values of > 0.75, between 0.75–0.5 and 0.5–0.3 are classified as strong, moderate and weak respectively, based on their absolute values.

Table 4: Euclidean similarity and distance indices of the five sediment stations

Stations	1	2	3	4	5
1	0.00				
2	**3.80**	0.00			
3	28.27	26.77	0.00		
4	29.46	27.50	**3.99**	0.00	
5	**27.44**	**28.35**	**55.10**	55.61	0.00

Ward-Euclidean: 0 and < 1; complete dissimilarity, ≥ 1; complete similarity, critical level of significance (C) = 0.05. The bolded values indicated similarity.

The result of the physcochemical evaluation of the sediment samples is shown in Table 1 and 2. The Total Organic Carbon (%), Total Nitrogen (%), Iron (µg/g, dried wt), and Chromium (µg/g, dried wt) were compared across the five stations repectively. The physicochemical results revealed that there was no significant difference ($P>0.05$) for TOC, Fe, Cr and Total nitrogen across the study stations. The observed differences between the Total Phosphorus (%), Cu (µg/g, dried wt), Pb (µg/g, dried wt) Zn (µg/g, dried wt) and Cd (µg/g, dried wt) across the sampled stations was significantly different ($P<0.05$). The total organic carbon (TOC) values were significantly higher during dry season ($p<0.001$) but there was no significant difference ($p>0.5$) across the five stations. The increment in organic matter content of the examined sediments may be due to the fine nature of sediments, putrefaction of mangrove vegetation and other vegetative remains and high rate of sedimentation during the dry season. The documented sediment borne TOC values were higher than values reported by [15] and [16] for the Ethiope-Benin River and Benin River respectively, but in agreement with values from selected major rivers in south-western Nigeria as reported by [17]. Substantial organic carbon values at threshold below 0.05% and above 3% have been associated with reduced abundance of benthic fauna and flora [16].

The results for the seasonal variation for the physicochemical parameters for sediments was shown in Table 2. The Total Organic Carbon (%), Iron (µg/g, dried wt), Zinc (µg/g, dried wt), Cadmium(µg/g, dried wt), Lead (µg/g, dried wt) and Chromium (µg/g, dried wt), were compared between dry season and wet season repectively. The results showed that there was a significant difference ($P<0.005$) across the study stations for TOC, Fe, Pb, Zn, . The observed differences between seasonal Total Nitrogen (%), Total Phosphorus (%) and Copper (µg/g, dried wt) values was statistically insignificant ($P>0.05$). The metal content of the aquatic sediments is comparable with concentrations of metals found in other tropical wetlands exposed to various levels of industrial pollution. Iron had the maximal mean value followed by Zinc, Copper, Lead, Chromium and Cadmium; Fe > Zn > Cu > Cr > Pb > Cd. The sediment borne Fe and Zn values can be regarded as not posing a serious threat to the overall mangrove ecosystem. Across the sampled stations, the observed differences in the mean Zn, Cu, Cd and Pb values were significantly different ($P<0.05$, $P<0.01$) whilst for Fe and Cr mean values, the differences were statistically insignificant ($P>0.05$).

Table 5: Contamination factors, Degree of contamination and Pollution load index for the heavy metal values of the mangrove sediments

n (5)	**Contamination Factors (CF) of a single metal**					**DC**	**Degree of Contamination (DC)**	**Pollution Load Index (PLI)**	
	Zn	Cu	Cd	Pb	Cr		Interpretation	PLI	Interpretation
Station 1	0.22	0.04	0.06	0.00	0.00	0.3		0.00	No pollution
Station 2	0.19	0.02	0.05	0.00	0.00	0.3		0.00	No pollution
Station 3	0.18	0.02	0.03	0.00	0.00	0.2	Very low degree of contamination	0.00	No pollution
Station 4	0.15	0.02	0.02	0.00	0.00	0.2		0.00	No pollution
Station 5	0.19	0.04	0.02	0.00	0.00	0.2		0.00	
Mean	**0.19**	**0.03**	**0.04**	**0.00**	**0.00**	**0.3**			
CF interpretation	Low contamination factor								

Table 6: Geo-accumulation index for the heavy metal values of the mangrove sediments

Stations	**Index of Geo-accumulation**					**Geo accumulation index classification**				
	Zn	**Cu**	**Cd**	**Pb**	**Cr**	**Elements**	**Mean I-Geo**	**Rank**	**Class**	**Results**
1	0.04	0.01	0.01	0.00	0.00	Zn	0.04	< 1	0	Not polluted
2	0.04	0.00	0.01	0.00	0.00	Cu	0.01	< 1	0	Not polluted
3	0.04	0.00	0.01	0.00	0.00	Cd	0.01	< 1	0	Not polluted
4	0.03	0.00	0.00	0.00	0.00	Pb	0.00	< 1	0	Not polluted
5	0.04	0.01	0.00	0.00	0.00	Cr	0.00	< 1	0	Not polluted
Average	**0.04**	**0.01**	**0.01**	**0.00**	**0.00**		0.04	< 1	0	Not polluted

Table 7: Potential Ecological Risk Index (PERI) of the sediments

Stations	**Zn**	**Cu**	**Cd**	**Pb**	**Cr**	**RI**	**Risk level**	**Interpretation**
1	0.22	0.19	1.71	0.01	0.00	2.14	A	Slightly polluted
2	0.19	0.10	1.41	0.02	0.00	1.71	A	Slightly polluted
3	0.18	0.09	0.91	0.01	0.00	1.18	A	Slightly polluted
4	0.15	0.11	0.69	0.01	0.00	0.96	A	Slightly polluted
5	0.19	0.19	0.64	0.01	0.00	1.03	A	Slightly polluted
Average	**0.19**	**0.14**	**1.07**	**0.01**	**0.00**	**1.40**	A	Slightly polluted

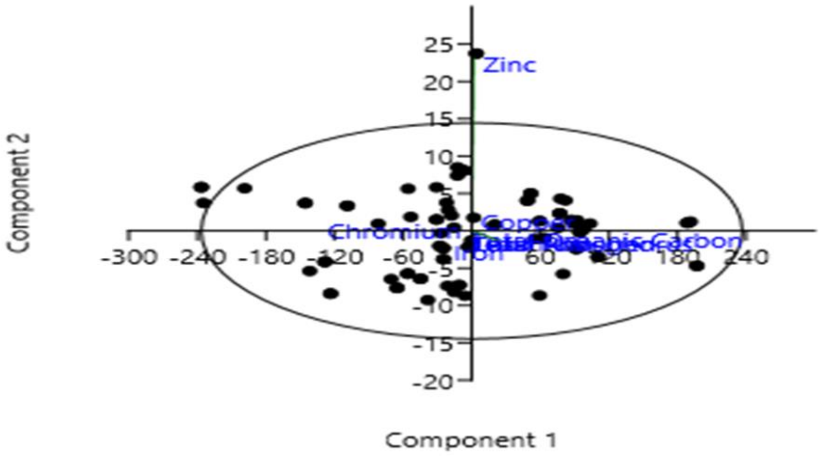

Fig. 1: Scatter plot for the physicochemical values of the sediments collected from Falcorp mangrove

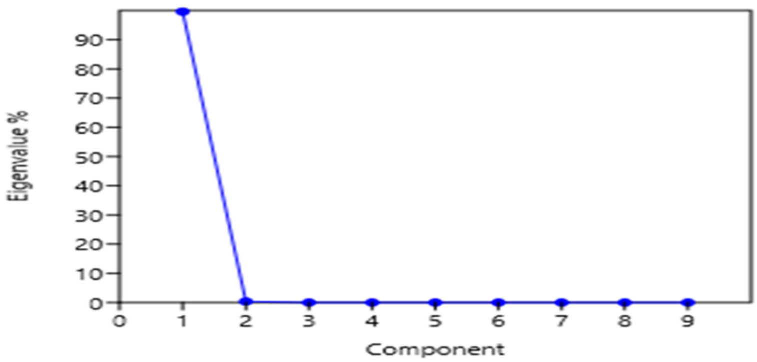

Fig. 2: Screen plot for the physicochemical values of the sediments

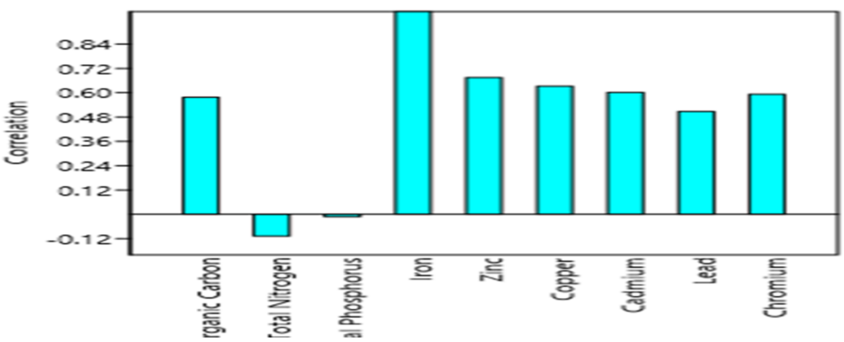

Fig. 3: Correlation plot for the physicochemical values of the sediments collected from Falcorp mangrove

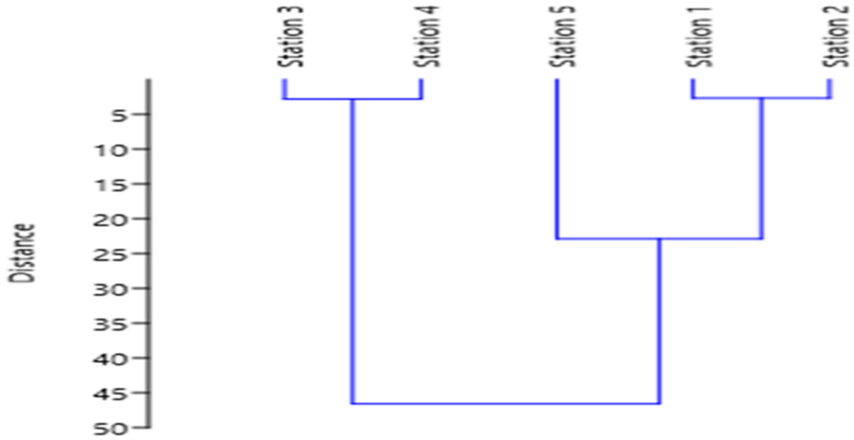

Fig. 4: Cluster analysis for the physicochemical values of the aquatic sediments

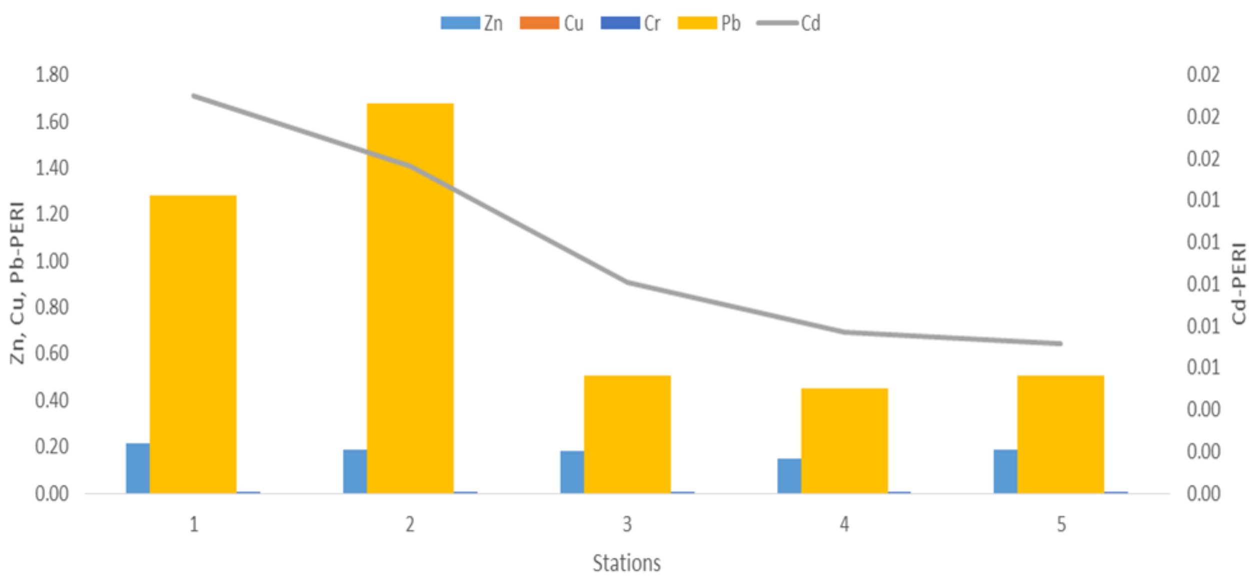

Fig. 5. Spatial variations of PERI values of the aquatic sediments

High Fe values have been documented in sediments collected from several parts of Nigeria [18],[19]; [16] [20]. The range of mean Zinc values recorded in the present study contrasted with the mean values reported by several researchers [21],[15], [16]. Ogbeibu *et al*. [16] suggested that the variations in zinc levels across different sampling points could be attributed to pollution from sewage runoff known to have a relatively high zinc content. The sediment associated Cu concentrations were comparatively lower than values documented by Puyate *et al*., [22] and Ogbeibu [16] which observed higher Cu values for sediments collected from Orogodo and Benin River respectively. Human exposure to increased copper levels have been associated with several symptoms which include; anaemia, liver and kidney damage, stomach and intestinal irritation respectively [23]. The range of mean Pb values documented in this report study were lower than the mean range of values (3.8 - 10.00 mg/kg) reported by Ogbeibu [15] and a range of values; 0.15 - 1.10 mg/kg documented by Ogbeibu *et al.* [16] with respect to aquatic sediments collected from Benin River. Cr is known to enter water bodies mainly from industrial waste discharge and disposal of Cr tainted products [7], [24]. The mean values recorded in this study were at variance and lower when compared with mean values which varied from 0.25 - 1.68 mg/kg for sediments collected from the Benin River [15]. The ingestion of large amounts of chromium (VI) ion has been documented to can cause stomach upsets and ulcers, convulsions, kidney and liver damage, and even death [25].

The PCA result based on the correlation matrix of the physical and chemical parameters was shown in Table 3. The PCA was conducted on the data sets which contained nine (9) variables analyzed in the sediments (Fig. 1). The PCA of the data sets generated 12 variables under 9 components with Eigenvalues < 1 (PC1-PC2) and >1 (PC3-PC9). These variables explained 99.99 and 0.00% of the total variance in the respective sediment quality. The contributions included - component 1, 2, 3, 4, 5, 6, 7, 8 and 9 accounted for the proportion as follows: 99.99, 0.37, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00 and 0.00% respectively (Table 2). The parameters of importance in each component included: 1; Fe (1.00), 2; Zn (1.00), 3; TOC (0.98) and Cu (0.68), 4; Cu (0.75), 5; Pb (0.82), 6; TN and TP (0.71 and 0.43), 7; TP (0.84) 8; Cr (0.97) and 9; Cd (0.99). Figures 1 and 2 showed the scatter plot and the relationship of the sediment physicochemical parameters in Falcorp mangrove swamp. There was a cluster of Cu TOC, Fe and Zn in components 1 and 2. Positive correlation existed between TOC, Fe, Zn, Cu, Cd, Pb and Cr, whilst a negative relationship existed between TN and TP (Fig. 3). The PC1 and PC2 contributed a larger percentage (99.99 and 0.37%) with respect to the trace metal loadings in the sediment PCA. The important parameters in each component were PC1; Fe (1.00), PC2; Zn (1.00) out of the nine (9) components. The source allotment could be attributed to trace metal contamination. The same observation was reported by Guo *et al*. [26] and Shen *et al*. [27] respectively. The Eigenvalues in this research were < 1 in PC1-PC2 and >1 in PC3-PC9; with respect to all the PCA components. Eigenvalues of 1.0 or greater have been regarded as been significant [28]. By implication, the maximal eigenvalue is usually regarded as been the most significant and should be one or greater for proper consideration in the course of conducting the PCA [14]. Factor loading values of > 0.75, between 0.5-0.75 and 0.3-0.5 has been classified as strong, moderate and weak respectively, with reference to their absolute values. The derived eigenvalues in this research revealed that the PC1-PC2 had strong absolute values and PC31-PC9 fall between moderate and weak absolute values. This trend also indicated that the parameters in PC1-PC2 components had a profound impact on the ecosystem and PC3-PC9 which had similar parameters as the latter, had a slight significant influence in the same ecosystem. The relationship between the parameters as revealed in the scatter plot also displayed a similar cluster between the respective physicochemical parameters; Cu TOC, Fe and Zn. However, a positive correlation existed between TOC, Fe, Zn, Cu, Cd, Pb and Cr whilst the relationship between Total Nitrates and Total Phosphate was negative. This trend is indicative of a strong interrelationship between the chemical constituents and the aquatic environment.

Table 4 shows the similarity and dissimilarity as defined by Euclidean distance and the combination of cluster based on Ward method is shown in Fig. 4. With reference to combinations of the clusters, the physical and chemical characteristics in station 5 were similar with stations 1 and 2 at the following distances station 5(27.44), station 1 (28.35) and station 2 (55.10). Also, the Ward procedure revealed that the existing physical and chemical attributes of both stations 3-4 and 1-2 were also similar at the following distances; 3.99 and 3.80 respectively. However, a dissimilarity was noticed in station 1 and 2 with stations 3 and 4 (Fig. 4). The cluster analysis dendrogram revealed that the existing physical and chemical conditions at station 5 were similar with stations 1 and 2 respectively. Furthermore, the Ward method revealed a similarity between the physical and chemical characteristics of 3-4 and 1-2 respectively. However, a dissimilarity was noticed in station 1 and 2 with stations 3 and 4. The dissimilarity that was noticed in stations could be attributed to the variations in this ecosystem.

The results of the CF, DC and PLI are shown in Table 5. The CF values for Zn, Cu, Cd, Pb and Cr fluctuated across the stations and were far lesser than 1 for all the sampled stations. The PLI values for the sediment were lesser than 1 for all the stations. The CF values for Zn, Cu, Cd, Pb and Cr varied across the sampled stations and showed distinct values which were far lesser than 1 at all the stations. Akoto *et al.,* [29] observed that CF values between 0.5 and 1.5 indicated that the metal source was either from the earth's crust or natural processes; whereas when the CF values were higher than 1.5, indicated that the likely source of the metal was anthropogenic. The mean CF values were below the above slated limits and this trend could be suggestive of the possible like hood of the natural origin of the sediment borne trace metals. The DC values for the selected metals were low for all the studied stations. The PLI values were less than 1 for all the sampled stations which was indicative of minimal heavy metal pollution at the respective stations.

The results of the *I-geo* in this study are shown in Table 6. The mean values varied from 0.00 to 0.04 and this trend denoted a non-polluted state and fall in class 0. This was also observed in all the stations. The *I*-geo values associated with the selected heavy metals were generally low (<1), which was indicative of minimal heavy metal contamination. This trend was in contrast with findings as reported by Naveedullah *et al*. [30].

The Potential Ecological Risk Indices for Zn, Cu, Cd, Pb and Cr for the respective five (5) sampled stations are shown in Table 7. The mean values varied from 0.00 to 1.07 and this trend indicated that the trace metal potential ecological risk of the respective sampling stations were slightly high. The Potential Ecological Risk Index had a maximal value of 2.14 for station 1 and low value of 0.96 for station 4. However, the ecological risk level was insignificant. The main donator of the potential ecological RIs came from Cd. Fig. 5 showed the spatial distribution of the selected trace metals across the stations and this result revealed that Cd was the major PERI. The potential ecological risk values of Zn, Cu, Cd, Pb and Cr ranged from 0.00 to 1.07. This trend was suggestive of a minimal potential ecological risk associated with the metal profiles of the sampled stations. The main donation of the potential ecological RIs as well as the main spatial variability came from Cd. This trend could be attributed to its higher toxicity response factor in comparison with other metals [31]. Turekian and Wedepohl [32], Klaassen [33] and Yisa *et al*. [34] reported the enhanced role of Cd in triggering ecological risks with respect to soils and sediments.

4. Conclusion

Varying amounts of trace metals were detected in the respective aquatic sediments. However, despite the different levels of anthropogenic activity around the vicinity of the swamp which include the disposal of waste materials, the presence of functional oil refinery and pipelines and bunkering, the potential ecological risks or threats arising from the trace metal profiles linked with the sediments collected at the respective stations was minimal or non-existent.

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