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Elemental Concentration and Potential Ecological Risk Assessment of Mangrove Surface Sediments in Conakry, Guinea

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Authors' contributions

This work was carried out in collaboration between both authors. Author NN designed the study, carried out the laboratory preparations, statistical analyses, literature review, wrote the protocol and the draft of the manuscript. Author HI designed and wrote the manuscript with author NN led the sampling and carried out XRF analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

Surface sediments of Conakry mangrove, Guinea were sampled and analyzed to assess their concentration and potential ecological risks. Seventeen trace elements and five major elements were analyzed using XRF. Mean, STDEV, correlation matrix, CF, C_d, EF, PI, MPI, Er^i, RI and PCI were used for data analyses. The results indicated contrasting element concentrations with location. Cl; Fe_2O_3 and Sc; MnO had the highest and lowest average concentrations among the trace and major elements used for the study. Relative to the UCC values, As, Pb, Zn, Ni, Cr, V, Cl, Fe_2O_3, MnO and P_2O_5 had higher values while Cu, Sr, Y, Nb, Zr, Th, Sc, F, TiO_2 and CaO had lower values. Fe_2O_3 majorly influenced the concentration of most of the elements. As enrichment had a potentially moderate to considerable ecological risk while Cr, Cu, Pb, Zn and Ni were found to have potentially low ecological risk.

Keywords: Mangrove sediment; trace element; major element; sediment pollution; element enrichment; ecological risk.

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1. INTRODUCTION

Mangroves are specialized plants that grow in intertidal zones. They are halophytic and have tangled root system. The intricate nature of mangrove root system increases the deposition rate of marine sediment load carried by either tides or waves as well as the upland sediment load carried by runoff. Thus, the mangrove environment is associated with high rate of deposition. Also, sediments deposited in mangrove environment are fluvial in nature and gradually pile up over time. They are often laden with contaminants from diverse sources [1]. Some of these non point sources of contaminants may be industrial, agricultural or even geogenic. Others include deposition from the atmosphere [2] and inflow from tides [3]. Notwithstanding these non point sources of contaminants, the magnitude of heavy metal contamination depends not only on their sources but also on the solid and aqueous phases of physicochemical properties, microbial activities as well as redox conditions [4]. However, among the organic and inorganic contaminants within the mangrove environment, heavy metals account for the considerable sources of poor ecological quality.

Therefore, assessment of elemental concentration in mangrove surface sediments can potentially provide in-depth information on the sediment quality as well as the ecological status of the mangrove environment. Given that mangroves are described as sink for heavy metals [5], it holds vital history of heavy metal concentration which might be either geogenic or anthropogenic or both [1]. There are limited studies on heavy metals in mangrove surface sediments in Guinea [6] and these studies analyzed only few metals.

It is against this backdrop that this study was undertaken to assess elaborate metal concentrations in Conakry mangrove sediments as well as their probable ecological risk. As such, this study seeks to deepen insight into (a) trace and major element concentration in mangrove surface sediments in Conakry, (b) evaluation of sediment contamination and (c) determination of the ecological risk of metal concentration in mangrove sediment.

2. MATERIALS AND METHODS

2.1 Study Area

Guinea has a coastal stretch of 1,614.5 km and a mangrove area of 2,039 km^2 [7]. Its mangroves are described as the best developed in West Africa with stands exceeding 25 meters in height and extends up to 160 km inland [8]. The span of mangroves is influenced remarkably by tides. Conakry is situated on an isthmus. It extends as far as the Peninsula of Kaloum and bordered by mangrove swamps. It lies between 9°30' to 9°40' to the north and 13°30' to 13°42' to the west. Conakry receives about six months of rainfall and up to 4,000 mm per annum [9]. Temperature ranges annually are between 23°C and 29°C [10]. Geologically, Conakry is made up of Jurassic mafic to ultramafic rocks of Kakoulima laccolith [11]. However, according to [8,12] other areas beyond Conakry consist of granitic rocks of precambrain age.

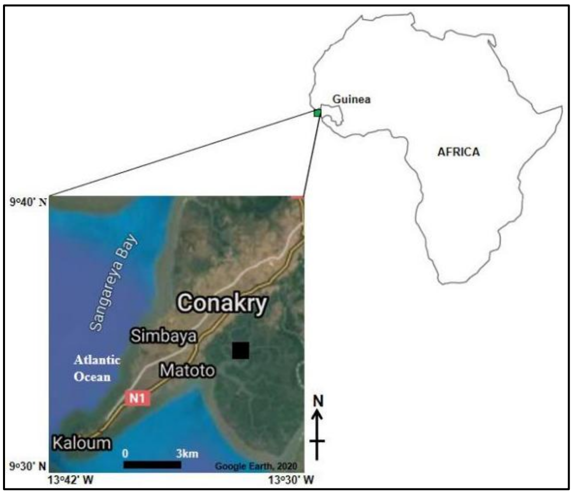

Fig. 1. Map of the study area showing mangrove distribution

2.2 Mangrove Surface Sediment Sampling and Preparation

The surface sediment samples from Conakry mangroves were obtained from seven locations using the bucket auger. Sampled sediments weighing up to 200g were packaged in plastic bags in the field and stored at 4^oC in a cooler. To reduce weight, the homogenized samples were air dried for 48 hours before repackaging them in zip-lock bags and placed in plastic boxes. The samples were exported and analyzed in Geoscience Laboratory, Shimane University, Japan. Sediment samples weighing about 50 g each were oven dried at 160^oC for 2 days. Using the automatic agate mortar and pestle grinder, the oven dried samples were made into powder after 20 minutes of grinding. After which about 5g of each of the powdered sediment samples were compressed into briquettes using a force of 200 kN for 60s.

2.3 Laboratory Analysis

Seventeen trace elements; As, Pb, Zn, Cu, Ni, Cr, V, Sr, Y, Nb, Zr, Th, Sc, TS, F, Br and Cl as well as five major elements; TiO_2, Fe_2O_3, MnO, CaO and P_2O_5 were analyzed using X-ray fluorescence (XRF) RIX-200 spectrometer. In accordance with [13], using pressed powder briquettes with average errors being <10% XRF analyses were done.

2.4 Statistical Analysis

The mean and standard deviations of the trace and major element concentrations in the mangrove surface sediment samples and correlation matrix to show the inter-element relationships in the study area were computed using Microsoft Excel 2013. As-Fe_2O_3, Pb-Fe_2O_3, Zn-Fe_2O_3 and Cu-Fe_2O_3 correlation graphs as well as normalized concentration graph using upper continental crust (UCC) were done using Kaleida Graph 4.0.

2.5 Sediment Pollution Assessment (SPA)

2.5.1 Contamination factor (CF)

To establish the extent of heavy metal contamination in the mangrove surface sediments of Conakry, the contamination factor was employed. Contamination factor is expressed in line with [14] as:

$$CF = C_{metal} / C_{background}$$

Where:

C_{metal} refers to the current metal concentration within the sediments.

$C_{background}$ refers to the background metal concentration of sediments.

The upper continental crust proposed by [15] was used as the background metal concentration. The CF is interpreted thus: CF < 1: signifies low contamination; 1 ≤ CF < 3: signifies moderate contamination; 3 = CF ≤ 6: signifies considerable contamination and CF ≥ 6: signifies very high contamination.

2.5.2 Degree of contamination (C_d)

To further enhance pollution determination in sediments, [16] suggested a sedimentological diagnostic tool known as degree of contamination which is defined thus:

$$C_d = \sum CF$$

It is used to calculate the degree of contamination of an element by summing up the CF of a given element in the samples. C_d is interpreted as: $C_d < 6$ shows low C_d; $6 < C_d < 12$ means moderate C_d; $12 < C_d < 24$ is considerable C_d while $C_d > 24$ is high C_d and shows strong anthropogenic pollution.

2.5.3 Enrichment factor (EF)

The determination of the anthropogenic impact of elemental enrichment in the surface sediments of Conakry mangrove was done using the enrichment factor. The EF uses a normalized approach where normalizing elements could be any of Al, Fe and Si [17] as well as Li, Sc, Ti and Zr [18]. This study used Fe as the normalizing element for the computation of the enrichment factor. The anthropogenic sources of Fe are insignificant, thus it was chosen as the element for normalization [19]. Thus, Fe is a conservative tracer and could be used to differentiate between natural and anthropogenic components in sediments [20]. EF is given as:

$$EF = (X_s/Fe_s)_{sediment} / (X_b/Fe_b)_{background}$$

Where: X_s refers to the element being considered from the sediment sample and Fe_s refers to the normalizer from an equivalent sample.

X_b is the element being considered from the background while Fe_b is the normalizer from the background.

The upper continental crust values proposed by [15] were used as the background concentration. The interpretation of EF is given thus: EF < 2 is depletion to minimal enrichment and pollution; EF 2 - 5 is moderate enrichment and pollution; EF 5 - 20 is significant enrichment and pollution; EF 20 - 40 is very high enrichment and pollution while EF>40 is extreme enrichment and pollution.

2.5.4. Pollution Index (PI)

The pollution index is a sediment pollution assessment tool developed by [21]. It makes use of the average and maximum contamination factor values of a metal in its computation. It is interpreted as; PI < 0.7 (unpolluted), 0.7 < PI < 1 (slightly polluted), 1 < PI < 2 (moderately polluted), 2 < PI < 3 (severely polluted) and PI > 3 (heavily polluted). The PI is expressed as:

$$PI = \sqrt{\frac{(Cf_{average})^2 + (Cf_{\max})^2}{2}}$$

Where: the average contamination factor value of a metal is its $Cf_{average}$ while the maximum contamination value of same metal is its Cf_{max}.

2.5.5 Modified pollution index (MPI)

The modified pollution index is a sediment pollution assessment tool developed by [22]. Instead of using contamination factor values of metal in its computation, the modified pollution index uses the average and maximum enrichment factors. The interpretation is as follows; MPI < 1 (unpolluted), 1 < MPI < 2 (slightly polluted), 2 < MPI < 3 (moderately polluted), 3 < MPI < 5 (moderately-heavily polluted), 5 < MPI < 10 (severely polluted) and MPI > 10 (heavily polluted). The PI is expressed as:

$$MPI = \sqrt{\frac{(Ef_{average})^2 + (Ef_{\max})^2}{2}}$$

Where: $Ef_{average}$ is average enrichment factor value of a metal while Ef_{max} is the maximum enrichment factor value of same metal.

2.6 Potential Ecological Risk Assessment (PERA)

2.6.1 Potential contamination index (PCI)

The potential contamination index was proposed by [23] and it is given as:

$$PCI = (Metal_{\text{sample maximum}}) / (Metal_{\text{background}})$$

Where: $metal_{\text{sample maximum}}$ refers to the maximum concentration of a metal in sediment while $metal_{\text{background}}$ refers to the background value of the same metal. The upper continental values of [15] were used as background values. It is interpreted thus: PCI < 1 is low contamination, 1 < PCI < 3 is moderate contamination and PCI > 3 is severe or very severe contamination.

2.6.2 Potential ecological risk factor (Er^i)

To determine the potential ecological risk of an element in the sediment, the potential ecological risk factor put forth by [16] was used. It is calculated as follows:

$$Er^i = Tr^i \times C^i_f$$

Where: Er^i is the potential ecological risk factor of element (i) while Tr^i is the toxic response factor of same element (i). C^i_f refers to the contamination factor of element (i). The toxic response factors of As, Cr, Cu, Pb, Zn and Ni were given as 10, 2, 5, 5, 1 and 5 respectively [16]. The Er^i values are interpreted as follows: Er^i < 40 is low potential ecological risk, 40 ≤ Er^i < 80 is moderate potential ecological risk, 80 ≤ Er^i < 160 is considerable potential ecological risk, 160 ≤ Er^i < 320 is high potential ecological risk and Er^i ≥ 320 is very high potential ecological risk.

2.6.3 Potential ecological risk index (RI)

The ecological risk index is a tool used to estimate the ecological risk posed by an element in the sediment. According to [16], it is calculated by summing up the Er^i and is interpreted as follows: RI < 150 is low ecological risk, 150 ≤ RI < 300 is moderate ecological risk, 300 ≤ RI < 600 is considerable ecological risk and RI ≥ 600 is very high ecological risk. The formula for RI is given thus:

$$RI = \sum Er^i$$

3. RESULTS AND DISCUSSION

3.1 Element Concentration in Mangrove Surface Sediments of Conakry

Trace and major element concentrations in the mangrove surface sediments of Conakry are presented on Tables 1 and 2 respectively. Also, the tables presented the comparison of the trace and major element concentrations with the UCC by [15].

The trace and major element concentrations obtained from the mangrove surface sediments of Conakry after XRF analysis showed wide variations among elements and at different locations. The elements are concentrated thus; Cl>TS>Cr>V>Zn>Zr>F>Ni>Pb>Sr>As>Br>Y>Nb >Cu>Th>Sc for the trace elements and Fe_2O_3>CaO>TiO_2>P_2O_5>MnO for the major elements. In comparison to the UCC values by [15], it was found that As, Pb, Zn, Ni, Cr, V and Cl had higher average concentration values while Cu, Sr, Y, Nb, Zr, Th, Sc and F had lower average values. Among the major elements, Fe_2O_3, MnO and P_2O_5 had higher concentrations while TiO_2 and CaO had lower concentrations relative to the UCC values.

3.2 Comparison of Metal Concentrations in Guinea and Nigeria Mangrove Surface Sediments

Guinea and Nigeria are both West African countries and thus have lots of climatic similarities. Guinea has the best developed mangroves in West Africa with stands exceeding 25 meters [8] while mangrove concentration in Nigeria is the largest not only in West Africa but also in Africa with stands of up to 40 meters [7]. Both Guinea and Nigeria mangroves are largely influenced by tides and are in the Atlantic East Pacific (AEP) mangrove group.

The graphical comparison of element concentrations in Guinea and Nigeria mangrove surface sediments was based on the data generated by this study and Niger delta mangrove surface sediment data from [24]. It is shown in Fig. 3. Twenty elements were compared and it was found that the Guinea mangrove surface sediments had higher average concentrations in As, Pb, Zn, Ni, Cr, V, F, Cl, Fe_2O_3, MnO, CaO and P_2O_5. However, Nigeria mangrove surface sediments had higher average element concentrations in Cu, Sr, Y, Nb, Zr, Th, Sc and TiO_2. Interestingly, both mangrove areas have similar trend in element concentrations.

3.3 Inter-element Relationship

The correlation matrix of element concentration in the mangrove surface sediments of Conakry was presented on Table 3. Sources of elements are defined using Fe_2O_3 and TiO_2 as proxies [25, 26]. According to [27], elements that show strong correlations with TiO_2 reflect only natural detrital inputs. This is because in sediments, lithogenic elements usually have a linear relationship with TiO_2. As such, where no correlation exists between TiO_2 and any given element, it then means that either anthropogenic or additional natural processes may have contributed to elemental enrichment [28].

Based on the analysis of mangrove surface sediment samples obtained from Conakry, there is a strong TiO_2-As-Pb-Cu-Cr-V, moderate TiO_2-Zn-Ni-Zr-Sc, weak TiO_2-Th-F-Cl and negative TiO_2-Sr-TS-Br associations. This implies that As, Pb, Cu, Cr and V concentration in the sediments are significantly influenced by TiO_2. TiO_2 has mild influence on the concentration of Zn, Ni, Zr and Sc. However, TiO_2 has no influence on the concentration of Sr, TS and Br in the sediments. Fe_2O_3 associated strongly with As, Pb, Zn, Cu, Ni, Cr, V and TiO_2. The Fe_2O_3-Sc is moderate while Fe_2O_3-Zr-Th-F-Cl is weak. However, Fe_2O_3 is negatively associated with Sr, TS and Br. This indicates that the concentration of As, Pb, Zn, Cu, Ni, Cr, V, Y and TiO_2 are strongly influenced by Fe_2O_3. Similarly, Fe_2O_3 has no influence on the concentration of Sr, TS and Br. In general, it could be concluded that Fe_2O_3 is the major geogenic determiner of element concentration in the mangrove surface sediments of Conakry. Also, the concentration of As, Pb, Zn, Cu, Ni, Cr, V and TiO_2 are largely lithogenic while the concentration of Sr, TS and Br are not.

Trace elements that are strongly and positively correlated have a common source and similar enrichment process [29]. Thus, the resultant suites of As-Pb-Zn-Cu-Ni-Cr-V in the surface sediments implies that these elements have a common source and enrichment process. Pb, Zn, Cu and P_2O_5 concentration in sediments are often influenced by anthropogenic factors [30]. This is because they are mostly used in both technological and agricultural activities [31]. As such, the strong positive P_2O_5-As-Pb-Zn-Cu-Ni-Cr-V relationship implies likely enrichment from a common anthropogenic source such as fertilizer application in surrounding upland areas. Also in sediments, Cu:Zn ratio can be employed in the

Table 1. Trace element concentrations (ppm) in Conakry mangrove surface sediment

As	Pb	Zn	Cu	Ni	Cr	V	Sr	Y	Nb	Zr	Th	Sc	TS	F	Br	Cl	
CKRY1	26	31	152	7	63	736	190	28	8	7	120	6	4	1172	47	9	6570
CKRY2	24	30	148	3	62	698	171	30	8	7	110	5	4	1038	60	8	5004
CKRY3	24	31	154	5	74	750	176	41	8	7	94	5	5	1175	230	10	6393
CKRY4	23	30	142	5	66	704	154	33	8	7	91	5	4	1295	-	12	9232
CKRY5	25	29	139	5	58	736	169	31	8	7	166	5	4	1150	74	9	7221
CKRY6	54	84	162	9	83	1122	319	27	9	7	139	5	5	1128	129	6	8615
CKRY7	46	72	163	7	84	899	279	34	9	7	128	7	6	986	126	6	5657
Average	31.71	43.86	151.43	5.86	70	806.43	208.29	32	8.29	7	121.14	5.43	4.57	1134.86	111	8.57	6956
STDEV	12.74	23.59	9.2	1.95	10.44	154.65	63.92	4.69	0.49	0	26.3	0.79	0.79	100.38	67.49	2.15	1525.69
UCC	4.4	18	70	32	38	80	98	266	17.4	12	188	8.95	15	-	561	-	142

Table 2. Major element concentration (ppm) in Conakry Mangrove Surface Sediment

TiO2	Fe_2O_3	MnO	CaO	P_2O_5	
CKRY1	0.42	17.67	0.17	0.66	0.20
CKRY2	0.38	16.22	0.15	0.68	0.19
CKRY3	0.39	16.38	0.15	0.86	0.21
CKRY4	0.36	15.54	0.15	0.69	0.19
CKRY5	0.43	16.15	0.16	0.73	0.20
CKRY6	0.52	24.2	0.17	0.68	0.37
CKRY7	0.49	22.53	0.18	0.84	0.32
Average	0.43	18.38	0.16	0.73	0.24
STDEV	0.06	3.50	0.01	0.08	0.07
UCC	0.67	5.33	0.10	3.44	0.16

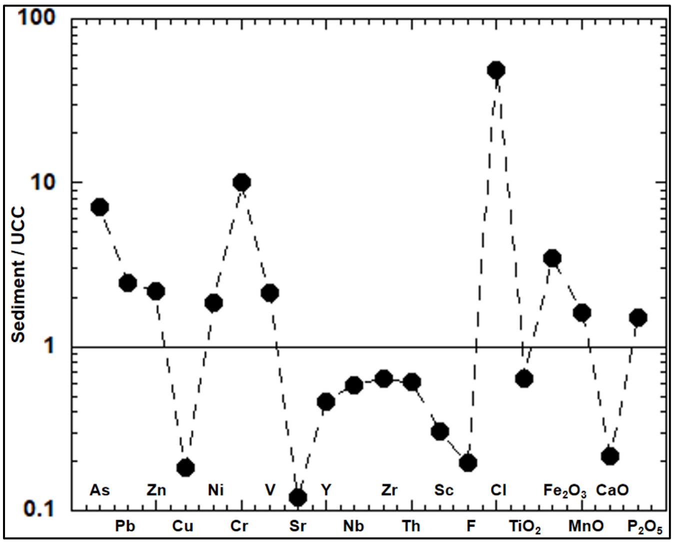

Fig. 2. Comparison of trace and major element concentration in surface sediments of Conakry mangrove. All values were normalized to the UCC values of [15]

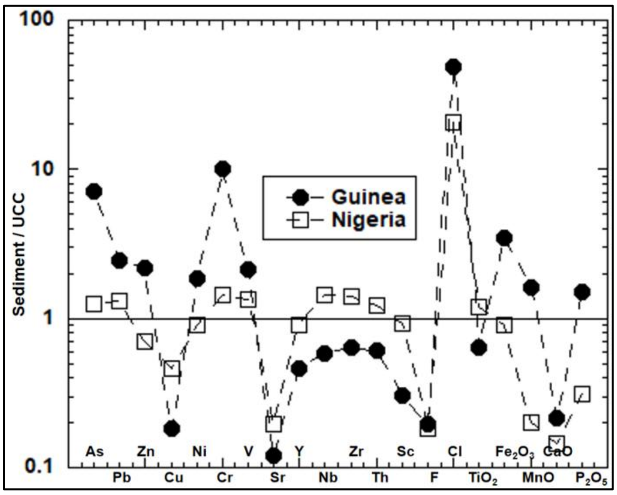

Fig. 3. Comparison of trace and major element concentration in surface sediments of Guinea and Nigeria mangrove. All values were normalized to the UCC values of [15]

Table 3. Correlation matrix of trace and major elements in surface sediments of the Conakry mangrove

	As	**Pb**	**Zn**	**Cu**	**Ni**	**Cr**	**V**	**Sr**	**Y**	**Zr**	**Th**	**Sc**	**TS**	**F**	**Br**	**Cl**	**TiO_2**	**Fe_2O_3**	**MnO**	**CaO**	**P_2O_5**
As	1																				
Pb	**1.00**	1																			
Zn	**0.81**	**0.82**	1																		
Cu	**0.82**	0.79	0.68	1																	
Ni	**0.85**	**0.88**	**0.90**	0.67	1																
Cr	**0.96**	**0.95**	0.75	**0.84**	**0.80**	1															
V	**0.99**	**0.99**	**0.86**	**0.83**	**0.85**	**0.96**	1														
Sr	-0.32	-0.27	0.00	-0.36	0.17	-0.33	-0.32	1													
Y	**0.98**	**0.99**	**0.82**	0.75	**0.88**	**0.90**	**0.97**	-0.22	1												
Zr	0.38	0.32	-0.03	0.34	-0.06	0.37	0.36	-0.50	0.32	1											
Th	0.38	0.39	0.55	0.37	0.43	0.16	0.41	0.00	0.50	0.10	1										
Sc	0.72	0.75	**0.84**	0.50	**0.91**	0.61	0.73	0.36	**0.81**	0.04	0.62	1									
TS	-0.46	-0.46	-0.55	-0.05	-0.37	-0.30	-0.49	0.10	-0.53	-0.34	-0.55	-0.56	1								
F	0.16	0.20	0.42	0.11	0.58	0.24	0.17	**0.81**	0.19	-0.46	-0.12	0.61	0.17	1							
Br	-0.83	-0.81	-0.75	-0.53	-0.60	-0.74	-0.85	0.38	-0.82	-0.53	-0.46	-0.62	**0.84**	0.13	1						
Cl	0.16	0.16	-0.20	0.40	0.07	0.30	0.10	-0.20	0.08	0.01	-0.41	-0.21	0.76	0.14	0.36	1					
TiO_2	**0.94**	**0.91**	0.73	**0.84**	0.71	**0.91**	**0.95**	-0.37	0.90	0.62	0.43	0.65	-0.51	0.05	-0.87	0.07	1				
Fe_2O_3	**0.99**	**0.99**	**0.86**	**0.84**	**0.85**	**0.95**	**1.00**	-0.33	**0.97**	0.36	0.46	0.73	-0.50	0.14	-0.85	0.09	**0.95**	1			
MnO	0.75	0.72	0.66	0.78	0.55	0.62	0.77	-0.38	0.76	0.52	**0.80**	0.60	-0.51	-0.21	-0.74	-0.10	**0.85**	**0.80**	1		
CaO	0.09	0.13	0.35	-0.05	0.48	0.02	0.11	**0.86**	0.21	-0.14	0.35	0.73	-0.30	0.79	-0.10	-0.35	0.10	0.10	0.09	1	
P_2O_5	**1.00**	**1.00**	**0.82**	**0.81**	**0.88**	**0.97**	**0.99**	-0.25	**0.98**	0.35	0.35	0.75	-0.44	0.25	-0.80	0.17	**0.93**	**0.98**	0.71	0.16	1

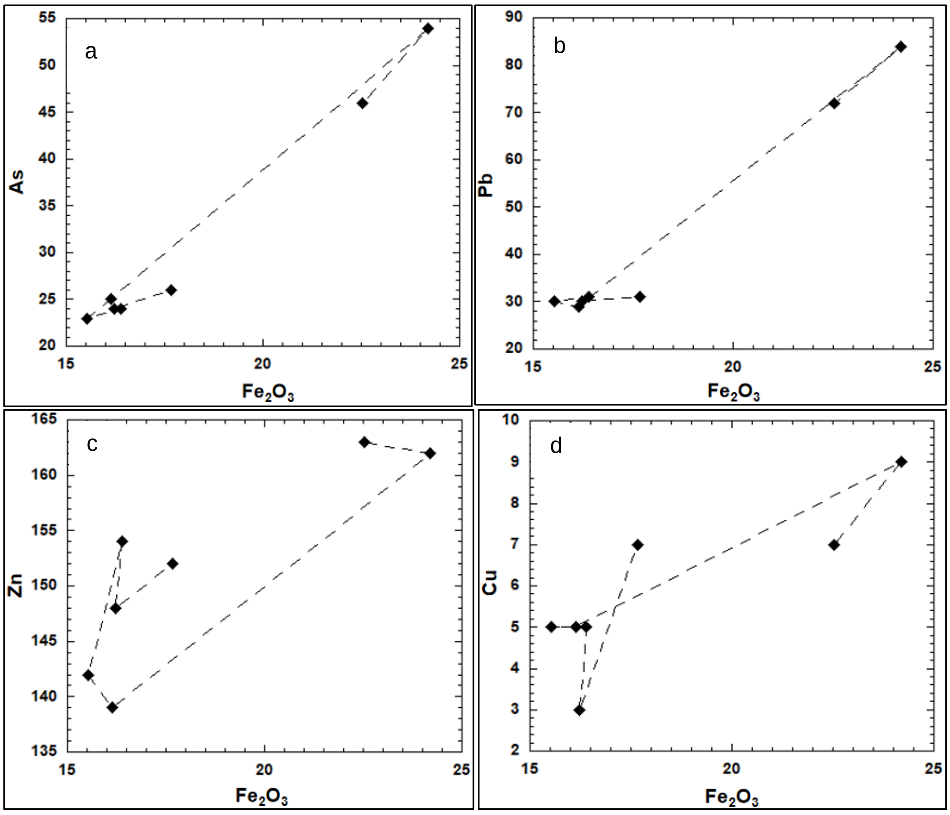

Fig. 4. a-d Correlations between Fe_2O_3 and As, Pb, Zn and Cu

description of redox conditions [32]. According to [33], an increase in the Cu:Zn ratio indicates a shift towards anaerobic conditions in sediments as a result of increased organic production and marks the beginning of eutrophication. This study found an increase in the Cu:Zn ratios in all the sampling locations. Specifically, the sampling locations CKRY1, CKRY2, CKRY3, CKRY4, CKRY5, CKRY6 and CKRY7 had Cu:Zn ratios of 1:21.71, 1:49.33, 1:30.80, 1:28.40, 1:27.80, 1:18.00 and 1:23.29 respectively. This shows that the sediments were at varying anoxic conditions as at the time of sampling. The As-Fe_2O_3, Pb-Fe_2O_3, Zn-Fe_2O_3 and Cu-Fe_2O_3 diagrams in Fig. 4 express the element correlations with Fe_2O_3 in Conakry mangrove surface sediments.

3.4 Sediment Pollution Assessment (SPA)

3.4.1 Contamination factor (CF) and degree of contamination (C_d)

The values of contamination factors (CF) and degree of contamination (C_d) of some biogenic elements in the surface sediments of Conakry mangrove are presented on Table 4. The interpretation of the values obtained were based on [14, 16] respectively. The CF of As and Cr in the surface sediment samples ranged from 5.23 to 12.27 and 8.73 to 14.03 with an average of 7.21 and 10.08 as well as C_d of 50.44 and 70.58 accordingly. This indicates that As and Cr contamination are very high with strong anthropogenic input. Cu has a CF range of 0.16 to 0.28 with an average of 0.18 and C_d of 1.29. Thus, Cu has low contamination and low C_d . The CF values of Pb, Zn and Ni ranged from 1.61 to 4.76; 1.99 to 2.33 and 1.63 to 2.21 with an average CF of 2.45, 2.16 and 1.84 respectively. Also, their C_d values are 17.15, 15.14 and 12.90 correspondingly. Hence, Pb, Zn and Ni are moderately contaminated or have a considerable degree of contamination.

3.4.2. Enrichment Factor (EF)

The enrichment factor values of some elements in the mangrove surface sediments of Conakry are presented on Table 5. The EF values of Pb, Zn, Cu, Ni, V, Sr, Y, Nb, Zr, Th, Sc and F are less than 2. However, Cu, Sr, Y, Nb, Zr, Th, Sc and F could be described as depleted while Pb, Zn, Ni and V are minimally enriched and polluted. As and Cr had EF values in the range of 2 to 5 and implies they are moderately enriched and polluted. The EF of Cl is less than 20 and implies significant enrichment and pollution. Further more, [34] posits that EF values between 0.5 and 1.5 indicates geogenically enriched elements while EF values greater than 1.5 are indicative of anthropogenically enriched elements. Thus, Pb, Zn, Ni and V enrichment are geogenic while the enrichment of As, Cr and Cl are anthropogenic.

3.4.3 Pollution index (PI) and modified pollution index (MPI)

The PI and MPI values obtained from the Conakry mangrove surface sediments are shown on Table 6. The values were interpreted based on [21, 22] for PI and MPI respectively. The PI value of Cu is less than 0.7 and implies that Cu is unpolluted. Zn and Ni had PI values less than 3. As such, they are severely polluted. The PI values of Pb, As and Cr exceeded 3 and therefore are heavily polluted. However, Cu, Pb, Zn and Ni had MPI values of less than 1. Thus, they are unpolluted. MPI value of As is 2.26 while that of Cr is 3.01. As such, As is moderately polluted while Cr is moderately-heavily polluted.

Table 4. Contamination factors and degrees of contamination of Conakry mangrove surface sediments

	As	Cr	Cu	Pb	Zn	Ni
CKRY1	5.91	9.20	0.22	1.72	2.17	1.66
CKRY2	5.45	8.73	0.09	1.67	2.11	1.63
CKRY3	5.45	9.38	0.16	1.72	2.20	1.95
CKRY4	5.23	8.80	0.16	1.67	2.03	1.74
CKRY5	5.68	9.20	0.16	1.61	1.99	1.53
CKRY6	12.27	14.03	0.28	4.76	2.31	2.18
CKRY7	10.45	11.24	0.22	4.00	2.33	2.21
Average	7.21	10.08	0.18	2.45	2.16	1.84
C_d	50.44	70.58	1.29	17.15	15.14	12.90

Table 5. Enrichment factors of Conakry mangrove surface sediments

	As	Pb	Zn	Cu	Ni	Cr	V	Sr	Y	Nb	Zr	Th	Sc	F	Cl
CKRY1	1.78	0.52	0.65	0.07	0.50	2.78	0.58	0.03	0.14	0.18	0.19	0.20	0.08	0.03	13.96
CKRY2	1.79	0.55	0.69	0.03	0.54	2.87	0.57	0.04	0.15	0.19	0.19	0.18	0.09	0.04	11.58
CKRY3	1.77	0.56	0.72	0.05	0.63	3.05	0.58	0.05	0.15	0.19	0.16	0.18	0.11	0.13	14.65
CKRY4	1.79	0.57	0.70	0.05	0.60	3.02	0.54	0.04	0.16	0.20	0.17	0.19	0.09	nd	22.30
CKRY5	1.88	0.53	0.66	0.05	0.50	3.04	0.57	0.04	0.15	0.19	0.29	0.18	0.09	0.04	16.78
CKRY6	2.70	1.03	0.51	0.06	0.48	3.09	0.72	0.02	0.11	0.13	0.16	0.12	0.07	0.05	13.36
CKRY7	2.47	0.95	0.55	0.05	0.52	2.66	0.67	0.03	0.12	0.14	0.16	0.19	0.09	0.05	9.42
Average	2.03	0.67	0.64	0.05	0.54	2.93	0.61	0.04	0.14	0.17	0.19	0.18	0.09	0.06	14.58

Table 6. Pollution Index and Modified Pollution Index of Conakry mangrove surface sediments

	As	Cr	Cu	Pb	Zn	Ni
PI	10.06	12.22	0.24	3.79	2.25	2.03
MPI	2.26	3.01	0.06	0.87	0.68	0.59

Table 7. Potential contamination index of Conakry mangrove surface sediments

	As	Cr	Cu	Pb	Zn	Ni
PCI	12.27	14.03	0.28	4.67	2.33	2.21

Table 8. Potential ecological risk factor and potential ecological risk index of Conakry mangrove surface sediments

	As	Cr	Cu	Pb	Zn	Ni
CKRY1	59.1	18.4	1.1	8.6	2.17	8.3
CKRY2	54.5	17.46	0.45	8.35	2.11	8.15

	As	Cr	Cu	Pb	Zn	Ni
CKRY3	54.5	18.76	0.8	8.6	2.2	9.75
CKRY4	52.3	17.6	0.8	8.35	2.03	8.7
CKRY5	56.8	18.4	0.8	8.05	1.99	7.65
CKRY6	122.7	28.06	1.4	23.8	2.31	10.9
CKRY7	104.5	22.48	1.1	20	2.33	11.05
Average	72.06	20.17	0.92	12.25	2.16	9.21
RI	504.4	141.16	6.45	85.75	15.14	64.5

3.5 Potential Ecological Risk Assessment (PERA)

3.5.1 Potential Contamination Index (PCI)

The potential contamination index values obtained varied among elements as presented on Table 7. It was found that As, Cr and Pb had PCI values above 3. This suggests that these elements have severe or very severe contamination potentials in the Conakry mangrove. Zn and Ni had PCI values of 2.33 and 2.21 respectively and thus, are of moderate contamination potential. However, Cu had a PCI value below 1 and as such, is of potentially low contamination within the Conakry mangrove.

3.5.2 Potential ecological risk factor (Er^i) and potential ecological risk index (RI)

There are variations in the potential ecological risk factors obtained for same element at different locations. However, the assessment of the potential ecological risk in the mangroves of Conakry was based on the average ecological risk factor for each of the elements examined. As had an average ecological risk factor of 72.06 and signifies that As in the Conakry mangrove posed a moderate potential ecological risk. Cr, Cu, Pb, Zn and Ni all had average risk values below 40. This implies that these elements have low potential ecological risk. Similarly, it was found that the RI of As is 504.4 and indicates that As is of considerable ecological risk. However, Cr, Cu, Pb, Zn and Ni were found to have RI values below 150. Thus, these elements are of low ecological risk. The Er^i and RI values are shown on Table 8.

4. CONCLUSION

The surface sediment samples of Conakry mangrove, Guinea were found to have variations in element concentration with location. These variations may not be entirely source bound but also due to some other factors such as redox conditions and microbial activities. Based on average concentrations, Cl; Fe_2O_3 and Sc; MnO had the highest and lowest concentrations among the analyzed trace and major elements respectively. TiO_2 has a strong As-Pb-Cu-Cr-V; weak Th-F-Cl and negative Sr-TS-Br associations. Fe_2O_3 was found to have strong association with As,Pb, Zn,Cu, Ni, Cr, V and TiO_2; weakly associated with Zr, Th, F and Cl but had negative association with Sr, TS and Br. Thus both TiO_2 and Fe_2O_3 geogenically influenced the concentration of most of the elements analyzed. However, Fe_2O_3 had a greater influence. The observed high Cu:Zn ratio in all the samples is a strong indication that the sediments were in an anoxic conditions.

As and Cr had very high contamination factors indicating strong anthropogenic pollution. Pb, Zn and Ni had moderate contamination and a considerable degree of contamination. The enrichment assessment showed that Cl was significantly enriched while As and Cr were moderately enriched. However, Pb, Zn, Ni and V were minimally enriched while Cu, Sr, Y, Nb, Zr, Th, Sc and F were depleted. Generally, the enrichment of As, Cr and Cl were anthropogenic but the enrichment of Pb, Zn, Ni and V were geogenic. The potential ecological risk assessment showed that As had a potentially moderate to considerable ecological risk but Cr, Cu, Pb, Zn and Ni had potentially low ecological risk.

APPENDIX A. SUPPLEMENTARY DATA

Supplementary data to this article can be sourced online from http://ir.lib.shimane-u.ac.jp/46655.

DISCLAIMER

The content of this research article such as texts, tables and graphs used by the authors are purely for information and advancement of knowledge. The content is not intended to be used for any other purpose. Also, the content is not to be used as the basis for any litigation. The research was not funded by the publishing firm rather it was funded by personal efforts of the authors with support from Shimane University.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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