Original Research Article

Comparative Assessment of Heavy Metal Concentrations, Environmental Risks and Phytoremediation Potentials of *R. racemosa* and *A. germinans* in Mangroves of Niger Delta, Nigeria

ABSTRACT

The concentrations of As, Pb, Zn, Cu, Ni, Cr, V, Sr, Y, Nb, Zr, Cl, TS, TiO_2, MnO, CaO and P_2O_5 in the mangrove sediments relative to concentrations in *R. racemosa* and *A. germinans* samples from Ogbogoro and Isaka in Niger Delta, Nigeria were assessed. A total of 4 core sediment, 6 *R. racemosa* and 4 *A. germinans*samples were collected through simple random sampling. Two core sediment samples of 10 cm depth and three *R. racemosa* leave, stem and root samples were collected from each of the sampled locations. However, one and three *A. germinans* leave, stem and root samples were collected from Ogbogoro and Isaka respectively. All the samples were oven dried, powdered, made into briquettes and analyzed using XRF. The results indicated contrasting heavy metal concentrations in the sediments, *R. racemosa* and *A. germinans* samples. Sr, Zr and CaO had higher concentrations in *R. racemosa* relative to *A. germinans* while Zn, Cu, Ni, Nb, Cl and TS are comparatively more concentrated in *A. germinans* than in *R. racemosa*. However, As, Pb, Y and P_2O_5 have similar concentrations in both mangrove species.Cr,V and TiO_2 were not detected in both *R. racemosa* and *A. germinans* while MnO was detected in *R. racemosa* but not detected in *A. germinans*. Similarity was observed in metal concentrations in the leaves, stems and roots of *R. racemosa* and *A. germinans*. The ecological risks of metal concentrations in both plants were determined using Contamination Factor (CF) and Pollution Load Index (PLI) while the phytoremediation potentials of the plants were assessed using Bio-concentration Factor (BCF) and Bio-translocation Factor (BTF). *R. racemosa* and*A. germinans* were found to be moderately contaminated though the PLI indicated that they are unpolluted. *R. racemosa* and *A. germinans* were found to have phytoremediation capacities in Cu, Ni, Sr, Zr, Cl, TS, MnO, CaO, P_2O_5 and Zn, Cu, Sr, Zr, CaO, P_2O_5 respectively.

Keywords: Rhizophora racemosa; Avicennia germinans; heavy metals; environmental risks; phytoremediation.

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1. INTRODUCTION

Mangroves are unique plants that have evolved to thrive in the interface between land and ocean in the humid climate of the tropical and subtropical regions of the world [1]. Precisely, these plants predominate along or close to rivers, intertidal areas, bays, estuaries, lagoons and creeks [2]. Temperature and rainfall [3] as well as salinity are the major factors regulating their distribution. Mangroves are among the most productive ecosystems of the world. Thus, they are home to many flora and funa. Also, they produce large amount of detritus that contribute to nutrients in off shore waters and as well, provide conducive breeding ground for many species of fish and other organisms.

The complex root system of mangroves enhances shore stability and soil formation by trapping sediments [4]. Hence, the description of the mangrove environment as a sink for not only clastics or sediments but also for CO_2, natural and anthropogenic pollutants.

Defew *et al*.[5] posit that among the organic and inorganic pollutants within the mangrove environment, heavy metals constitute the major source of poor ecological quality. Put differently, high concentrations of heavy metals in mangrove sediments cause loss of mangroves [6]. The mangroves of Niger Delta, Nigeria are exposed to pollution mostly due to oil related activities. For instance, a total of 6, 817 oil spills occurred in the Niger Delta between 1976 and 2001 [7]. Similarly, some of the estuarine rivers in the area are used for the discharge of both point and non-point wastes as well as means of transportation [8]. These and other related human activities increase the pollution load of the mangrove sediments. Thus, polluted sediments within the mangroves could in turn become pollution source [9].

Although there are some studies on metal concentrations in mangrove sediments and plant species in Niger Delta [10; 4], there is dearth of information on the ecological risk of heavy metal accumulation in mangrove plant species. It is against this backdrop that this study seeks to assess the environmental risks of heavy metal concentrations in Niger Delta mangrove sediments in comparison with metal accumulations in *R. racemosa* and *A. germinans*. Specifically, the study focuses on: (a) assessment of metal concentrations in Niger Delta mangrove sediments, (b) assessment of metal concentrations in leaves, stems and roots of *R. racemosa* and *A. germinans* in Niger Delta mangrove, (c) assessment of environmental risks of metal concentrations in *R. racemosa* and *A. germinans* using CF, PLI and (d) assessment of phytoremediation potentials of *R. racemosa* and *A. germinans* using BCF and BTF.

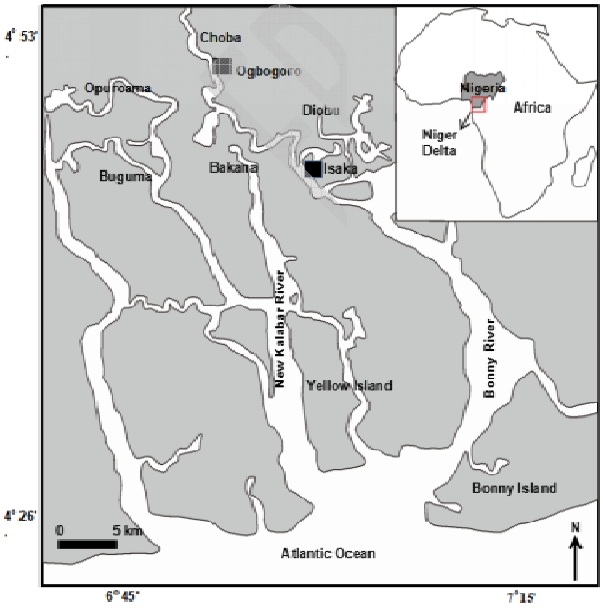

Figure 1: Study area map showing sampling locations. Modified from [11]

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2. MATERIALS AND METHODS

2.1 STUDY SITE

The Ogbogoro mangrove forestsalong the banks of the New Kalabar River and Isaka mangrove forestsalong the banks of the Bonny River (4°26 to 4°53N and 6°45 to 7°15) were used for this study (Fig.1). These two rivers are among the most stressed rivers in Niger Delta [8]. They drain through the areas of hydrocarbon exploration and exploitation [12], these rivers are used for the discharge of both point and non point wastes as well as serve as means of transportation [8]. Both rivers emptied into the Atlantic Ocean and equally serve as tidal inlets. The climate is the equatorial type with high relative humidity all year round and mean annual rainfall of about 4,500 mm [13]. Temperatures are high all year round and ranges between 18°C to 33°C [13]. Geologically, the area is made up of alternating sequence of gravel, sand, silt, clay and alluvium estimated to be about 2, 000 meters thick [15]. Settlements, oil and gas industries, fishing and crop farming are the major land use within the study area[4].

2.2 STUDY SPECIES

R. *racemosa* also known as red mangroves and *A. germinans*(black mangrove) are the mangrove species used for this study. The *R. racemosa* belongs to the family of Rhizophoraceae while *A. germinans*belongs to the acanthus family, Acanthaceae [16], *R. racemosa* is the most abundant and pioneer mangrove species in Niger Delta which occupies the wet and more saline areas while *A. germinans*is comparatively less abundant and occupies the drier and less saline upland areas [17]. However, in some instances, both species inhabit together. Both species are limited to the Atlantic East Pacific (AEP) with largest concentration on the Atlantic coast of West Africa [3; 18]. *R. racemosa* has numerous aerial stilt roots and can grow to a height of 45 m [17] while *A. germinans* is smaller and has apneumatophores. The locals mostly exploit them for firewood and timber.

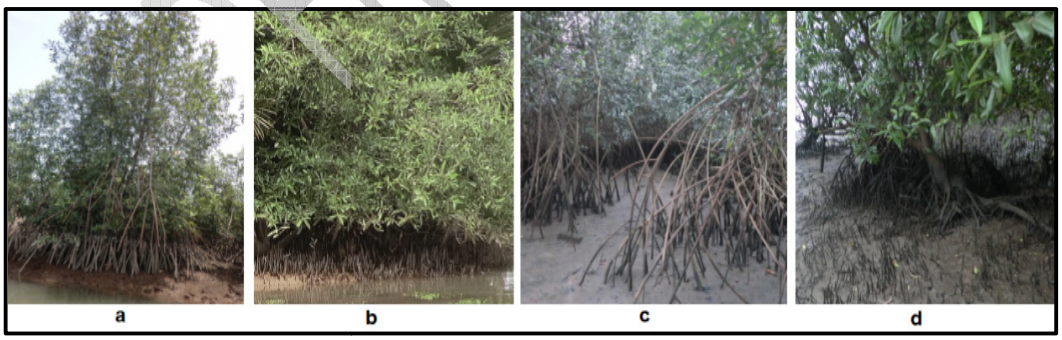

Figure 2: Images of *R. racemosa*and *A. germinans* in Ogbogoro and Isaka (Source: Fieldwork, 2017).

[a] *R. racemosa*in Ogbogoro,[b] *A. germinans* in Ogbogoro

[c] *R. racemosa i*n Isaka,[d] *A. germinans* in Isaka

2.3 SEDIMENT SAMPLING AND PREPARATION

Sediment core samples were collected from Ogbogoro and Isaka at a depth of 10 cm. Two core samples were collected from each location (n = 2). The cores were taken using a transparent 2-inch diameter PVC pipe. Prior to coring, the PVC pipes were decontaminated using ethanol. The cores were manually driven into the muddy mangrove sediments and carefully retrieved. Homogenization of the retrieved core sediment samples was done after which they were placed in ziplock bags, labeled and transported out and stored at 4^{o}C. The samples were air dried for 48 hours to reduce weight before repackaging and putting them in plastic box for export to the Earth Science Laboratory, Shimane University, Japan.

About 30 g each of the sediment samples were put in decontaminated beakers and covered with aluminium foil and using the ISUZU Muffle Furnace, they were oven dried at 160^{o}C for 48 hours. Sediment grinding was done using the Automatic Agate Mortar and Pestle for 20 minutes. The powdered sediments were made into briquettes by compressing about 5 g each using 200 kN for 60 seconds.

2.4 *R. racemosa* AND *A. germinans* SAMPLING AND PREPARATION

The *R. racemosa* samples were equally collected from Ogbogoro and Isaka. The stilt aerial roots, stems and leaves of three *R. racemosa* were sampled in each location (n = 3) while one (n =1) and three (n =3) samples of pneumatophores, stems and leaves of *A. germinans*werecollected from Ogbogoro and Isaka respectively. The samples were cut into smaller sizes and placed in plastic ziplock bags and labeled. The samples were immediately taken to the Nigerian Stored Products Research Institute (NSPRI) Port-Harcourt where they were dried at 80^{o}C for 24 hours. Then, they were repackaged and carefully arranged in plastic boxes, sealed and exported to the Earth Science Laboratory, Shimane University, Japan.

About 20 g of the root, stem and leaf samples each was put in decontaminated beakers, covered with aluminium foil and using the ISUZU Muffle Furnace, they were oven dried at 110^{o}C for 24 hours and later at 160^{o}C for 48 hours. They were ground using the Automatic Agate Mortar and Pestle for 20 minutes. Also, the powdered *R. racemosa* samples were made into briquettes by compressing about 5 g each using 200 kN for 60 seconds.

2.5 LABORATORY ANALYSIS

Eleven trace elements; As, Pb, Zn, Cu, Ni, Cr, V, Sr, Y, Nb and Zr as well as fourmajor elements; TiO_2,MnO, CaO and P_2O_5 were analyzed for both sediment and *R. racemosa* samples. Using X-ray fluorescence (XRF) RIX-200 spectrometer. In accordance with [19], all the XRF analysis were made from pressed powder briquettes with average errors being less than $\pm$ 10 %.

2.6 STATISTICAL ANALYSIS

The mean concentrations of the trace and major elements in sediment, *R. racemosa* and *A. germinans*sampleswere done using

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Microsoft Excel 2013. KaleidaGraph 4.0 was used to plot the graphs.

2.7 ENVIRONMENTAL RISK ANALYSIS (ERA)

2.7.1 CONTAMINATION FACTOR (CF)

To determine the extent of heavy metal contamination in the sub-core sediments of Niger Delta mangroves, the contamination factor was used. [20] expressed contamination factor thus:

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

Where:

C_{metal} is the current metal concentration in the plant tissues.

$C_{background}$ is the background metal concentration of sediments.

In this study, the upper continental crust proposed by [21] was used as the background metal concentration. The CF is interpreted as follows: CF < 1: signifies low contamination; 1 ≤ CF < 3: signifies moderate contamination; 3 = CF ≤ 6: signifies considerable contamination and CF ≥ 6: signifies very high contamination [20].

2.7.2 POLLUTION LOAD INDEX (PLI)

To determine the magnitude of heavy metal concentrationsin *R. racemosa* and *A. germinans* plant samples, the bio-concentration factor was applied. According to [20], pollution load index is given as:

$$PLI = \sqrt[n]{CF_1 \times CF_2 \ldots \times CF_n}$$

Where:

n is the number of metals and CF is the contamination factor.

PLI value < 1 is unpolluted, PLI = 1 indicates metal load that approximates to the background concentrations while PLI > 1 is polluted [22].

2.8 PHYTOREMEDIATION POTENTIAL ANALYSIS (PPA)

2.8.1 BIO-CONCENTRATION FACTOR (BCF)

To determine the extent of heavy metal concentrationsin the leaves , stems and roots of the *R. racemosa* and *A. germinans* plant samples from the Niger Delta mangroves, the bio-concentration factor was employed. According to [23], bio-concentration factor is expressed thus:

$$BAF\ (leaves) = L_{mc} / S_{mc}$$

$$BAF\ (stems) = St_{mc} / S_{mc}$$

$$BCF = R_{mc} / S_{mc}$$

Where:

L_{mc}, St_{mc} and R_{mc} are metal concentrations in stems and leaves respectively while

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S_{mc} is the soil metal concentration.

BCF > 1 is an indication of hyperaccumulation [24].

2.8.2 BIO-TRANSLOCATION FACTOR (BTF)

The rate at which metals concentrated on the *R. racemosa* and *A. germinans* roots were transferred to the stems and leaves was determined using bio-translocation factor (BTF). According to [25], bio-translocation factor is given as concentration in shoot divided by concentration in root. In line with this formula, this study formulated bio-translocation factors for leaves and stems as follows:

BTF (leaves) = L_{mc} / R_{mc}

BTF (stem) = St_{mc} / R_{mc}

Where:

L_{mc} and St_{mc} are metal concentrations in leaves and stems respectively while

R_{mc} is the metal concentration in the root.

BTF > 1 indicates effective translocation [26; 27].

3. RESULTS AND DISCUSSION

3.1 HEAVY METAL CONCENTRATIONS IN NIGER DELTA MANGROVE SEDIMENTS

Details of the heavy metal concentrations in Niger Delta mangrove sediments, their distribution (spatially and vertically) and physico-chemical parameters have been reported earlier. See Nwawuike and Ishiga [11; 12; 4].

Table 1: Mangrove sediment metal concentrations

Trace Elements	Sediments (ppm)
As	7.15
Pb	20.65
Zn	50.40
Cu	16.15
Ni	30.60
Cr	111.80
V	123.15
Sr	59.50
Y	16.00
Nb	16.65
Zr	255.35
Cl	7378.75
TS	24848.50
Major Elements	
TiO_2	0.35
MnO	0.02
CaO	0.60
P_2O_5	0.10

Source: [4]

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3.2 COMPARISON BETWEEN METAL CONCENTRATIONS IN *R. racemosa* AND *A. germinans*

The mean heavy metal concentrations in the leaves, stems and roots of *R. racemosa* and *A. germinans* are shown in Table 2. The table indicates that the heavy metal concentrations differed in different parts of *R. racemosa* and *A. germinans* as well as among heavy metal types analyzed. The sequences of heavy metal concentrations in *R. racemosa* leaves, stems and roots are: Cl>TS>Sr>Zr>Zn>Ni>Pb>Y>Nb>Cu>As; Cl>TS>Sr>Zn>Zr>Ni>Pb>Cu>Y>Nb>As and Cl>TS>Zn>Sr>Zr>Ni>Pb>Cu>Y>Nb>As respectively. For the major elements, the trends are CaO>MnO>P_2O_5 in leaves and CaO>P_2O_5>MnO in both stems and roots. However, in *A. germinans*, the metal concentration sequences are Cl>TS>Zn>Sr>Zr>Ni>Pb>Cu>Y>Nb>As in the leaves, Cl>TS>Zn>Sr>Zr>Ni>Pb>Cu>Y>Nb>As in the stems and Cl>TS>Zn>Sr>Ni>Zr>Pb>Cu>Y>Nb>As in the roots. The major elements have same concentration pattern in *A. germinans*; CaO>P_2O_5. As (7.15) and MnO (0.02) have the least concentrations of the trace and major elements in the sediments and also are the least concentrated in *R. racemosa* while As and P_2O_5 are the least in *A. germinans*. Though TS (24848.50) and CaO (0.60) are most abundant among the analyzed trace and major elements in the sediments, Cl and CaO were most abundant in *R. racemosa* and *A. germinans*.

Interestingly, Cr,V and TiO_2 were not detected in both *R. racemosa* and *A. germinans* while MnO was detected in *R. racemosa* but not detected in *A. germinans*. The non detection of Cr, V, TiO_2 and MnO despite being available in the sediments might be due to phytoexclusion [4] or low bioavailability of these metals in the sediments [28]. Sr, Zr and CaO had higher concentrations in *R. racemosa* relative to *A. germinans* while Zn, Cu, Ni, Nb, Cl and TS are comparatively more concentrated in *A. germinans* than in *R. racemosa*. However, As, Pb, Y and P_2O_5 have similar concentrations in both mangrove species. The observed differences in metal concentrations in *R. racemosa* and *A. germinans* might be due to variations in metal uptake mechanisms of the plants. This according to [29] includes uptake by roots, xylem loading and transport to shoots. Comparison of metal concentrations in sediments with concentrations in *R. racemosa* and *A. germinans* is shown in Fig. 3 while the comparison of metal concentration trends in *R. racemosa* and *A. germinans* leaves, stems and roots are presented in Fig. 4.

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Table 2: Mean metal concentrations in leaves, stems and roots of *R. racemosa* and *A. germinans*

Trace Elements	**Samples**	***R.racemosa* (ppm)**	***A. germinans* (ppm)**
	Leaves	1.00	0.79
	Stems	1.00	1.01
As	Roots	1.75	1.62
	Leaves	4.80	5.91
	Stems	6.60	6.33
Pb	Roots	6.85	6.88
	Leaves	36.30	99.90
	Stems	121.5	127.19
Zn	Roots	169.65	117.90
	Leaves	1.75	5.54
	Stems	3.50	3.50
Cu	Roots	2.85	4.07
	Leaves	8.45	11.34
	Stems	19.90	19.73
Ni	Roots	17.10	25.42
	Leaves	n.d.	n.d.
	Stems	n.d.	n.d.
Cr	Roots	n.d.	n.d.
	Leaves	n.d.	n.d.
	Stems	n.d.	n.d.
V	Roots	n.d.	n.d.
	Leaves	216.50	56.49
	Stems	207.45	64.01
Sr	Roots	109.30	37.13
	Leaves	2.55	2.90
	Stems	2.40	2.45
Y	Roots	2.75	3.04
	Leaves	1.80	2.12
	Stems	1.85	1.94
Nb	Roots	2.10	2.20
	Leaves	45.15	23.08
	Stems	42.90	23.51
Zr	Roots	29.75	23.59
	Leaves	66842.25	125399.41
	Stems	14164.65	37276.18
Cl	Roots	43334.15	47829.56
	Leaves	14834.80	24136.00
	Stems	3846.30	5385.00
TS	Roots	3018.75	14045.00
Major Elements	**Sample**	***R.racemosa***	***A. germinans***
TiO_2	Leaves	n.d.	n.d.
	Stems	n.d.	n.d.
	Roots	n.d.	n.d.
MnO	Leaves	0.15	n.d.
	Stems	0.15	n.d.
	Roots	0.05	n.d.
CaO	Leaves	5.15	1.93
	Stems	5.20	2.26
	Roots	2.58	1.13
P_2O_5	Leaves	0.60	0.75
	Stems	0.45	0.45
	Roots	0.35	0.24

n.d. ----- not detected, ppm ----- parts per million

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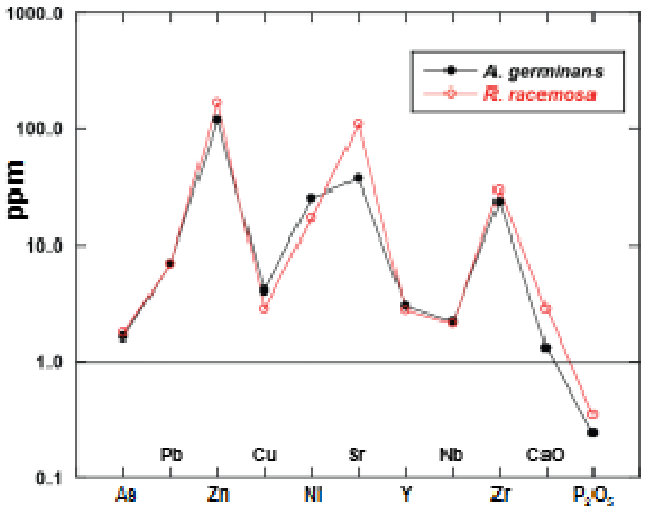

Figure 3: Concentrations of metals in sediments in comparison with concentrations in *R. racemosa* and *A. germinans*

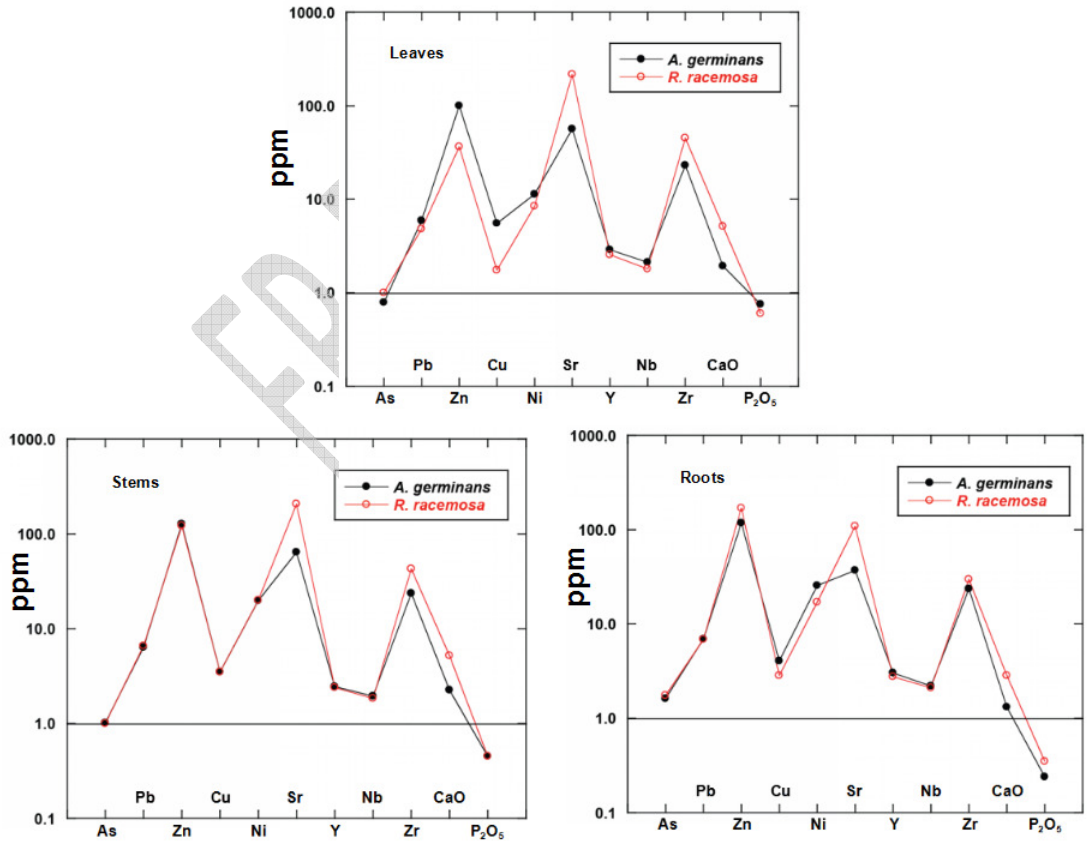

Figure 4: Comparison of metal concentration trends in *R. racemosa* and *A. germinans* leaves, stems and roots

ppm ----- parts per million

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3.3 HEAVY METAL CONTAMINATION IN *R. racemosa* AND *A. germinans*

The extent of heavy metal contamination in *R. racemosa* and *A. germinans* was determined using the contamination factor (CF) with emphasis on biogenic metals. Though this approach is primarily applied to sediments, however, in this study, an attempt was made to apply it to plants. The interpretation of CF adopted was based on [20]. The CF of *R. racemosa* and *A. germinans* are shown in Table 3. The results indicate that As in the leaves and stems of *R. racemosa* and *A. germinans* has a CF of 0.5 while for the roots, it is 0.89 and 1.92 respectively. Pb, Zn, Cu and Ni all have varying CFs for the leaves, stems and roots. In *R. racemosa*, stems and roots have Zn contamination factor of 1.71 and 2.39 while Ni has a contamination factor of 1.00 in the stems. Thus, Zn is moderately contaminated in *R. racemosa* stems and roots while in the stems, Ni has a moderate contamination. Similarly, in *A. germinans*, Zn is moderately contaminated in the leaves (1.41), stems (1.80) and roots (1.93) while As (1.92) and Ni (1.26) are moderately contaminated in the roots.

Table3: Contamination Factors of *R. racemosa* and *A. germinans* in Niger Delta

		CF of Metals				
R. racemosa		**As**	**Pb**	**Zn**	**Cu**	**Ni**
	Leaves	0.5	0.24	0.51	0.07	0.42
	Stems	0.50	0.33	**1.71***	0.14	**1.00***
	Roots	0.89	0.34	**2.39***	0.12	0.86
A. germinans						
	Leaves	0.50	0.29	**1.41***	0.22	0.58
	Stems	0.50	0.33	**1.80***	0.14	0.99
	Roots	**1.92***	0.46	**1.93***	0.17	**1.26***

**moderately contaminated*

3.4 POLLUTION LOAD INDEX (PLI) OF*R. racemosa* AND *A. germinans*

The pollution load index (PLI) was used to highlight the pollution severity of metal concentrations in *R. racemosa* and *A. germinans*. Normally, it is used to indicate the the number of times by which the metal concentrations in sediments are more than the background concentrations [30]. However, in this study, it was applied to indicate the extent by which metal concentrations in *R. racemosa* and *A. germinans* are higher than the background metal concentrations in the sediments. The calculated PLI values are presented in Table 4 and Fig. 5. The results show that *R. racemosa* has PLI of 0.27 (leaves), 0.52 (stems) and 0.59 (roots) while in *A. germinans*, the PLI of leaves, stems and roots are 0.47, 0.61 and 0.81 respectively. According to [22], PLI < 1 is unpolluted, PLI = 1 indicates metal load that approximates to the background concentrations while PLI > 1 is polluted. Thus, the PLI status of the *R. racemosa* and *A. germinans* in Niger Delta mangrove is unpolluted. This finding is consistent with the submission of [4] that low metal concentrations of metals in *R. racemosa* leaves show that the detrital food chain might be uncontaminated.

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Table 4: PLI of *R. racemosa* and *A. germinans* in Niger Delta

Mangrove species	PLI			Status
	Leaves	Stems	Roots	
R. racemosa	0.27	0.52	0.59	Unpolluted
A. germinans	0.47	0.61	0.81	Unpolluted

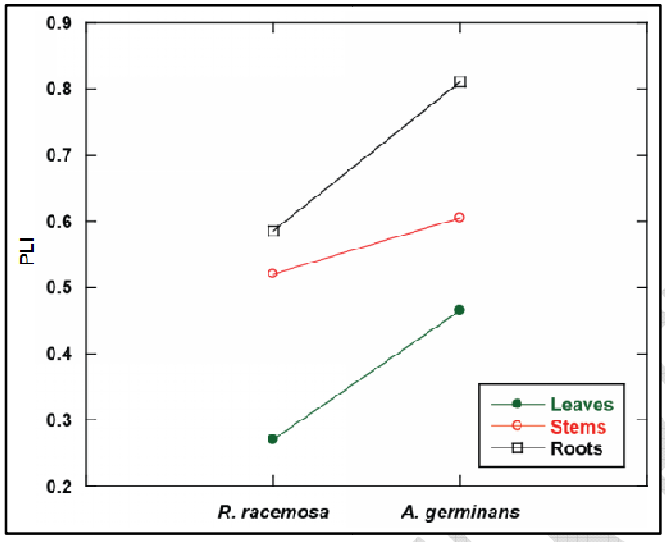

Figure 5: Pollution load in *R. racemosa* and *A. germinans*

3.5 PHYTOREMEDIATION POTENTIALS OF *R. racemosa* AND *A. germinans*

The mangroves of Niger Delta are within the areas of hydrocarbon exploration and exploitation [12]. This area suffers persistent environmental pollution due to industrial and oil related activities. According to [31], mangroves are generally considered to have the ability to accumulate metals and tolerate relatively high levels of heavy metal pollution. Also, they participate in bio-chemical remediation of both organic and inorganic pollutants [32]. However, little work has been done on phytoremediation in mangroves around the world [33]. It therefore becomes imperative to assess the phytoremediation potentials of *R. racemosa* and *A. germinans* which are dominant native mangrove species in Niger Delta. The bio-concentration factor (BCF) and bio-translocation factor (BTF) are essential tools used to estimate phytoremediation potentials [31; 34]. Specifically, BCF highlights the extent to which metal concentrations in tissue relate to concentrations in sediments [35]. Also, metal accumulating plants have the capability of having bioconcentration levels of the pollutants in their tissues above that of the contaminated media [36]. BTF is used to indicate the rate of metal concentrations in the shoot relative to the root [37].

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3.5.1 BIO-CONCENTRATION FACTOR IN*R. racemosa* AND*A. germinans* IN NIGER DELTA MANGROVES

The results of the bio-concentration factors of heavy metals in leaves, stems and roots of *R. racemosa* and *A. germinans* in Niger Delta are shown in Table 5. It was found that the BCF of Sr, Cl, MnO, CaO and P_2O_5 in the leaves; Zn, Sr, Cl, MnO, CaO and P_2O_5 in the stems and roots of *R. racemosa* are greater than 1. This indicates that *R. racemosa* has high efficiency in bio-accumulation of these metals. However, As, Pb, Zn, Cu, Ni, Y, Nb, Zr and TS in the leaves; As, Pb, Cu, Ni, Y, Nb, Zr and TS in the stems and roots of *R. racemosa* have BCF of less than 1 indicating inefficiency in the bio-accumulation of these elements. In *A. germinans*, the BCF of Zn, Cl, CaO and P_2O_5 in the leaves and roots; Zn, Sr, Cl, CaO and P_2O_5 in the stems are above 1 and thus indicates that these metals are efficiently bio-accumulated. On the contrary, the BCF of As, Pb, Cu, Ni, Sr, Y, Nb, Zr and TS in leaves and roots; As, Pb, Cu, Ni, Y, Nb, Zr and TS in the stems of *A. germinans* are less than 1 and therefore not efficiently bio-accumulated. MnO was not detected in *A.germinans* and as such has no BCF.

Table 5: Bio-concentrations in *R. racemosa* and *A. germinans*

Trace Elements	*R. racemosa*			*A. germinans*		
	BCF_L	**BCF_S**	**BCF_R**	**BCF_L**	**BCF_S**	**BCF_R**
As	0.14	0.14	0.24	0.11	0.14	0.23
Pb	0.23	0.32	0.33	0.29	0.31	0.33
Zn	0.72	**2.41**	**3.37**	**1.98**	**2.52**	**2.34**
Cu	0.11	0.22	0.18	0.34	0.22	0.25
Ni	0.28	0.65	0.56	0.37	0.64	0.83
Sr	**3.64**	**3.49**	**1.84**	0.95	**1.08**	0.62
Y	0.16	0.15	0.17	0.18	0.15	0.19
Nb	0.11	0.11	0.13	0.13	0.12	0.13
Zr	0.18	0.17	0.12	0.09	0.09	0.09
Cl	**9.06**	**1.92**	**5.87**	**16.99**	**5.05**	**6.48**
TS	0.60	0.15	0.12	0.97	0.22	0.57
Major Elements						
MnO	**7.50**	**7.50**	**2.5**	-	-	-
CaO	**8.58**	**8.67**	**4.75**	**3.21**	**3.76**	**2.18**
P_2O_5	**6.00**	**4.50**	**3.50**	**7.51**	**4.50**	**2.41**

3.4.2 BIO-TRANSLOCATION FACTOR IN *R. racemosa* AND *A. germinans* IN NIGER DELTA MANGROVES

The BTF of the*R. racemosa* and *A. germinans* leaves and stems in Niger Delta Mangroves are presented in Table 6. The results indicate that As, Pb, Zn, Cu, Ni, Y and Nb in *R. racemosa* and As, Pb, Zn, Ni, Y, Nb and Zr in *A. germinans* have BTF of below 1 which is an indication of ineffective translocation of these metals in the leaves. However, Sr, Zr, Cl, TS, MnO, CaO and P_2O_5 in *R. racemosa* and Cu, Sr, Cl, TS, CaO and P_2O_5 in *A. germinans* have BTF greater than 1 in their leaves and this indicates phytoextraction of these metals. In the stems, As, Pb, Zn, Y, Nb and Cl in *R. racemosa* and As, Pb, Cu, Ni, Y, Nb, Cl and TS in *A. germinans* have BTF less than 1 and implies that these metals are inefficiently translocated in the stems of these mangrove plants. But, Cu, Ni, Sr, Zr, TS MnO, CaO and P_2O_5 in *R. racemosa* and Zn, Sr, Zr,CaO and P_2O_5 in *A. germinans* have BTF greater than 1. As such, these metals are efficiently translocated in the roots. This implies that *R. racemosa* is

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capable of in-situ phytoremediation of Cu, Ni, Sr, Zr, Cl, TS, MnO, CaO and P_2O_5 while *A. germinans* is capable of in-situ phytoremediation of Zn, Cu, Sr, Zr, Cl, TS, CaO and P_2O_5.

Table 6. Heavy metal bio-translocation factors in *R. racemosa* and *A. germinans*

Trace Elements	*R. racemosa*		*A. germinans*	
	BTF_L	BTF_S	BTF_L	BTF_S
As	0.57	0.57	0.49	0.63
Pb	0.70	0.96	0.86	0.92
Zn	0.21	0.72	0.85	**1.08**
Cu	0.61	**1.23**	**1.36**	0.86
Ni	0.49	**1.16**	0.45	0.78
Sr	**1.98**	**1.90**	**1.52**	**1.72**
Y	0.93	0.87	0.95	0.81
Nb	0.86	0.88	0.96	0.88
Zr	**1.52**	**1.44**	0.98	**1.00**
Cl	**1.54**	0.33	**2.62**	0.78
TS	**4.91**	**1.27**	**1.72**	0.38
Major Elements				
MnO	**3.00**	**3.00**	-	-
CaO	**1.81**	**1.82**	**1.47**	**1.72**
P_2O_5	**1.71**	**1.29**	**3.12**	**1.87**

4. CONCLUSION

Variations were observed on metal concentrations in R. racemosa and A. germinans. Sr, Zr and CaO had higher concentrations in *R. racemosa* relative to *A. germinans* while Zn, Cu, Ni, Nb, Cl and TS are comparatively more concentrated in *A. germinans* than in *R. racemosa*. However, As, Pb, Y and P_2O_5 have similar concentrations in both mangrove species. The observed differences in metal concentrations in *R. racemosa* and *A. germinans* might be due to variations in metal uptake mechanisms of the plants. However, Cr,V and TiO_2 were not detected in both *R. racemosa* and *A. germinans* while MnO was detected in *R. racemosa* but not detected in *A. germinans*. The non detection of C, V, TiO_2 and MnO despite being available in the sediments might be due to phytoexclusion.

In *R. racemosa*, stems and roots have Zn contamination factor of 1.71 and 2.39 while Ni has a contamination factor of 1.00 in the stems. Thus, Zn is moderately contaminated in *R. racemosa* stems and roots while in the stems, Ni has a moderate contamination. Similarly, in *A. germinans*, Zn is moderately contaminated in the leaves (1.41), stems (1.80) and roots (1.93) while As (1.92) and Ni (1.26) are moderately contaminated in the roots. PLI status of the *R. racemosa* and *A. germinans* in Niger Delta mangrove is unpolluted.*R. racemosa* has high efficiency in bio-accumulation of Sr, Cl, MnO, CaO and P_2O_5 in the leaves; Zn, Sr, Cl, MnO, CaO and P_2O_5 in the stems and roots while *A. germinans*is efficient in bio-accumulating Zn, Cl, CaO and P_2O_5 in the leaves and roots; Zn, Sr, Cl, CaO and P_2O_5 in the stems. It was found that *R. racemosa* and *A. germinans* has phytoremediation capacities in Cu, Ni, Sr, Zr, Cl, TS, MnO, CaO, P_2O_5 and Zn, Cu, Sr, Zr, CaO, P_2O_5 respectively.

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COMPETING INTEREST

The authors hereby declare that there is no competing interest.

REFERENCES

1. United Nations Environmental Programme (UNEP). Mangroves of Western and Central Africa. UNEP-Regional Seas Programme/UNEP-WCMC. 2007.

2. Feka, ZN. Sustainable Management of Mangrove Forest in West Africa: A New Policy Perspective? Ocean and Coastal Management. 2015; 116: 341 - 352.

3. Lo, EYY; Duke, NC; Sun, M. (2014), "Phylogeographic Pattern of Rhizophora (Rhizophoraceae) Reveals the Importance of both Vicariance and Long-Distance Ocean Dispersal to Modern Mangrove Distribution", BMC Evolution Biology.2014; 14, 83. doi: 10.1186/1471-2148-14-83.

4. Nwawuike,N; Ishiga, H. Heavy Metal Concentrations in Mangrove Sediments and *R. racemosa*inNiger Delta, Nigeria. Journal of Geography, Environment and Earth Science International.2018a; 17 (4): 1 - 11.

5. Defew, LH; Mair, JM; Guzman, HM. An Assessment of Metal Contamination in Mangrove Sediments and Leaves from Punta Mala Bay, Pacific Panama. Maritime Pollution Bulletin. 2005; 50: 547 - 552.

6. Fernandes, L; Nayak, GN; Ilangovan, D. Geochemical Assessment of Metal Concentrations in Mangrove Sediments along Mumbai Coast, India. World Academy of Science, Engineering Technology. 2012; 61: 258 - 263.

7. United Nations Development Programme (UNDP). Niger Delta Human Development Report. Lagos: Perfect Printers Ltd. 2006; P.76.

8. Uzoukwu, PU; Leton, TG; Jamabo, NA. Survey of the Physical Characteristics of the Upper Reach of the New Kalabar River, Niger Delta, Nigeria. Trends in Applied Sciences Research. 2014; 9: 494 - 502.

9. Harbinson, P. Mangrove Mud: A Sink and a Source for Trace Metals. Marine Pollution Bulletin. 1986; 17, 246 - 250.

10. Erakhrumen, AA. Assessment of In-Situ Natural Dendroremediation Capability of Rhizophora racemosa in a Heavy Metal Polluted Mangrove Forest, Rivers State, Nigeria. Journal of Applied Science, Environment and Management. 2015; 19 (1): 21 - 27.

11. Nwawuike, N; Ishiga, H. Geochemical Evaluation of Surface Sediments in Niger Delta Mangrove, Nigeria. Journal of Environment and Earth Science 2018b; 8 (2), 48 - 60.

12. Nwawuike, N; Ishiga, H.Elemental Composition of Core Sediments in Niger

UNDER PEER REVIEW

Delta Mangrove, Nigeria.Journal of Geography, Environment and Earth Science International. 2018c; 16 (3), 1 - 18.

13. Adejuwon, JO.Rainfall Seasonality in the Niger Delta Belt Nigeria. Journal of Geography and Regional Planning. 2012; 5(2), 51 - 60. doi: 10.5897/JGRP11.096.

14. United Nations Development Programme (UNDP). Niger Delta Bioderversity Project. UNDP Project Document. 2012.

15. Ekwere, A; Ekwere, S; Obim, V. Heavy Metal Geochemistry of Stream Sediments from Parts of the Eastern Niger Delta Basin, South Eastern Nigeria.*RMZ-M&G*2013; **60**, 205 - 210.

16. McKee, KL; Mendelssohn, IA; Hester, MW. Re-examination of pore water sulfide concentrations and redox potentials near the aerial roots of *Rhizophora mangle* and *Avicennia germinans*. American Journal of Botany. 1988; 75 (9): 1352–1359.

17. Chima UD; Larinde SL. Deforestation and Degradation of Mangroves in the Niger Delta Region of Nigeria: Implications in a Changing Climate. 38th Annual Conference of the Forestry Association of Nigeria, 2016; volume 38.

18. Ellison, A; Farnsworth, E; Moore, G. *Avicennia germinans*. *The IUCN Red List of Threatened Species* 2010: e.T178811A7613866. http://dx.doi.org/10.2305/IUCN.UK.2010-2.RLTS.T178811A7613866.en. Downloaded on 30 December 2018.

19. Ogasawara, M.Trace Element Analysis of Rock Samples by X-ray Fluorescence Spectrometer Using Rh Anode Tube. Bulletin of the Geological Survey Japan.1987; 38, 57 - 68.

20. Tomlinson, D. C; Wilson, CR; Jeffrey, DW. Problems in the Assessment of Heavy-metal Levels in Estuaries and the Formation of a Pollution Index. Helgolander Meeresuntersuchungen. 1980;33 (1 -4), 566 - 575.

21. Taylor, SR; McLennan, SM. The Continental Crust: Its Composition and Evolution. Oxford: Backwell Scientific Publications. 1985; p. 312.

22. Cabrera, F; Clemente, L; Barrientos, DE. Heavy Metal Pollution of Soils Affected by the Guadiamar Toxic Flood. The Science of the Total Environment. 1999; 242 (1 - 3): 117 - 129.

23. Yoon, J; Cao, X; Zhou, Q; Ma, LQ. Accumulation of Pb, Cu and Zn in Native Plants Growing on a Contaminated Florida Site. Science of the Total Environment. 2006; 368, 456 - 464. doi: 10.1016/j.scitotenv.2006.01.016.

24. Cluis, C.Junk-greedy Greens: Phytoremediation as a New Option for Soil Decontamination. BioTecch Journal. 2004; 2, 61 - 67.

25. Yanqun, Z; Yuan, L; Jianjun, C; Haiyan, C; Li, Q; Schvartz, C. Hyperaccumulation of Pb, Zn and Cu in Herbaceous Grown on Lead-Zinc Minning Area in Yunnan, China. Environmental International. 2005; 31, 755 - 762.

26. Baker, AJM; Brooks, RR.Terrestrial Higher Plants which Hyperaccumulate Metallic Elements: A Review of their Distribution, Ecology and Phytochemistry. Biorecovery. 1989; 1, 81 - 126.

UNDER PEER REVIEW

27. Rezvani, M; Zaefarian, F.Bioaccumulation and Translocation Factors of Cadmium and Lead in Aeluropus Littoralis. Australian Journal of Agricultural Engineering. 2011; 2 (4), 114 - 119.

28. Usman, ARA; Alkredaa, RS; Al-Wabel, MI. Heavy Metal Concentration in Sediments and Mangroves from the Coast of Red Sea: Avicennia marina as Potential Metal Bioaccumulator. Ecotoxicology and Environmental Safety. 2013; 97: 263 - 270. doi: 10.1016/j.ecoenv.2013.08.009.

29. Clemens, S; Palmgren M. G; Kramer, U.A Long Way Ahead: Understanding and Engineering Plant Metal Accumulation. Trends in Plant Sciences. 2002;7, 309 - 315.

30. Nweke, MO; Ukpai, SN. Use of Enrichment, Ecological Risk and Contamination Factors with Geoaccumulation Indexes to Evaluate Heavy Metal Contents in the Soils around Ameka Mining Area, South of Abakaliki, Nigeria. Journal of Geography, Environment and Earth Science International. 2016; 5 (4): 1 - 13. doi: 10.9734/JGEESI/2016/24908.

31. Khan, MU; Ahmed, M; Shaukat, SS; Nazim, K; Ali, QM. Effect of Industrial Waste on Early Growth and Phytoremediation Potential of *Avicennia marina* (FORSK.) V. PB. 2013; 45 (1): 17 - 27.

32. Mac-Farlane, GR; Claudia, EK; Simon, PB. Accumulation and Partitioning of Heavy Metals in Mangroves: A Synthesis of Field-based Studies. Chemosphere. 2007; 69: 1454 - 1464.

33. Lacerda, LD. Trace Metals in Mangrove Plants: Which Show High Concentrations? In Mangrove Ecosystem Studies in Latin America and Africa (Eds.): Kerfive, B; Lacerda, LD; Drop, ES. UNESCO: Paris. 1997; 171 - 178.

34. Singh, N; Kaur, M; Katnoria, JK. Analysis of Bio-accumulation of Metals in Aquatic Environment of Beas River Basin: A Case Study from Kanjli Wetland. GeoHealth. 2017; 93 - 105. doi: 10.1002/2017GH000062.

35. Qiu, YW; Yu, KF; Zhang, G; Wang, WX. Accumulation and Partitioning of Seven Trace Metals in Mangroves and Sediment Cores from three Estuarine Wetlands of Hainan Island, China. Journal of Hazardous Mater. 2011; 190: 631 - 638.

36. Erakhrumen, A.A.Potentials of Rhizophora racemosa for Bio-Indication and Dendroremediation of Heavy Metal Contamination in a Mangrove Forest, Ondo State, Nigeria. Nigerian Journal of Agriculture, Food and Environment. 2014; 10(4): 1-5.

37. Usman, ARA; Lee, SS; Awad, YM; Lim, KJ; Yang, JE; Ok, YS. Soil Pollution Assessment and Identification of Hyperaccumulating Plants in Chromated Copper Arsenate (CCA) Contaminated Sites, Korea. Chemosphere. 2012; 87:872 - 878.

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