*Asian Journal of Environment & Ecology*

*8(3): 1-13, 2018; Article no.AJEE.46734*
*ISSN: 2456-690X*

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

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***Authors' contributions***

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

***Article Information***

DOI: 10.9734/AJEE/2018/46734
Editor(s):
(1) Dr. Sylwia Myszograj, Department of Water Technology, Sewage and Wastes, University of Zielona Gora, Poland.
Reviewers:
(1) Ekoa Bessa Armel Zacharie, University of Yaounde I, Cameroon.
(2) Timur Chis Ovidius, Universitatea Ovidius din Constanta, Romania.
Complete Peer review History: http://www.sdiarticle3.com/review-history/46734

***Original Research Article***

***Received 01 November 2018***
***Accepted 16 January 2019***
***Published 22 January 2019***

## 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

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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.*

## 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.

## 2. MATERIALS AND METHODS

### 2.1 Study Site

The Ogbogoro mangrove forests along the banks of the New Kalabar River and Isaka mangrove forests along the banks of the Bonny River ($4^{o}26$ to $4^{o}53$N and $6^{o}45$ to $7^{o}15$) 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 [13,14]. 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].

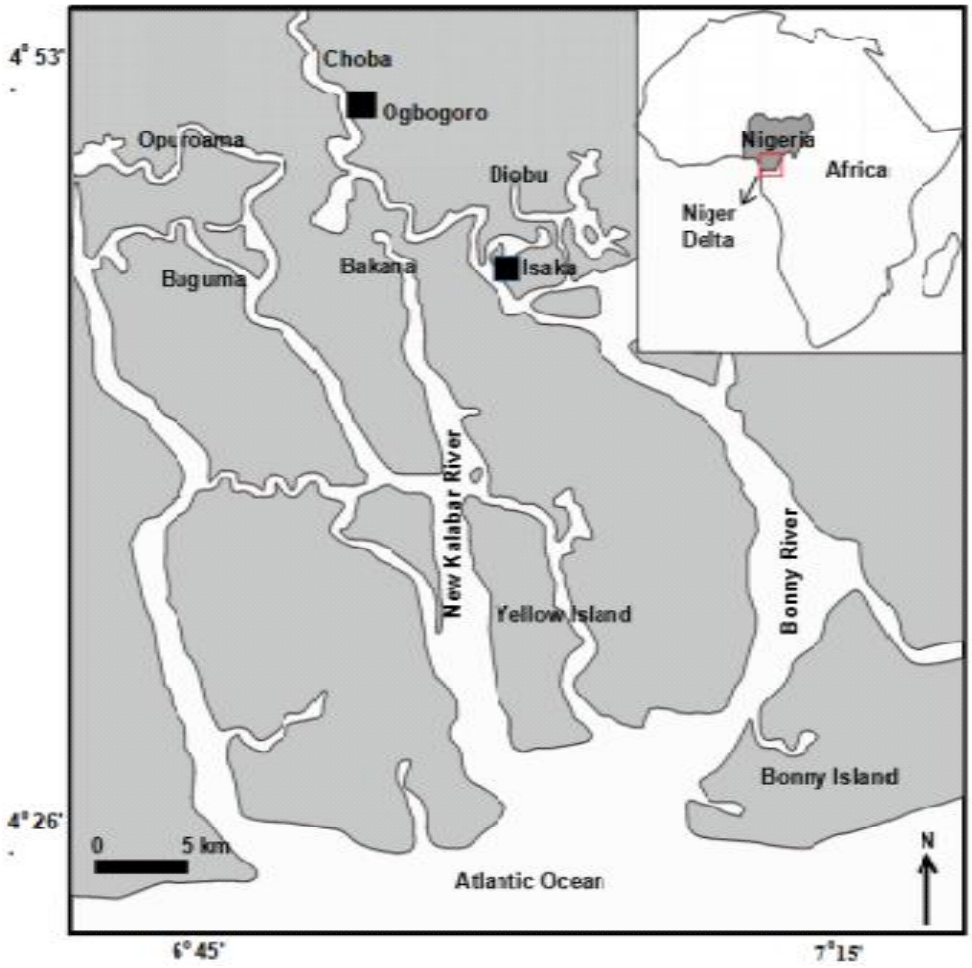


**Fig. 1. Study area map showing sampling locations. Modified from [11]**

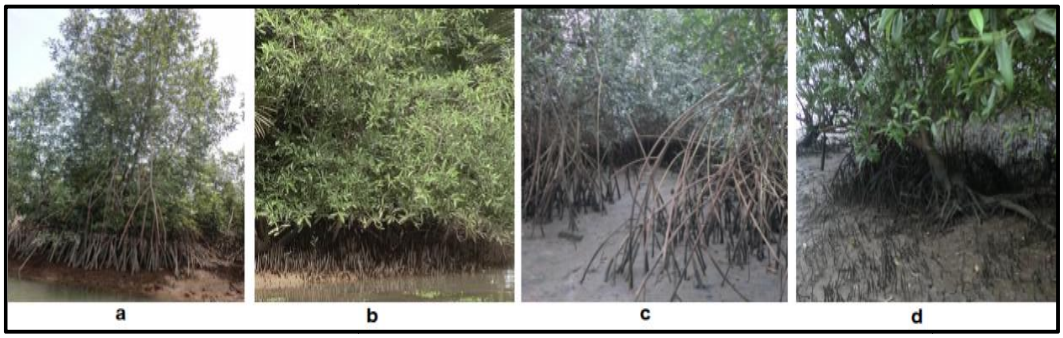


**Fig. 2. Images of *R. racemosa* and *A. germinans* in Ogbogoro and Isaka**

*(Source: Fieldwork, 2017)*

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

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

## 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.

## 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°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°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* were collected 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°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°C for 24 hours and later at 160°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 four major 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* samples were done using 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. Tomlinson et al. [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 Taylor and McLennan [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 concentrations in *R. racemosa* and *A. germinans* plant samples, the bio-concentration factor was applied. According to Tomlinson et al. [20], pollution load index is given as:

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

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 concentrations in 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 Yoon et al. [23], bio-concentration factor is expressed thus:

$BCF\ (leaves) = L_{mc} / S_{mc}$
$BCF\ (stems) = St_{mc} / S_{mc}$
$BCF = R_{mc} / S_{mc}$

Where:

$L_{mc}$, $St_{mc}$ and $R_{mc}$ are metal concentrations in stems and leaves respectively while
$S_{mc}$ 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 Yanqun et al. [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].

### 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*.

**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]*

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 Clemens et al. [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.

### 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.

### 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

**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) |
|---|---|---|---|
| As | Leaves | 1.00 | 0.79 |
| | Stems | 1.00 | 1.01 |
| | Roots | 1.75 | 1.62 |
| Pb | Leaves | 4.80 | 5.91 |
| | Stems | 6.60 | 6.33 |
| | Roots | 6.85 | 6.88 |
| Zn | Leaves | 36.30 | 99.90 |
| | Stems | 121.5 | 127.19 |
| | Roots | 169.65 | 117.90 |
| Cu | Leaves | 1.75 | 5.54 |
| | Stems | 3.50 | 3.50 |
| | Roots | 2.85 | 4.07 |
| Ni | Leaves | 8.45 | 11.34 |
| | Stems | 19.90 | 19.73 |
| | Roots | 17.10 | 25.42 |
| Cr | Leaves | n.d. | n.d. |
| | Stems | n.d. | n.d. |
| | Roots | n.d. | n.d. |
| V | Leaves | n.d. | n.d. |
| | Stems | n.d. | n.d. |
| | Roots | n.d. | n.d. |
| Sr | Leaves | 216.50 | 56.49 |
| | Stems | 207.45 | 64.01 |
| | Roots | 109.30 | 37.13 |
| Y | Leaves | 2.55 | 2.90 |
| | Stems | 2.40 | 2.45 |
| | Roots | 2.75 | 3.04 |
| Nb | Leaves | 1.80 | 2.12 |
| | Stems | 1.85 | 1.94 |
| | Roots | 2.10 | 2.20 |
| Zr | Leaves | 45.15 | 23.08 |
| | Stems | 42.90 | 23.51 |
| | Roots | 29.75 | 23.59 |
| Cl | Leaves | 66842.25 | 125399.41 |
| | Stems | 14164.65 | 37276.18 |
| | Roots | 43334.15 | 47829.56 |
| TS | Leaves | 14834.80 | 24136.00 |
| | Stems | 3846.30 | 5385.00 |
| | 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*

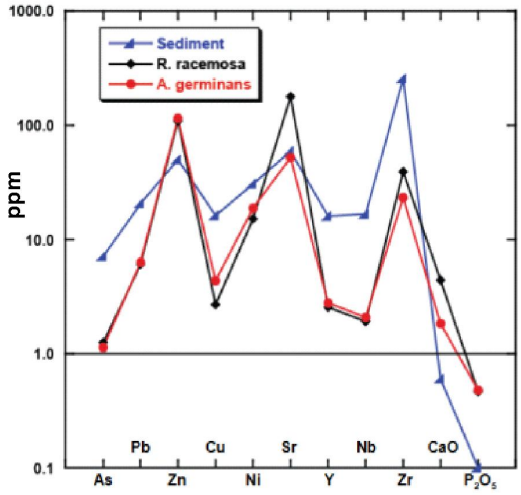


**Fig. 3. Concentrations of metals in sediments in comparison with concentrations in *R. racemosa* and *A. germinans***

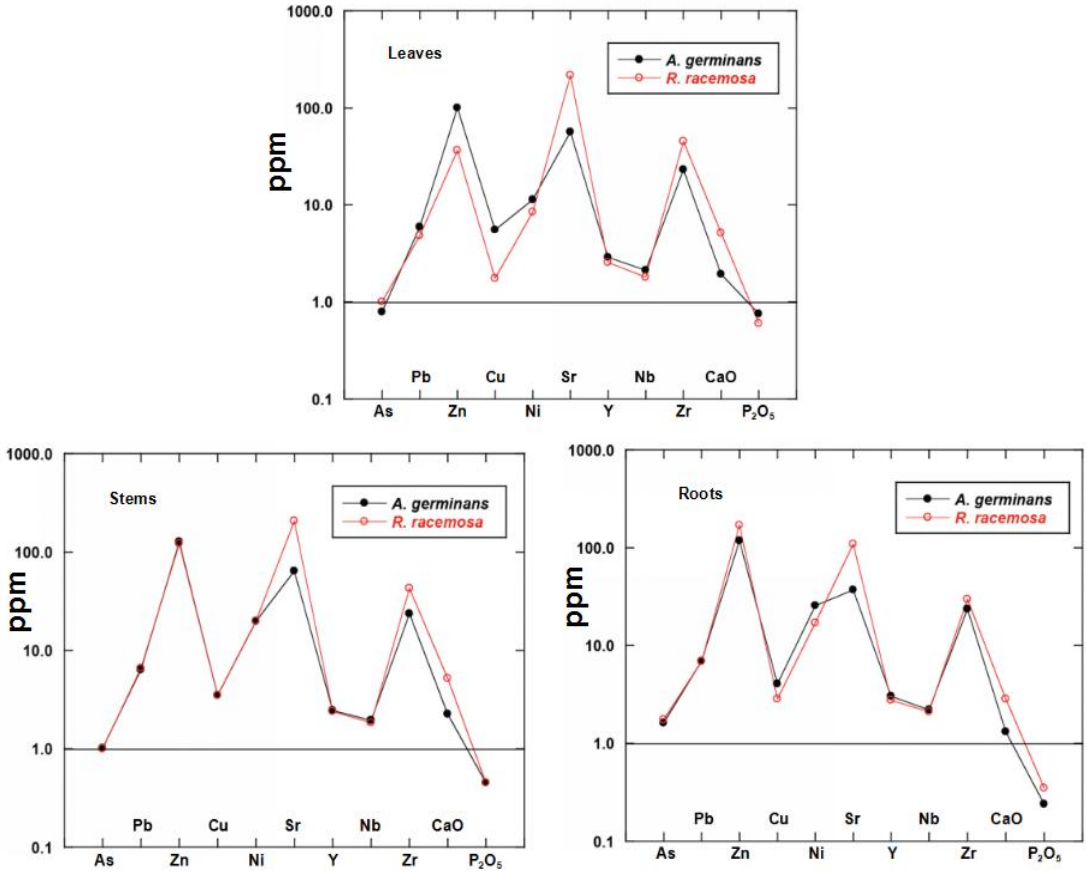


**Fig. 4. Comparison of metal concentration trends in *R. racemosa* and *A. germinans* leaves, stems and roots**

*ppm ----- parts per million*

**Table 3. Contamination factors of *R. racemosa* and *A. germinans* in Niger Delta**

| | | CF of metals | | | | |
|---|---|---|---|---|---|---|
| ***R. racemosa*** | | **As** | **Pb** | **Zn** | **Cu** | **Ni** |
| | Leaves | 0.50 | 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*

**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 |

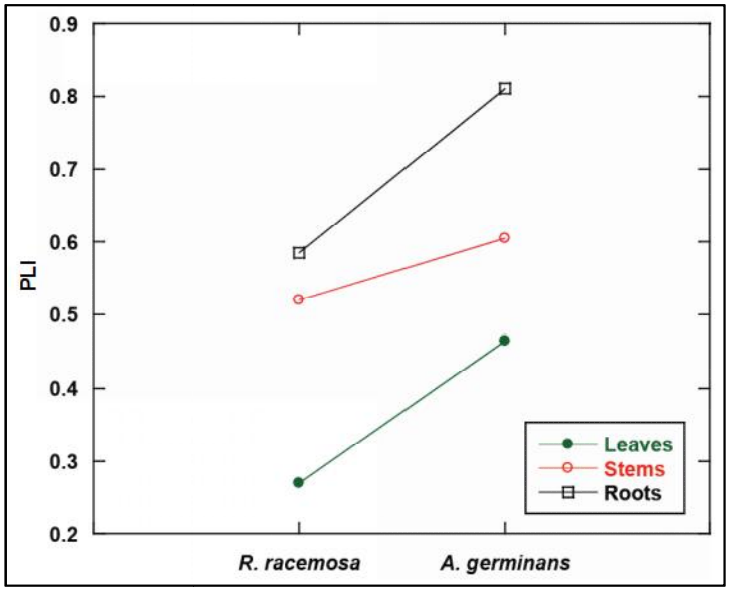


**Fig. 5. Pollution load in *R. racemosa* and *A. germinans***

(roots) while in *A. germinans*, the PLI of leaves, stems and roots are 0.47, 0.61 and 0.81 respectively. According to Cabrera et al. [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 Nwawuike and Ishiga [4] that low metal concentrations of metals in *R. racemosa* leaves show that the detrital food chain might be uncontaminated.

### 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 Khan et al. [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].

### 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.

### 3.5.2 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,

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

| | *R. racemosa* | | | *A. germinans* | | |
|---|---|---|---|---|---|---|
| **Trace elements** | **$BCF_L$** | **$BCF_S$** | **$BCF_R$** | **$BAF_L$** | **$BAF_S$** | **$BCF_R$** |
| 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** |

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

| Trace elements | *R. racemosa* | | *A. germinans* | |
|---|---|---|---|---|
| | $TSF_L$ | $TSF_S$ | $TSF_L$ | $TSF_S$ |
| 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** |

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 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 $P_2O_5$.

## 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.

## ACKNOWLEDGEMENTS

The authors are grateful to the Ministry of Agriculture, Forestry and Fisheries, Kobe, Japan for import permission, Nigerian Agricultural Quarantine Service, Port Harcourt for export permit for the samples and Nigerian Stored Products Research Institute (NSPRI), Port Harcourt for drying the plant samples; Dr. Nwajiaku, IM for her statistical suggestions Dr. Ubouh, E.A and Osujieke, D for their help during sample collection.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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