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Short Communication

Phytoremediation potential of *Eichornia crassipes* in metal-contaminated coastal water

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ABSTRACT

The potential of *Eichornia crassipes* to serve as a phytoremediation plant in the cleaning up of metals from contaminated coastal areas was evaluated in this study. Ten metals, As, Cd, Cu, Cr, Fe, Mn, Ni, Pb, V and Zn were assessed in water and the plant roots and shoots from the coastal area of Ondo State, Nigeria and the values were used to evaluate the enrichment factor (EF) and translocation factor (TF) in the plant. The critical concentrations of the metals were lower than those specified for hyperaccumulators thus classifying the plant as an accumulator but the EF and TF revealed that the plant accumulated toxic metals such as Cr, Cd, Pb and As both at the root and at the shoot in high degree, which indicates that the plant that forms a large biomass on the water surface and is not fed upon by animals can serve as a plant for both phytoextraction and rhizofiltration in phytoremediation technology.

1. Introduction

Eichornia crassipes (water hyacinth) is a member of pickerlweed family (Pontederiaceae) (Bailey, 1949; Chillers, 1991). It originated in tropical South America, but has become naturalized in many warm areas of the world: Central America; North America (California and southern states); Africa; Asia and Australia (Bailey, 1949; Center and Spencer, 1981). It reproduces sexually by seeds (Agami and Reddy, 1990) and is one of the most productive plants on earth thus it is considered the world's worst aquatic plant (Charudattan, 1986). It forms dense mats that interfere with navigation, recreation, irrigation and power generation (Center and Spencer, 1981). These mats competitively exclude native submersed and floating-leaved plants (Harun et al., 2008). The low oxygen conditions develop beneath the water hyacinth mats and the dense floating mats impede water flow and create good breeding conditions for mosquitoes (Charudattan, 1986). However, its rate of breeding, its other qualities and the growing research work on the use of plants for remediation of chemical contamination in the environment inform the need for the investigation of this plant for phytoremediation potentials.

Phytoremediation, the use of plants to remove pollutants from the environment, is a growing field of research in environmental studies because of the advantages of its environmental friendliness, cost effectiveness and the possibility of harvesting the plants for the extraction of absorbed contaminants such as metals that cannot be easily biodegraded for recycling among others (Maine et al., 2001, 2004; Skinner et al., 2007; Malik, 2007). However, phytoremediation is being limited by its time-consuming nature because of the natural cycle of plants which is long but with highly productive plants such as *E. crassipes* this disadvantage may not be significant. Also, phytoremediation works best when the contaminants discharged into the environment are within the reach of the plant roots. Thus, the formation of dense mats on the water surface by the plant and its fibrous roots system enhance its spread and the degree to which the contaminants discharged into the water system reach its roots. Likewise, its broad leaves may tolerate high metal concentration. Thus, *E. crassipes* possesses the qualities that favour its potential use in water and wastewater phytoremediation. Limited works exist in the literature on the phytoremediation capacity of *E. crassipes* (Zaranyika et al., 1994; Soltan and Rashed, 2003; Harun et al., 2008). Harun et al. (2008) reported the site-related effects of *E. crassipes* in the remediation of metal contamination while phytoremediation generally depends on the plant age, degree of site contamination, the ability of the plants to accumulate large quantities of metals in their tissues and other biochemical factors (Brooks et al., 1998; Wei et al., 2009). There are also limited data on the capacity of *E. crassipes* to remediate a broad spectrum of metals particularly the highly toxic ones and limited data on phytoremediation of contaminated water bodies as against remediation of soil that is more common.

The objective of this study is therefore to evaluate the potential of *E. crassipes* as a phytoremediation plant in coastal water that has been reported as contaminated with metals (Adebowale et al., 2008a).

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2. Methods

2.1. Study area

Ondo coastal area used for this study falls within Lat. 5°50′N–6°09′N and Long. 4°45′E–5°05′E. It is an estuarine coastal zone with an entry point at Awoye (Site 2 – Lat. 5°54′N and Long. 4°59E) where runoff and fresh river water are exchanged between the upland and the Atlantic Ocean. The water close to this estuarine point is made brackish by the continuous intrusion of saline water from the open coastal ocean. The salinity of the water within the coast ranged from 0.88 to 29.8 based on the increasing distance from the discharge point into the Atlantic Ocean. The complete watershed area is over 2000 km^2. The zone witnesses a wet season (April–October) and dry season (November–March). During the wet season, the average rainfall index is about 3000 mm, turbulent physical mix is higher and the average temperature is 28 °C. The average rainfall index for the dry season is 800 mm and the mean temperature is 32 °C.

There are dispersed communities within the coast and a fast growing population size of less than a million people. The vast majority of the settlements scattered around the coast dispose their waste generated by domestic activities directly into the water while oil exploration at Ukua (Site 1 – Lat. 5°50′N and Long. 5°04′E) classified the area as one of the regions called Niger Delta zone in Nigeria. The rivers and streams that traverse several settlements of the coast discharge into the open ocean through this estuary and there are exchanges of water between the ocean and the coastline. Commercial activities in the area are carried out with speedboats used for transportation of goods by the people while inhabitants of some parts of the estuary use the water for recreational (swimming) purpose. Water hyacinth forms dense mats on the water surface of the non-saline part of the estuary and this is much common during the wet season. The crude-oil exploration, the domestic activities and the non-existence of any waste treatment plant in the area have been responsible for the increased metal impacts on the area (Adebowale et al., 2008a). However, the need to investigate on the potential cleaning up of the environment by phytoremediation using an existing weed in the environment is presented here.

2.2. Sampling and preservation of samples

Plant samples were randomly collected across the coast where they exist and were sealed in air-tight polyethylene bags. The collections were not site specific as in the case of water samples because of their migrating abilities but have correlation with the sites where water samples were collected. The plant floats on the water course and is driven by the water current. The plant was not found as the distance got close to the discharge point into

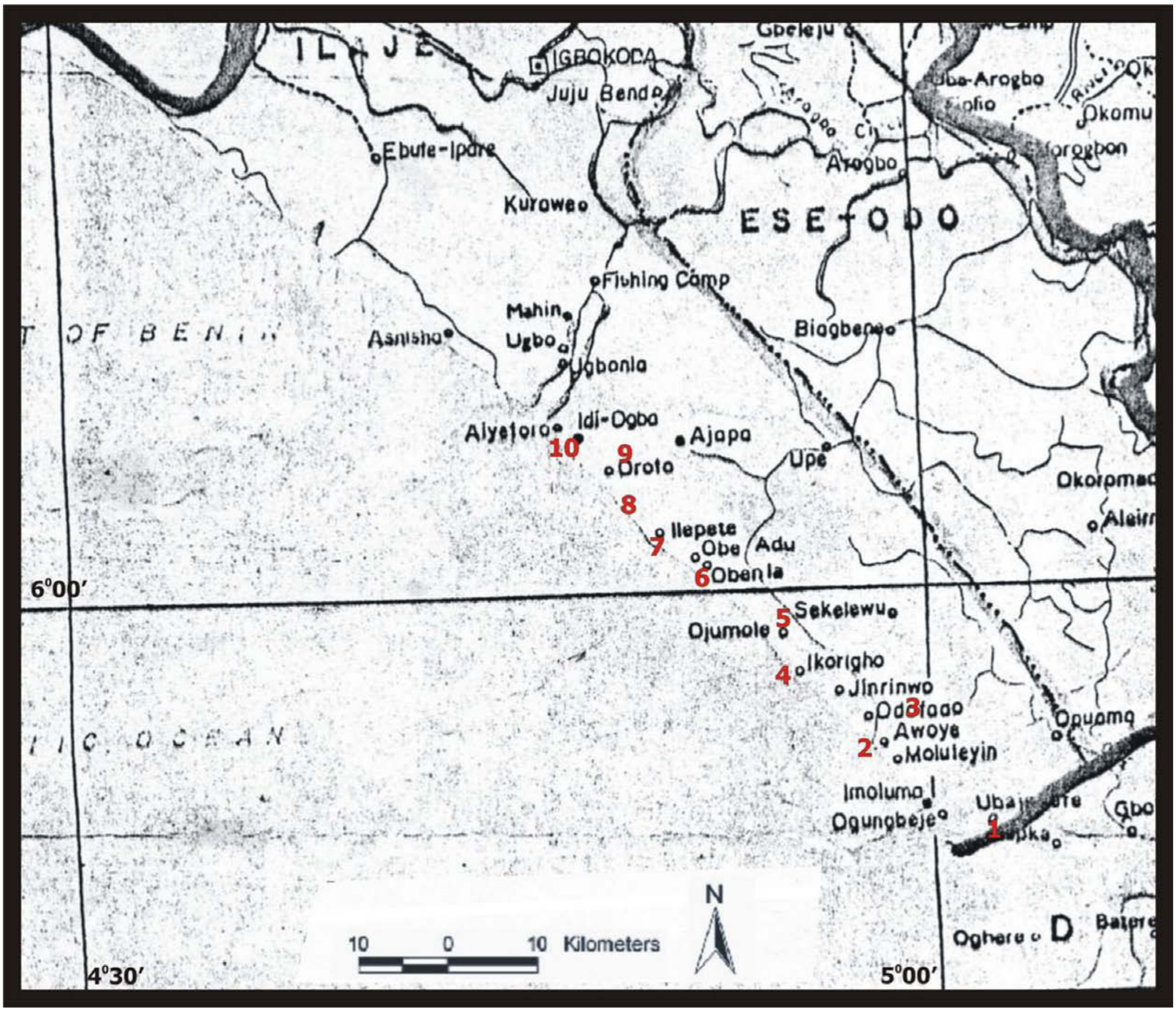

Fig. 1. Map of the coastal area of Ondo State and the sampling point.

the ocean which indicates its inability to survive in salty water. Samples of water were collected from 10 identified different locations along the coast (Fig. 1) to represent the entire coast. Prior to sampling, all the sampling equipments were pre-treated as specified by American Public Health Association (APHA, 1995). Samples of a litre each of water per sampling point were collected for the determination of metals using high density polyethylene (HDPE) bottles. These samples were preserved with 2 ml of conc. HNO_3 (Ultrex) per litre and were kept at 4 °C till analysed. The sampling quality control in water was ensured by introducing bottle blanks and field replicate samples which were analysed to measure the integrity of the samples and reproducibility, respectively. The blanks were less than 5% of the parameters determined in the samples while the replicate samples concentrations had relative standard deviation (RSD) between 8% and 15%.

2.3. Chemical analysis

Water samples (50 mL) were digested with 2 M HNO_3 at 95 °C for 2 h and were made up to 100 mL in a volumetric flask with demineralised water. The digestion was done in glassware previously soaked in nitric acid and washed with demineralised water. The digested samples were analysed for metals in duplicate using a Buck Scientific Flame Atomic Absorption Spectrophotometer (AAS) Model 205. Sample blanks were also analysed and results that were between 1% and 5% of each metal determined in samples were used to correct for any contamination in the course of the analysis.

The plant samples were separated into root and shoot (leaves and stalks) to determine the accumulation trend from water to root and to the shoot. They were each dried in an oven at 60 °C till well dried. The dried samples were ground before digestion. Five hundred milligrams of dried weight of each fraction were digested with 10 mL of $HClO_4$ and HNO_3 mixture (1:3) at about 80 °C for 4 h. The resulting cleared coloured solutions were made up to a mark in a volumetric flask (25 mL) with demineralised–distilled water. All the reagents that were used were of analytical grade and all the reaction vessels were treated well to avoid external contributions of the metals. Sample blanks were analysed to correct for possible external contributions while replicate samples were also evaluated and all the analyses were done in triplicate to ensure reproducibility of the results. The digested samples were analysed for ten metals (As, Cd, Cu, Cr, Fe, Mn, Ni, Pb, V and Zn) using AAS Buck Scientific Model 205A.

2.4. Data analysis

The mean and the standard error of mean of the metals in water and plant sample parts were calculated. Translocation factor which is a ratio of the concentration of metals (μg/g) in the plant shoot and leaves to that of the metals in root (μg/g) was also evaluated while the enrichment factor measuring the degree of enrichment and transfer of metals into the plant sample by the water was evaluated by the ratio of the metal in plant (μg/g) to the metal in the water (mg/L).

3. Results and discussion

3.1. Metal content in plant parts and water

The results of the concentrations of the metals studied in the different parts of the plant and in the water are presented in Table 1. Fe and Mn had the highest concentration in both the plant parts. This result correlates with earlier studies of the area that reported Fe and Mn as abundant in the water and sediment sourced from the geological structure of the area (Adebowale et al., 2008a,b). Zn was next in abundance to these two metals. The concentrations of the metals in the tissues (in part per million) were much higher in degree than their corresponding concentrations in the water sample with the same unit. This indicates that the plant accumulates metals from this contaminated coast and that it is an indicator of appropriate biological condition that can aid in the purification of the coast from metal contamination. The potential of *E. crassipes* to serve as a phytoremediation plant is dependent on the condition that it meets the general characteristics of phytoremediation plants. The most effective phytoremediation plants are those classified as hyperaccumulators (Lasat, 2002; Wei et al., 2009) while accumulators are also used.

Table 1
Metals contents in plant parts and water samples.

Metals	Plants parts (μg/g)		Water (μg/L)
	Root	Shoot	
As	0.16 ± 0.02	0.38 ± 0.02	8.18 ± 0.98
Cd	0.19 ± 0.06	0.50 ± 0.06	11.21 ± 1.08
Cu	31.40 ± 2.70	56.58 ± 0.98	45.41 ± 2.57
Cr	5.05 ± 0.34	10.12 ± 0.39	1330 ± 11.22
Fe	290.13 ± 14.46	636.17 ± 29.10	5780 ± 30.24
Mn	364.40 ± 26.55	681.88 ± 34.05	8360 ± 36.78
Ni	0.72 ± 0.01	1.41 ± 0.01	62.09 ± 4.70
Pb	0.39 ± 0.03	0.65 ± 0.06	18.16 ± 0.98
V	1.49 ± 0.49	3.35 ± 0.11	94.18 ± 1.67
Zn	131.88 ± 10.60	223.09 ± 15.62	3280 ± 20.05

Hyperaccumulators are characterized based on four features. First, the concentration in the shoots (stems or leaves) of a hyperaccumulator should be 10,000 μg/g for Zn and Mn; above 1000 μg/g dry mass for As, Pb, Cu, Ni and Co; 100 μg/g for Cd and 1 μg/g for Au (Baker and Brooks, 1989; Srivastava et al., 2006). Second, translocation property, metal concentrations in the shoots of a plant should be higher than those in the roots (translocation factor, concentration in shoots/roots > 1) (Baker and Brooks, 1989). Third, enrichment property evaluated as enrichment factor (concentration in plant/habitat > 1) (Wei et al., 2006). Lastly, tolerance property, a hyperaccumulator should have high tolerance to toxic contaminants.

The first item listed above is a unique characteristic of hyperaccumulators, while the remaining three features are shared with accumulators. Although shoot concentration of metals depends on the increase in the metal concentration in the habitat, accumulators display consistently lower levels than hyperaccumulators. Accumulators will not exceed the shoot concentrations described above (Baker and Brooks, 1989; Zhou et al., 2006). Thus, the critical concentrations of the metals investigated in this study which are lower than the values presented in the first item listed above indicate it as an accumulator than as a hyperaccumulator. The lower values obtained for the shoot metal concentrations than those characteristic of hyperaccumulators are related to the degree of contamination of this site compared with the mass of the plant that formed dense mats on the water surface all of which absorb metals from the water body. Thus, the potential of *E. crassipes* as a phytoremediation plant will be further assessed by the other features of such plants.

3.2. Enrichment factors of *E. crassipes*

The enrichment factors (EF) that measure the degree of metal transfer from the water to the plant roots and shoots for different metals were comparatively assessed and the results are presented in Fig. 2. Generally, the degree of enrichment of the shoot is higher than that of the root for the ten metals which indicates that the

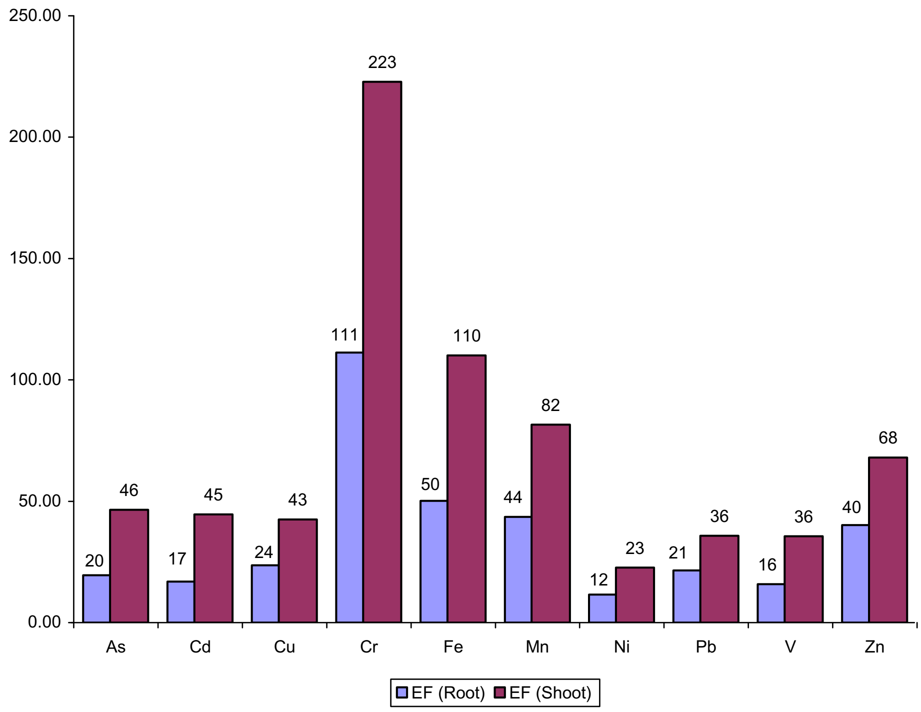

Fig. 2. Graph of enrichment factors of metals from the coastal to the shoot and root of *Eichornia crassipes.*

metals are transferred into the upper part of the plant. Also, the EF was much greater than 1 which is required for phytoremediation plants. The least EF observed in the study was 12 which corresponded to Ni metal transfer to the plant root. Cr is the most transferred metal into both the root and the shoot followed by Fe, Mn and Zn in the decreasing order. The accumulation of Cr by the plant indicates a potential usefulness of *E. crassipes* in cleaning up this metal which has been listed out as a priority pollutant along with As by the United States Environmental Protection Agency (USEPA) with a carcinogenicity classification A (human carcinogen). Cadmium and lead are also classified in the same list with a carcinogenicity classification B (probable human carcinogen) (USEPA, 1999; Pekey, 2006). Thus, the observed results of EF for As, Cd, Cr and Pb both at the root and at the shoot reveal its potential value as a phytoremediation plant. The plant shoot and root can be harvested from the water course as it is a floating plant and the fact that it forms a dense mat cover on the water implies its ability to clean up a wider area and for quick uptake of the metals. The EF values of the other metals are equally interesting but some of the metals have beneficial biological functions. This result indicates that the contamination of this site with metals such as Pb, Cd and Cr associated with the crude-oil exploration and domestic activities reported earlier (Adebowale et al., 2008a) is being managed by *E. crassipes* so as to reduce the effect on lives and the ecosystem of the Atlantic ocean.

Literatures have reported that the success of phytoextraction of metals depends on factors such as the degree of site contamination, plant's ability to intercept, absorb and accumulate metals in shoots, metal availability for uptake into roots governed by its dissolution into aqueous phase and ultimately the interaction between the plant habitat, the metals and the plant itself which is complex and controlled by climatic conditions making phytoremediation more of a site-specific technology than a generic one (Ernst, 1996; Lasat, 2002; Harun et al., 2008; Wei et al., 2009). Therefore, the low critical concentrations of the metals in water and plant parts are indication of a less contaminated environmental condition with the time of the study (August 2008) being the peak of wet season where high dilution by atmospheric precipitation and higher perturbation of the water system were observed (Agunbiade et al., 2008).

However, the high EF indicates the plant's ability to intercept, absorb and accumulate metals in both its root and shoot; the high bioavailability of the metals that are already in aqueous phase for easy uptake by the plant and favourable interaction between the metals, the plant and the aquatic habitat where the plant grows. The uptake rate of the plant for metals was predicted at approximately 0.5 μg/day using the predictive mathematical model which relates transpiration stream concentration factor (TSCF), transpiration rate (T) of vegetation and the concentration of contaminant in site water (C) as reported in the literature (Burken and Schnoor, 1998; Evans and Furlong, 2003). The equation was slightly modified by using Ksp of some metal salts in place of Kw used in the model. Thus, *E. crassipes* exhibits high potential as a metal accumulator for the phytoremediation purpose. This cost-effective, naturally growing plant biomass can be harvested from the contaminated water course with the use of drag net (1 mm mesh size). The harvested plant can be disposed off by composting or incineration. The composting requires additional co-composting materials to dilute the contaminants to permissible levels while the ash product from incineration can be disposed off in a hazardous waste landfill or considered for recycling depending on the value of the metal (Evans and Furlong, 2003). This approach of phytoremediation is justified as cost saving because of the large area covered, the small resultant product generated from the incinerator and the space it will occupy in the landfill.

3.3. Translocation and phytoremediation classification of E. crassipes

Another important feature of phytoremediation plants is the translocation of the metals from the root to the plant shoot which must be above 1 if the plant has to be an effective phytoremediator. The result of the assessment of the translocation factor of *E. crassipes* is presented in Fig. 3. The translocation of the metals into the shoot is higher than that into the root which implies that the plant

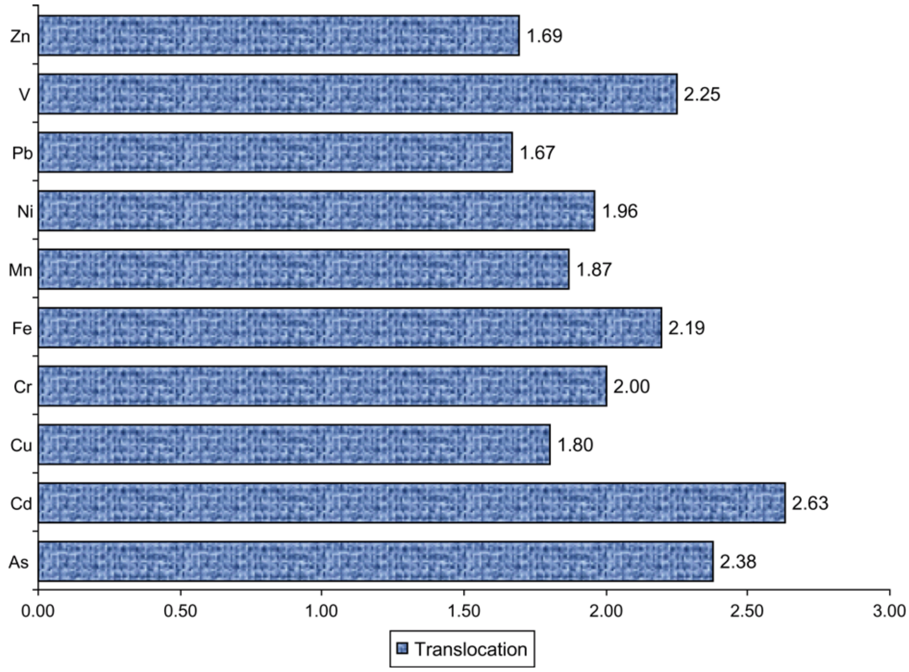

Fig. 3. Graph of translocation of metals from the root to the shoot.

has a high capacity to absorb the metals in the stalk and the leaves than the root. The leaves of *E. crassipes* are broad, large and spongy. Thus, it has a higher tendency to absorb metals in its leaves. The translocation of Cd is ranked highest followed by those of As, V, Fe, Cr in the decreasing order. This is because previous works had shown that Cd displaces Ca and Na via an ion-exchange mechanism (Romero-Gonzalez et al., 2001; Brinza et al., 2009). The translocation of other metals that were investigated was lower that 2 but higher than 1.5 which are indicators of a significant degree of metals movement from the root. In the phytoremediation classification of plants, plants with higher concentration in shoots are classified as phytoextractors because of their genetic potential to absorb metals into the stalk and the leaves while those that maintain metal absorption or adsorption at the root level are classified as plants for rhizofiltration among other classifications (Kuperberg et al., 1999). Thus, the translocation factor of *E. crassipes* best classified it as suitable for phytoextraction of metals from contaminated water bodies while the EF earlier discussed reveals its ability to serve as rhizofiltration plant in phytoremediation technology. *E. crassipes* is a plant that is not eaten by humans or animals and is abundant in the coastal water. Thus, its ability to accumulate metals in its root above the concentration in the water habitat where it grows and in the stalk and leaves above the root concentration is a positive indicator of its potential capacity to serve as a phytoremediation plant coupled with the non-existence of a sign of the toxic effect of the metals on the plant when sampled. The optimum removal condition by the plant is observable when the pH of the coastal water is between 5.5 and 6.5 which increases the free ion concentration of the metals in the coastal water; the metals' mobility and their bioavailability. Below this pH the growth of this macrophyte is hindered and the metals precipitate into the sediment phase and are not bioavailable. Furthermore, low salinity (less than 2‰) and increased dissolved oxygen (above 6 mg/L) are favourable conditions for the plant growth and its metal uptake.

4. Conclusion

In this study *E. crassipes* has been found to accumulate metals in both its root and shoot in a high degree and also to be capable of transferring the metals absorbed into the shoot to give higher translocation factors. It is therefore concluded from this study that the plant being a large biomass on the water course with broad leaves and being a weed not consumed by animals could serve as an effective phytoremediation plant.

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