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Phytoaccumulation Potential of Three Endogenous Poaceae Species Grown on the Akouedo Landfill (Abidjan, Côte d'Ivoire)

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Abstract

The selection of adequate plant species is a prerequisite for cleaning-up trace metal contaminated-soils by phytoaccumulation which is a cost-effective and environmentally-friendly technology. The potential of *Panicum maximum*, *Eleusine indica* and *Cynodon dactylon* to uptake trace metals from the soil of the Akouedo landfill was investigated. The concentrations of trace metals in soil were also considered. Moreover, the accumulation of Zn, Ni, Cu, Pb and Cd was assessed based on bioconcentration factor, translocation factor. The results showed high concentration values in the soil of the abandoned and the operation site of the landfill compare to the control site. The highest concentrations of trace metals in the plant shoot were observed with *P. maximum* for Ni. In root biomass, Zn, Cu and Cd showed high concentrations with *P. maximum*, *E. indica* and *C. dactylon*. Furthermore, the highest values of bioconcentration factor (BCF) and the translocation factor (TF) for Ni, were respectively 111.98 ± 82.45 and 4.26 ± 1.75 and were recorded with *P. maximum*. *P. maximum*, suggesting that it can be considered as a Ni hyperaccumulator.

Keywords

Trace Metals, Phytoaccumulation, Poaceae, Landfill

1. Introduction

Soil contamination by trace metals is an environmental issue of great concerns because most of trace metals are generally nonessential but detrimental to humans, plants and soil biota [1]. Extensive use of agrochemicals (pesticides and fertilizer) and transportation also play an important role in trace metals contamination in agricultural soil and soil present near highways [2] [3]. Irresponsible disposal of industrial effluents, mine tailing, municipal wastes and trace metals enriched waste sludge are the primary causes of soil pollution [4] [5]. Consequently, soils pollution by trace metals is responsible for losses in soil fertility, food contamination, ecotoxic effects and risks to human health. In addition, intake of cereals which are grown in trace metals (Cd, Cr and Zn) contaminated soil poses health risk to human due to accumulation of metals in food crops [6]. Chen *et al.* [7] suggested that long term trace metals contamination negatively affects the microbial biodiversity and their activity. Unlike organic contaminants, trace metals cannot be degraded [8] [9]. In addition, as far as clean-up of soils contaminated by metal trace metals is concerned, conventional remediation techniques fall short of expectation due to their high cost [10], whereas phytoremediation can be considered as an economical and effective alternative in some cases of metal trace elements pollution [8]. Furthermore, those conventional remediation technologies (soil flushing/washing, vitrification, surface capping, landfilling, electro-kinetic extraction) influence soil properties, fertility and biodiversity [11]. Phytoremediation is an ecologically sensitive method that can be used for the reclamation of contaminated soil without disturbing the soil fertility and biodiversity [12] [13] [14]. This offers an attractive, environmentally friendly, aesthetically pleasing, publically acceptable and cost-effective approach to remove metal trace elements from soil [15] [16]. Among phytoremediation technologies, phytoextraction is widely regarded as a promising technology. In fact, phytoextraction uses hyperaccumulator and accumulator to remove contaminants from the soil [17]. Research on hyperaccumulators has led to intensive screening of many plant species [18]. Two main strategies are currently applied: the first one considers the use of hyperaccumulator plants with exceptional metal accumulating capacity. And the second one implies the use of high biomass producing plants which can also sometimes accumulate large quantities of metal trace elements [19]. In the first case, the use of hyperaccumulator plants is mainly limited by low biomass production, while in the second case plants producing high biomass concentrate low amounts of metals [20] [21]. Moreover, hyperaccumulators identified are non-endemic to tropical areas, such as Côte d'Ivoire. To develop phytoremediation technologies, the identification and evaluation of the potential of the local plants species to accumulate metal trace elements must be done. Thus, Messou *et al.* [22] reported that Poaceae species grown on the Akouedo landfill may be suitable candidates to accumulate trace metals (Pb, Cd, Ni, Cu and Zn). However, these authors did not provide any experimental data on the ability of Poaceae species to accumulate such metals. The aim of this study is to assess the potential of three Poaceae species (*Panicum maximum*, *Eleusine indica*, *Cynodon dactylon*) to accumulate trace metals (Pb, Cd, Ni, Cu and Zn) in order to provide a scientific base for phytoaccumulation application.

2. Materials and Methods

2.1. Description of Study Area

The Akouedo landfill is located in the District of Abidjan. It is situated between 395,800 - 397,500 m·N and 591,100 - 593,000 m·W, and covers an area of about 153 ha (**Figure 1**). Previous studies [23] showed that the soil of this landfill was contaminated by metal trace elements. In the superficial stratum (less than 50 cm depth), the average concentrations of zinc (Zn), chromium (Cr), cadmium (Cd), lead (Pb), iron (Fe), and copper (Cu) were respectively of 250, 50, 5, 140, 1 400 and 80 ppm. The mean value of pH was 8.25 [23]. Moreover, a control site was selected in the District of Abidjan. However, this site was relatively far from Akouedo landfill, *i.e.*, near the Banco National Park (**Figure 1**). The control site was located between 382075.466 - 384193.133 m·N and 599019.676 - 600806.458 m·W.

2.2. Plants and Soil Sampling

Both soils and plants were sampled at the Akouedo landfill and the control site. For the Akouedo landfill, two different sampling zones were chosen. Indeed, on this landfill there is an abandoned site (AS) which was first used for waste disposal. Since the AS was saturated, a neighboring site was chosen for waste disposal (Operating Site (OS). For both, nine plots were established for soil sampling on the AS and OS. For the control site (CS), three plots were defined. The plots were established as representative of the study site as possible. This choice also aimed at getting abundant biomass when plants are harvested. For plants sampling, only mature plants were taken. 10, 20 and 40 plants, of respectively *Panicum maximum*, *Eleusine indica and Cynodon dactylon*, were randomly harvested (uprooted) on each plot. The plants were separated into roots and shoots. After that separation process, the plant samples were first washed with tap water and next with distillated water, to remove surface dust and soil. Finally, the samples were oven-dried at 65˚C for 72 hours. After drying, the vegetal material was milled into a homogenous powder after their dry weights were determined. **Table 1** presents a list of plant samples (roots and shoots) obtained in each zone.

Table 1. List of plant samples (PaM: *Panicum maximum*; ElI: *Eleusine indica*; CyD: *Cynodon dactylon*; S: shoot; R: Root).

Species	Plant samples		
	Abandoned site	Operating site	Control site
Panicum maximum	PaM-S1; PaM-R1	PaM-S2; PaM-R2	PaM-S3; PaM-R3
Eleusine indica	ElI-S1; ElI-R1	ElI-S2; ElI-R2	ElI-S3; ElI-R3
Cynodon dactylon	CyD-S1; CyD-R1	CyD-S2; CyD-R2	CyD-S3; CyD-R3

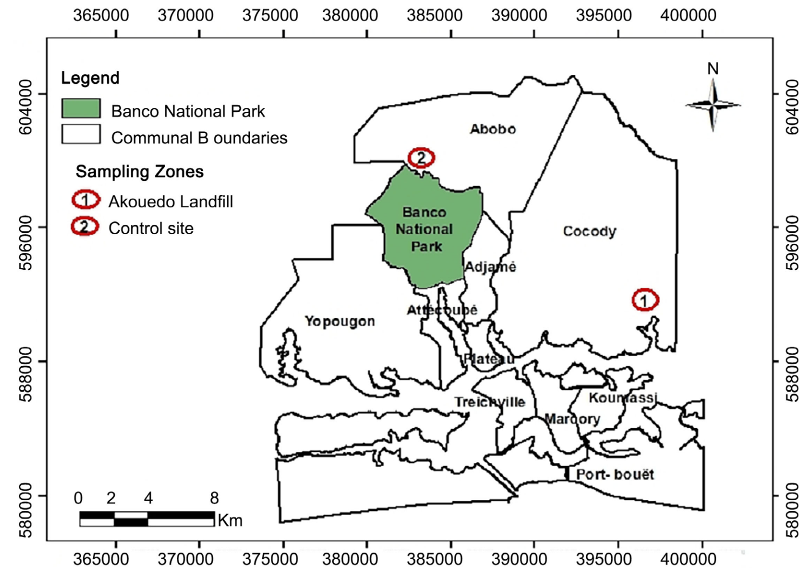

Figure 1. Location of the sampling zones.

For soil sampling, steel auger was used. The soil samples were collected at depths of 0 - 10 cm, 10 - 20 cm, 0 - 30 cm and 30 - 40 cm. On each plot, soils samples were taken at each corner (4) and one in the center. A composite sample was prepared at the same depth on each plot. Soil samples were collected in plastic bags, air-dried and ground to pass through a 2 mm sieve. A total of 72 soil samples were collected from the landfill zones, while 12 samples were obtained from the control site.

2.3. Chemical Analyses

The phytoavailable fraction of metals in the soil samples was performed with ammonium acetate-ethylenediamine tetra-acetatic acid (EDTA) according to the NFX 31 - 120 procedure [24]. Concentrations of Cd and Pb were determined using graphite furnace atomic absorption spectrophotometer (GFAAS) and Cu, Ni and Zn were determined using a flame atomic absorption spectrophotometer (FAAS).

To determine total metals content in the plant's samples, a graphite furnace atomic absorption spectrophotometer and a flame atomic absorption spectrophotometer were used post-digestion. The analytical processes for the vegetal material involved incineration and acid digestion with HCl.

2.4. Data Analysis

The Bioconcentration Factor (BCF) was used to determine the quantity of metal trace elements that is absorbed by the plant from the soil. This is an index of the ability of a plant to accumulate a particular metal with respect to its concentration in the soil [25] [26] and is calculated using the following formula:

$$\text{BCF} = \frac{[\text{Metal}]_{\text{shoot+root}}}{[\text{Metal}]_{\text{soil}}} \quad (1)$$

The higher the BCF value the more suitable is the plant for phytoextraction [27]. BCF Values > 2 were regarded as high values.

To evaluate the phytoextraction potential of the plants, the translocation factor (TF) was used. This ratio is an indication of the ability of a plant to translocate metals from its roots to its shoots [28] [29]. It is represented by the ratio:

$$TF = \frac{[\text{Metal}]_{\text{shoot}}}{[\text{Metal}]_{\text{root}}} \quad (2)$$

Hence, trace metals that are accumulated by plants and largely stored in the roots of plants are indicated by TF values < 1. On contrary, when TF values > 1, this indicates that the metals are much stored in the shoot.

2.5. Statistical Analysis

Statistical analysis of the data was carried out using Statistica software version 7.1. To verify the statistical significance of metal content in the vegetal biomass, data were analyzed using the parametric test (LSD Fisher) and the non-parametric test (Kruskall-Wallis). Statistical significance was defined at the level of $p < 0.05$. This was performed with R software version 3.1.1.

3. Results

3.1. Biomass Vegetal

The shoot and root biomasses of *Panicum maximum* were more important than those of *Eleusine indica* and *Cynodon dactylon* and (**Table 2**). They were 93.6 ± 6.3 g·plant^{-1} and 22.4 ± 2.1 g·plant^{-1} on the abandoned site (AS), respectively, for the shoot and root biomass. However, on the operating site (OS), *P. maximum* recorded a shoot biomass of 96.9 ± 7.8 g·plant^{-1} and root biomass of 23.4.1 ± 4.6 g·plant^{-1}. On the control site (CS), *P. maximum* presented shoot and root biomasses of respectively, 95.1 ± 5.6 g·plant^{-1} and 22.8 ± 3.4 g·plant^{-1}.

3.2. Soil Metals Concentration

Trace metals concentrations in the soil of landfill site were much higher than those of the control site. For the abandoned site (AS) and the operating site (OS), mean trace metals concentrations ranged respectively from 86.70 ± 15.78 to 84.25 ± 14.62 mg·kg^{-1} of Zn, 26.06 ± 4.51 to 17.83 ± 3.03 mg·kg^{-1} of Pb, 17.98 ± 4.29 to 10.39 ± 1.84 mg·kg^{-1} of Cu, 1.65 ± 0.23 to 1.40 ± 0.15 mg·kg^{-1} of Ni and from 0.72 ± 0.09 to 0.62 ± 0.06 mg·kg^{-1} of Cd. In contrast, the control site contained 25.86 ± 21.61 mg·kg^{-1}, 2.19 ± 0.21 mg·kg^{-1}, 1.23 ± 0.21 mg·kg^{-1}, 0.25 ± 0.03 mg·kg^{-1} and 0.02 ± 0.01 mg·kg^{-1}, respectively for Zn, Pb, Cu, Ni and Cd.

3.3. Trace Metals Concentration in the Plant Biomass

3.3.1. Zinc

Zn concentrations obtained in root biomass are higher than those in the shoot part, regardless of the species and site considered (**Figure 2**). For *P. maximum*, concentrations in shoot biomass ranged from 80 to 211 mg/kg dw, 64 to 234 mg/kg dw, and 18.1 to 59.7 mg/kg dw at the abandoned site, operating site and control sites, respectively. In, root biomass, it ranged from 163 to 635 mg/kg dw (abandoned site), 90 to 452 mg/kg dw (operating site) and 9.5 to 68.6 mg/kg dw (control site). The mean concentrations in shoot and root biomass at the abandoned site and operating sites were significantly different (Fisher's LSD test: $p < 0.05$). Comparing the mean concentrations in the root biomass at the three sites, the mean concentration recorded at the control site is significantly different from those obtained at the two sites at the Akouedo lanfill (Fisher LSD test: $p < 0.05$).

Table 2. Shoot and root dry biomass ($g \cdot plant^{-1}$; mean ± standard deviation).

Species	Abandoned site		Operating site		Control site	
	Shoot	Root	Shoot	Root	Shoot	Root
Panicum maximum	93.6 ± 6.3	22.4 ± 2.1	96.9 ± 7.8	23.4 ± 4.6	95.1 ± 5.6	22.8 ± 3.4
Eleusine indica	22.3 ± 2.1	9.5 ± 1.8	23.4 ± 2.8	7.8 ± 0.9	23.6 ± 1.2	8.1 ± 0.6
Cynodon dactylon	10.2 ± 1.3	1.7 ± 0.3	10.3 ± 1.2	1.7 ± 0.4	10.1 ± 0.7	1.7 ± 0.2

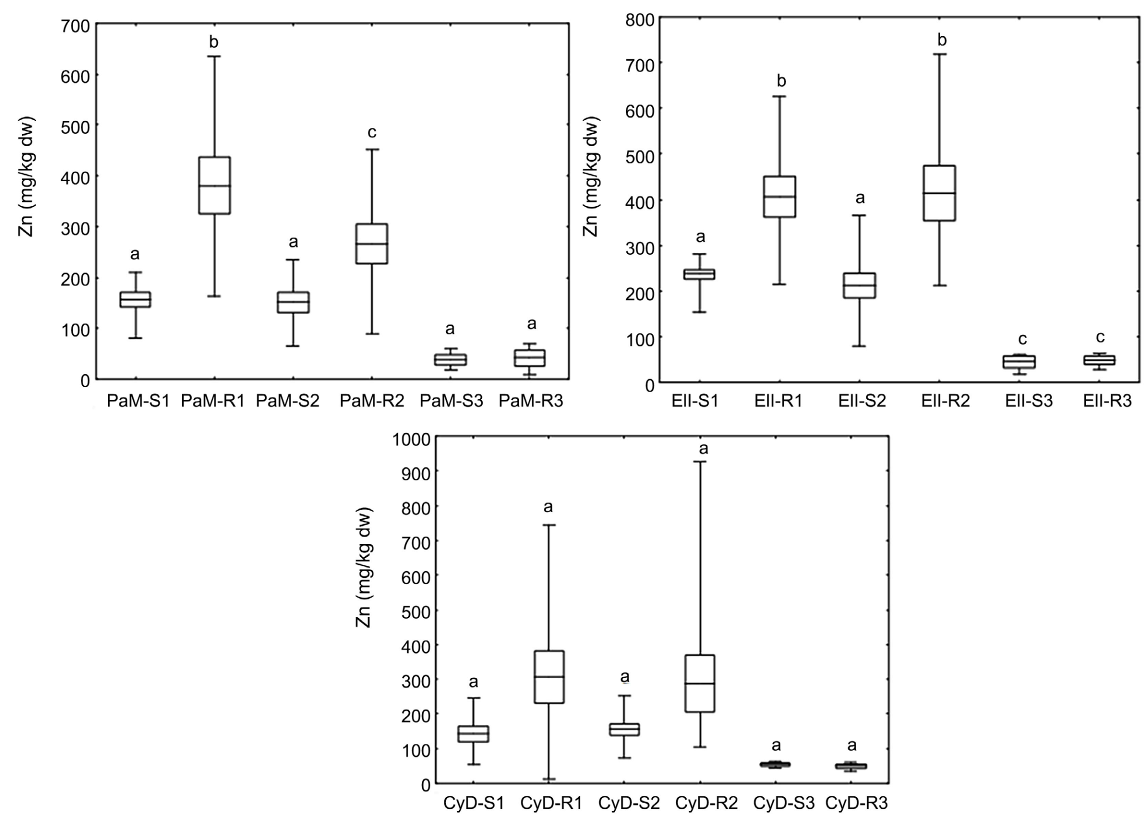

Figure 2. Zn concentration in the shoot (S) and root (R) of *Panicum maximum* (PaM), *Eulesine indica* (EII) and *Cynodon dactylon* (CyD).

Concerning *E. indica*, Zn concentrations in the shoot biomass ranged from 154 to 280 mg/kg dw (abandoned site), from 80 to 365 mg/kg dw (operating site) and from 17 to 61.6 mg/kg dw (control site). For root biomass, it ranged from 216 to 626 mg/kg dw, 211 to 718 mg/kg dw, and 28.1 to 64.6 mg/kg dw at the abandoned site, operating site and control sites, respectively. The mean Zn concentrations recorded in the shoot and root biomass of *E. indica* at the two landfill sites differed significantly (Fisher's LSD test: $p < 0.05$). Comparing the mean concentration of Zn at the three sites, it can be seen that the average concentrations obtained in the shoot and root biomass at the control site were significantly different from those of abandoned and operating sites (Fisher LSD test: $p < 0.05$).

Regarding to *C. dactylon*, Zn concentrations in shoot biomass ranged from 54 to 246 mg/kg dw (abandoned site), 73 to 251 mg/kg dw (operating site), and 45 to 65 mg/kg dw (control site). In root biomass, concentrations ranged from 12 to 746 mg/kg dw (abandoned site), 107 to 927 mg/kg dw (operating site), and 35 to 60 mg/kg dw (control site). Mean Zn concentrations in shoot and root biomass of *C. dactylon* were not significantly different (Kruskall-Wallis test: $p > 0.05$) at any site. However, the mean concentrations recorded in the shoot and root biomass at both landfill sites were higher than those obtained at the control site.

3.3.2. Nickel

Ni was most concentrated in the shoot biomass of *P. maximum* at all three studies sites (**Figure 3**). Ni concentrations in shoot biomass ranged from 1 to 383 mg/kg dw (abandoned site), from 2 to 172 mg/kg dw (operating site), and from 0.2 to 9.2 mg/kg dw (control site). Root biomass concentrations ranged from 5 to 141 mg/kg dw (abandoned site), 10 to 71 mg/kg dw (control site).

Mean Ni concentrations in shoot and root biomass of *P. maximum* collected at the abandoned site (85 - 53 mg/kg dw), the operating site (72.8 - 29.6 mg/kg dw) and the control site (3.2 - 0.2 mg/kg dw) were not significantly different (Fisher's LSD test: $p > 0.05$).

For *E. indica*, considering shoot biomass, Ni concentrations ranged from 2 to 240 mg/kg dw (abandoned site), 1 to 174 mg/kg dw (operating site) and 0.2 to 9.2 mg/kg (control site). In contrast, root biomass concentrations ranged from 6 to 149 mg/kg dw (abandoned site), from 15 to 204 mg/kg dw (operating site) and from 0.15 to 0.19 mg/kg dw (control site).

As for the mean Ni concentrations recorded in the shoot and root biomass of *E. indica*, they were not significantly different (Fisher's LSD Test: $p > 0.05$) across the three sites. However, the mean concentrations in shoot and root biomass obtained at the two landfill sites are higher than those obtained at the control site.

For *C. dactylon*, shoot biomass, these ranged from 4 to 115 mg/kg dw, 4 to 71 mg/kg dw, and 0.1 to 7.3 mg/kg dw at the abandoned site, operating site, and control sites, respectively. In contrast, root biomass concentrations ranged from 4 to 175 mg/kg dw (abandoned site), from 9 to 64 mg/kg dw (operating site) and from 0.2 to 0.9 mg/kg dw (control site). The mean Ni concentrations obtained in the shoot and root biomass of *C. dactylon* did not differ significantly (Kruskall-Wallis Anova: $p > 0.05$) among the three sites. Furthermore, these mean registered concentrations in biomass at the abandoned and operating sites are higher than those obtained at the control site.

3.3.3. Copper

Considering the three sites, Cu concentrations in the root biomass were higher than that of the shoot biomass of *P. maximum* (**Figure 4**). In shoot biomass, Cu concentrations ranged from 21 to 104 mg/kg dw (abandoned site), from 6 to 120 mg/kg dw (operating site) and from 0.1 to 5.8 mg/kg dw (control site). In contrast, root biomass concentrations ranged from 32 to 218 mg/kg dw (abandoned site), from 29 to 162 mg/kg dw (operating site) and from 4.7 to 18.4 mg/kg dw (control site). Comparing the mean concentrations in the root biomass, the control site differed significantly from the mean concentrations obtained at the two landfill sites (Fisher LSD Test: $p < 0.05$).

For *E. indica*, Cu concentrations obtained in shoot biomass ranged from 5 to 117 mg/kg dw (abandoned site), from 13 to 95 mg/kg dw (operating site), and from 0.2 to 9.1 mg/kg dw (control site). In the root biomass, concentrations ranged from 22 to 375 mg/kg dw, 21 to 220 mg/kg dw, and 9.9 to 16.2 mg/kg dw at the abandoned site, operating site, and control site, respectively.

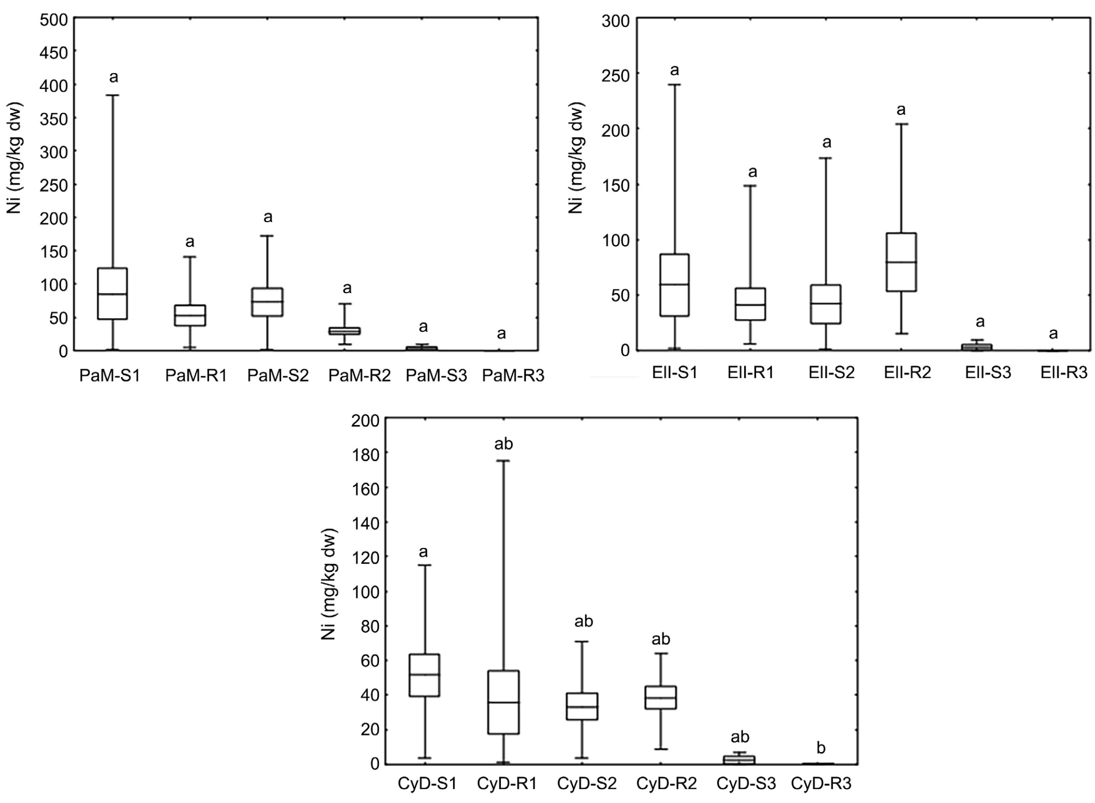

Figure 3. Ni concentration in the shoot (S) and root (R) of *Panicum maximum* (PaM), *Eulesine indica* (ElI) and *Cynodon dactylon* (CyD).

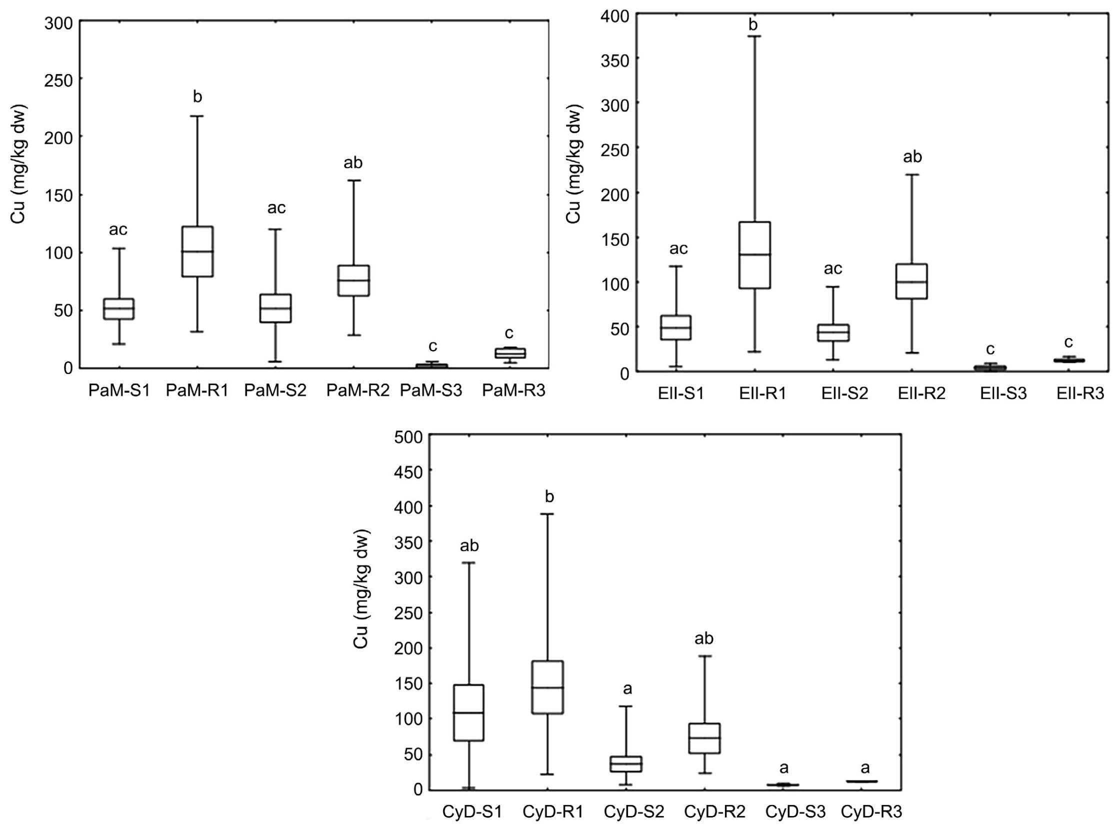

Figure 4. Cu concentration in the shoot (S) and root (R) of *Panicum maximum* (PaM), *Eulesine indica* (ElI) and *Cynodon dactylon* (CyD).

Considering the root biomass, we note that the average concentration of Cu obtained on the control site differs significantly from those recorded on the old site and the site in operation (Fisher's LSD test: $p < 0.05$). Concerning *C. dactylon*, Cu concentrations obtained in the shoot biomass vary between 4 and 320 mg/kg dw (abandoned site), between 8 and 119 mg/kg dw (operating site) and between 6.2 and 9 mg/kg dw (control site). Considering the root biomass, the recorded concentrations were between 22.7 and 388 mg/kg dw, between 23.9 and 189 mg/kg dw and between 11.4 and 13.5 mg/kg dw, respectively, at the abandoned site, operating site and the control site. The mean Cu concentrations recorded in the shoot and root biomass of *C. dactylon* were not significantly different (Fisher's LSD test: $p > 0.05$) at each of the sites considered. However, they are higher in the biomass from the two landfill sites.

3.3.4. Lead

In the shoot biomass of *P. maximum*, Pb concentrations (**Figure 5**) ranged from 5 to 83 mg/kg dw (abandoned site), from 1.3 to 26.6 mg/kg dw (operating site) and from 1.9 to 7.3 mg/kg dw (control site). Pb concentrations in the root biomass ranged from 10.9 to 99.4 mg/kg dw, 10 to 41.2 mg/kg dw, and 2.4 to 5.6 mg/kg dw at the abandoned site, operating site and control site, respectively. The mean Pb concentrations recorded in the shoot and root biomass of *P. maximum* at the abandoned site showed a significant difference (Fisher's LSD test: p <

0.05). In contrast, the mean Pb concentrations recorded in the shoot and root parts at the operating and control sites were not significantly different (Fisher's LSD Test: $p > 0.05$).

Pb concentrations in shoot biomass of *E. indica*, ranged from 0.9 to 29.1 mg/kg dw, 9.5 to 170 mg/kg dw, and 0.6 to 1.7 mg/kg dw on the abandoned site, operating site, and the control site, respectively. In the root biomass, Pb concentrations ranged from 10.3 to 50.3 mg/kg dw (abandoned site), from 8.3 to 93.5 mg/kg dw (operating site) and from 0.9 to 2 mg/kg dw (control site). Mean Pb concentrations in shoot and root biomass of *E. indica* were not significantly different (Fisher's LSD test: $p > 0.05$) at any site. However, the mean concentrations in shoot and root biomass obtained at the two landfill sites are higher than those obtained at the control site.

For *C. dactylon*, Pb concentrations in shoot biomass ranged from 2 to 43.5 mg/kg dw (abandoned site), 0.3 to 71.9 mg/kg dw (operating site) and 1.3 to 3.3 mg/kg dw (control site). In root biomass, concentrations ranged from 7.6 to 116 mg/kg dw at the abandoned site, from 3.9 to 61.5 mg/kg dw at the operating site, and from 1.7 to 3.1 mg/kg dw at the control site.

Mean Pb concentrations recorded in the shoot and root biomass of *C. dactylon* were not significantly different (Kruskall-Wallis Anova: $p > 0.05$), regardless of the site considered. However, the average concentrations obtained in the biomasses at the two landfill sites are higher than at the control site.

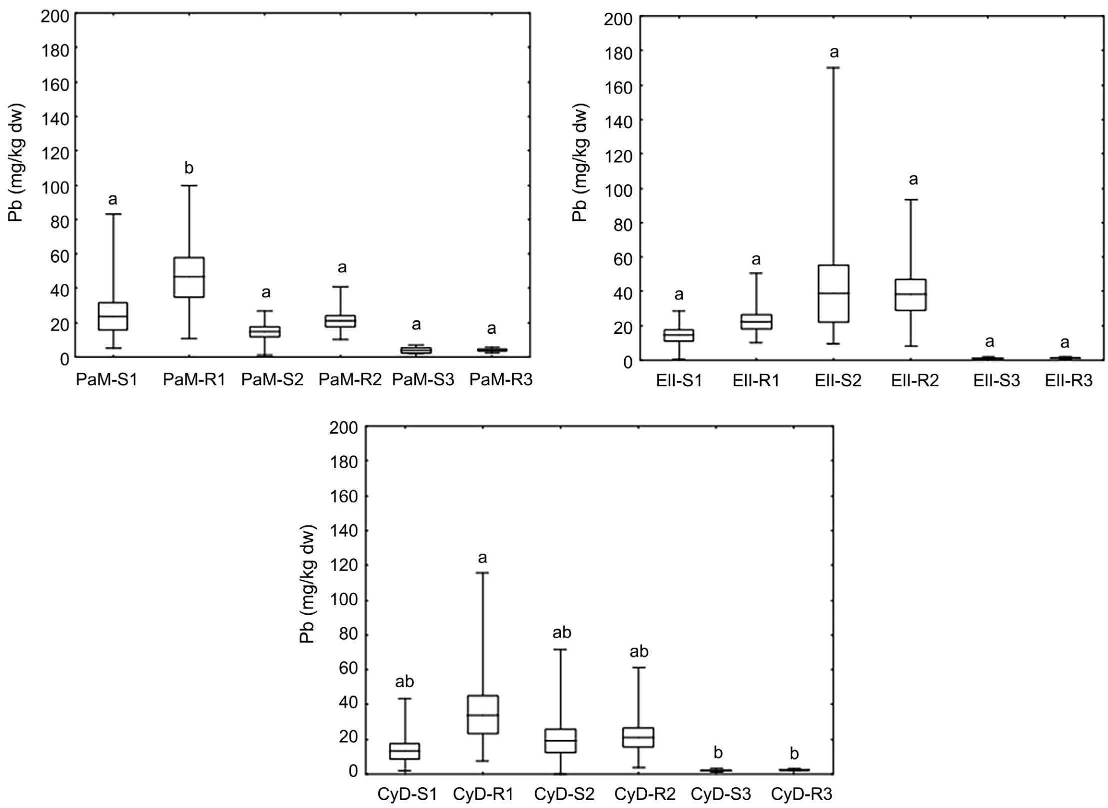

Figure 5. Pb concentration in the shoot (S) and root (R) of *Panicum maximum* (PaM), *Eulesine indica* (ElI) and *Cynodon dactylon* (CyD).

3.3.5. Cadmium

In general, the root biomass presents the highest concentrations of Cd, whatever the site considered (**Figure 6**). Cd concentrations obtained in the shoot biomass vary between 0.04 and 2.33 mg/kg dw (abandoned site) and between 0.04 and 0.48 mg/kg dw (operatin site). In the root biomass, it ranged from 0.30 to 1.66 mg/kg dw at the abandoned site and from 0.03 to 0.73 mg/kg dw at the operating site. In contrast, at the control site, concentrations in the shoot and root parts were less than 0.05 mg/kg dw. The mean concentrations in the shoot and root biomass of *P. maximum* were not significantly different (Fisher's LSD test: $p > 0.05$) at any site.

As for *E. indica*, Cd concentrations obtained in the shoot biomass were between 0.06 and 0.16 mg/kg dw (abandoned site) and between 0.08 and 0.92 mg/kg dw (operating site). In the root biomass, it ranged from 0.23 to 2.84 mg/kg dw at the abandoned site and from 0.04 to 1.47 mg/kg dw at the operating site. In contrast, the Cd concentrations obtained in the shoot and root parts at the control site are less than 0.04 mg/kg dw. The mean Cd contents recorded in the shoot and root biomass of *E. indica* at the abandoned site differed significantly (Fisher's LSD test: $p < 0.05$).

For *C. dactylon*, Cd concentrations in shoot biomass ranged from 0.06 to 2.46 mg/kg dw (abandoned site) and from 0.13 to 0.41 mg/kg dw (operating sites). In the root biomass, concentrations ranged from 0.21 to 4.42 mg/kg dw ((abandoned site) and from 0.22 to 2.19 mg/kg dw (operating site). In the shoot and root biomass from the control site, Cd concentrations are well below 0.04 mg/kg dw. The mean Cd levels in the shoot and root biomass of *C. dactylon* were not significantly different (Fisher's LSD test: $p > 0.05$). Considering the three sites, the average concentrations obtained in the biomasses on the abandoned site and the operating site, were higher than those recorded on the control site.

3.3.6. Bioconcentration and Translocation Factor

The average BCF of *Panicum maximum* ranged from 0.34 ± 0.08 to 97.17 ± 36.75 (**Table 3**). On the landfill site (abandoned site and operating site), the lowest BCF was observed with Cd and the highest with Ni. Zn and Ni showed high values of BCF on the tree sites. For *Eleusine indica*, the average BCF ranged from 0.27 ± 0.05 (Cd) to 111.98 ± 82.45 (Ni). The results showed that, the BCF values were above 1 on the abandoned site and the operating site for Zn, Ni, Cu and Pb. BCF values for Cd were lower than 1, on the tree sites.

Furthermore, BCF of *Cynodon dactylon*, were highest for Ni on abandoned site (55.61 ± 17.25), operating site (39.26 ± 10.53) and control site (9.14 ± 8.70). The BCF were not signifcantly different on the sampling site with *C. dactylon* ($p > 0.05$).

The TF values of the 3 Poaceae species ranged from 0.12 ± 0.09 to 4.26 ± 1.73 (**Table 3**). *P. maximum* and *E. indica* presented low TF values (<1) for Zn and Cu on the abandoned site and the operating site. Furthermore, the results showed that the high TF values were observed for Ni with *P. maximum*, *E. indica* and *C. dactylon*.

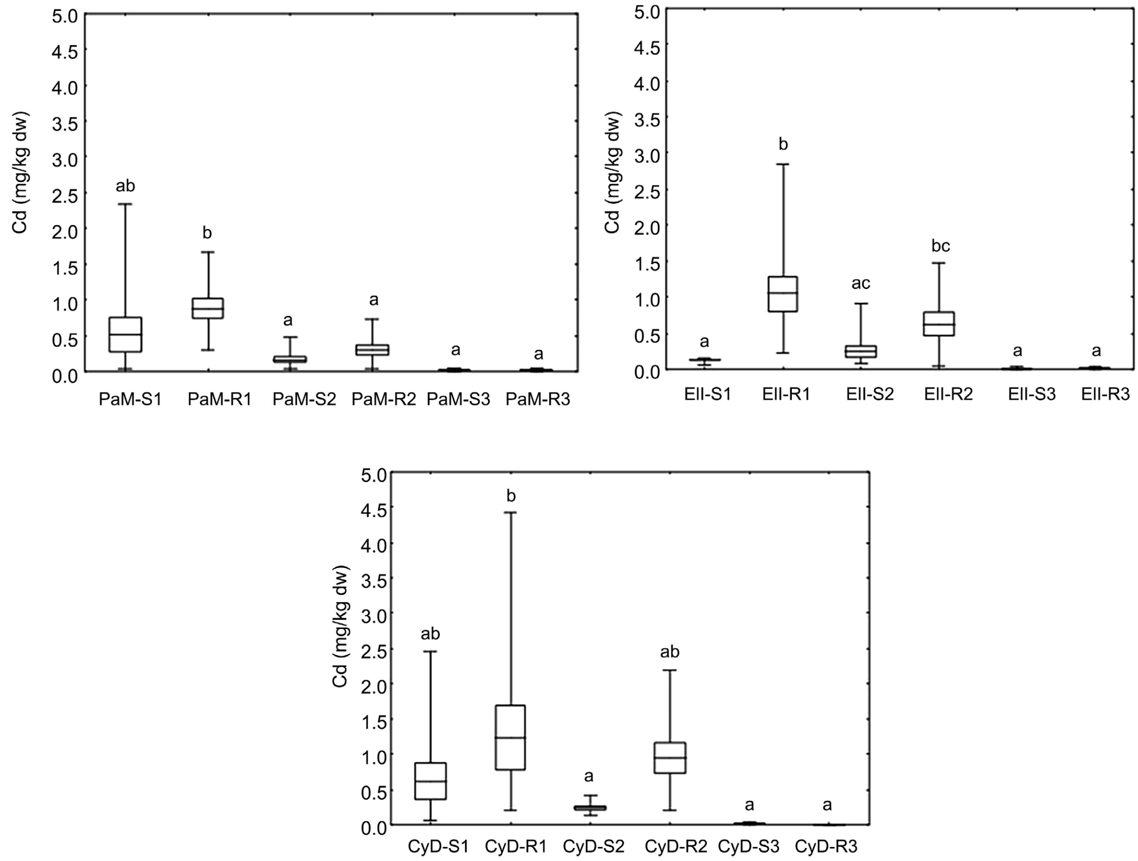

Figure 6. Cd concentration in the shoot (S) and root (R) of *Panicum maximum* (PaM), *Eulesine indica* (ElI) and *Cynodon dactylon* (CyD).

Table 3. Bioconcentration Factor (BCF) and Translocation factor (TF) values (Means values of each factor of the same line with the same letter are not statistically different).

Species	Trace metals	BCF			TF		
		Abandoned site	Operating site	Control site	Abandoned site	Operating site	Control site
Panicum maximum	Zn	4.97 ± 1.76^{a}	3.77 ± 1.32^{a}	4.11 ± 2.56^{a}	0.51 ± 0.09^{a}	0.63 ± 0.09^{a}	1.78 ± 1.04^{a}
	Ni	97.17 ± 36.75^{ab}	12.33 ± 7.81^{a}	7.42 ± 6.72^{b}	1.92 ± 0.65^{a}	4.26 ± 1.73^{b}	2.53 ± 1.84^{ab}
	Cu	5.24 ± 1.30^{a}	11.36 ± 4.02^{a}	1.03 ± 0.88^{a}	0.67 ± 0.15^{a}	0.97 ± 0.36^{a}	0.12 ± 0.09^{a}
	Pb	2.28 ± 0.92^{a}	1.23 ± 0.53^{a}	1.26 ± 0.48^{a}	0.91 ± 0.42^{a}	0.84 ± 0.19^{a}	0.92 ± 0.20^{a}
	Cd	1.03 ± 0.43^{a}	0.34 ± 0.08^{a}	1.21 ± 0.76^{a}	0.48 ± 0.16^{a}	1.40 ± 0.89^{a}	0.99 ± 0.67^{a}
Eleusine indica	Zn	7.16 ± 2.41^{a}	4.70 ± 1.27^{a}	3.96 ± 2.38^{a}	0.67 ± 0.09^{a}	0.59 ± 0.11^{a}	0.88 ± 0.14^{a}
	Ni	111.98 ± 82.45^{a}	50.94 ± 19.64^{ab}	1.38 ± 0.64^{b}	1.55 ± 0.55^{a}	1.68 ± 1.25^{a}	2.85 ± 1.65^{a}
	Cu	5.30 ± 2.56^{a}	13.96 ± 8.42^{a}	3.08 ± 2.12^{a}	0.89 ± 0.50^{a}	0.85 ± 0.47^{a}	0.40 ± 0.27^{a}
	Pb	1.48 ± 0.63^{a}	2.75 ± 0.95^{a}	0.40 ± 0.07^{a}	0.88 ± 0.28^{a}	1.56 ± 0.84^{a}	0.84 ± 0.13^{a}
	Cd	0.27 ± 0.05^{a}	0.60 ± 0.28^{a}	0.62 ± 0.33^{a}	0.18 ± 0.04^{a}	1.44 ± 1.09^{a}	0.72 ± 0.09^{a}
Cynodon dactylon	Zn	4.18 ± 1.49^{a}	3.12 ± 0.85^{a}	5.95 ± 2.84^{a}	1.50 ± 0.65^{a}	0.73 ± 0.12^{a}	1.18 ± 0.33^{a}
	Ni	55.61± 17.25^{a}	39.26 ± 10.53^{a}	9.14 ± 8.70^{b}	3.59 ± 1.05^{a}	1.24 ± 0.53^{b}	3.10 ± 2.25^{ab}
	Cu	12.53 ± 6.51^{a}	9.32 ± 4.22^{a}	4.77 ± 0.85^{a}	1.06 ± 0.46^{a}	0.91 ± 0.30^{a}	0.62 ± 0.06^{a}
	Pb	1.20 ± 0.48^{a}	2.50 ± 1.48^{a}	0.71 ± 0.09^{a}	0.56 ± 0.21^{a}	2.13 ± 1.11^{a}	0.92 ± 0.08^{a}
	Cd	1.12 ± 0.43^{a}	0.55 ± 0.16^{a}	0.81 ± 0.80^{a}	0.73 ± 0.37^{a}	0.38 ± 0.08^{a}	0.59 ± 0.21^{a}

4. Discussion

The results recorded indicate an accumulation of trace metal elements by *P. maximum*, *E. indica* and *C. dactylon*. The presence of these species on the site of the Akouedo landfill would be linked to their tolerance mechanisms developed in the face of the pollution of the soils with trace metals from the Akouedo landfill. Indeed, these plant species have developed adaptations that allow them to exclude, tolerate, or even accumulate high concentrations of trace metals in their tissues [30]. The plant does this by chelating through amino acids, GSH, metallothioneins and organic acids, or through compartmenting with vacuoles, and antioxidative defense mechanism upregulation [31] [32] Those characteristics could be due to ecophysiological mechanisms for tolerance and uptake trace metals. Moreover, the main source of accumulation of trace metals by plants on the Akouedo dump would be the soil, without however excluding foliar inputs. Evaluation of the concentrations of Cd, Cu, Ni, Pb and Zn accumulated in the biomasses of the species *E. indica*, *P. maximum and C. dactylon* revealed significant quantities of trace metals. Indeed, the works of Ogoko [33], Hamza *et al.* [34], Anarado *et al.* [35], Ancheta *et al.* [36], Opokou *et al.* [37], Azeez *et al.* [38] and Coulibaly *et al.* [39] showed the capacity of trace metals (Pb, Cd, Zn; Cu) accumulation of these three Poaceae species. However, *P. maximum* and *E. indica* species have higher root contents of Zn, Cu and Pb than those obtained in shoot biomass. These results were associated to transfer factors lower than 1 for these trace metals. It would thus limit the transfer of these trace metals to the shoot parts. Indeed, these trace metals could be complexed with a ligand or sequestered in a root cell compartment [40] [41]. However, it has bioaccumulation factors greater than 2, which would justify an input of atmospheric deposition into the study area. This source of trace metals would be related to waste collection vehicles on the site and the dispersion of air pollutants from urban traffic. Also, these bioaccumulation factor values for Zn and Cu are likely due to the essential element or trace element nature of these two trace metals for the plant [42]. Bioaccumulation factors further indicated that Cd was least accumulated by all three species. This could be justified by the fact that Cd is not essential for the growth of plant species and it is toxic to plants [43]. Cadmium toxicity results in damage to plant membranes and destruction of cell biomolecules and organelles [44]. Furthermore, the uptake of trace metals is generally dependent on exposure time and plant species, but also on root morphology [45]. For example, plants with many fine roots accumulate metals more than those with large and few roots [46]. *P. maximum* and *E. indica* species have similar root morphologies; this would explain the relatively high trace metals concentrations obtained in root biomass compared to those recorded in shoot biomass. However, the species *E. indica*, presents TF value higher than 1 for Pb and Cd on the operating site, thus would be adapted for the phytoextraction of these trace metals. Ni registered bioaccumulation factors largely superior to 2, sometimes reaching 55, 97 and 118, respectively for *C. dactylon*, *P. maximum* and *E. indica*. In addition to these bioaccumulation factors, transfer factors are all higher than 1 for all three species. In addition, the mean trace metals concentrations in dry shoot biomass at the landfill sites compared to the control site confirm the Ni hyperaccumulative nature of these three species. This potential for Ni hyperaccumulation by these three species would likely be related to the high diversity of Ni hyperaccumulators. Ni is one of the best candidates for the phytoextraction process [47] [48]. However, *P. maximum* would exhibit the highest degree of hyperaccumulation of the three Poacae species. Thus, this species would be the ideal plant for nickel extraction, as it meets the criteria defined by Chaney et al [49] for the ideal plant for phytoextraction.

5. Conclusion

The study showed high contamination of the soil of the Akouédo landfill by trace metals. Furthermore, the plants species showed metals accumulation potential. For metals accumulation in the plant shoot biomass, Ni was high uptaked by *Panicum maximum*. *P. maximum*, *Eleusine indica* and *Cynodon dactylon* showed the highest values in the root for Zn, Cd and Cu. The BCF and TF values indicated the higher ratio for Ni with *A. spinosus*, *E. indica* and *C. dactylon*. Among the species, *P. maximum*, presented phytoaccumulation capability for Ni.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Khan, M.A., Khan, S., Khan, A. and Alam, M. (2017) Soil Contamination with Cadmium, Consequences and Remediation Using Organic Amendments. *Science of the Total Environment*, **601-602**, 1591-1605. https://doi.org/10.1016/j.scitotenv.2017.06.030

[2] Ali, H., Khan, E. and Ilahi, I. (2019) Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation. *Journal of Chemistry*, **4**, 1-14. https://doi.org/10.1155/2019/6730305

[3] Zeng, P., Guo, Z., Cao, X., Xiao, X., Liu, Y. and Shi, L. (2018) Phytostabilization Potential of Ornamental Plants Grown in Soil Contaminated with Cadmium. *International Journal of Phytoremediation*, **20**, 311-320.

https://doi.org/10.1080/15226514.2017.1381939

[4] Mao, X., Jiang, R., Xiao, W. and Yu, J. (2015) Use of Surfactants for the Remediation of Contaminated Soils: A Review. *Journal of Hazardous Materials*, **285**, 419-435. https://doi.org/10.1016/j.jhazmat.2014.12.009

[5] Ye, S., Zeng, G., Wu, H., Zhang, C., Dai, J., Liang, J., *et al.* (2017) Biological Technologies for the Remediation of Co-Contaminated Soil. *Critical Reviews in Biotechnology*, **37**, 1062-1076. https://doi.org/10.1080/07388551.2017.1304357

[6] Wang, Q.R., Cui, Y.S., Liu, X.M., Dong, Y.T. and Christie, P. (2003) Soil Contamination and Plant Uptake of Heavy Metals at Polluted Sites in China. *Journal of Environmental Science and Health*, *Part A*, **38**, 823-838. https://doi.org/10.1081/ESE-120018594

[7] Chen, L., Luo, S., Li, X., Wan, Y., Chen, J. and Liu, C. (2014) Interaction of Cd-Hyperaccumulator *Solanum nigrum* L. and Functional Endophyte *Pseudomonas* sp. Lk9 on Soil Heavy Metals Uptake. *Soil Biology and Biochemistry*, **68**, 300-308. https://doi.org/10.1016/j.soilbio.2013.10.021

[8] Lasat, M.M. (1999) Phytoextraction of Metals from Contaminated Soil: A Review of Plant/Soil/Metal Interaction and Assessment of Pertinent Agronomic Issues. *Journal of Hazardous Substance Research*, **2**, Article No. 5. https://doi.org/10.4148/1090-7025.1015

[9] Ghosh, M. and Singh, S.P. (2005a) A Review on Phytoremediation of Heavy Metals and Utilization of Its Byproducts. *Applied Ecology and Environmental Research*, **3**, 1-18. https://doi.org/10.15666/aeer/0301_001018

[10] Mench, M.J., Didier, V.L., Loffler, M., Gomez, A. and Masson, P. (1994) A Mimicked *In-Situ* Remediation Study of Metal-Contaminated Soils with Emphasis on Cadmium and Lead. *Journal of Environmental Quality*, **23**, 785-792. https://doi.org/10.2134/jeq1994.00472425002300010010x

[11] Khalid, S., Shahid, M., Niazi, N.K., Murtaza, B., Bibi, I. and Dumat, C. (2017) A Comparison of Technologies for Remediation of Heavy Metal Contaminated Soils. *Journal of Geochemical Exploration*, **182**, 247-268. https://doi.org/10.1016/j.gexplo.2016.11.021

[12] Zloch, M., Kowalkowski, T., Tyburski, J. and Hrynkiewicz, K. (2017) Modeling of Phytoextraction Efficiency of Microbially Stimulated *Salix dasyclados* L. in the Soils with Different Speciation of Heavy Metals. *International Journal of Phytoremediation*, **19**, 1150-1164. https://doi.org/10.1080/15226514.2017.1328396

[13] Ahmad, R., Tehsin, Z., Malik, S.T., Asad, S.A., Shahzad, M., Bilal, M., Shah, M.M. and Khan, S.A. (2016) Phytoremediation Potential of Hemp (*Cannabis sativa* L.): Identification and Characterization of Heavy Metals Responsive Genes. *Clean—Soil, Air, Water*, **44**, 195-201. https://doi.org/10.1002/clen.201500117

[14] Xiao, R., Ali, A., Wang, P., Li, R., Tian, X. and Zhang, Z. (2019) Comparison of the Feasibility of Different Washing Solutions for Combined Soil Washing and Phytoremediation for the Detoxification of Cadmium (Cd) and Zinc (Zn) in Contaminated Soil. *Chemosphere*, **230**, 510-518. https://doi.org/10.1016/j.chemosphere.2019.05.121

[15] Raskin, I., Smith, R.D. and Salt, D.E. (1997) Phytoremediation of Metals: Using Plants to Remove Pollutants from the Environment. *Current Opinion in Biotechnology*, **8**, 221-226. https://doi.org/10.1016/S0958-1669(97)80106-1

[16] Zhu, Y.G. and Shaw, G. (2000) Soil Contamination with Radionuclides and Potential Remediation. *Chemosphere*, **41**, 121-128. https://doi.org/10.1016/S0045-6535(99)00398-7

[17] Wei, S.H., Niu, R.C., Srivastava, M., Zhou, Q.X., Wu, Z.J., Sun, T.H., Hu, Y.H. and Li, Y.M. (2009) *Bidens tripartite* L.: A Cd-Accumulator Confirmed by Pot Culture and Site Sampling Experiment. *Journal of Hazardous Materials*, **170**, 1269-1272. https://doi.org/10.1016/j.jhazmat.2009.05.078

[18] Kuzovkina, Y.A., Knee, M. and Quigley, M.F. (2004) Cadmium and Copper Uptake and Translocation in Five Willow (Salix L.) Species. *International Journal of Phytoremediation*, **6**, 269-287. https://doi.org/10.1080/16226510490496726

[19] Angle, J.S. and Linacre, N.A. (2005) Metal Phytoextraction—A Survey of Potential Risks. *International Journal of Phytoremediation*, **7**, 241-254. https://doi.org/10.1080/16226510500215779

[20] Salt, D.E., Smith, R.D. and Raskin, I. (1998) Phytoremediation. *Annual Review of Plant Physiology and Plant Molecular Biology*, **49**, 643-668. https://doi.org/10.1146/annurev.arplant.49.1.643

[21] Masarovicova, E. and Kralova, K. (2012) Plant-Heavy Metal Interaction: Phytoremediation, Biofortification and Nanoparticles. In: Montanaro, G. and Dichio, B., Eds., *Advances in Selected Plant Physiology Aspects*, In Tech, Rijeka, 75-102. https://doi.org/10.5772/33722

[22] Messou, A., Coulibaly, L., Doumbia, L. and Gourene, G. (2013) Plants Diversity and Phytoaccumulators Identification on the Akouédo Landfill (Abidjan, Côte d'Ivoire). *African Journal of Biotechnology*, **12**, 253-264. https://doi.org/10.5897/AJB12.1664

[23] Kouamé, K.I., Goné, D.L., Savané, I., Kouassi, E.A., Koffi, K., Goula, B.T.A. and Diallo, M. (2006) Mobilité relative des métaux lourds issus de la décharge d'Akouédo et risque de contamination e la nappe du Continental Terminal (Abidjan-Côte d'Ivoire). *Scientific African*, **2**, 39-56. https://doi.org/10.4314/afsci.v2i1.61133

[24] AFNOR (1999) Norme NF X 31-120. In: AFNOR, Ed., *Recueil de normes*, *qualité des sols*, AFNOR, Paris, 7 p.

[25] Ghosh, M. and Singh, S.P. (2005b) A Comparative Study of Cadmium Phytoextraction by Accumulator and Weed Species. *Environmental Pollution*, **133**, 365-371. https://doi.org/10.1016/j.envpol.2004.05.015

[26] Maldonado-Magaña, A., Favela-Torres, E., Rivera-Cabrera, F. and Volke-Sepulveda, T.L. (2011) Lead Bioaccumulation in *Acacia farnesiana* and Its Effect on Lipid Peroxidation and Glutathione Production. *Plant Soil*, **339**, 377-389. https://doi.org/10.1007/s11104-010-0589-6

[27] Blaylock, M.J., Salt, D.E., Dushenkov, S., Zakharova, O., Gussman, C., Kapulnik, Y., Ensley, B.D. and Raskin, Y. (1997) Enhanced Accumulation of Pb in Indian Mustard by Soil-Applied Chelating Agents. *Environmental Science & Technology*, **31**, 860-865. https://doi.org/10.1021/es960552a

[28] Marchiol, L., Assolari, S., Sacco, P. and Zerbi, G. (2004) Phytoextraction of Heavy Metals by Canola (*Brassica napus*) and Radish (*Raphanus sativus*) Grown on Multicontaminated Soil. *Environmental Pollution*, **132**, 21-27. https://doi.org/10.1016/j.envpol.2004.04.001

[29] Waranusantigul, P., Kruatrachue, M., Pokethitiyook, P. and Auesukaree, C. (2008) Evaluation of Pb Phytoremediation Potential in *Buddleja asiatica* and *B. paniculata*. *Water*, *Air*, *& Soil Pollution*, **193**, 79-90. https://doi.org/10.1007/s11270-008-9669-0

[30] Gall, J.E., Boyd, R.S. and Rajakaruna, N. (2015) Transfer of Heavy Metals through Terrestrial Food Webs: A Review. *Environmental Monitoring and Assessment*, **193**, 187-201. https://doi.org/10.1007/s10661-015-4436-3

[31] Ali, H., Khan, E. and Sajad, M.A. (2013) Phytoremediation of Heavy Metals-Concepts and Applications. *Chemosphere*, **91**, 869-881.

https://doi.org/10.1016/j.chemosphere.2013.01.075

[32] Bielen, A., Remans, T., Vangronsveld, J. and Cuypers, A. (2013) The Influence of Metal Stress on the Availability and Redox State of Ascorbate, and Possible Interference with Its Cellular Functions. *International Journal of Molecular Sciences*, **14**, 6382-6413. https://doi.org/10.3390/ijms14036382

[33] Ogoko, E.C. (2015) Accumulation of Heavy Metal in Soil and Their Transfer to Leafy Vegetables with Phytoremediation Potential. *American Journal of Chemistry*, **5**, 125-131.

[34] Hamzah, A., Hapasri, R.I. and Priyadarshini, R. (2017) The Potential of Wild Vegetation Species of *Eleusine indica* L. and *Sonchus arvenis* L. for Phytoremediation of Cd-Contaminated Soil. *Journal of Degraded and Mining Lands Management*, **4**, 797-805. https://doi.org/10.15243/jdmlm.2017.043.797

[35] Anarado, C.E., Mmeka, O.P., Anarado, C.J.O. and Umedum, N.L. (2018) Phytoremediation Potentials of *Dieffenbachia bownanii* and *Eleusine indica* for Cadmium, Lead, Zinc and Cobalt. *IOSR Journal of Applied Chemistry*, **11**, 68-71.

[36] Ancheta, M.H., Quimado, M.O., Tiburan, C.L., Doronila, A. and Fernando, E.S. (2020) Copper and Arsenic Accumulation of *Pityrogramma calomelanos*, *Nephrolepis biserrata*, and *Cynodon dactylon* in Cu- and Au-Mine Tailings. *Journal of Degraded and Mining Lands Management*, **7**, 2201-2208. https://doi.org/10.15243/jdmlm.2020.073.2201

[37] Opoku, P., Gikunoo, E., Kwesi, A. and Foli, G. (2020) Removal of Selected Heavy Metals and Metalloids from an Artisanal Gold Mining Site in Ghana Using Indigenous Plant Species. *Cogent Environmental Science*, **6**, Article ID: 1840863. https://doi.org/10.1080/23311843.2020.1840863

[38] Azeez, J.O., Olowoboko, T.B., Bada, B.S., Odedina, J.N. and Onasanya, O.O. (2020) Evaluation of Soil Metal Sorption Characteristics and Heavy Metal Extractive Ability of Indigenous Plant Species in Abeokuta, Nigeria. *International Journal of Phytoremediation*, **22**, 872-884. https://doi.org/10.1080/15226514.2020.1717433

[39] Coulibaly, H., Ouattara, P.J.-M., Messou, A. and Coulibaly, L. (2021) Phytoextraction of Trace Metals (Cd, Ni and Pb) by *Panicum maximum* Grown on Natural Soil. *Open Journal of Applied Sciences*, **11**, 929-945. https://doi.org/10.4236/ojapps.2021.118068

[40] Clemens, S., Palmgren, M.G. and Kramer, U. (2002) A Long Way Ahead: Understanding and Engineering Plant Metal Accumulation. *Trends in Plant Science*, **7**, 309-315. https://doi.org/10.1016/S1360-1385(02)02295-1

[41] Yang, X., Feng, Y., He, Z. and Stofella, P.J. (2005) Molecular Mechanisms of Heavy Metal Hyperaccumulation and Phytoremediation. *Journal of Trace Elements in Medicine and Biology*, **18**, 339-353. https://doi.org/10.1016/j.jtemb.2005.02.007

[42] Kim, R.Y., Yoon, J.K., Kim, T.S., Yang, J.E., Owens, G. and Kim, K.R. (2015) Bioavailability of Heavy Metals in Soils: Definitions and Practical Implementation—A Critical Review. *Environmental Geochemistry and Health*, **37**, 1041-1061. https://doi.org/10.1007/s10653-015-9695-y

[43] Jali, P., Pradhan, C. and Das, A.B. (2016) Effects of Cadmium Toxicity in Plants: A Review Article. *Scholars Academic Journal of Biosciences*, **4**, 1074-1081.

[44] Abbas, T., Rizwan, M., Ali, S., Adrees, M., Zia-ur-Rehman, M., Qayyum, M.F., Ok, Y.S. and Murtaza, G. (2017) Effect of Biochar on Alleviation of Cadmium Toxicity in Wheat (*Triticum aestivum* L.) Grown on Cd-Contaminated Saline Soil. *Environmental Science and Pollution Research*, **25**, 25668-25680. https://doi.org/10.1007/s11356-017-8987-4

[45] Grant, C.A., Buckley, W.T., Bailey, L.D. and Selles, F. (1997) Cadmium Accumulation in Crops. *Canadian Journal of Plant Science*, **78**, 1-17. https://doi.org/10.4141/P96-100

[46] Das, P., Samantaray, S. and Rout, G.R. (1997) Studies on Cadmium Toxicity in Plants: A Review. *Environmental Pollution*, **98**, 29-36. https://doi.org/10.1016/S0269-7491(97)00110-3

[47] Gupta, A. and Balomajumder, C. (2015) Phytoremediation of Heavy Metals and Its Mechanism: A Brief Review. *Journal of Integrated Science and Technology*, **3**, 51-59. http://pubs.iscience.in/jist

[48] Muthusaravanan, S., Sivarajasekar, N., Vivek, J.S., Paramasivan, T., Naushad, M., Prakashmaran, J., Gayathri, V. and Al-Duaij, O.K. (2018) Phytoremediation of Heavy Metals: Mechanisms, Methods and Enhancements. *Environmental Chemistry Letters*, **16**, 1339-1359. https://doi.org/10.1007/s10311-018-0762-3

[49] Chaney, R.L., Malik, M., Li, Y.M., Brown, S.L., Brewer, E.P., Angle, J.S. and Baker, A.J.M. (1997) Phytoremediation of Soil Metals. *Current Opinion in Biotechnology*, **8**, 279-284. https://doi.org/10.1016/S0958-1669(97)80004-3