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Phytoextraction potential of *Sporobulus pyramidalis* found in an abandoned battery industry environment in Nigeria

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Abstract

The levels of heavy metals (Cd, Cr, Ni, Pb, Sb and V) in *Sporobulus pyramidalis* plant species from an abandoned battery industry environment were determined during the wet and dry seasons as follows: The ranges in metal concentrations during the wet and dry seasons were 0.002, 0.420; 0.036 and 36.10 $\mu g\, g^{-1}$, respectively. The coefficients of variation for the metals during wet and dry season ranged between none to 151.724% and 13.838–214.935%, respectively. The results showed higher levels of the metals in *S. pyramidalis* during the dry than wet season. Results obtained from both wet and dry season when compared with background values, Federal Environmental Protection Agency and other international standards revealed that the plant species accumulated high levels of these heavy metals which was evident in concentrations exceeding maximum tolerable limits. The health implications of consuming this plant and any other plant or crop within this environment are discussed.

Keywords: *Heavy metal,* Sporobulus pyramidalis, *phytoextraction, battery*

Introduction

The potential for environmental pollution started during the industrial revolution and since then attempts to control pollution have continued since 1820 [21,24,27,28]. Pollutants are often introduced into the atmosphere, water bodies and soil as a result of anthropogenic

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activities and natural phenomena, which subsequently affect the ecosystem as well as human health [2,19,27].

Metals and metallic components may be released by natural sources such as rock weathering and volcanic eruption [10].

Anthropogenic sources of these metals to the environment include mining, industrial discharge, combustion of leaded fuel, agricultural runoffs and domestic waste waters [29].

Industries discharge their wastes containing heavy metals into terrestrial and aquatic environments and depending on certain reactions such as speciation these metals become available in the environment and hence to plants [13]. Characteristically, heavy metals are non-biodegradable and, therefore, stable and persistent in the environment [24,27] and the stability of these metals enhances their distribution [12].

Heavy metals discharged into our environment including their (1) distribution and reactions in the ecosystem and (2) subsequent uptake and distribution in plants is of great concern for human health. There exists an indispensable link in the food chain whereby plant life provides a source of trace elements directly or indirectly for herbivorous animals which depend on plants for their nutrition [10]. Therefore, conscious efforts should be made to reduce the quantity of pollutants to permissible limits before discharging wastes into any natural body, to avoid extinction or irreversible effects that might be detrimental to humans, plants and animals which interact in the environment.

The aim of this study was to (1) evaluate the concentration of some heavy metals (Cd, Cr, Ni, Pb, Sb and V) in *Sporobulus pyramidalis* within an industrial environment, (2) correlate the levels of these metals in plants taken from this study area, (3) assess the pollution status of the abandoned Sunshine Batteries Industry environment and (4) compare the results obtained to data from previous studies. Furthermore, recommended measures for reducing the levels of these pollutants in this environment are provided.

Methods

The abandoned battery industry is located at Ukana in Essien Udim Local Government Area of Akwa Ibom State, Nigeria (Figure 1). The Local Government Area is located in a typical tropical climate characterized by distinct wet and dry seasons. The wet season sometimes begins in March or April and is characterized by heavy storms of short duration. The resultant effects include erosion hazards on uncovered steep, sloped lands. In this study area, heavy rainfalls usually occur between June and September and sometimes spill over to October and November [27]. During this period, rainfall over a large portion of this environment exceeds surface evapotranspiration for much of the year and soil leaching occurs [27]. Consequently, the leached surface soil becomes slight to moderately acidic, although the subsoil may remain neutral or alkaline [6].

Most of the spent Pb and sludge from this industry were discharged and stored in drums. These drums which contained antimonial-Pb were still found in the premises of the abandoned industry at the time this investigation was carried out.

Sampling procedures

Sampling of *S. pyramidalis* was carried out within the Sunshine Battery Industry environment where battery wastes was stored in open drums. These drums are still found in the premises of the industry. Sampling was carried out randomly at five designated points: close to the drums (Station I) and at other four points about 200 m away from each

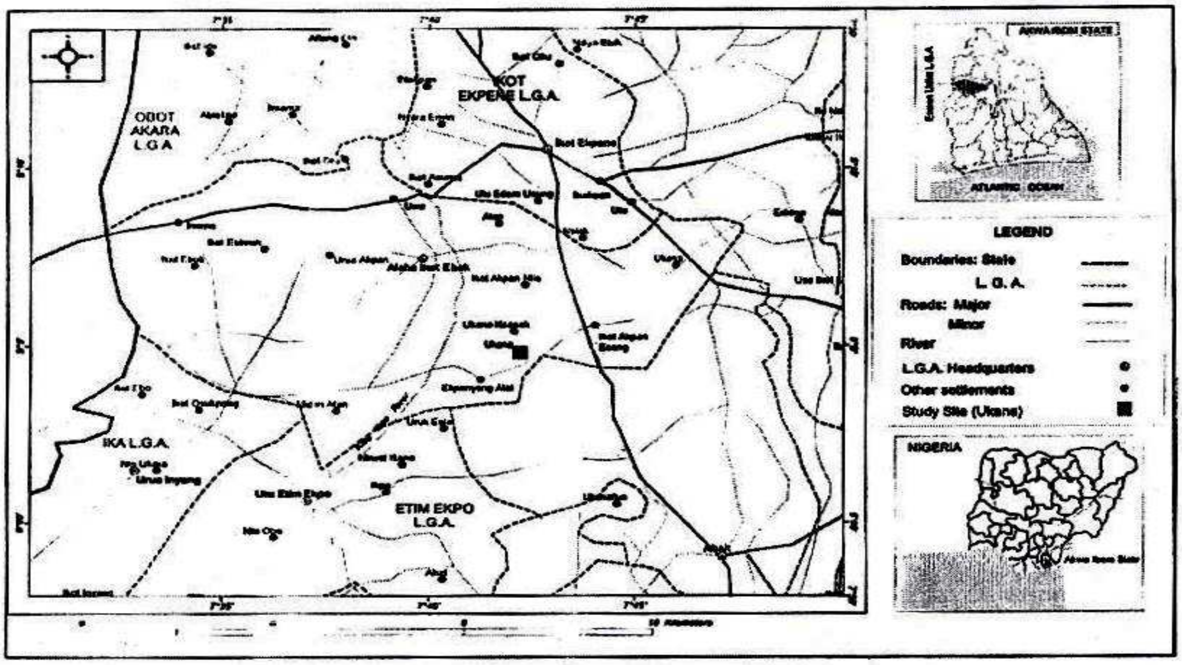

Figure 1. Essien Udim Local Government Area showing the Study Site (Ukana).

drum (Stations II–V) control samples of *S. pyramidalis* were also collected 10 km away from the industry (Stations I–II).

Leaves of *S. pyramidalis* [P. Beauv] were collected and put into a metal-free calico-cloth [25]. The bags containing the samples were labelled and taken to the lab for pre-treatment and analysis. The samples were oven dried at 50–60°C and then ground into powder using mortar and pestle and stored. Five grams of the powder was weighed into a crucible and ashed in a furnace at 500–700°C for 4 h, removed after ashing and kept to cool before being leached with 5 mL of 6 M HCl and subsequently made up to 20 mL with distilled water. The solutions obtained were analyzed for six metals using Pye Unicam 939/959 Atomic Absorption Spectrophotometer with an air-acetylene burner equipped with an automatic readout facility. Procedural blanks were also run for the same elements. The detection limit in $\mu g\,g^{-1}$ for all the elements determined was $0.00005\,\mu g\,g^{-1}$ ($0.001\,mg\,kg^{-1}$). Recoveries of over 99% were obtained confirming the precision of the analytical technique employed. Statistical analysis was done using Analyse-it® software.

Results and discussion

The mean concentrations of six heavy metals (Cd, Cr, Ni, Pb, Sb and V) in *S. pyramidalis* [P. Beauv] from six stations within Sunshine Battery Industry environment and a background site (Station VI) as well as correlation coefficients in wet and dry seasons are given in Tables I–III. Analysis of variance comparing the mean concentrations in the samples in each season was also determined.

Table I. Concentrations of heavy metals in *S. pyramidalis* P. Beauv. wet season ($\mu g\, g^{-1}$).

Sample-ID	Cd	Cr	Ni	Pb	Sb	V
Station-I	0.01	0.44	0.01	0.002	0.2	0.002
Station-II	0.008	0.42	0.002	0.002	0.09	0.004
Station-III	0.01	0.43	0.01	0.002	0.002	0.01
Station-IV	0.01	0.38	0.01	0.003	ND	0.007
Station-V	0.01	0.49	0.01	0.002	ND	0.004
Station-VI	BDL	0.03	BDL	BDL	BDL	BDL
X	0.001	0.42	0.006	0.002	0.06	0.005
SD	0.003	0.022	0.003		0.09	0.003
CV (%)		5.238			151.724	

Table II. Concentrations of heavy metals in *S. pyramidalis* P. Beauv. dry season ($\mu g\, g^{-1}$).

Sample-ID	Cd	Cr	Ni	Pb	Sb	V
Station-I	0.005 ± 0.004	0.95 ± 0.56	1.11 ± 0.09	129.83 ± 0.67	0.75 ± 0.12	0.53 ± 0.38
Station-II	0.01 ± 0.004	0.28 ± 0.1	1.11 ± 0.26	17.47 ± 19.04	0.014 ± 0.02	0.55 ± 0.14
Station-III	0.026 ± 0.03	0.29 ± 0.17	1.19 ± 0.48	12.26 ± 10.91	0.007 ± 0.007	0.32 ± 0.22
Station-IV	0.066 ± 0.034	0.36 ± 0.07	1.06 ± 0.18	$18.15 + 24.34$	0.001 ± 0.0	0.54 ± 0.02
Station-V	0.072 ± 0.07	0.61 ± 0.26	0.81 ± 0.13	$2.82 + 2.2$	0.001 ± 0.0	0.46 ± 0.07
Station-VI	BDL	0.4 ± 0	0.18 ± 0.0	BDL	BDL	0.05 ± 0.0
X	0.036	0.496	1.055	36.104	0.154	0.478
SD	0.031	0.286	0.146	52.75	0.331	0.096
CV (%)	86.111	57.661	13.838	146.106	214.935	20.084

Table III. Correlation matrix between the heavy metal concentrations in *S. pyramidalis* for both wet and dry season.

	Pb	Ni	V	Cd	Cr	Sb
Pb	−0.190	0.027	0.362	0.538	−0.265	−0.258
Ni	−0.309	−0.619	−0.131	0.927*	0.081	−0.276
V	−0.582	0.384	−0.714	0.238	−0.720	−0.609
Cd	0.198	−0.210	−0.420	0.460	0.424	0.236
Cr	0.295	−0.259	−0.313	−0.355	0.514	0.382
Sb	0.921*	0.308	0.451	−0.763	0.711	0.911*

Critical $r = 0.878$.
*Significant correlations ($p < 0.05$, $n = 5$).

In the wet season, the least mean concentration of Pb recorded was $0.002\,\mu g\, g^{-1}$ at Station IV, while during the dry season the highest Pb level of $129.83\,\mu g\, g^{-1}$ was observed at Station I and the least Pb level in the season was $2.82\,\mu g\, g^{-1}$ at Station V. The mean levels of Pb observed in both wet and dry seasons were 0.002 and $36.1\,\mu g\, g^{-1}$. The mean Ni level in the wet season observed was $0.006\,\mu g\, g^{-1}$, while in the dry season the mean level was $1.06\,\mu g\, g^{-1}$.

Mean concentrations of V in the wet and dry seasons were 0.005 and $0.48\,\mu g\, g^{-1}$, respectively. The mean concentrations of Cd in both wet and dry seasons were 0.01 and

0.04 $\mu g\,g^{-1}$, respectively. Mean level of Cr obtained in both wet and dry season were 0.42 and 0.5 $\mu g\,g^{-1}$ equally, mean concentrations of Sb obtained in the wet and dry seasons were 0.06 and 0.15 $\mu g\,g^{-1}$, respectively. The mean concentrations of metals in the plant samples collected from the six stations during both wet and dry season followed the trend:

$$\text{Wet season: } Cr > Sb > Cd > V > Ni > Pb$$
$$\text{Dry season: } Pb > Ni > Cr > V > Sb > Cd$$

From the above trend, it is noteworthy that non-essential heavy metals like Cd, Pb, Sb with low ionic potential e.g. Cd(II), have a greater tendency to migrate and accumulate in vegetation and more likely to be leached from industrial waste [10]. The coefficients of variation for all the metals considered in *S. pyramidalis* in both wet and dry season ranged between none to 151.7% and 3.8–214.9%, respectively. Comparing coefficients of variation obtained in this study with that obtained by [27] for the same study area (5.3 and 46.6% in wet season, 5.3 and 42.5% in dry season), the coefficients of variation obtained in this study where higher, indicating persistent presence of these heavy metals. Statistical analysis carried out showed significant differences in deposition of these heavy metals in plants for wet and dry seasons.

The results obtained showed variations in the concentration of heavy metals in *S. pyramidalis*. The concentrations of these heavy metals determined were remarkably higher in the dry than wet season indicating that the pollution of this environment was more intense during the dry season. Higher levels of these metals may be attributed to the speciation of these metals in this environment, pH and the immobility of these fractions in the dry season compared to mobility of these fractions in the wet season [13,14,29].

Higher concentrations of Pb were found in the dry than wet season and may attributable to the fact that Pb being the major raw material used in the manufacture of battery may have accumulated in the industrial wastes and later released to the industrial environment. According to [7,15,17], Pb usually accumulates in the clay fraction of a soil profile. The low concentration values obtained in the wet season was due to more acidic conditions (pH 2.16) which produced desorption of these cations into solution making them available for uptake by plants. Hesse [11], found that most heavy metals are less available to plants under alkaline than under acid conditions. The levels of Pb obtained in the dry season were above the maximum tolerable level (0.1 ppm) in plants [1]; and may have been responsible for the decline in the growth of some of the plants observed. Black [5] and Leita et al. [16] obtained similar values in *I. scorodinia* which substantially had reduced plant growth.

The observed mean concentrations of Pb obtained in the dry season were higher than those obtained by Udosen [27] for *Arthropteris orientalis* during the same season in this environment. The increase in concentration of Pb in *S. pyramidalis* may be attributable to bioaccumulation. The values obtained for Pb in both wet and dry season showed no significant difference while the coefficient of variation in the wet season suggested persistent presence of Pb in the study area.

It was confirmed from studies that toxicants including heavy metals are absorbed into plants are dependent upon factors such as solubility, pH, genetic tolerance, stage of growth of the plant age, type of tissue as well as exposure of the plant to the toxicants [3]. Pb is not markedly absorbed by roots of plants owing to its low solubility potential in water [26], yet high levels of this metal in the plants suggests possible absorption of this metal from the soil on which the plants grew. Moreover, the presence of about 0.1 ppm Pb reduces heterotrophic activity in microflora which may in turn enhance bioaccumulation of Pb in plants.

Cd concentrations were lower in the dry than wet season. This may be attributed to Cd having low ionic potential (2) and a greater tendency to accumulate in vegetation in the wet than dry season. However, comparing the levels of Cd obtained in this study with maximum level of $5\,mg\,kg^{-1}$ reported by Chen and Lee (1999) and Bowen [8], the observed concentration is far lower. Bryan [9] obtained a concentration of $2\,\mu g\,g^{-1}$ in *Lithorina littorea*. John et al. (1972) also showed that plant size and yield were reduced when 50 mg Cd were added to 500 g of soil. Toxicity due to Cd in this environment may not have occurred since the levels in this study were within tolerated limits. However, unlike most of the other heavy metals; Cd is taken up easily by many plants at low pH and high temperature and exists in the stable form, Cd^{2+} (a relatively soluble ion that behaves like Ca^{2+}) [23]. This makes this metal readily available to plants and therefore capable of accumulating in the foodchain [26].

Sb was found at higher values in the dry than wet season. The lower concentrations of Sb observed in the wet season may be attributed to Sb being leached. Sb is considered toxic in both acute (100 mg per day) and chronic ($>100\,mg\,kg^{-1}$) cases [18]. Like As, Sb(III) salts are 10-fold higher than Sb(V) salts and are present in this environment is due to binding with Pb (antimonial-lead) as the raw material for the manufacture of batteries. The mean concentration obtained in this study were lower than those obtained by [27] in this same study area, but the amount in this environment was above the acceptable limits of $0.03\,mg\,kg^{-1}$ in plants in both seasons [4].

Although there have not been any reported effects of Sb on plants, Sb decreased the lifespan of rats and mice when they were fed with Sb-contaminated feeds [20]. Therefore, pollution produced by Sb due to its persistent presence in this environment may be a problem.

Ni levels were higher in the dry than wet season and exceeded the natural limit in plants ($1–5\,mg\,kg^{-1}$) [1,22]. At levels of $0.5–2\,mg\,L^{-1}$, it is toxic to plants and rats at 50 mg per day. The presence of Ni in this environment may be attributed to anthropogenic sources like burning of fossil fuels in the environment which must have settled on the foliage of *S. pyramidalis*. The coefficient of variation shows that Ni was still stable in this environment.

Cr concentrations were high in both seasons and this may be attributable to Cr being an essential element in plants, but the mean concentrations observed in both seasons were above natural limit in plants ($0.05\,\mu g\,g^{-1}$) [30]. Bryan [9] found high concentrations of $0.5–10\,mg\,L^{-1}$ Cr(VI) was toxic to plants. The concentration of Cr was high and may pose a threat in this environment if consumed by animals. The coefficient of variations shows that Cr was stable in this environment.

V generally varies from the range of $0.1–100\,mg\,kg^{-1}$ dry weight in plants [30]. High concentrations of V were observed in *S. pyramidalis* during the dry season, which was above natural levels in plants ($0.5\,mg\,kg^{-1}$), and in edible vegetables ($0.001–0.5\,mg\,kg^{-1}$) [4]. These high levels in the dry season may be attributable to absence of non-exchangeable nutrients or precipitation of this metal. Levels of $10–40\,mg\,L^{-1}$ are toxic to plants, 0.25 mg per day is toxic and 2–4 mg per day lethal to rats [4].

The presence of V in this environment is due to anthropogenic sources like the generators which were the main source of power supply to the industry. Automobile fumes also may have contributed certain levels of V in the form of particulates into this environment which may have resulted in the pollution of this study area, and the coefficient of variation shows that this metal was stable in this environment.

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