

Full Length Research Paper

Lead uptake of water plants in water stream at Kiteezi landfill site, Kampala (Uganda)

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Received 29 September, 2014; Accepted 8 April, 2015

The purpose of this study was twofold: (i) to quantify the lead (Pb) uptake by two water plants reeds (*Phragmites australis*) and papyrus (*Cyperus papyrus*) in water stream at Kiteezi landfill site, Kampala (Uganda) and (ii) to compare the two species in Pb uptake downstream. As such, leachate samples were collected at the inlet and outlet of the waste water treatment plant (WWTP) at Kiteezi landfill site. A total of 6 plant samples of both plant species, *P. australis* and *C. papyrus*, were picked from three different sites at intervals of 10, 20 and 30 m taken from the exit point of the WWTP, as the reference point. All samples were taken to the laboratory for analysis in a cool container. The concentration of Pb in the samples was measured using the atomic absorption spectrometer (AAS), Perkin Elmer Model. The obtained data was analyzed using descriptive statistics and two-way Anova. The results showed that there was no significant difference ($P > 0.05$) in the mean Pb content up taken by both plants (reeds and papyrus). Significant quantities of Pb were present in the plants in the range of 1.68 to 5.46 mg/100 g. The removal efficiency of the plants was found to be 12.4 times higher than WWTP. The highest concentrations of Pb were found downstream at a distance of 30 m away from the reference point. Although, the plants were generalized as having equal uptake levels, the two species had different mechanisms with reeds being accumulators and papyrus being excluders. Therefore, reeds are preferable phytoremediators since when harvested by cutting as practiced by some communities in Uganda, the Pb can easily be removed from the environment.

Key words: Lead-uptake, excluders, accumulators, phytoremediation, leachates and Kiteezi.

INTRODUCTION

Leachate from dumping sites, especially open dumps, contain heavy metals which compromise water quality (Kamarudzaman et al., 2011). Heavy metals are some of the causes of contamination in the environment. They are some trace elements and also defined as elements with metallic properties and atomic number greater than 20. It is a term that can also include light elements such as

copper, with an atomic weight of 63. Heavy metals are commonly known for their toxicity. Despite the fact that some heavy metals such as chromium, copper, iron and zinc are essential for life in small quantities, others such as lead and cadmium do not have a vital function and could be harmful to organisms even in small concentrations (Nhapi et al., 2012).

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Heavy metal contamination is usually a result of various human activities such as mining and smelting, metalliferous electroplating, internal combustion engine operation, energy and fuel production, fertilizer and pesticide application and the generation of municipal solid waste. Metals enter the municipal solid waste stream from different sources. These include batteries, house dust and paint chips, light bulbs, consumer electronics, ceramics, lead foils such as wine bottle closures, used motor oils, plastics, some inks and also glass (Woodbury, 1992). Movement of these contaminants into non contaminated areas as dust or leachates through the soil is one of the ways that contaminate the ecosystems (Tangahu et al., 2011). Since metals are not easily biodegraded, eliminating them from the environment, necessitates their removal. Currently, not even highly industrialized countries can afford to clean up contaminated sites. For example in Germany, 30% of the soils from contaminated areas are cleaned up in soil remediation facilities, while the rest is stored untreated in waste disposal facilities (Csaba, 2011).

Various methods are being adopted to free the environment from these kinds of contaminants, though majority of them are expensive and not very efficient. Chemical technologies generate large volumetric sludge and thus higher costs. Thermal technologies degrade the valuable component of the soils (Tangahu et al., 2011), hence making the methods not the most efficient. Recent concerns regarding the environmental contamination have led to the discovery of adequate methods to assess the presence and mobility of metals in soil, water and wastewater (Shtangeeva et al., 2004). Currently, phytoremediation, which is the use of special species of plants to remove heavy metals from soil and water, has become an effective and affordable technological solution in the extraction of metals from soil. This is basically because the method is environmentally friendly and cost effective. This method takes advantage of the unique and selective uptake capabilities of plant root systems, together with translocation, bioaccumulation and degradation abilities of the entire plant body. Many species of plants have been successful in absorbing lead, cadmium, arsenic and various radionuclides from soils.

For example Kim et al. (2003) studied heavy metal accumulation in *Polygonum thunbergii* and the soil from Man-Kyung River watershed, Korea, and noted that there was detectable presence of heavy metals in the plant in the order of Zn (2427.3 µg/g) > Cu (863.2 µg/g) > Pb (320.8 µg/g) > Cd (7.4 and 10.1 µg/g) in only the stem and root respectively). The soil samples contained detectable zinc (24.5 µg/g) > lead (17.5 µg/g) > copper (8.4 µg/g) with undetectable cadmium content. This study rendered the plant a very good phyto-extractor. Odong et al. (2013), also studied a range of macrophyte plants to see if anyone was able to clean up waste water and absorb toxic matter from abattoir effluent that is a major source of pollution entering Lake Victoria, in his study,

papyrus and weeds were tested and it was found that papyrus was able to remove the highest concentration of four grams of phosphorus per kilogram dry weight from the waste water.

Lead as a metal occurs naturally in the earth, it has many industrial uses and is found in trace amounts everywhere in the environment. It is a very toxic and dangerous metal when ingested in the human body. In humans, exposure to lead can result in biological effects such as problems in the synthesis of gastrointestinal tract, joints, reproductive system and acute chronic damage to the nervous system, depending on the level and duration of the exposure. Research has proven that lead contributes to 0.2% of all deaths and 0.6% of all disability in life globally (WHO, 2009). Developing fetus and infants are more sensitive to the effects than the adults.

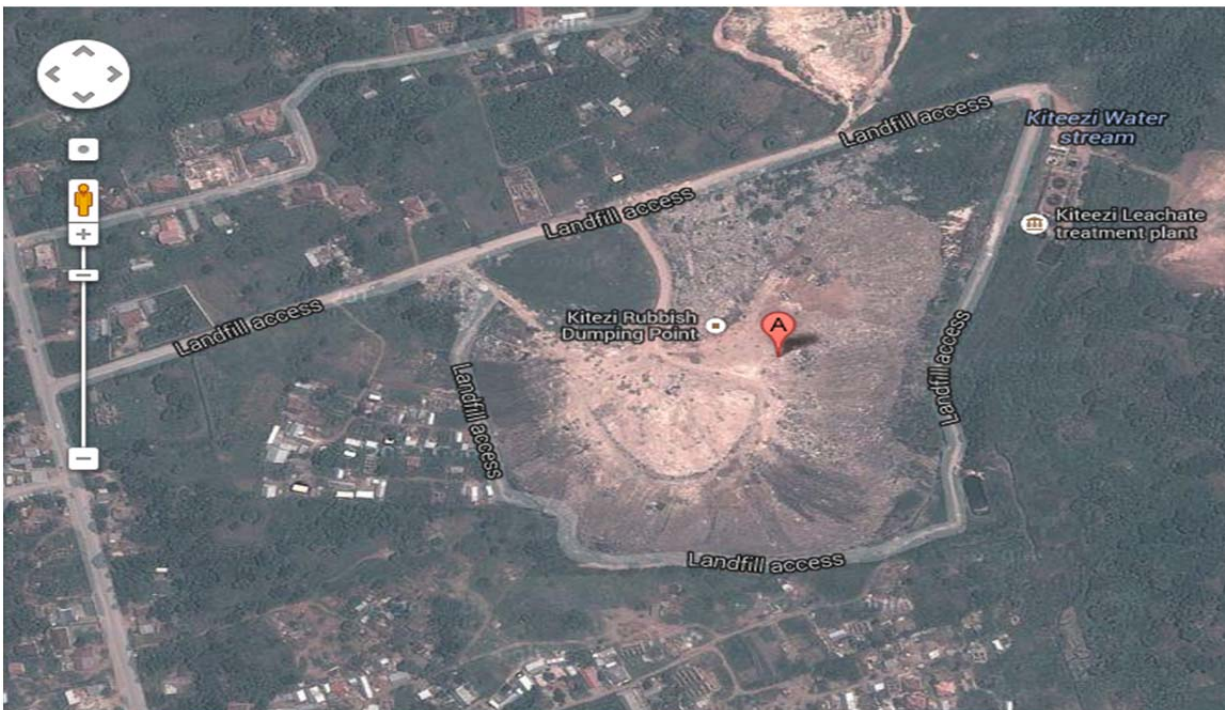
Land filling is the primary means of disposal of both residual municipal solid waste and many hazardous wastes in Uganda. According to Ngategize (2000), the current and only landfill site in Kampala is at Kiteezi. It is further situated within a human settlement community, where it has caused social discomfort and environmental pollution. During the process of land filling, waste is subjected to aerobic decomposition which creates social tensions among the communities near the landfills especially odour pollution, flies, vermin and pests (Sabiiti and Katongole, 2012). It is against this background, that this study's main objective was twofold: (i) to quantify the lead uptake by the two water plants, reeds (*Phragmites australis*) and papyrus (*Cyperus papyrus*) in water stream at Kiteezi landfill site, Kampala (Uganda) and (ii) to compare the two species in Pb uptake downstream and as a result suggest which of the species should be promoted to improve the water quality downstream: (i) to quantify the lead (Pb) uptake by the two reeds in the water stream and (ii) to compare the two species in Pb uptake downstream.

MATERIALS AND METHODS

Study area

This study was conducted in Kiteezi landfill site, located at the north of Kampala City, an average distance of 12 km from the city central. Kiteezi landfill site serves the 5 divisions of Kampala, namely, Kampala Central, Nakawa, Lubaga, Makindye and Kawempe. The present access to the site from Kampala City is through Kampala-Gayaza road (about 9 km), then branch off to the left from Mpererwe and follow the road heading to Namulonge for about 4 km. Currently, it is the only landfill site at which Kampala's solid waste is disposed. The neighboring areas of Kiteezi land fill include: Kasangati, Kawempe, Nangabo, Namalere, Bulamoiro, Buye and Kalerwe.

Geographically, Kiteezi is located at latitude: 0° 25' 0" and longitude: 32° 34' 00" as depicted in Map 1. The site was opened in 1996 and it covers an area of 29 acres. By then, KCCA in 2007 acquired an additional six acres to the south of the existing landfill for expansion purposes.



Map 1. Satellite image of Kiteezi landfill location (Source: Google maps).

Experimental procedure

Leachate sample collection and analysis

The leachate samples were collected, preserved and stored in 500 ml plastic bottles. The bottles were first cleaned thoroughly with de-ionized water, then rinsed thrice with the sample leachate before the final collection. The leachate samples were collected by directly inserting 500 ml plastic water bottles in the leachate and picking up the samples. The inlet samples were picked at the inlet collection point, where all the leachate from the landfill is drained to, before it is piped to the water treatment plant. The outlet samples were picked just at the exit of the waste water treatment plant, by also inserting the bottles into the leachate as the leachate is being discharged out of the waste water treatment plant pipes. The samples were then preserved and stored in the 500 ml plastic bottles.

The temperature and pH was measured in the field using portable HACH meters. The leachate was collected from two sampling sites which were, the inlet and outlet of the waste water treatment plant, respectively. The samples were analyzed for lead concentration by digesting them in a solution of 1:3 hydrochloric (50 ml) and nitric acid (150 ml), respectively. Five milliliters of HCl/HNO₃ (1:3 v/v) was added to the leachate samples to make up to a 25 ml volumetric flask. The solutions were filtered with Whatman filter paper. The actual concentrations of lead were determined using an atomic absorption spectrophotometer (Perkin Elmer Model).

Plant sample collection and analysis

The field survey was conducted to identify which of the two species (papyrus and reeds), accumulated exceptionally high concentrations of lead and the extraction coefficients. Samples were collected from

three sites at intervals of 10 m apart, along the stream length, from the start of the stream, at the exit of the treatment plant.

One individual of each plant species was picked from the three different sites of the study area, making a total of six plants. Each plant sample was thoroughly washed in running tap water for 5 min, and with a solution of phosphate free detergent for 15 s, then with tap water for another 15 s. The samples were then carefully rinsed with deionized water twice and separated into shoots, stems and roots. The samples were then oven dried at 105°C for 48 h, ground into fine powder using a blender and sieved through a nylon sieve. Different weights of each plant part sample ranging from 1-5 g, depending on the availability of the sample, were weighed into nickel crucibles that had been initially conditioned and their respective weights recorded. Each plant part were replicated three times, the samples were then carbonized by heating them on a hotplate for 1 h until the powder turned black.

This was followed by dry ashing, which refers to the use of muffle furnace capable of maintaining temperatures of 500 - 600°C. Water and volatiles are vaporized and organic substances are burned in the presence of oxygen in air to carbon dioxide and the oxides of nitrogen. Most minerals are converted to oxides, sulphates, phosphates, chlorides and silicates. Elements such as Fe, Se, Pb and Hg may partially volatilize with this procedure so, other methods must be used if ashing is a preliminary step for specific elemental analysis. Most dry ashing samples need no preparation while fresh vegetables need to be dried prior to ashing.

The carbonised samples were then immediately transferred to the furnace (with the arrangement of the crucibles recorded) and left to ignite for 4-6 h at 550°C, after this period, the furnace was then turned off and not opened until the temperatures dropped to 250°C or below and using safety tongs the samples if well ashed (with no black spots seen), the crucibles were transferred into a desiccator to cool and the weight of sample plus crucible recorded. The concentrations of lead in shoots, stems and roots were determined using the different weights of respective plant samples

Table 1. Lead (Pb) concentration ($\mu\text{g/g}$) determined in the influent and effluent of the water treatment plant.

Leachate	Concentration ($\mu\text{g/g}$)
Influent	0.63
Effluent	0.58

Table 2. Mean Pb content (mg/100 g) of the triplicates of shoots, stems and roots of papyrus (P) and reeds (R) determined.

Distance from reference point (m)	P _{roots}	P _{stem}	P _{shoot}	ΣLead^*	R _{roots}	R _{stem}	R _{shoot}	ΣLead^*
A (10)	1.29	1.71	0.15	3.14	0.58	0.33	0.77	1.68
B (20)	2.45	0.71	0.49	3.65	1.63	1.00	1.71	4.34
C (30)	1.61	1.29	0.82	3.72	1.69	1.35	2.42	5.46

Lead*: the sum of Lead content in the whole plant, P- papyrus, R- reeds.

digested with 5 ml of 20% HCl and the mixture boiled for 5 min on a hot plate. The solution was filtered into 25 ml volumetric flasks and made to the mark using distilled water. The lead concentration was measured using a flame atomic absorption spectrophotometer. Extraction coefficient was calculated as:

$$\text{Extraction coefficient} = \frac{\text{lead concentration in shoot}}{\text{lead concentration in water}} \quad (1)$$

Equation 1 can be used to evaluate the ability of the plants to accumulate heavy metals.

Determination of waste water treatment plant efficiency

The efficiency of waste water treatment plant was determined using Equation 2.

$$E_0 = \frac{\Delta Pb}{Pb_{in}} \times 100 \quad (2)$$

Where Pb_{in} is lead in the effluent, E_0 is efficiency of the WWTP

$$E_0 = \frac{(0.63 - 0.58)}{0.63} \times 100 = 7.94\%$$

Data analysis

The data was analyzed using Microsoft Excel package, in which tools like two way-ANOVA (analysis of variance) and other descriptive statistics were used. The data was analyzed in terms of mean and standard deviation. These tools were used to determine the variations of the mean lead concentration in the two species of plants at the three different sites (the two independent variables) and to which level of confidence the variation is if it existed. Using $p > 0.05$, shows non-significant difference in the means, the information helped to check if the determined values conform to a normal distribution.

RESULTS AND DISCUSSION

Table 1 shows the lead concentration in the leachate at Kiteezi landfill site, Kampala, Uganda. The lead at the inlet to the water treatment plant was detected and found to be $0.63 \mu\text{g/g}$ and that at the outlet to be $0.58 \mu\text{g/g}$. The efficiency of the plant was determined from Equation 2 and found to be very poor, 7.94%. This in addition to the build-up of lead in the soil and the stream containing the plants, makes the stream act as a plug flow reactor (where concentrations of pollutants vary along the directions of flow), contributing to the fact that the plants have a higher lead uptake as compared to what the water treatment plant has is depicted in Table 2.

It was noted that the Pb concentration generally increased with distance (10-30 m) away from the reference point (exit point of the WWTP). This trend was attributed to the fact that as distance increased, flow rate reduced, thus making the plants have more contact time with the leachate and hence the increased concentrations in the amounts of lead extracted.

For the reeds, it was found that they accumulated more lead in their shoots than in the roots. This makes the shoot to root ratio > 1 and thus rendering the plant an accumulator (Baker and Whiting, 2002). Also, the stems were seen to have lower concentrations of lead than shoots, and this was attributed to a biological factor that the stems contain vascular bundles (xylem and phloem), that are essential in translocation (xylem), when the transported elements reach the shoots and are subjected to other processes like transpiration, this takes away the water and thus leaving higher concentrations of solids in the shoots.

Papyrus was found to have more lead accumulated in the roots than in the shoots, similar results were reported by Odong et al. (2013). Hence, shoot to root ratio was $<$ than 1 and thus rendering papyrus an excluder (Baker

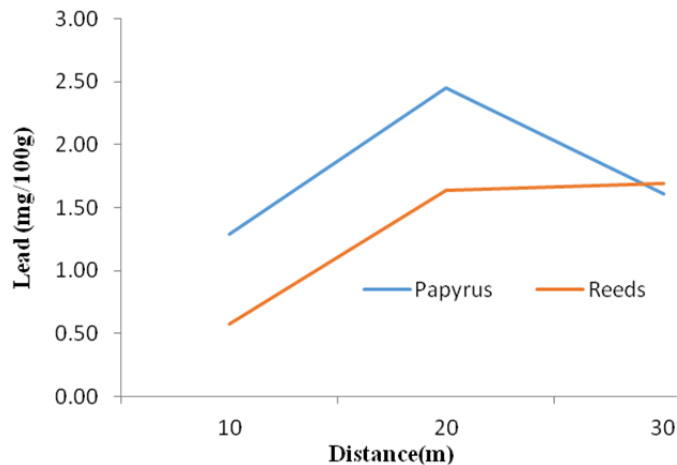


Figure 1. Variation of lead in roots ($P > 0.05$).

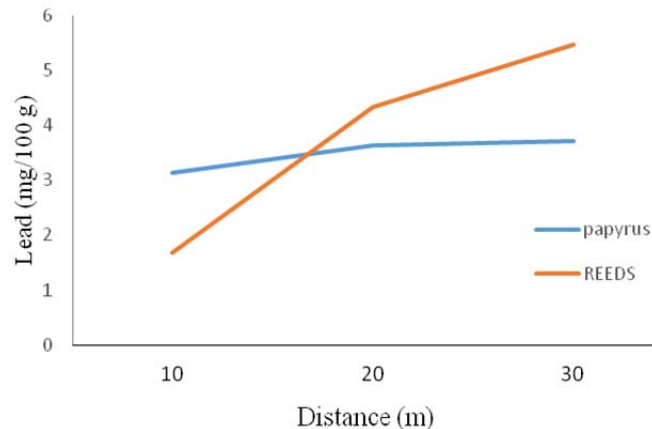


Figure 4. Variation of lead in whole plants ($P > 0.05$).

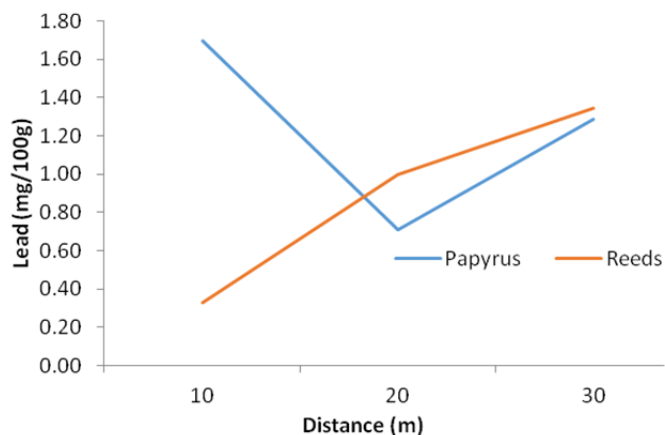


Figure 2. Variation of lead in stems ($P > 0.05$).

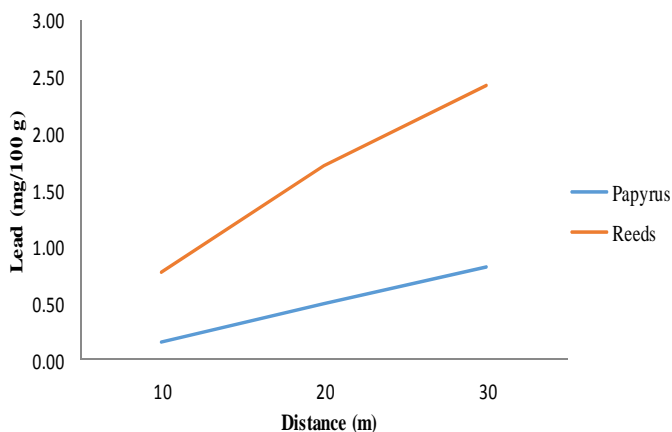


Figure 3. Variation of lead in shoots ($P > 0.05$).

that at 30 m (1.61 mg/100 g) and this was attributed to the fact that, at the spot where this particular plant was picked, there was a ditch thus making it deeper and having a more root to contact time as compared to the plant at 30 m. On comparing a specific part of both plant species, the variation of lead was as shown in the Figures 1, 2, 3 and 4. Figure 1 shows that papyrus roots had a higher lead concentration as seen above, but for both plants, they increased in the order of $C > B > A$. Figure 2 shows that the accumulation of lead in the stems increased gradually for reeds in the order of $C > B > A$, while for papyrus it was in the order of $A > C > B$. Figure 3 depicts reeds accumulated more lead in the shoots than papyrus but in the order of $C > B > A$ for both plants.

On comparing the results with two-way Anova, it was found that all comparisons showed $P > 0.05$, this implied that there was no significant difference in variation of the mean lead content of all the parts and the plants as a whole (Figure 4). On further analysis, also the plants were found to be more efficient than the waste water treatment plant as depicted in Table 3.

Conclusions

Significant quantities of lead were present in both the leachate and the plant parts. The waste water treatment plant was found to have a low lead removal efficiency of 7.94%. The removal efficiency of the plants was 12.4 times higher than that of the waste water treatment plant. The plants were generalized as having the same lead uptake levels, since there was no significant difference ($P > 0.05$) in the comparisons made for the two plant species. On an exhaustive analysis of plant parts, and from the different profiles of the plant parts made, it was also noted that the two species had different uptake mechanisms, with the reeds being rendered accumulators while papyrus are excluders. Therefore, the study proposes that more of the reeds could be propagated

and Whiting, 2002). At 20 m, the papyrus roots were found to contain 2.45 mg/100 g which was greater than

Table 3. The plants' efficiencies (E_{rp} and E_p) at the different distances in comparison with the WTP efficient (E_0).

Distance from reference point (m)	Plant efficiency (%)		Efficiency ratio	
	Reeds (E_r)	Papyrus (E_p)	$\left(\frac{E_r}{E_0}\right)$	$\left(\frac{E_p}{E_0}\right)$
10	96.5	98.2	12.2	12.4
20	98.7	98.4	12.4	12.5
30	98.9	98.4	12.4	12.5

due to the fact that they are accumulators, which makes it easier to eliminate the lead (Pb) when they are harvested by cutting them down (Kim et al., 2003) unlike the excluders that keep the lead (Pb) in the roots.

Conflict of interests

The author(s) declare no conflict of interest that may include any of the following:

Funding: Research support for this work (including salaries, equipment, supplies, reimbursement for attending symposia, and other expenses) by any organization that may gain or lose financially through publication of the paper.

Employment: Recent (that is, while engaged in the research project), present or anticipated employment by any organization that may gain or lose financially through publication of the paper.

Personal financial interests: Stocks or shares in companies that may gain or lose financially through publication; consultation fees or other forms of remuneration from organizations that may gain or lose financially; patents or patent applications whose value may be affected by publication.

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