ASSESSMENT OF SELECTED NATIVE PLANTS GROWING ALONG NAIROBI RIVER FOR UPTAKE OF COPPER, ZINC AND CADMIUM

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Abstract

Nairobi River has high quantities of heavy metals emanating mainly from industrial and domestic wastes. Phytoremediation is a promising alternative to conventional clean-up methods; however, not enough information is available on plant species suitable for this application, especially in Kenya. Plant screening on contaminated sites is necessary and may lead to the identification of more species. A phytoremediation study was carried out along Nairobi River in six sites; Kikuyu, Kawangware, Chiromo, Gikomba, Njiru, and Fourteen falls. The objective of this study was to ascertain the extent of heavy metal pollution and the potential of *Polygonum senegalensis (P. senegalensis), Amaranthus hybridus* (*A. hybridus*) and *Eichhornia crassipes (E. crassipes)* as phytoremediants. The heavy metals studied were Copper (Cu), Cadmium (Cd) and Zinc (Zn) in the selected native plants (biotic indicators), water and soil (abiotic indicators). The metals were detected using the atomic absorption spectrophotometer (AAS). The observed values of heavy metals in water, soil and plants did not vary significantly ($p>0.05$) among the sampling sites. The mean concentration of these metals in soil (43.01 ± 0.03 mg/Kg) was higher than the values recorded in water (37.61 ± 0.65 mg/L). The ability of the plants to take up heavy metals (BCF) was evaluated from the ratio of metal concentration in the plants and water. The Bio-concentration factor (BCF) obtained was *P. senegalensis*: 8.83 ± 0.62, *A. hybridus*; 8.44 ± 0.59 and *E. crassipes*: 7.56 ± 0.42. The BCF show that the selected plants accumulate Cu, Zn and Cd from water. The mean concentrations of heavy metals obtained in the plants are: Cu 6.73 ± 0.74 mg/Kg, Zn 16.53 ± 2.59 mg/Kg and Cd 2.57 ± 0.83 mg/Kg. Based on the results observed in the plants, Zn showed the largest accumulation and can be considered as one of the major pollutants of Nairobi River. The results showed differences in accumulation of metals - Zn, Cu and Cd - in different plant organs, roots > stems > leaves. This study showed that *P. senegalensis* and *A. hybridus* can accumulate Cu, Zn and Cd even when the concentrations of the metals in the abiotic components (soil and water) of the aquatic environment is low, suggesting that the plants are promising candidates for phytoremediation of aquatic ecosystems polluted with Cu, Zn and Cd.

Key words: Native plants, Nairobi River, copper, zinc, cadmium

1.0 Introduction

1.1 Study Area

The Nairobi River and its tributaries traverse through the Nairobi County which is the Kenyan Capital. It is the main river of the *Nairobi River Basin,* a complex of several parallel streams flowing eastwards i.e. Ngong River, Mathare River and Motoine River. All of them join east of Nairobi and meet the Athi River, eventually flowing to the Indian Ocean. These rivers are mostly narrow and highly polluted. The main stream, *Nairobi River*, bounds the northern city centre and is partly canalized. Nairobi River lies between 1° 11′ 59″ S and 37° 9′ 26″ E (Figure 1-1)

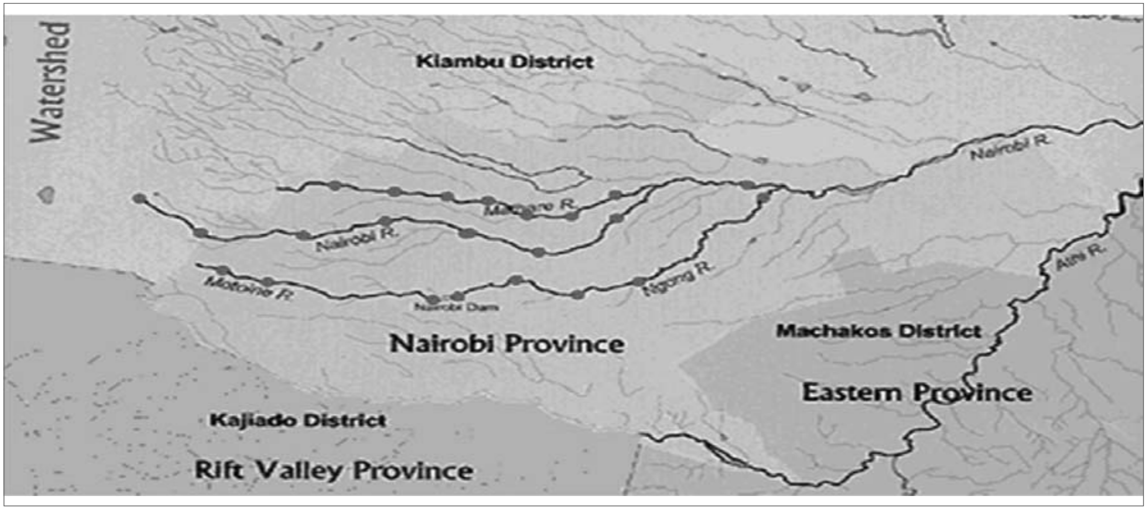

Figure 1: Location of Nairobi River as the main stream of Nairobi River Basin

Ecologically, the study area lies within agro-ecological zones which range from humid, through semi-humid to semiarid lands. However, land-use systems are highly influenced by rainfall patterns, topography and human activities. The area has two distinctive land-use systems, comprising agriculture, which is the main land use in the Kiambu area, and industry, which is the predominant land use in Nairobi city and its environs. Population growth and industrial production has increased the volume of domestic waste and effluent load discharged into the rivers passing through the city and has caused a serious deterioration in water quality. The source of Nairobi River is the Kikuyu springs at an altitude of 2000 m above sea level. From Kikuyu the river flows eastwards through Dagoretti, Kawangware, Chiromo, the central business district, Eastleigh and Kariobangi sewage treatment works. After Kariobangi the Nairobi River runs through barren Njiru quarry sites where the Gitathuru and Ruaraka Rivers join it. The Nairobi River then flows past the Nairobi Falls and Fourteen Falls. The river joins the Athi River and eventually the Sabaki River which discharges its water into the Indian Ocean at Malindi on the East African coast.

1.2 Sources of Pollution in Nairobi River

Water pollution is mainly a result of human activities and makes the water dangerous to human beings, unfit for industrial use and adversely affects the aquatic biota. Water pollution is associated with human population explosion and industrialization. The main sources of water pollution are industrial discharge, sewage, agricultural waste, fertilisers, and seepage from waste sites, decaying plant life, road, railway and sea accidents involving large oil carriers (Kinchella and Hyland, 1993).The city has experienced rapid industrialization and growth in population during the last 100 years (Okoth and Otieno, 2001). This rapid growth has not been matched by development of infrastructure to deal with waste disposal. As a result problems have arisen with regard to garbage, human and industrial waste disposal leading to pollution of the water resources. Sources of pollution of the Nairobi River include industrial effluent, effluent from petrol stations and motor vehicle garages, surface run off, factories and other business premises, raw sewage from broken or overloaded sewers as well as raw sewage from informal settlements (Ndwaru, 1994; Otieno, 1995; Okoth and Otieno, 2001).

1.3 Environmental Issues Facing Nairobi River

Pollution of rivers and streams is one of the crucial environmental problems. Although some kinds of water pollution can occur through natural processes, it is mostly as a result of human activities. Kenya's scarce water resources are under threat from pollution with the major sources of pollution being domestic/municipal and industrial. Human settlements along the Nairobi River have increased dramatically due to the growth of the city and population increase. This has raised serious concern for the environmentalists on the state of Nairobi River for several decades. The River has seen a massive deterioration in quality with the increase in population of the city. This increase in the city's population coupled with a sluggish economy has led to the mushrooming of slums, which tend to reside next to the riverbanks of which sanitation facilities are non-existent. Since the communities are not served by amenities and public utilities, they have tended to discharge their raw sewage into the streams next to them. This has lead to the well being of communities living downstream of the Nairobi River being adversely affected. Also lack of environmental awareness and law enforcement capacity has left Nairobi residents with a deplorable situation impacting adversely on all who live in, or indeed visit the city.

1.4 Phytoremediation

Phytoremediation, an emerging cleanup technology for contaminated soils, groundwater, and wastewater that is both low-tech and low-cost, is defined as the engineered use of green plants (including grasses, forbs, and woody species) to remove, contain, or render harmless such environmental contaminants as heavy metals, trace elements, organic compounds, and radioactive compounds in soil or water.This definition includes all plant-influenced biological, chemical, and physical processes that aid in the uptake, sequestration, degradation, and metabolism of contaminants, either by plants or by the free-living organisms that constitute the plant's rhizosphere. Phytoremediation takes advantage of the unique and selective uptake capabilities of plant root systems, together with the translocation, bioaccumulation, and contaminant storage/degradation abilities of the entire plant body. Several comprehensive reviews have been written on this subject, summarizing many important aspects of this novel plant-based technology. The basic idea that plants can be used for environmental remediation is very old and cannot be traced to any particular source. However, a series of fascinating scientific discoveries combined with an interdisciplinary research approach have allowed the development of this idea into a promising, cost-effective, and environmentally friendly technology. Phytoremediation can be applied to both organic and inorganic pollutants, present in solid substrates (e.g. soil), liquid substrates (e.g. water), and the air (Lone et al., 2008).

1.5 Case studies

Several aquatic species have been identified and tested for the phytoremediation of heavy metals from the polluted water. These include sharp dock (*Polygonum amphibium* L.), duck weed (*Lemna minor* L.), water hyacinth (*Eichhornia crassipes*), water lettuce (*P. stratiotes*), water dropwort (*Oenathe javanica* (BL) DC), calamus (*Lepironia articulate*), pennywort (*Hydrocotyle umbellate* L.) (Prasad and Freitas, 2003). The roots of Indian mustard are found to be effective in the removal of Cd, Cr, Cu, Ni, Pb and Zn, and sunflower can remove Pb, U, Cs-137 and Sr-90 from hydroponic solutions (Zaranyika and Ndapwadza, 1995; Wang *et al*., 2002; Prasad and Freitas, 2003).The potential of duck weed was investigated by Zayed *et al*., 1998 for the removal of Cd, Cr, Cu, Ni, Pb and Se from nutrient-added solution and the results indicate that duck weed is a good accumulator for Cd, Se and Cu, a moderate accumulator for Cr, but a poor accumulator of Ni and Pb. Dos Santos and Lenzi, 2000 tested aquatic macrophyte (*Eiochhornia crassipes*) in the elimination of Pb from industrial effluents in a green house study and found it useful for Pb removal. Wang *et al*., 2002 conducted a pot experiment to test five wetland plant species, i.e., sharp dock, duckweed, water hyacinth, water dropwort and calamus for their possible use in remedying the polluted waters. The results show that sharp dock was a good accumulator of N and P. Water hyacinth and duckweed strongly accumulated Cd with a concentration of 462 and 1420 mg/kg, respectively. Water dropwort achieved the highest concentration of Hg, whereas the calamus accumulated Pb (512 mg/Kg) substantially in its roots. Other studies show that microorganisms, genetically modified organisms, bacteria and algae can also be used to remediate polluted sites.

2.0 Materials and Methods

All reagents (HCl and HNO_3) used were of analytical grade. All glassware were washed and rinsed with 10% HCl followed by distilled water to avoid metal contamination. Sample preparation and analysis were carried out using standard methods of analysis (Association of Official Analytical Chemists - AOAC-)

2.1 Sampling and Sampling Sites

Soil and water samples were collected in triplicate from six sampling sites; Kikuyu, Kawangware, Chiromo, Gikomba, Njiru and Fourteen Falls. Three native aquatic plants, *P.senegalensis, A. hybridus* and *E. crassipes* were collected from Nairobi River along the river bank (Figure 2-1). Samples were collected during the months of February and March 2012, the dry season only. The sites were chosen considering relevance as point sources of pollution, assumed mid-point of the river, along feeder river discharge canals and the source to serve as a control.

2.2 Sample Pre-treatment

Water samples were collected as grab samples in pre-cleaned containers in triplicates from all sites and treated with nitric acid (2%); these were stored in a cool box and transported to the laboratory. Soil samples, approximately 500g were scooped with a shovel at a maximum depth of 10 cm and homogenized before a laboratory sample was drawn. Samples were stored in polythene bags. The aquatic plants were collected by hand, washed with river water to remove sediment particles. The collected plant species were placed in plastic bags, labeled carefully and brought to the laboratory. Polythene tools were used in sampling and storing the collected matrices to avoid metal contamination.

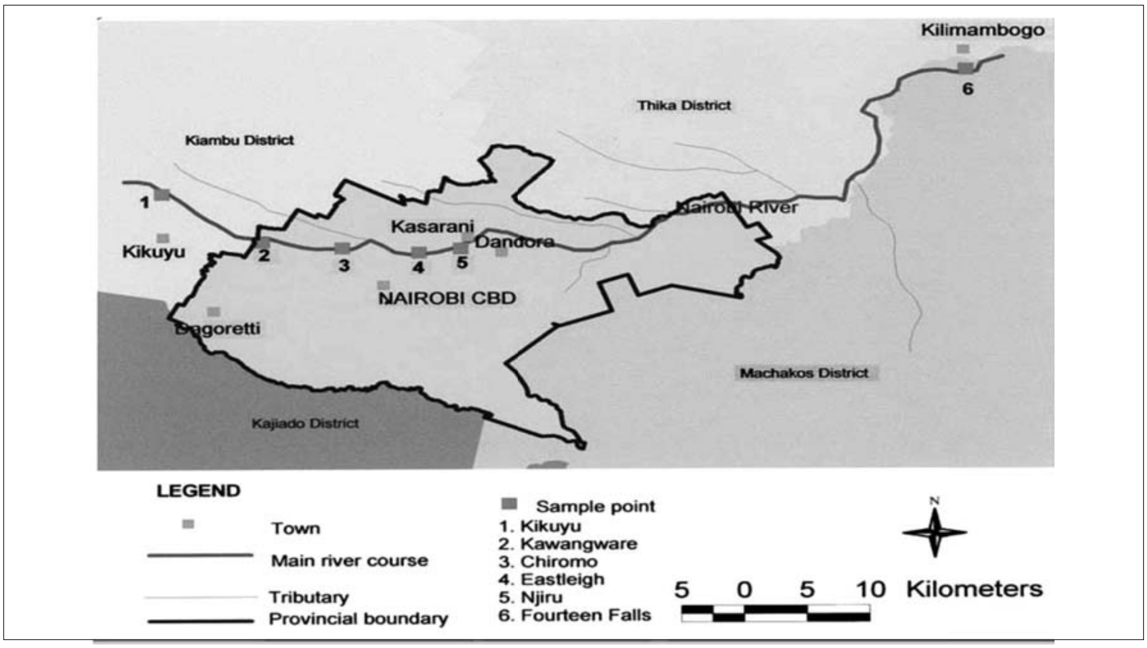

Figure 2-1: Sampling sites

2.3 Water Samples

Water samples were thoroughly mixed and aliquots of 50 ml taken in triplicates. These were acid digested with nitric acid until clear solutions were obtained; digests were filtered with Whatman No. 42 and stored in plastic bottles.

2.4 Plant Samples

Plant samples were dried in an oven (WTB Binder) at 105°C. Each aquatic plant species was sorted into different parts: roots, stems and leaves. The different parts were then crushed using pestle and mortar for further analysis. Samples were extracted, wet digested with nitric acid and filtered through Whatman filter paper no. 42. The digests were then diluted to 100 ml with distilled water.

2.5 Soil samples

Soil samples were air dried, then crushed in a mortar and pestle and sieved through 2 mm governorates sieve to remove plant parts and debris. Well mixed samples of approximately 2g each, weighed using a digital analytical balance (Mettler Toledo) with an accuracy of 0.001g, were placed in 250 ml glass beakers and wet digested with nitric acid until clear solutions were realised. The resulting solutions were filtered using Whatman filter paper no. 42 and then diluted to 100 ml with distilled water. The digests were stored in the refrigerator in pre-cleaned containers and analysis carried out within one week.

2.6 AAS Analysis

Flame atomic absorption spectrophotometer (AAS - Shimadzu AA 7000) was used in the analysis. The concentrations of the metals were determined in triplicates. The accuracy and precision of the analytical procedure were determined. A series of standards were prepared for instrumental calibration by serial dilution of working solutions (100 mg/l) prepared from analytical grade stock solutions (1000 mg/l) from Sigma and Aldrich INC., USA. For the elements (Cu, Zn, Cd) six standard solutions of different concentrations were prepared in 0.1M HNO_3 within linear concentration range (Table 2-1). The calibration curves were prepared for each of the metals investigated by least square fitting. Quality assurance was guaranteed through triple determinations and use of blanks for correction of background and other sources of error.

Table 2-1: Concentration of calibrating standards

Metal	Concentration of calibrating standards, mg/l
Cu	0, 0.2, 0.4, 0.6, 0.8 and 1.0.
Zn	0, 0.2, 0.4, 0.6, 0.8 and 1.0.
Cd	0, 0.02, 0.04, 0.06, 0.08 and 0.1

2.7 Data Analysis

The concentrations of heavy metals in various matrices are presented as arithmetic mean with standard deviation (mean ± standard deviation). Statistical analyses were done at p = 0.05 (Miller and Miller, 1998). The Bio - concentration factor (BCF) was also calculated (Zayed *et al* 1998).

$$BCF = \left(\frac{P}{E}\right)i$$

Where i denote the heavy metal and BCF is the bio-concentration factor and is dimensionless. P represents the trace element concentration in plant tissues (mg/kg dry weight); E represents the trace element concentration in the water (mg/l). The results are presented in tables and graphs.

3.0 Results and Discussion

3.1 Heavy Metal Concentration in Water Samples

The six sampling sites recorded varying concentration levels of the metals investigated (Table 3-1).

Table 3-1: Heavy metal concentration in water samples (mg/L).

Site	Cu	Zn	Cd
1	17.15 ± 0.5	30.58 ± 2.6	21.58 ± 0.8
2	18.35 ± 0.2	40.38 ± 3.8	25.78 ± 1.8
3	23.25 ± 0.8	39.54 ± 4.5	37.85 ± 4.5
4	28.65 ± 1.2	85.64 ± 5.6	40.35 ± 5.6
5	25.65 ± 0.3	80.54 ± 6.2	36.28 ± 2.5
6	25.65 ± 1.5	70.95 ± 4.8	28.69 ± 1.2

Mean±standard deviation, n=10 key: Cu- copper, Zn- zinc, Cd- cadmium

Zinc was the most predominant followed by cadmium then copper. The mean concentration of Zn in water ranged from 85.64 ± 5.6 mg/L in site 4 to 30.58 ± 2.6 mg/L in site 1. This difference is significant ($p < 0.05$) and could be as a result of traffic pollution, effluent discharge or informal settlements along the two sites. The maximum amount of copper was found in site 4 at 28.65 ± 1.2 mg/L while the least amount was found in site 1 at 17.15 ± 0.5 mg/L. This difference is not significant ($p > 0.05$). The highest amount of cadmium was found in site 4 at 40.35 ± 5.6 mg/L while the least amount in site 1 (21.58 ± 0.8 mg/L). This difference is significant ($p < 0.05$). The results show that site 1 is also polluted with the heavy metals studied despite being the source of the river, which was used as a control. This could be attributed to the presence of flower farms in the area. The pollution may be due to the intensive use of agrochemicals containing heavy metals as active ingredients or contaminants.

3.2 Metal Concentration in Soil Samples

The heavy metal contents in soil is presented in Table 3-2, indicating wide variations of heavy metals along Nairobi River. Similar to the water samples, zinc was found to be the most predominant of the heavy metals studied, followed by cadmium then copper. The highest amount of zinc was observed in Njiru (101.7 ± 6.2 mg/kg), while the least amount was observed in Kikuyu (35.25 ± 2.6 mg/kg). The high Zn content could be attributed to the sewage treatment plant or quarry activity in the area. This difference is significant p < 0.05. Copper and cadmium levels were high in fourteen falls (32.01 ± 1.5 mg/kg) and Njiru (49.7 ± 2.5 mg/kg) respectively.

Table 3-2: Heavy metals concentrations in soil (mg/kg)

Site	**Cu**	**Zn**	**Cd**
1	18.77 ± 0.5	35.25 ± 2.6	22.71 ± 0.8
2	20.35 ± 0.2	42.1 ± 3.8	28.33 ± 1.8
3	25.5 ± 0.8	44.5 ± 4.5	45.87 ± 4.5
4	31 ± 1.2	92.5 ± 5.6	48.6 ± 5.6
5	31.7 ± 0.3	101.7 ± 6.2	49.7 ± 2.5
6	32.01 ± 1.5	72.1 ± 4.8	31.02 ± 1.2

Mean ± Standard deviation, n = 10 Key: Cu- copper, Zn- zinc, Cd- cadmium

The concentrations of heavy metals were higher in the soil samples than those calculated for the same heavy metals in the river water. This may be due to pre-concentration of the heavy metals in the soil and dilution effect in water due to water flow. Of the analyzed heavy metals, Zn was the most abundant in soil (101.7 ± 6.2 mg/kg) and water (85.64 ± 5.6 mg/kg), followed by Cd with a concentration of 49.7 ± 2.5 mg/kg in the soil and 40.35 ± 5.6 mg/kg in the water. Cu exhibited the receding trend in both soil and water. Cu varied significantly ($p < 0.05$) between the following sites: site 2 and 5, site 1 and 2 and site 1 and 6, Cd: site 1 and 2 and site 4 and 1. This trend provides an understanding that the soil obtains the heavy metals mainly from the water. The values of the ratio between element concentrations in the soil and those in the water were low (0.82-1.19, 0.99-1.39, 0.65-1.65) for Zn, Cd and Cu respectively (Table 3-3).

Table 3-3: Heavy metal concentration in soil and water and ratios between the concentration in the soil and that in the water

Metal	**Soil**	**Water**	**Soil/water**
Cu	26.55 ± 0.6	23.12 ± 0.4	0.65 – 1.65
Zn	64.77 ± 1.5	57.94 ± 0.9	0.82 – 1.42
Cd	37.71 ± 0.8	31.76 ± 0.5	0.99 – 1.39

Mean ± Standard deviation, n = 18. Key: Cu- copper, Zn- zinc, Cd- cadmium

3.3 Heavy Metal Concentration in the Native Plants

Table 3-4 shows the mean values of concentration of three elements in three species of native plants. The mean concentration values of the elements in the plants decrease according to this sequence: Zn > Cu > Cd. The highest mean concentration value was recorded in *P. senegalensis* (11.14 ± 0.48 mg/Kg), followed by *A. hybridus* (9.6 ± 0.32 mg/Kg), and *E. crassipes* (8.6 ± 0.012 mg/Kg). Among all studied metals, the lowest Cd content was recorded in water hyacinth

(2.15 ± 0.01 mg/kg), while the greatest amount of Zn was observed in *P. senegalensis* (21.79 ± 0.4 mg/kg).

Table 3-4: Mean heavy metal concentration (mg/Kg) in plant species

Element/Taxon	**Cu**	**Zn**	**Cd**	**Mean**
P. senegalensis	8.73 ± 0.08	21.79 ± 0.4	2.91 ± 0.01	11.14
A. hybridus	7.27 ± 0.05	17.42 ± 0.2	4.11 ± 0.03	9.6
E. crassipes	7.23 ± 0.05	16.32 ± 0.1	2.15 ± 0.01	8.6
Mean	7.74	18.51	3.06	
Standard deviation, SD	0.85	2.89	0.99	

The concentration of individual metal also varies from species to species. The content of Zn ranged from 21.79 ± 0.4 mg/kg in *P. senegalensis* to 17.42 ± 0.2 mg/kg in *A. hybridus* and 16.32 ± 0.1 mg/kg in *E. crassipes*. The Cd content was found lowest in *E. crassipes* (2.15 mg/kg), followed by 2.91 mg/kg in *P. senegalensis* and highest in *A. hybridus* (4.11 ± 0.03 mg/kg). On the other hand, *P. senegalensis* showed higher amounts of Cu (8.73 ± 0.08 mg/kg), while equal amount of the same was recorded in *A. hybridus* (7.27 ± 0.05 mg/kg) and *E. crassipes* (7.23 ± 0.05 mg/kg).

The mean values of three heavy metals fluctuate in roots of the plant species. All the species studied had great amounts of Zn, i.e. 36.29 ± 0.7, 31.94 ± 0.4 and 27.6 ± 0.3 mg/Kg in *P. senegalensis, A. hybridus* and *E. crassipes* respectively. However, lower amounts of heavy metals were recorded in *E. crassipes*. Roots of aquatic plants absorb heavy metals from the sediments and accumulate high concentrations (Baldantoni *et al.*, 2004). Similarly our findings revealed the high accumulation of heavy metals registered in roots of *P. senegalensis* and *A. hybridus*.

The mean concentration of heavy metal of stems of three aquatic plants varies from species to species. The higher values of Zn and Cu were observed in *P. senegalensis* and *A. hybridus*, respectively, compared to Cd. On the other hand, stems of *E. crassipes* showed high amount of Zn, Cu and Cd in a recessive manner. The accumulation of heavy metals in leaves of three native aquatic plants is exhibited by high accumulation of Zn, and Cu in all the plants, while a high accumulation of Cd in *A. hybridus* (1.41 ± 0.03 mg/kg).

The order of the accumulation of heavy metals in various parts of aquatic species:

1. Root heavy metal accumulators: *P. senegalensis, A. hybridus,* and *E. crassipes*.
2. Stem heavy metal accumulators: *P. senegalensis, A. hybridus,* and *E. crassipes*.
3. Leaves heavy metal accumulators: *P. senegalensis, E. crassipes*, *and A. hybridus.*

The stems and/or leaves of submerged plants accumulated lower concentrations of trace elements than roots, which is well substantiated with the findings of Baldantoni *et al.*, 2005. Thus, among the selected plant species, *P. senegalensis* and *A. hybridus* appear to be the best monitoring species due to their availability along Nairobi River.

3.4 Bio-concentration of Heavy Metals (Cu, Zn and Cd) in the Native Plants

The ability of the plants to take up heavy metals (BCF) was evaluated from the ratio of metal concentration in the plants and water. Table 3-5 gives mean values of Bio Concentration Factor (BCF.) for each species and element. The mean BCF value of the elements in the plants decreases according to this sequence: Zn > Cu > Cd. This sequence (which is rather different from that of the mean concentrations of elements in the plants) reflects the capacity of the plant species to accumulate elements independently from their concentration in the water, that is, the regulation capacity of the plants. Mean concentration factors for the various elements calculated for *P. senegalensis* are higher (8.83 ± 0.6), followed by *A. hybridus* (8.44±0.7), then *E. crassipes* (7.56 ± 0.3). Of all metals, the lowest BCF value of Cd was observed in *E. crassipes* (1.81 ± 0.2), while the highest value of Zn was recorded in *P. senegalensis* (19.46 ± 0.7). Low BCF of Cd was recorded in water hyacinth (1.81 ± 0.003), while maximum content of the same was registered in *A. hybridus* (3.45 ± 0.01), no significant difference ($p > 0.05$). On the other hand, minimum BCF of Cu was registered in *E. crassipes* (6.29 ± 0.05), while high amount of the same was observed in *P. senegalensis* (7.59 ± 0.1), no significant difference ($p>0.05$). The BCF of Zn ranged from 14.57 ± 0.09 to 15.55 ± 0.09 and 19.46 ± 0.2 in *E. crassipes*, *A. hybridus* and *P. senegalensis* respectively.

Table 3-5: Bio concentration factor (BCF)

Element/Taxon	**Cu**	**Zn**	**Cd**	**Mean**
P. senegalensis	7.59 ± 0.1	19.46 ± 0.2	2.45 ± 0.01	8.83
A. hybridus	6.32 ± 0.07	15.55 ± 0.09	3.45 ± 0.01	8.44
E. crassipes	6.29 ± 0.05	14.57 ± 0.09	1.81 ± 0.003	7.56
Mean	6.73	16.53	2.57	
Standard deviation, SD	0.74	2.59	0.83	

The results of the present study include assessment of three heavy metals (Cd, Cu, and Zn) and evaluation of their toxicity status in different plant parts of three native aquatic plant species.

The accumulation of heavy metals by various species in descending order is as follows:
Zn – *P.* senegalensis>*E. crassipes*>*A. hybridus*.
Cu – *P. senegalensis*> *E. crassipes*> *A. hybridus*.
Cd – *P. senegalensis*> *A. hybridus*>*E. crassipes*.

3.7.1 Spatial Variation of Cu, Zn and Cd within the Sampling Sites in the Different Matrices

The six sampling sites recorded varying concentration levels of the metals investigated in soil, water and the plants. The results show that site 4 and 5 are more polluted with zinc and cadmium compared to the other sites. The level of Cu at all sites does not differ significantly ($p > 0.5$). Site 4 and 5 high pollution status may be due to effluent discharge, human and motor traffic, agricultural run-off coming through several drains along with washing and bathing activities by local inhabitants and cattle wading at peripheral villages in site 5 and 4. The high level of Zn and Cu might be due to agricultural run-off on sediments in the reservoir, carrying various Zn and Cu-based pesticides used in agricultural practices. This largely agrees with findings of Jones *et al.*, 1991 in Lake Averno, and Siegel *et al.*, 1994 in Ginka sub-basin, south of Lake Manzala.

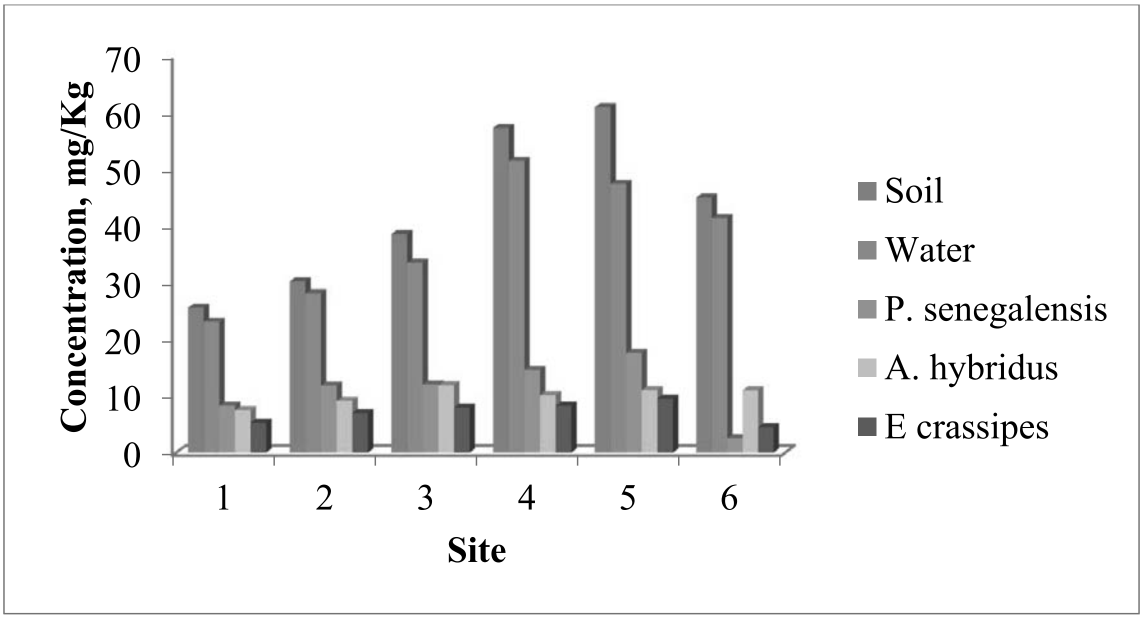

Figure 3-8: Variation of heavy metals within the sampling sites in the different matrices

4.0 Conclusion and Recommendation

4.1 Conclusion

The phytoremediation study conducted in this work provides significant information regarding suitability of native plants (*P. senegalensis*, *E. crassipes*and *A. hybridus*) as bio-indicators for Cu, Zn and Cd heavy metal pollution. Bio-concentration factor (BCF) of each plant was determined. The better accumulator was found to be *P. senegalensis* with a BCF of 8.83 ± 0.6 followed by *A. hybridus* and *E. crassipes* with BCF of 8.44 ± 0.7 and 7.56 ± 4.58 respectively. The heavy metal concentration in water samples were in the range of 29.03 – 34.49, 22.37 – 23.87 and 53.36 – 62.52 mg/L for Cu, Cd and Zn respectively. In the digested soil samples metal concentration ranges were 25.81 – 27.31, 60.11 – 69.27 and 34.98 – 40.44 mg/Kg for Cu, Zn and Cd respectively. The concentration in the plants suggests that the plants had removed most of the heavy metals from the parent water. From this work, *A. hybridus* and *P. senegalensis* were found to be reasonably good phytoremediants which can be used for effectively removing Cu, Zn and Cd polluted waters. These plants are suitable phytoremediants because they are able to accumulate Cu, Zn and Cd to a satisfactory degree. While the metal concentration in the water samples (37.61 ± 0.65 mg/L) were lower compared to that in soil (43.01 ± 0.30 mg/Kg) the plants were rich in heavy metal content. This is evidence of pre – concentration of heavy metals from water. The research hypothesis that plants growing along Nairobi River do not offer significant clean-up potential by accumulation or uptake of heavy metals is rejected. Due to removal of heavy metals from polluted waters by plants, determination of heavy metal pollution in any water body by direct analysis of water samples may not be accurate because it will not reflect the real bio-available pollutant level in the water. This is because most of the heavy metal will be removed from the water to biota and sediment resident in the same water “use of bio-indicators like the plants studied here would be more accurate”.

4.2 Recommendation

This study evaluated the use of native plants for the remediation of heavy metal (Cu, Zn, and Cd) polluted aquatic ecosystem (Nairobi River). Thus the use of *P. senegalensis* and *A. hybridus* is recommended for phytoremediation of water polluted with Cu, Zn and Cd. Research related to this relatively new technology needs to be promoted, emphasized and expanded in developing countries like Kenya since it is low cost. Phytoremediation offers a viable solution to water pollution problems. This calls for multidisciplinary collaboration between universities, research institutes, and other interested parties to create teams to address questions like agronomic practices needed for successful establishment of vegetation; development or identification of locally available plant species for specific remediation requirements and fate and final disposal of biomass, particularly containing high concentration of metal.

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