HEAVY METAL CONTAMINATION OF MANGROVE SEDIMENTS AND THE ASSOCIATED BIOTA IN DAR ES SALAAM, TANZANIA

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ABSTRACT

Mangrove wetlands are efficient in trapping pollutants that may have detrimental effects on mangrove dependent food chains. Mangrove ecosystems that are within urban areas are likely to suffer more from chemical pollution than those in rural areas. Heavy metals in mangrove plant parts, sediments and crabs from mbweni, msimbazi and mtoni mangrove ecosystems in dar es salaam were analysed using an atomic absorption spectrophotometer, in order to assess the impact of heavy metal pollution on mangrove biota. Sediment samples from msimbazi and mtoni mangrove areas which are located within the city, had higher levels of pb, zn and cu than those from mbweni mangrove stand, which is far from the city centre. For instance, the concentration of pb was $31.6 \pm 9.6 \, \mu gg^{-1}$ dw at msimbazi, $17.9 \pm 10.7 \, \mu gg^{-1}$ dw at mtoni and $13.3 \pm 3.5 \, \mu gg^{-1}$ dw at mbweni mangrove area. Crabs generally contained higher concentrations of heavy metals (pb, zn and cu) on dry weight basis compared with sediment and mangrove plant parts. Copper enrichment in crabs, for example, was more than six times compared with the concentration in sediment samples from msimbazi mangrove mangrove forest. Of the seven heavy metals (pb, zn, cu, co, ni, cr and v), only pb, zn and cu were found to be of anthropogenic origin. Overall, the mangroves and associated biota in mangrove forests, that are within the city, had higher levels of heavy metals compared with mangrove forests growing away from the city.

INTRODUCTION

Pollution is currently a major threat to many mangrove ecosystems in Tanzania, the sources of which include industrial and municipal wastes, as well as agro-chemicals such as pesticides and fertilizers. Some of these wastes contain heavy metals that are considered persistent pollutants. The problem of pollution of mangrove ecosystems is to a large extent caused by human beings who regard rivers and streams as cheap disposal sites for wastes. With the present rate of industrialization resulting from privatization of major economic sectors, it implies that water pollution in Tanzania will also increase. Mangrove ecosystems can effectively be used for water purification, by reducing suspended solids in the receiving waters and adsorbing some heavy metals in the sediments (Ajamal & Khana 1989). However, impacts of heavy metal pollution in mangrove ecosystems have not been fully investigated (Tam & Wong 1993, 1995, Tam et al. 1995) Information on the fate of pollutants in mangrove ecosystems is still insufficient. In recent years many industrialized countries have initiated programs for monitoring and abatement of pollution problems particularly with respect to heavy metals (Carlton 1974).

ecosytems, in-depth information on the transport and fate of the pollutants is a prerequisite. Tanzania still has inadequate waste treatment facilities in residential and industrial areas. In the city of Dar es Salaam, for instance, most industrial wastes are disposed of into natural drainage systems such as Msimbazi and Kizinga rivers. These rivers also receive wastes from residential and agricultural areas. Most of the wastes are possibly retained in mangrove stands that occur at the mouths of these rivers (Ak'habuhaya & Lodenius 1988, de Wolf *et al*. 2001).

Pollution of mangrove wetlands is a major concern because of the extent of interaction with humans (Machiwa 1999). Mangrove ecosystems also harbour vulnerable life forms e.g. larval stages of fish as well as supporting many commercial, research, educational and tourism activities (Thom 1969, Carlton 1974, Zimmerman & Thom 1982).

In developing nations, human chronic exposure to heavy metal pollution is possibly common but is difficult to notice because of inadequate medical attention. Acute exposure to heavy metal pollution is a rare event, but whenever it occurs it raises immediate great public concern. Knowledge on the pathways of heavy metal enrichment in mangrove ecosystems is a necessity for a cost effective pollution monitoring program. The present study assessed the extent of heavy metal contamination of mangrove ecosystems around the city of Dar es Salaam

METHODS

Study area
Three main mangrove stands in Dar es Salaam were selected for sampling between March and May 2000 (Figure 1).

Mbweni mangrove stand is located at longitude 39¾ 25' E and latitude 6¾ 34' N about 30 km from the city centre of Dar es Salaam. The mangrove forest is located at the mouth of Mpigi River which mainly drains agricultural areas. Mbweni mangrove forest is dominated by short trees and shrubs, the majority of them are less than 5 m tall. The area coverage of the mangrove forest is approximately 107.3 ha (Semesi 1991). The dominant mangrove species in the area are *Sonneratia alba* J. Smith, *Avicennia marina* (Forsk) Vierh and *Rhizophara mucronata* Lamk. The area is also inhabited with crabs such as *Neosarmatium meinerti* de Mann and *Uca* species.

Mtoni Kijichi mangrove stand is located at the mouth of Kizinga River near Mbagala, at longitude 39¾ 41' E and latitude 6¾ 45' N about 2.5 km south of the Port of Dar es Salaam. Mangrove trees are found on both sides of the creek, covering a distance of approximately 1.5 km upstream. Close to the river mouth there were many tributaries, there were also a number of storm water and wastewater drainage systems from adjacent residential areas which discharge into the mangrove area. The stand was dominated by *S. alba, A. marina, R. mucronata* and *Ceriops tagal* Perr. Fishing activities were conducted in the area, mainly for small finfish, shrimps and edible crabs.

Msimbazi mangrove stand is located at Msimbazi river mouth within the city of Dar es Salaam at latitude 6° 47' S and longitude 39°E. River Msimbazi has a large portion of its drainage basin located within of the city of Dar es salaam. The mangrove stand covers an area of approximately 0.5 ha and is dominated by *A. marina*.
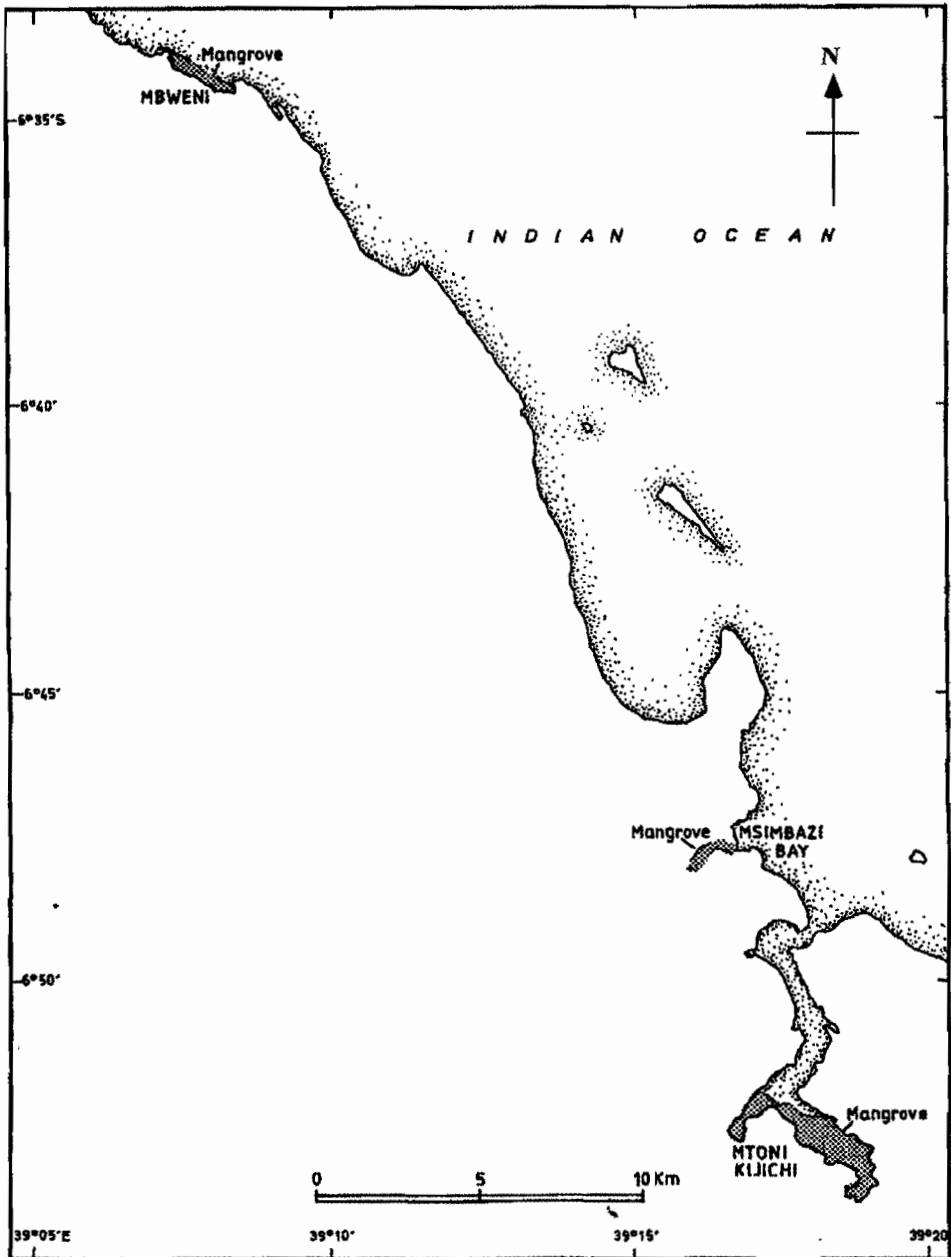
Fig. 1:   Map of part of Dar es Salaam Region showing the mangrove stands that were studied.

Sampling and analysis of samples

Sampling was done during low tide when the interior of the mangrove forests was accessible by foot. The line transect plot method (English *et al.* 1994) was used to locate sampling points for sediment and mangrove plant samples. In each mangrove forest, three transects, 10 m. apart, parallel to the shoreline, were established. Sampling was done after an interval of 5 m in each transect.

Thirty surface (top 5 cm) sediment samples were collected in each forest along the three transects which were established. Sediment samples were collected using hand held short plastic cores of 6 cm internal diameter (Ndaro *et al.* 1995) and kept in clean plastic bags. Coarse materials were removed by sieving through 2 mm mesh sieve. The samples were immediately oven dried to constant weight at 80°C and then crushed using pestle and mortar. Approximately 0.5 g of homogenized dry sediment sub-samples were accurately weighed and leached with 0.1 M HCl (2 ml) for 24 h in order to extract the weakly bound metal fraction. Samples were then filtered through previously acid washed Watman filter papers. The filtrate was made up to 100 ml with distilled water. Heavy metals (Cu, Cr, Ni, Pb, Zn, Co, and V) were determined using an Atomic Absorption Spectrophotometer (AAS), Perkin-Elmer model 300, operated in the flame mode. Cu, Cr, Ni, Pb, Zi and Co were analysed using air/acetylene gas; V was analysed using nitrous oxide/acetylene flame. All chemicals used were of analytical grade (AnalaR).

Mangrove prop roots and senescent leaves that were about to be shed were collected from *A. marina* species in Msimbazi, Mtoni and Mbweni mangrove forests. Also, live specimens of *N. meinerti* crabs were collected in the terrestrial fringe zone from the three mangrove forests and placed in a cool box immediately after capture. Mangrove root and leaf samples were kept in plastic bags in the field and processed in the laboratory according

to Silva *et al.* (1990). Mangrove plant parts and crab samples were washed with distilled water and oven dried to constant weight at 80°C. Dried samples were accurately weighed and ashed in a furnace at 450° for 12 hr. Accurately weighed (0.5 g) sub-samples of homogenized ash samples were extracted with hot 0.1 M HCl (2 ml). Samples were then filtered through previously acid washed Watman filter papers. The filtrate was made up to 100 ml with distilled water. Heavy metals were analysed using an AAS. Statical non-parametric tests were used in data analysis and followed Zar (1984).

RESULTS

Lead concentration

The highest concentration of geochemically available Pb (31.6 ± 9.6 μgg^{-1} dw) was found in Msimbazi forest. Lead content in Mtoni mangrove sediment was 17.9 ± 10.7 μgg^{-1} dw and in Mbweni mangrove sediment was 13.3 ± 3.5 μgg^{-1} dw (Fig. 2). A Friedman's test showed that there was a significant difference in Pb concentration in sediment samples from the three forests (Fr = 12.600, P = 0.0080). Dunn's multiple comparison test, confirmed that the difference in Pb concentration was significant between Msimbazi and Mtoni (P< 0.05) as well as Msimbazi and Mbweni (P < 0.001) mangrove sediments. The difference in the concentration of Pb in Mtoni and Mbweni mangrove sediment samples was not statistically significant (P > 0.05).

Lead concentration in *A. marina* roots was highest (28.6 ± 6.4 μgg^{-1} dw) in Msimbazi mangroves (Fig. 2). Roots of Mtoni and Mbweni mangroves had almost equal Pb content (23.1 ± 0.4 μgg^{-1} dw and 23.9 ± 0.1 μgg^{-1} dw respectively). A Friedman's test showed a significant difference in Pb concentration in roots from the three sampling sites (Fr = 15.800, P < 0.0001). Dunn's multiple comparison test, confirmed that the

differences in Pb concentration in mangrove roots from Msimbazi and Mbweni as well as those from Msimbazi and Mtoni were statistically significant (P < 0.05). The difference in Pb content in roots of Mtoni and Mbweni, was not significant (P > 0.05).
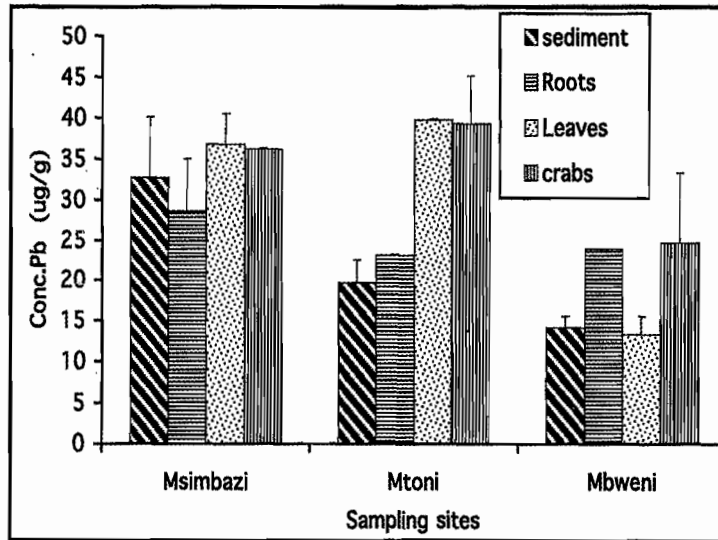

Fig. 2: Mean concentration ± SEM μgg⁻¹ (dw) of lead in mangrove sediment (weakly bound fraction), *Avicennia marina* parts and crabs of Mtoni, Msimbazi and Mbweni mangrove ecosystem

The highest concentration of Pb (39.7 ± 0.2 μgg⁻¹ dw) in *A. marina* leaves was found in Mtoni while the lowest concentration (13.3 ± 2.2 μgg⁻¹ dw) was found in Mbweni mangroves. The Pb content (36.8 ± 3.7 μgg⁻¹ dw) of Msimbazi mangrove leaves was almost equal to that of Mtoni mangrove leaves (Fig. 2). The differences in the concentration of Pb in leaves from Msimbazi, Mtoni and Mbweni mangrove stands was statistically significant (Fr =15.800, P < 0.0001). showed that the differences in concentration were significant for mangrove leaves from Mtoni and Mbweni (P < 0.001) as well as for Msimbazi and Mbweni forests (P < 0.05). However, there was no significant difference in the concentration of Pb in mangrove leaves from Mtoni and Msimbazi (P > 0.05).

The highest concentration of Pb (39.3 ± 5.8 μgg⁻¹ dw) in *N. meinerti* was found in Mtoni crabs (Fig. 2), followed by Msimbazi crabs (36.2 ± 0.1 μgg⁻¹ dw) and Mbweni crabs (24.7 ± 8.6 μgg⁻¹ dw). The concentration of Pb in crabs of Mbweni forest was almost double the concentration in mangrove leaves from the same forest. The difference in Pb concentration in crabs of the three forests was significant (Fr = 9.000, P = 0.0099). The differences in concentration were significant between crabs of Mtoni and Mbweni as well as between crabs of Msimbazi and Mbweni (P < 0.05), but not between crabs of Mtoni and Msimbazi (P > 0.05) (Dunn's multiple comparison test).

Zinc concentration

Zinc concentration was generally low in the three mangrove forests. Zinc content of the geochemically available heavy metal fraction of the sediment was 31.7 ± 2.4 μgg^{-1} dw in Msimbazi, 27.1 ± 5.7 μgg^{-1} dw in Mtoni and 10.1 ± 2.5 μgg^{-1} dw in Mbweni mangrove sediment samples (Fig. 3). Friedman's test showed a significant difference in Zn concentration in sediment samples of the three forests ($Fr = 10.400$, $P = 0.0034$). Dunn's multiple comparison test, confirmed that the difference in Zn content was significant between Msimbazi and Mbweni ($P < 0.05$) as well as between Mtoni and Mbweni sediment samples ($P < 0.001$). The difference in the concentration of Zn in Mtoni and Msimbazi sediment samples was not statistically significant ($P > 0.05$).
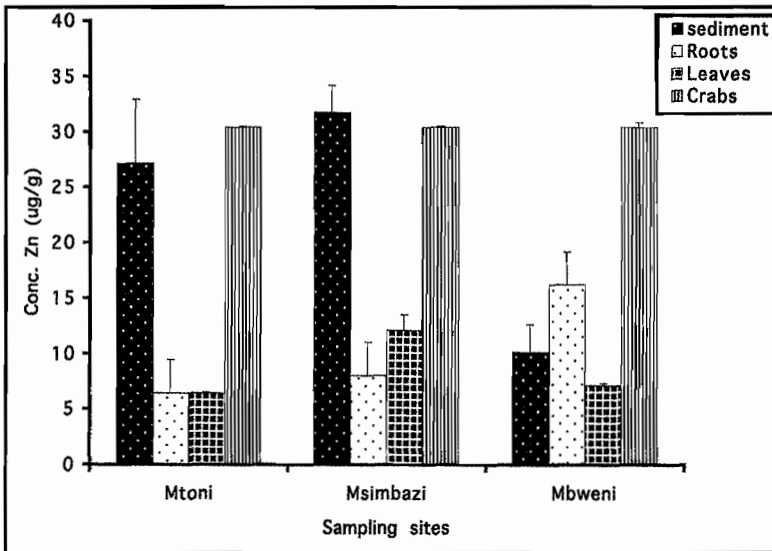

Fig. 3:   Mean concentration $\pm$ SEM μgg^{-1} (dw) of zinc in mangrove sediments (weakly bound fraction), *Avicennia marina* parts and crabs of Mtoni, Msmbazi and Mbweni mangrove ecosystem.

A. marina root samples from Mbweni had the highest concentration (16.2 ± 0.1 μgg^{-1} dw) of Zn and the lowest concentration (6.4 ± 0.1 μgg^{-1} dw) was obtained in Mtoni root samples (Fig. 3). Mangrove root samples from Msimbazi had Zn content of 8.0 ± 0.2 μgg^{-1} dw. The results indicated a significant difference in Zn concentration in mangrove roots (Friedmans test, $Fr = 15.200$, $P = 0.0001$). Dunn's multiple comparison test showed that the difference in Zn content was significant between root samples from Mbweni and Mtoni, as well as from Msimbazi and Mbweni ($P < 0.001$), but was not significant between root samples from Mtoni and Msimbazi ($P > 0.05$).

marina leaf samples that were collected in Msimbazi had Zn content of 12.1 ± 1.4 μgg^{-1} dw, Mbweni leaf samples had 7.1 ± 0.2 μgg^{-1} dw and Mtoni samples had the lowest concentration of 6.4 ± 0.1 μgg^{-1} dw (Fig. 3). Friedman's test indicated a significant

difference in Zn content of leaf samples from the three forests (Fr = 8.769, P = 0.0075). Dunn's multiple comparison test, showed that the difference in concentration was significant between Mtoni and Msimbazi as well as between Msimbazi and Mbweni samples (P < 0.05). *N. meinerti* crabs had almost similar concentration of Zn (30 μgg^{-1} dw) in the three forests (Fig. 3).

Copper concentration

The concentration of the weakly bound Cu in the sediment samples from Msimbazi was 3.2 ± 0.9 μgg^{-1} dw, at Mtoni the concentration was

1.2 ± 0.8 μgg^{-1} dw, and at Mbweni the concentration was 0.4 μgg^{-1} dw (Fig. 4). Friedman's test showed a significant difference (Fr = 9.8, P = 0.0063) in the concentration of Cu in sediment samples of the three mangrove forests. Dunn's multiple comparison test, confirmed that the difference in the concentration of Cu in the sediment was significant between Msimbazi and Mbweni (P< 0.01) as well as between Mtoni and Msimbazi forests (P < 0.05). The difference the concentration of Cu in Mtoni and Mbweni mangrove sediment samples was not statistically significant (P > 0.05).
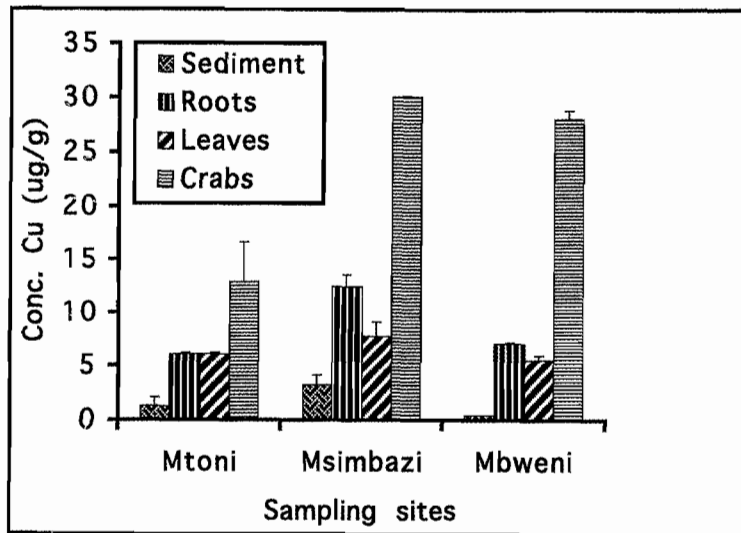

Fig. 4:   Mean concentration ± SEM μgg^{-1} (dw) of copper in mangrove sediments (weakly bound fraction), *Avicennia marina* parts and crabs of Mtoni, Msimbazi and Mbweni mangrove ecosystem.

The concentration of Cu in *A. marina* roots from Msimbazi forest was 12.4 ± 1.1 μgg^{-1} dw, mangrove roots from Mtoni contained 7.1 ± 0.1 μgg^{-1} dw and mangrove roots from Mbweni had 6.0 ± 0.1 μgg^{-1} dw (Fig. 4). Friedman's test showed that the difference in Cu concentration in root samples from the three forests was not significant (Fr = 5.097, P = 0.0789).

The highest concentration of Cu (7.7 ± 1.4 μgg^{-1} dw) in *A. marina* leaves was obtained in samples from Msimbazi forest. Mbweni and Mtoni leaf samples had 5.4 ± 0.5 μgg^{-1} dw and 6.0 ± 0.1 μgg^{-1}

dw respectively (Fig. 4). Friedman's test showed a significant difference in Cu concentration in the leaves of the three forests (Fr = 9.800, P = 0.0063). Dunn's multiple comparison test, suggested that the difference in the concentration of Cu was significant between leaf samples from Mtoni and Mbweni (P < 0.05). The difference in concentration between leaf samples from Mtoni and Msimbazi as well as from Msimbazi and Mbweni forests was however not significant (P > 0.05). The concentration of Cu in *N. meinerti* crabs from Msimbazi (30.0±0.1 µgg⁻¹dw), Mbweni (28.0±0.7 µgg⁻¹dw) and Mtoni (28.9

± 3.8 µgg⁻¹dw) mangrove forests (Fig. 4) was not significantly different (Friedman's test, Fr = 2.516, P = 0.2851).

Nickel concentration
Nickel concentrations in all sediment samples from the three forests showed narrow variation (Fig. 5). The concentration of weakly bound Ni in the sediment was 24.6 ± 1.7 µgg⁻¹ dw in Mbweni forest, 22.3 ± 6.8 µgg⁻¹ dw in Msimbazi forest and 21.4± 13.2 µgg⁻¹ dw in Mtoni forest. There was no significant difference in Ni concentration in sediment samples of the three forests (Friedman's test, Fr = 0.7500, P = 0.7943).
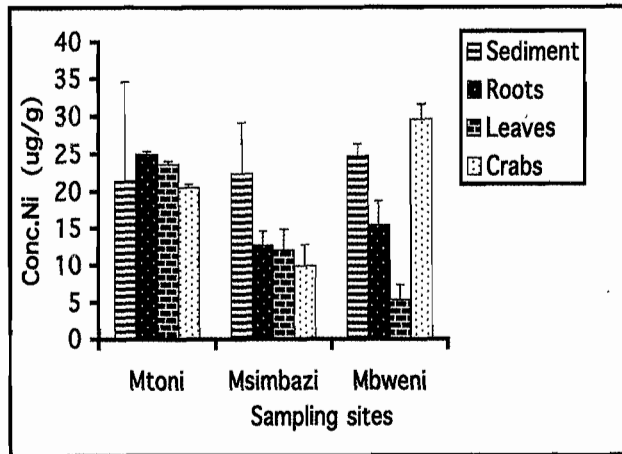

Fig. 5: Mean concentration ± SEM µgg⁻¹ (dw) of nickel in mangrove sediments (weakly bound fraction), *Avicennia marina* parts and crabs of Mtoni, Msimbazi and Mbweni mangrove ecosystem.

The concentration of Ni in *A. marina* roots was low and showed slight variation between the forests (Fig. 5). Mtoni *A. marina* roots had the highest Ni concentration (24.9 ± 0.4 µgg⁻¹dw), followed by Mbweni (15.3 ± 3.2 µgg⁻¹ dw) and Msimbazi (12.6 ± 2.0 µgg⁻¹ dw). Friedman's multiple comparison test, indicated that there was no significant difference in Ni content of root samples from the three forests (Fr =1.400, P = 0.6013).

A. marina leaves of Mtoni and Msimbazi forests had Ni content of equal magnitude as the roots (Fig. 5). Mtoni leaf samples had the highest amount (23.6 ± 0.5 µgg⁻¹ dw) followed by Msimbazi (12.0 ±2.8 µgg⁻¹ dw) and Mbweni (5.3 ± 2.0 µgg⁻¹ dw). Friedman's test indicated a significant difference in the concentration of Ni in the three forests (Fr =18.200, P < 0.0001). Dunn's multiple comparison test, showed that the difference was significant between leaf

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samples from Mtoni and Msimbazi as well as between Mtoni and Mbweni forests (P < 0.001). The difference in Ni concentration between leaf samples from Msimbazi and Mbweni forests was not significant (P > 0.05).

N. meinerti crabs from Mbweni forest had Ni content of 29.6 ± 5.5 µgg⁻¹ dw, Mtoni crabs, 20.5 ± 5.3 µgg⁻¹ dw and Msimbazi crabs, 9.9 ± 0.6 dw (Fig. 5). Friedman's test indicated a significant difference in Ni concentration in the crabs of the three forests (Fr = 12.000, P = 0.011). Dunn's multiple comparison test, confirmed that the statistical difference in Ni concentration between crabs of Msimbazi and

Mbweni forests was significant (P < 0.01). The difference in concentration was however not significant between crabs of Mtoni and Msimbazi as well as between crabs of Mtoni and Mbweni forests (P > 0.05).

Cobalt concentration
The concentration of the weakly bound cobalt in the sediment samples was generally low (Fig. 6), it was 12.8 ± 1.8 µgg⁻¹ dw, at Mbweni, 5.0 ± 3.9 µgg⁻¹ dw, at Msimbazi and 5.0 ± 1.9 µgg⁻¹ dw at Mtoni. Friedman's test showed that the difference in the concentration of Co in sediment samples from the three forests was not significant (Fr = 5.250, P = 0.0789).

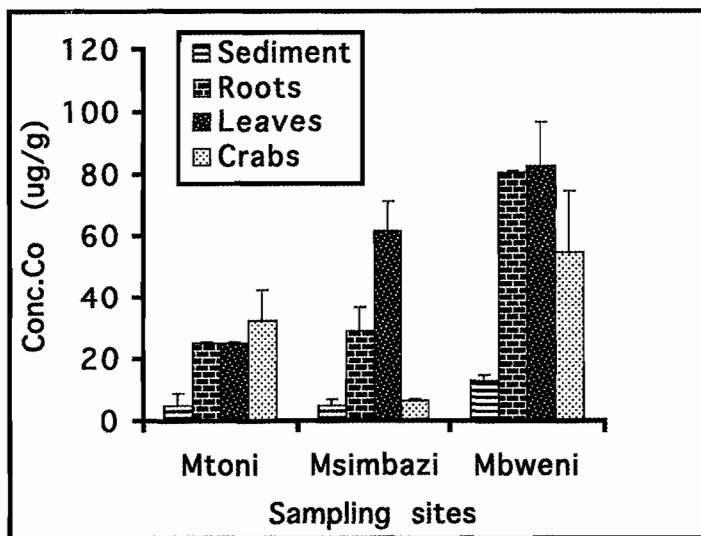Fig. 6:   Mean concentration ± SEM µgg⁻¹ (dw) of cobalt in mangrove sediments (weakly bound fraction), *Avicennia marina* parts and crabs of Mtoni, Msimbazi and Mbweni mangrove ecosystem

The concentration of cobalt in *A. marina* roots from the three forests showed a wide variation, in Mbweni forest was 80.6 ± 0.2 µgg⁻¹ dw, in Msimbazi was 28.8 ± 8 µgg⁻¹ dw and in Mtoni forest was 25.1 ± 0.4 µgg⁻¹ dw (Fig. 6). The there was a significant difference in Co concentration in *A. marina* roots of the three

forests (Friedman's test, Fr = 15.200, P = 0.0001). Dunn's multiple comparison test, confirmed that the difference in the concentration of Co in *A. marina* roots was significant between Mtoni and Mbweni as well

as between Msimbazi and Mbweni mangroves (P < 0.001).

In leaves, the highest Co concentration (82.5 ± 14.0 µgg⁻¹ dw) was detected in Mbweni mangroves, the concentration in *A. marina* leaves from Msimbazi mangroves was 61.3 ± 10.0 µgg⁻¹ dw. *A. marina* leaves of Mtoni mangrove forest had Co content of 25.1 ± 0.4 µgg⁻¹ dry wt (Fig. 6). Friedman's test showed that there was a significant difference in Co concentration in mangrove leaves (Fr = 9.800, P = 0.0063). Dunn's multiple comparison test showed that the difference in concentration of Co in *A. marina* leaves from Mtoni and Mbweni mangrove forests was statistically significant (P < 0.05). The difference between Co concentration in *A. marina* leaves from Msimbazi and Mtoni as well as Msimbazi and

Mbweni forests was however not significant (P > 0.05).

The concentration of Co in *N. meinerti* crabs from Mbweni mangrove area was 54.7 ± 20.0 µgg⁻¹ dw, and the lowest concentration (6.5 ± 10.6 dw) was found in crabs from Msimbazi mangrove stand. Crabs from Mtoni mangrove area had Co content of 32.0 ± 10.6 µgg⁻¹ dw (Fig. 6). Friedman's test indicated a significant difference in Co concentration in crabs from the three forests (Fr = 12.000, P = 0.011). Dunn's multiple comparison test, confirmed that the difference in Co concentration was significant between crabs from Msimbazi and Mbweni forests (P < 0.01). The differences between Co concentration in crab samples from Mtoni and Msimbazi as well as from Mtoni and Mbweni forests were not significant (P > 0.05).
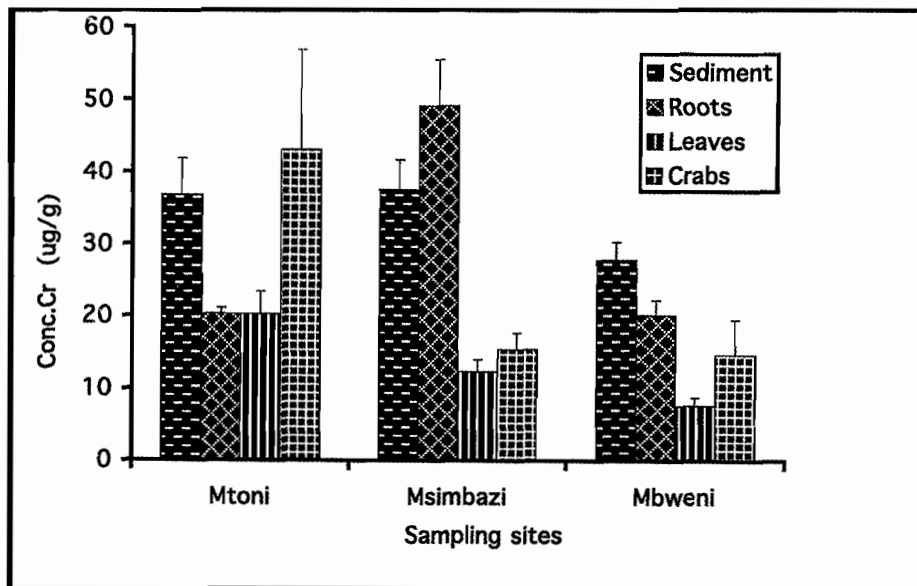

Fig. 7:   Mean concentration ± SEM µgg⁻¹ (dw) of chromium in mangrove sediments (weakly bound fraction), *Avicennia marina* parts and crabs of Mtoni, Msimbazi and Mbweni mangrove ecosystem

Chromium concentration

The weakly bound chromium concentration in the mangrove sediments was high in the three forests (Fig. 7). The concentration was 37.5 ± 4.2 µgg⁻¹ dw in Msimbazi forest. Mtoni and Mbweni sediments contained 36.8 ± 5.1 µgg⁻¹ dw and 27.8 ± 2.5 µgg⁻¹ dw respectively. Friedman's test showed no significant difference in the concentration of Cr in sediments from the three mangrove stands (Fr = 5.250, P = 0.0789).

The concentration of Cr in *A. marina* roots was 49.2 ± 0.8 µgg⁻¹ dw in Msimbazi, 20.3 ± 6.4 µgg⁻¹ dw in Mtoni and 20.1 ± 2.0 µgg⁻¹ dw in Mbweni forests (Fig. 7). There was a significant difference in Cr concentration in *A. marina* roots from the three forests (Friedman's test, Fr = 13.000, P= 0.0003). Dunn's multiple comparison test, showed that the difference in Cr concentration in *A. marina* roots was significant between Mtoni and Msimbazi, as well as Msimbazi and Mbweni mangrove forests (P < 0.001). The difference in the concentration of Cr in *A. marina* root samples from Mtoni and Mbweni forests was not significant (P > 0.05)

The concentration of Cr in *A. marina* leaves was 20.3 ± 3.1 µgg⁻¹ dw in Mtoni forest, the lowest Cr concentration (7.6 ± 1.2 µgg⁻¹ dw) was found in *A. marina* leaves from Mbweni mangrove area. The concentration of Cr was 12.4 ± 1.6 µgg⁻¹ dw in mangrove leaves that were collected in Msimbazi forest (Fig. 7). Friedman's test indicated that there was a significant difference in Cr concentration in *A. marina* leaves from the three forests (Fr = 11.400, P= 0.0020). Dunn's multiple comparison test, proved that the difference in Cr concentration in the *A. marina* leaves was significant between Mtoni and Mbweni mangrove stands (P < 0.01). The differences in concentration of Cr in leaf samples from Mtoni and Msimbazi as well as from Msimbazi

and Mbweni forests was not significant (P > 0.05).

The highest Cr concentration (44.1 ± 5.0 µgg⁻¹ dw) was found in *N. meinerti* crabs from Mtoni mangrove stand followed by crabs from Mbweni (15.0 ± 2.1 µgg⁻¹ dw), and Msimbazi (14.3 ± 4.8 µgg⁻¹ dw) forests (Fig. 7). Friedman's test showed that there was no significant difference in Cr concentration in crabs from the three mangrove forests (Fr = 3.000, P = 0.2851).

Vanadium concentration

The concentration of the weakly bound vanadium in the sediment was 74.2 ± 16.3 µgg⁻¹ dw.in Msimbazi forest. In Mtoni and Mbweni sediment samples, the concentration of the geochemically available V was 42.5 ± 12.5 µgg⁻¹ dw and 28.1 ± 11.3 µgg⁻¹ dw respectively (Fig. 8). Friedman's multiple comparison test gave a significant difference in V concentration in sediment samples from the three forests (Fr = 12.600, P = 0.0059). Dunn's multiple comparison test, confirmed that the difference to V concentration in the sediment was significant between Mtoni and Msimbazi mangrove stands (P< 0.05) as well as between Msimbazi and Mbweni mangrove forests (P < 0.001). The concentration of V in Mtoni and Mbweni mangrove sediment sample was not statistically different (P > 0.05).

The concentration of the vanadium in *A. marina* root samples from Mbweni forest was 60.1 ± 3.8 µgg⁻¹ dw and in Mtoni samples the concentration was 48.3 ± 2.5 µgg⁻¹ dw (Fig. 8). The concentration of vanadium in the *A. marina* roots from Msimbazi forest was relatively low (10.6 ± 4.5 µgg⁻¹ dw). Friedman's test showed a significant difference between the concentrations of V in *A. marina* roots from the three forests (Fr =16.800, P < 0.0001). Dunn's multiple comparison test, confirmed a significant difference in V concentration in *A. marina* roots between Msimbazi and Mbweni

forests ($P < 0.001$) and between Msimbazi and Mtoni forests ($P < 0.05$). There was no significant difference in V concentration in *A. marina* roots from Mtoni and Mbweni mangrove forests ($P > 0.05$).

The concentration of V in the *A. marina* leaf samples from Msimbazi forest was 32.0 ± 2.2 μgg^{-1} dw. Vanadium content of leaf samples from Mtonii and Mbweni forests were 24.2 ± 8.5 μgg^{-1} dw and 11.6 ± 0.1 μgg^{-1} dw

respectively (Fig. 8). Friedman's test indicated a significant difference in V content of *A. marina* leaves from the three forests ($Fr =15.800$, $P < 0.0001$). Dunn's multiple comparison test, confirmed that the differences in the concentration of V in *A. marina* leaves from Mtoni and Mbweni as well as Msimbazi and Mbweni forests were significant ($P < 0.05$). However, there was no significant difference between the concentration of V in *A. marina* leaves from Mtoni and Msimbazi mangrove stands ($P > 0.05$).
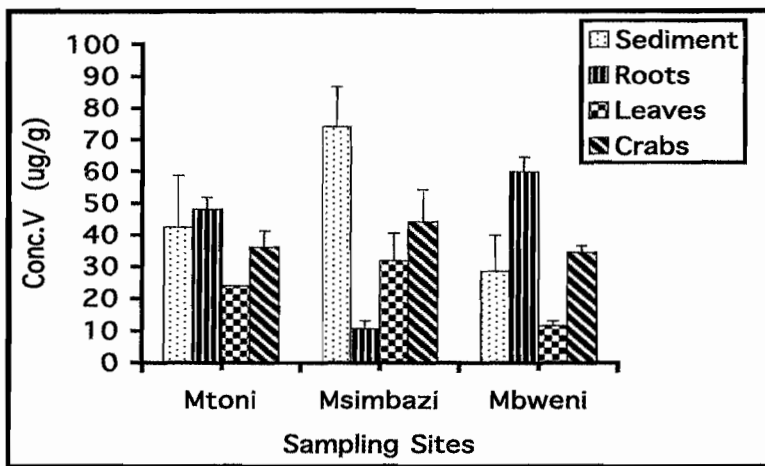

Fig. 8: Mean concentration $\pm$ SEM μgg^{-1} (dw) of vanadium in mangrove sediments. (weakly bound fraction), *Avicennia marina* parts and crabs of Mtoni, Msimbazi and Mbweni mangrove ecosystem

Vanadium content of *N. meinerti* crabs from Msimbazi mangrove area was 44.0 ± 10.2 μgg^{-1} dw. Crabs from Mbweni and Mtoni forests had a V content of 36.0 ± 2.2 μgg^{-1} dw and 34.2 ± 5.2 μgg^{-1} dw respectively (Fig. 8). Friedman's test did not indicate a significant difference in the concentration of V in the crabs from the three forests ($Fr = 0.8571$, $P = 0.6543$).

DISCUSSION

Mangroves absorb heavy metals from sediments through the root system. Heavy

metals available for plant absorption are those that are geachemically mobile in the sediment. The concentration of heavy metals in mangrove vegetation is therefore expected to be proportional to the levels of those metals in the weakly bound sediment fraction. Absorbed metals are transported in the entire plant through the shoot system. *N. meinerti* crabs are obligate mangrove litter (leaves and propagules) feeders in East African mangrove forests (Jones 1984, Machiwa & Hallberg 1995). These crabs are expected to acquire a body burden of heavy metals in a direct

proportion to the concentration of heavy metals in their food items.

Lead pollution

The concentration of Pb in sediment was higher in Msimbazi mangrove stand than in the other forests. Sediment samples from Mtoni and Mbweni mangrove forests, had almost similar concentration. The elevated concentration of Pb in Msimbazi mangrove sediments can be due to the proximity of the forest to the heavy traffic of motor vehicles that use leaded petrol in the city. Domestic and industrial wastes are also discharged into Msimbazi River from residential and industrial areas that occur within its drainage basin that forms about 50% city area (Kondoro 1996). Another important source of Pb in Msimbazi forest can be storm water runoff from the city, which may contain Pb from old paints on buildings or automobiles, as well as garages and fuel filling stations. Also one of the tributaries of Msimbazi River drains the former city damp site of Tabata, which still contain solid wastes likely to contain Pb.

The present study shows that Msimbazi mangrove sediments are contaminated with Pb. Even though the level of industrialization in Dar es Salaam is relatively low, roadside and atmospheric deposition cause significant Pb pollution of localized areas such as mangrove ecosystems within the city.. Zheng *et al.* (1997), reported that in Yingluo Bay the concentration of Pb in the mangrove sediment was between 7.7 - 84.7 $\mu gg^{-1}dw$. Such a wide range of the concentration in a small area indicates that the source of lead is linked to human activities. de Wolf *et al.*, (2001) found relatively low amount of Pb (ca 7 μgg^{-1} dw) in Msimbazi sediment samples. However, their sample size was probably small to be representative of the whole forest area.

The levels of Pb in *A. marina* from Mtoni and Msimbazi mangrove forests were almost equal, probably reflecting a similar source. There is a

possibility of atmospheric deposition of Pb directly onto mangroves that grow within the city. The concentration of Pb in *A. marina* leaf samples from Msimbazi and Mtoni forests was higher than in roots samples from the respective forests, suggesting an atmospheric source of some of the Pb on leaf samples. *A. marina* plant samples from Mbweni mangrove forest had the lowest concentration of lead, consistent with the low level of Pb in the sediment. Mbweni forest is furthest from the city center therefore is less affected by automobile emissions. The results also show that the concentration of Pb was highest in *N. meinerti*. Generally, the concentration of Pb decreased in the order of: crabs> leaves > roots > sediments in Msimbazi and Mbweni forests. The higher concentration of Pb in *N. meinerti* probably suggest that the crabs feed on Pb contaminated mangrove litter.

Zinc pollution

The results showed a significant difference in Zn concentration in sediments of the three forests. Msimbazi and Mtoni sediments had higher concentration of Zn compared to Mbweni. The variation in concentration probably reflects the differences in the sources of Zn input in the three forests. Anthropogenic input of Zn is more likely in Msimbazi and Mtoni forests that are closest to the city centre. Msimbazi River transports wastes from industries within the city, such as, Tanzania Breweries, soap factories, metal work Industries and Urafiki textiles. On the other hand, Kizinga River transports industrial wastes from Karibu textile, and wastes caused by road tankers washing at Mtoni suburb.

The concentration of Zn was almost similar in roots and leaves of Mtoni mangrove. In Msimbazi, the leaves contained higher Zn level than roots this may suggest that bio-available Zn is higher in Msimbazi forest.

Copper pollution

The results showed that the concentration of Cu was highest in sediments from Msimbazi mangrove stand, followed by Mtoni, then Mbweni indicating external input. Flora and fauna of the three forests do not indicate significant contamination. The enrichment of Cu in the sediments of the three forests showed a similar pattern as that of Zn. It is possible that the two elements have a common source, most likely of anthropogenic origin. Mbweni mangrove sediment samples had low concentration of both Zn and Cu probably because of absence of industrial activities in the catchment of Mpigi River. The concentration of copper in *A. marina* roots and leaves was relatively high in Msimbazi forest, reflecting the relatively high level of Cu in Msimbazi mangrove sediment.

Nickel, Cobalt, Chromium and Vanadium pollution

The results showed no significant difference in the concentration of Ni, Co, Cr and V in the sediments of the three mangrove forests. Because of the uniform distribution of these four elements in the mangrove sediments, the concentration in the sediment probably indicates the natural background values in the local soils.

Each of the four elements had almost equal concentration in the sediments of the three mangrove forests, but the levels of these metals were different in *A. marina* and crabs of the three forests. The differences in the concentration of the heavy metals in mangrove biota, probably reflect variations in the ages of *A. marina* and *N. meinerti* samples as well as differences in environmental parameters such as. redox state, organic matter content, pH, salinity of the sediment etc, in the three forests. These factors determine the availability elements to mangrove plants.

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