HEAVY METAL LEVELS IN PADDY SOILS AND RICE (*ORYZA SATIVA* (L)) FROM WETLANDS OF LAKE VICTORIA BASIN, TANZANIA

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ABSTRACT

A survey of paddy fields in Lake Victoria Basin (LVB) wetlands was conducted at a wider scale in different locations including closer to mining and within urbanized areas in Tanzania. The objective of the study was mainly to assess the present situation with regard to levels of heavy metals in O. sativa grains harvested locally as well as to set the baseline levels of some heavy metals in paddy fields. The results showed that the levels of Cadmium, Chromium, Copper, Lead, Zinc and total Mercury in brown rice are generally within the acceptable levels for human food. However, higher concentration of Hg was found in the husks, suggesting the significance of atmospheric dispersal of Hg in the basin. It is also worthwhile noting that all the sampled paddy fields in LVB have heavy metal concentrations within limits for production of safe rice for human consumption.

Keywords: Wetlands; Lake Victoria Basin; Heavy metals; Paddy soil; Rice;

INTRODUCTION

Heavy metal contents of agricultural soils can affect human health directly through consumption of crops grown in contaminated soils. There is clear evidence linking human renal tubular dysfunction with contamination of rice with Cd in subsistence farms in Asia (Chaney *et al*. 2005). Indeed, in Asia rice has been identified as one of the major sources of Cd and Pb intakes for humans (Moon *et al*. 1995, Jung and Thornton 1997, Shimbo *et al* 2001, Zhang and Ke 2004, Fangmin *et al*. 2006). In Japan, Tsukahara *et al*. (2003) reported specifically that rice was the main source Cd contamination in humans, however there are efforts to minimize heavy metal pollutants in food stuffs. One of the recent approaches to reduce pollution of food crops grown on contaminated soil is to plant pollution safe cultivars, the varieties that are less efficient heavy metal accumulators (Yu *et al*. 2006). It has also been reported that crops have different abilities to absorb and accumulate metals in their different parts and that there is a wide variation in metal uptake and translocation between plant species and even between cultivars of the same species (Kurz *et al*. 1999, Arao and Ae 2003, Li *et al*. 2003a,b, Liu *et al*. 2003a,b, 2005, Yu *et al*. 2006). Plants absorb heavy metals from the soil, the surface 25 cm depth zone of soil is the most affected by such pollutants resulting from anthropogenic activities. Heavy metals accumulate in this soil layer due to the relatively high organic matter content. This depth zone is also where roots of most cereal crops are located (Ross 1999; Micó *et al*. 2007). The plant part of interest for direct transfer of metal pollutants to humans is the edible part such as the grains. In the case of cadmium which is among the most geochemically mobile toxic metals, is readily taken up by plants and translocated to aerial plant parts where it accumulates (Satarug *et al*. 2003). There a number of reports on concentrations of toxic metals such as Cd in rice and paddy soils in Japan, China and Indonesia (Masironi 1977, Suzuki *et al*. 1980, Rivai *et al*. 1990, Suzuki and Iwao 1982, Herawati *et al*. 2000), such studies are few elsewhere where rice is cultivated including Tanzania.

Lake Victoria Basin extends into territories of Tanzania, Uganda, Kenya, Rwanda and Burundi, sustaining a number of urban centres. The area of the Tanzanian portion of the basin is 79,570 km^2 which is about 40% of the total LVB area. The basin is characterised by multi-sectoral activities of economic importance and is endowed with natural resources of social-economic value, which include water, land, forests, wetlands and the associated biota etc. The major wetlands in the Tanzania part of the basin occupy approximately 4220 km^2 (LVEMP, 2006) and rice is the main crop which is cultivated in the wetlands. The exploitation of the basin resources, especially mining, makes it vulnerable to pollution and other human induced disturbances. The soils are prone to pollution through surface runoff, groundwater and atmospheric mediated transport of contaminants from industrial and municipal sources (Nriagu 1990, Alloway and Jackson 1991, van Straaten 2000, Machiwa 2003a,b, Tamatamah *et al*. 2005). Because of their characteristic soils, the wetlands adjacent to Lake Victoria are natural barriers that allow trapping of pollutants from runoff, thus affording cleaning up of water before entering the lake (DHV Consultants BV 1998). The type of soil in the wetlands is mainly the so called "mbuga" soils, which is also characteristic of flat areas, valley bottoms, flood plains and swamps in the basin. The soils are dark grey or black in colour, hard when dry and crack, these soils swell when wet and become sticky. These wetland soils are fertile, rich in organic matter and favour accumulation of heavy metals (DHV Consultants BV 1998).

Heavy metals may find their way to the LVB wetlands via contaminated runoff from urban, industrial and mining sources (van Straaten 2000, Machiwa 2003b). Despite the increasing mining activities, urbanization, industrial and agricultural developments in the LVB, few studies have focused on heavy metal contents of wetland areas close to Lake Victoria that have been converted to agricultural fields for food crop production. Rice is one of the leading staple foods in Tanzania and widely grown in wetland areas around Lake Victoria, in Mwanza, Mara and Shinyanga Regions. Nevertheless, little is known on concentrations of heavy metal pollutants in rice from LVB. The two studies on Hg content of rice from LVB by Machiwa (2003b) and Taylor *et al*. (2005) covered only part of the basin, therefore the observed mercury concentrations in the few rice samples cannot be extrapolated to the entire basin. Based on this fact, there was a need to extend the sample collection to areas of LVB that were not covered by the previous studies. The present study was undertaken in order (i) to assess the concentrations of heavy metals in paddy soils and rice from wetlands that are used for rice cultivation in LVB (ii) to compare the heavy metal concentrations among sampling locations in LVB wetlands under rice cultivation (iii) to relate the heavy metal concentration in paddy soils and in rice plant material from LVB wetlands.

MATERIAL AND METHODS

Location of the study area

Soil and rice samples were collected from farms in wetlands that are located closer to Lake Victoria within the area from latitude 01^o 29.2´S to 02^o 54.8´S and from longitude 031^o 54.9´E to 033^o 50.7´E. The sampling stations are indicated in the study site map (Fig. 1), the exact positions with their respective names are shown in Table 1. For convenience, the stations are grouped into four main sites, namely Geita (GD), Mwanza city (MC), Magu (MD) and Bunda (BD).

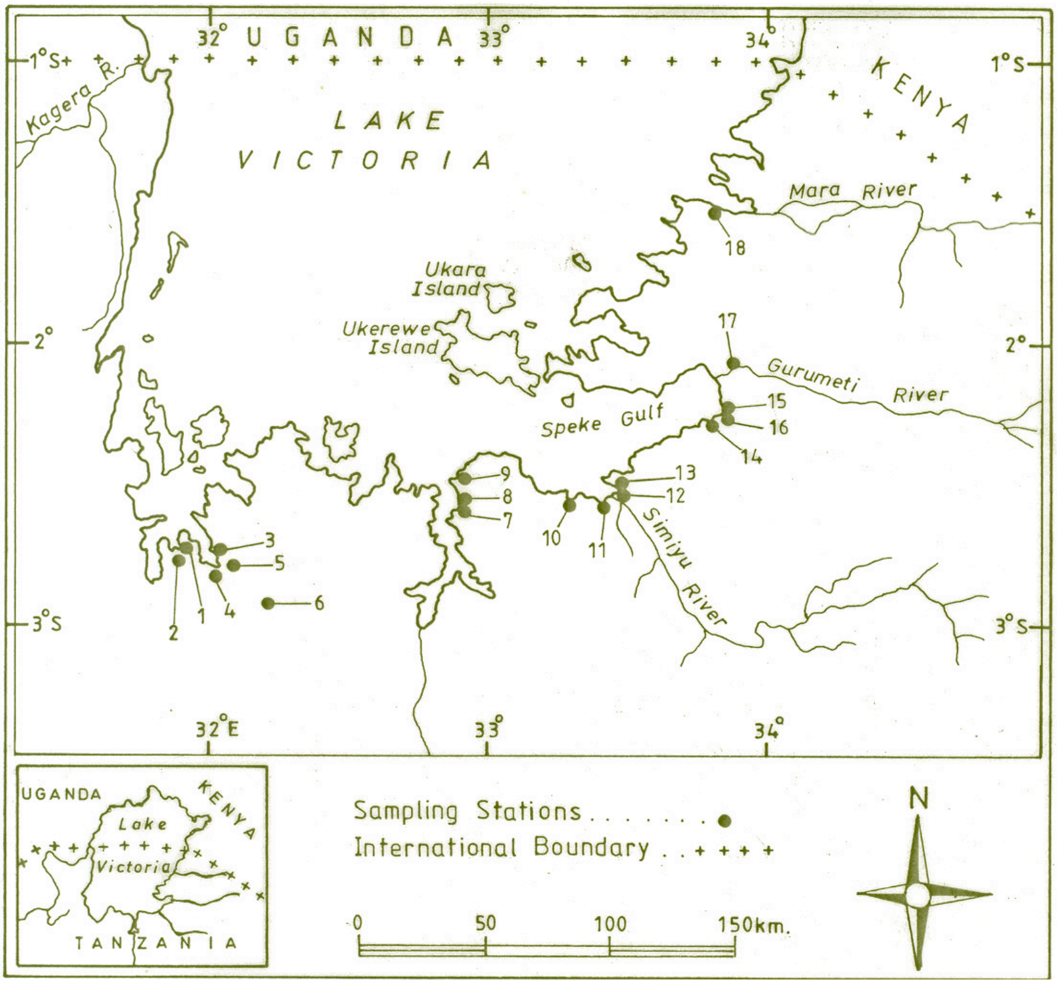

Figure 1: Map of Lake Victoria Basin, Tanzania showing the sampling stations for paddy soil and rice.

Table 1: **Names and locations of sampling stations for paddy soils and paddy rice samples**

Station No. & Name	Location	Description
Geita District (GD)		
1. Butundwe	S 02° 42.800′/ E 031° 55.273′	Rural, remote from mining activity
2. Busaka	S 02° 44.572′/ E 031° 54.929′	Rural, remote from mining activity
3. Saragurwa	S 02° 46.514′/ E 032° 02.029′	Within 50 km from gold mining site
4. Nungwe-1	S 02° 47.606′/ E 032° 01.395′	Within 50 km from gold mining site
5. Nungwe-2	S 02° 47.559′/ E 032° 01.464′	Within 50 km from gold mining site

Station No. & Name	Location	Description
6. Lyamchele	S 02° 54.892′/ E 032° 11.401′	Within 3 km from Geita Town
Mwanza City (MC)		
7. Butimba	S 02° 34.435′/ E 032° 54.120′	Urban area
8. Mkuyuni	S 02° 33.220′/ E 032° 54.449′	Urban area
9. Ilemela	S 02° 28.225′/ E 032° 54.931′	Urban area
Magu District (MD)		
10. Ngashe	S 02° 34.118′/ E 033° 17.020′	Rural area
11. Kandawe	S 02° 35.163′/ E 033° 24.583′	Rural area
12. Bubinza	S 02° 31.893′/ E 033° 28.838′	Rural area
13. Kiloleni	S 02° 29.303′/ E 033° 28.481′	Rural area
14. Kashishi	S 02° 16.183′/ E 033° 48.654′	Rural area
15. Itongo	S 02° 15.202′/ E 033° 50.333′	Rural area
16. Ramadi	S 02° 15.197′/ E 033° 50.722′	Rural area
Bunda District (BD)		
17. Mbugani	S 02° 04.195′/ E 033° 52.251′	Game reserve area
18. Kyabakari	S 01° 29.252′/ E 033° 49.029′	Rural area

Sample collection and analysis

Sampling of soil and paddy rice was conducted in May - June 2006 just before harvesting time. Soil samples were taken from 0 to 25 cm depth from rice cultivated fields at same locations where rice plant materials were sampled (Lokeshwari and Chandrappa 2006). Soil sampled were air dried to constant weight and passed through 1 mm sieve. Grains of mature rice plant (*Oryza sativa* (L)) samples were collected from paddy fields for ensuring the original locations of samples. Paddy rice (rice grains with husks) was air dried to constant weight and husks were removed using pestle and mortar. The polished rice (paddy rice without husks) was then ground to a fine powder. The other sub-samples of paddy rice were similarly ground.

Well homogenized soil, polished rice and paddy rice samples were weighed (0.5 g) into separate teflon acid digestion tubes, then 8ml concentrated HNO_3 and 2 ml 30% H_2O_2 were added in each digestion tube and were tightly closed with screw caps. The samples were placed in a Milestone ethos plus microwave and digested at 200 °C for 30 min. with a microwave power of 1000 W (Thomson and Wash 2003). The digested samples were diluted to 100 ml with deionised water. The concentrations of Cd, Cr, Cu, Pb and Zn in the samples were determined on a Varian VISTA MPX CCD simultaneous ICP-OES. Internal standard solutions were used to calibrate the instrument. The organic matter content of the dried soil samples was determined by loss of weight on ignition at 550°C in a muffle furnace (Rump and Krist, 1992).

Total Hg (THg) was analysed following Akagi and Nishimura (1991) procedure, where 0.5 g of dried soil or rice (polished rice and paddy rice) samples were weighed in 50 ml volumetric flasks. De-ionized water (1 ml) was added, the flasks were swirled to ensure complete wetting of samples, 2 ml (1 + 1 HNO_3 and $HClO_4$) was then added followed with 5 ml of H_2SO_4. The samples were heated at 200 ± 5 °C for 30 minutes without covering the flasks and then cooled to room temperature and diluted to 50 ml with de-ionized water. Total Hg in soil and rice samples was analysed with a semi automatic Mercury analyzer (HG 201, Sanso Seisakusho Co. Ltd).

Concentrations of all metals in soil, polished and paddy rice samples are expressed on dry weight basis.

Quality control/Quality assurance and statistical analysis

Certified Reference Materials (CRMs), DORM-2 and DOLT-2 from National Research Council Canada as well as BCR-143 and BCR–60 from Institute for Reference Materials and Measurements (Belgium) were used for QA/QC purposes. The laboratory results for concentrations of Cd, Pb, Cr, Cu and Zn in the CRMs were in agreement (less than ± 5%) with the certified values. Statistical analysis of data was based on comparison between sites, using Kruskal-Wallis nonparametric test, post hoc analysis was performed by Dunn's multiple comparison test. Relationships between heavy metal concentrations in soil and plant material were based on Spearman rank correlation.

RESULTS

Organic matter and heavy metals in wetland soils

Organic matter in paddy soils from LVB ranged from 1.8 to 12.4% (Table 2). The differences in organic matter content between the four sites (Figure 2a) were significant ($p = 0.026$, KW = 9.227), soils from Magu had the highest contents of organic matter. Higher copper concentration in the soil was also observed in samples from Magu (Fig. 2a), although the difference in Cu content of the soils from the four sites was not statistically significant ($p > 0.05$). Cadmium concentration was generally low in the soil samples (Fig. 2b) with no significant difference among sites ($p > 0.05$). The concentration of Pb in the soil ranged from 8.0 to 28.5 µg g^{-1}, (the mean was 18.9±7.4 µg g^{-1}). Likewise, there was no significant difference in Pb concentration in the soil between the sites ($p > 0.05$). The concentration of Cr in soil samples ranged from 11.4 to 39.4 µg g^{-1} where Mwanza City recorded the highest concentration of all the sampling sites. It was however observed that there was no significant difference in Cr concentration in the soils of the four sites ($p>0.05$). Zinc concentration was higher in some samples from Magu and Mwanza city than the average of 59.8 µg g^{-1} (Table 2), with significant difference ($p = 0.031$; KW = 8.894) among sites (Fig. 2c). Dunn's multiple comparison test showed a significant difference ($p < 0.05$) in Zn concentration between soils of Geita and Magu as well as between soils of Bunda and Magu. Total Hg content was highest (69.3 ng/g) in soil samples from Nungwe area (Table 2), however, the THg concentration was not significantly different ($p>0.05$) among the four sampling sites (Fig. 2d).

Table 2: Mean concentrations (±SD) of metals and organic matter contents of soil samples from rice growing wetlands in Lake Victoria Basin

STN No	Org.M %	Cd µg g^{-1}	Cr µg g^{-1}	Cu µg g^{-1}	Pb µg g^{-1}	Zn µg g^{-1}	Hg µg g^{-1}
1	4.6	0.47±0.01	18.3±5.6	13.3±1.1	20.0±6.5	46.6±5.2	26.1±2.9
2	8.4	0.29±0.02	19.8±4.9	12.5±1.1	18.6±3.6	33.4±1.0	16.2±2.1
3	4.0	0.48±0.04	18.4±2.6	9.4±3.1	12.7±5.5	18.3±2.1	17.6±3.5
4	5.1	0.15±0.01	22.2±5.8	19.7±2.2	13.5±2.4	20.7±1.1	69.3±11.1
5	6.8	0.44±0.04	25.6±3.2	17.0±3.1	17.9±3.6	18.5±3.1	25.0±8.9
6	2.4	0.52±0.07	27.0±6.3	16.9±4.2	26.2±4.8	73.4±2.5	9.5±3.11
7	3.1	0.74±0.06	14.6±3.6	9.2±1.1	25.0±2.6	58.4±2.3	19.0±6.3
8	4.9	0.88±0.07	21.1±2.1	21.7±1.2	25.6±3.7	91.7±5.6	50.6±8.1
9	4.2	0.16±0.01	39.4±9.9	2.6±0.1	13.4±2.3	39.5±2.6	3.2±0.3
10	5.3	0.81±0.07	28.6±3.1	22.8±4.2	25.9±2.6	104.1±10.1	19.3±4.5
11	6.3	0.52±0.03	11.4±3.2	22.0±2.2	28.5±3.7	158.0±13.2	17.6±4.1
12	7.3	0.68±0.02	14.3±2.4	12.5±3.1	21.7±2.4	83.1±12.2	15.9±3.4
13	5.7	0.54±0.02	26.9±5.9	21.0±2.2	19.3±1.7	67.2±9.9	18.5±2.9

STN No	Org.M %	Cd µg g^{-1}	Cr µg g^{-1}	Cu µg g^{-1}	Pb µg g^{-1}	Zn µg g^{-1}	Hg µg g^{-1}
14	6.9	0.41±0.03	24.8±2.3	15.1±1.1	10.2±1.3	56.4±11.2	4.7±1.31
15	9.9	0.47±0.02	25.3±2.4	14.9±4.1	16.4±1.5	97.6±12.6	14.2±4.3
16	12.4	0.66±0.04	29.2±8.9	18.1±6.1	24.0±2.6	128.2±15.9	15.8±3.9
17	4.3	0.29±0.03	15.4±1.6	7.3±1.1	21.9±2.4	69.4±14.6	10.3±2.1
18	1.8	0.19±0.01	20.3±2.0	6.4±0.1	8.0±0.2	13.7±1.7	7.1±1.3

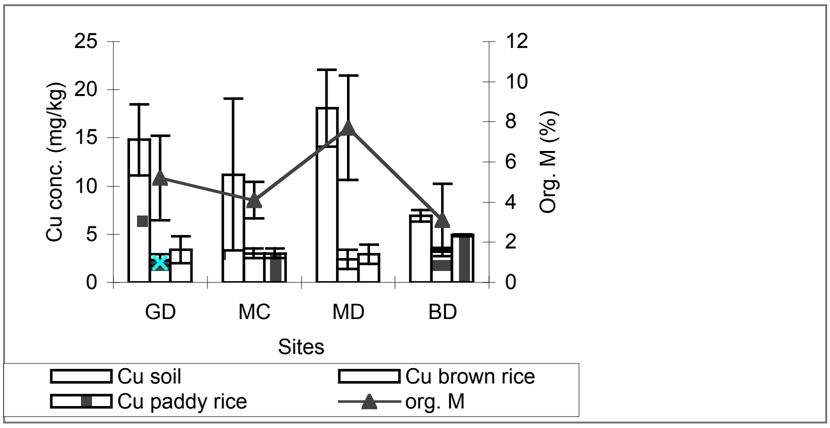

Fig. 2a

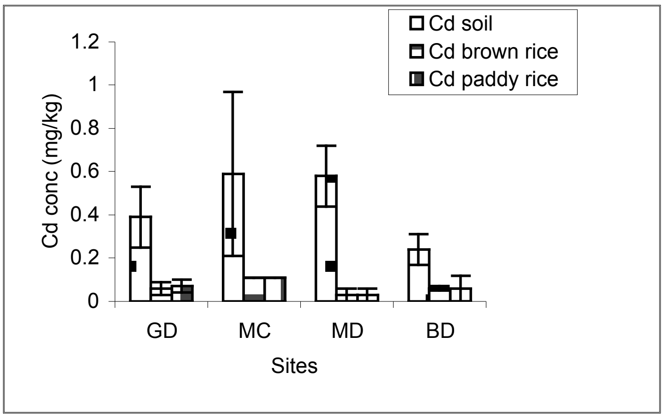

Fig. 2b

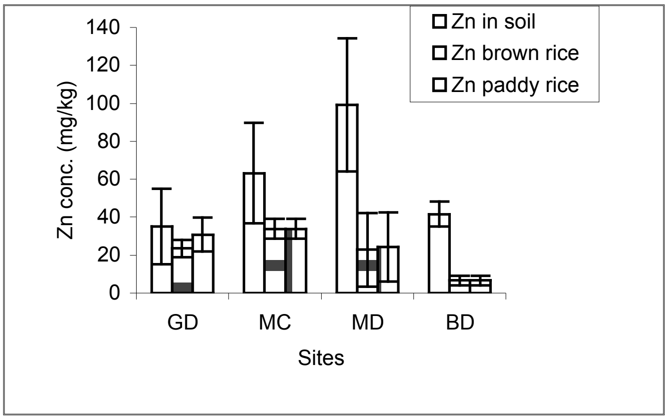

Fig. 2c

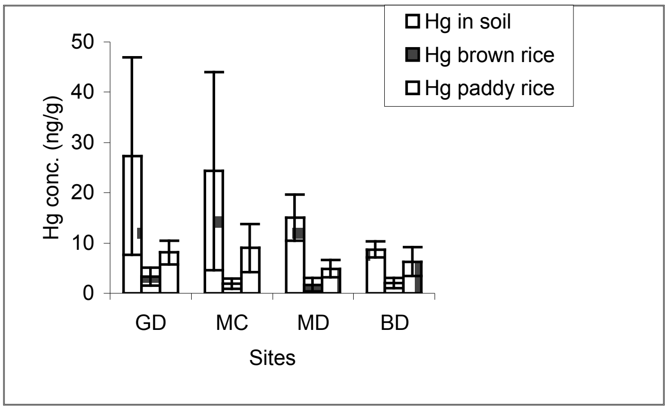

Fig. 2d

Figure 2: (a) Organic carbon content in paddy soil and copper (b) cadmium (c) zinc and (d) total mercury concentrations in paddy soil, paddy and brown rice from Geita (GD), Mwanza City (MC), Magu (MD) and Bunda (BD) in Lake Victoria Basin.

Concentration of heavy metals in plant material

The concentration of Cu in polished rice ranged from 0.8 to 3.7µg g^{-1} (Table 3). There was no significant difference in the concentration of Cu in polished rice samples from the four sites in LVB ($P<0.05$). It was observed that most of the polished rice samples from the study sites had Cadmium concentration below detection limit and only a few had concentration of Cd up to 0.1µg g^{-1}. There was no significant difference in Cd concentrations among rice samples ($P>0.05$). The results showed that Cr and Pb were high in some paddy soils from Mwanza city where the mean concentration was 25.0±10.5 and 21.3±5.6 µg g^{-1} respectively, however, Cr was below detection limit in most of the rice samples and the mean concentration of Pb in polished rice was 0.10±0.06 µg g^{-1}. Other heavy metals including Hg had low concentrations in brown rice which did not significantly vary among the four study sites (Fig. 2c and d).

Table 3: Mean concentrations (±SD) of metals in brown rice and paddy rice (in parentheses) samples from Lake Victoria Basin

STN No	Cd $\mu g\ g^{-1}$	Cr $\mu g\ g^{-1}$	Cu $\mu g\ g^{-1}$	Pb $\mu g\ g^{-1}$	Zn $\mu g\ g^{-1}$	Hg $\mu g\ g^{-1}$
1	0.05±0.01	<0.01	3.0±0.2	0.19±0.09	18.5±0.4	3.3±0.3
	(0.06)	(<0.01)	(4.0±0.3)	(0.21±0.11)	(22.1±0.4)	(5.7±0.9)
2	0.12±0.01	0.03	1.6±0.1	0.13±0.06	25.4±0.7	4.8±0.5
	(0.12)	(0.03)	(2.1±0.2)	(0.18±0.09)	(32.2±0.8)	(7.2±1.1)
3	0.09±0.02	<0.01	1.9±0.1	0.17±0.10	27.8±0.7	2.4±0.3
	(0.09)	(<0.01)	(2.8±0.2)	(0.25±0.14)	(38.2±0.9)	(11.4±3.7)
4	0.06±0.01	<0.01	2.5±0.2	0.19±0.06	23.7±0.7	0.5±0.1
	(0.08)	(<0.01)	(4.1±0.2)	(0.28±0.03)	(32.3±0.9)	(8.7±2.5)
5	0.04±0.00	<0.0	1.7±0.3	0.17±0.04	17.0±0.4	2.4±0.4
	(0.04)	(<0.01)	(1.7±0.1)	(0.21±0.06)	(17.0±0.5)	(4.8±0.3)
6	0.03±0.00	<0.0	3.3±0.2	0.13±0.03	28.5±0.7	6.2±1.0
	(0.03)	(1.01)	(5.9±0.3)	(0.28±0.04)	(43.2±1.4)	(10.5±2.1)
7	0.11±0.02	<0.01	3.7±0.1	0.16±0.02	39.6±1.1	2.4±0.8
	(0.11)	(<0.01)	(3.7±0.4)	(0.22±0.02)	(39.6±1.0)	(3.6±1.0)
8	0.11±0.01	<0.01	2.6±0.1	0.19±0.04	34.8±1.2	2.9±0.6
	(0.11)	(<0.01)	(2.6±0.1)	(0.31±0.05)	(34.8±0.9)	(8.2±1.2)
9	0.12±0.02	<0.0	2.6±0.2	0.13±0.02	27.0±1.0	0.5±0.1
	(0.12)	(<0.01)	(2.6±0.3)	(0.13±0.02)	(27.0±1.1)	(15.2±5.9)
10	0.07±0.01	0.03	3.6±0.1	0.17±0.05	47.5±2.3	<0.1
	(0.07)	(0.03)	(3.6±0.1)	(0.29±0.05)	(47.5±2.4)	(2.4±1.1)
11	0.03±0.00	<0.0	3.2±0.4	0.17±0.04	48.7±2.4	3.4±0.9
	(0.03)	(<0.01)	(3.2±0.2)	(0.18±0.06)	(48.7±2.9)	(4.9±0.8)
12	0.10±0.0	<0.0	3.1±0.1	0.19±0.02	38.2±1.4	0.5±0.1
	(0.10)	(<0.01)	(3.1±0.1)	(0.19±0.03)	(38.2±1.8)	(2.9±0.5)
13	<0.001	<0.0	2.2±0.3	<0.001	2.5±0.0	0.5±0.1
	(<0.001)	(0.01)	(3.3±0.3)	(<0.001)	(3.7±0.0)	(5.7±1.0)
14	<0.001	0.02	0.8±0.1	<0.001	10.8±0.1	1.4±0.4
	(<0.001)	(0.02)	(0.8±0.3)	(<0.001)	(10.8±0.2)	(5.6±0.9)
15	<0.001	<0.01	1.7±0.2	<0.001	5.4±0.1	3.4±1.0

STN No	Cd $\mu g\ g^{-1}$	Cr $\mu g\ g^{-1}$	Cu $\mu g\ g^{-1}$	Pb $\mu g\ g^{-1}$	Zn $\mu g\ g^{-1}$	Hg $\mu g\ g^{-1}$
	(<0.001)	(0.01)	(2.5±0.1)	(<0.001)	(9.5±0.1)	(7.7±1.3)
16	<0.001	0.02	2.4±0.1	<0.001	6.7±0.0	2.4±0.6
	(<0.001)	(0.02)	(4.0±0.1)	(<0.001)	(11.0±0.1)	(5.3±0.4)
17	0.05±0.00	<0.01	3.6±0.1	<0.001	4.1±0.0	2.9±0.5
	(0.05)	(<0.01)	(4.9±0.2)	(<0.001)	(4.1±0.0)	(9.1±1.8)
18	0.07±0.01	<0.01	3.2±0.3	<0.001	9.0±0.3	1.0.±0.1
	(0.07)	(<0.01)	(4.8±0.2)	(<0.001)	(9.0±0.5)	(3.4±0.2)

The results showed that with the exception of THg, all heavy metals occur in the polished rice at concentrations higher than 90% of the total amount in the paddy rice. For the case of THg, over 50% of the concentration was associated with the husks (Fig. 2e) and about 100% of the total concentration of Cd was found in the polished rice. There were no significant correlations ($p > 0.05$) between total metals in paddy soil samples and heavy metal contents in rice samples.

DISCUSSION

Concentration of heavy metals in paddy soils

Total concentrations of heavy metals in the LVB paddy soils were generally similar to values in agricultural soils in the Mediterranean region as reported by Micó *et al*. (2007). It has been reported by Ikingura and Akagi (2002) that atmospheric fallout of mercury decreased with distance from the gold ore processing sites and DHV Consultants BV (1998) observed that metals leached from mine tailings were almost completely trapped in wetland soils a short distance from the tailings. Therefore, the present results augment previous observations that metals leached from mining wastes are immobilized within the adjacent soils. The concentration of Cd in paddy soils of LVB is 0.45 $\mu g\ g^{-1}$ on average, similar to 0.45 $\mu g\ g^{-1}$ reported in Japanese paddy soils (Iimura, 1981) which is below the maximum allowable limit of 0.5 $\mu g\ g^{-1}$ (by using 0.1M HCl for soil extraction) set for such soils (Pendias and Pendias, 1992). Studies have demonstrated that high concentration of toxic heavy metals such as Cd, Pb and Hg reduce soil fertility and agricultural output (Lokhande and Kalkar, 1999). Indeed, Cd concentration above 20 $\mu g\ g^{-1}$ in soil reduces rice plant biomass by poisoning the roots and restricting growth (Herawati *et al*. 2000). Micó *et al*. (2007) reported mean values of metals in agricultural soils from European Mediterranean region which are comparable with the concentrations of metals in paddy soils in LVB (Table 4). These concentrations are equal or lower than those reported in agricultural soils in the Spanish Mediterranean region (Andreu and Gimeno-Garcia 1996, Facchinelli *et al*. 2001). It is worthwhile noting that the concentration of metals in paddy soils from LVB are within limits for safe rice production. The average Hg concentration of paddy soils in LVB was 18.9 ng g^{-1}. This suggests that mercury pollution is not quite alarming in these paddy fields. The present results on Hg concentrations are in agreement with those of Taylor *et al*. (2005) who reported that generally Hg concentration was low (< 0.05 $\mu g\ g^{-1}$) in cultivated soils in rural LVB even though their sample collection did not extend to the present study area.

Concentration of heavy metals in rice

High Cu and Zn concentrations in the environment have in most cases been associated with industrialization. For instance, Chino (1981) reported differences in Cu and Zn contents of polished rice grown in normal and contaminated soils in Japan. The concentrations were 3.3 and 15.5 µg g^{-1} respectively for normal soils, whereas in contaminated soils the rice attained 3.7 and 20.5 µg g^{-1} respectively. On the average, the concentrations of Cu and Zn in rice from LVB were 2.8 and 21.7 µg g^{-1} respectively. The concentration of Zn in LVB rice is comparable to Japanese rice (15.2 – 23.4 µg g^{-1}, reported by Masironi, 1977; Ohmomo and Sumiya, 1981; and Herawati *et al*. 2000) and Indonesian rice (19.0 – 24.9 µg g^{-1} , reported by Suzuki *et al.* 1980 and Koyama *et al*. 1988) as well as Chinese rice (21.5 µg g^{-1}, reported by Herawati *et al.* 2000). Therefore, the observed concentration of Zn in LVB rice does not necessarily indicate contamination. The level of Cu in LVB rice is lower compared with that reported by Ohmomo and Sumiya (1981) and Herawati *et al.* (2000) in rice from Japan (2.7 – 3.7 µg g^{-1}). Rice from other countries also with relatively high Cu contents are Indonesia (Suzuki *et al*. 1980), China and Taiwan (Masironi 1977). The concentrations are 3.4 µg g^{-1}, 4.2 µg g^{-1}, and 4.4 µg g^{-1} respectively. The Cu and Zn content in rice is of lesser importance because the elements normally occur at lower concentration than the maximum allowable in food (Table 4).

Table 4: Comparison of concentrations of metals (µg g^{-1}) in LVB and the European Mediterranean region (EMR) (Micó *et al.* 2007) soils as well as concentration of metals in LVB brown rice against FAO/WHO recommended limits for rice/cereal grains.

Metal	LVB soils	EMR soils	LVB rice	Recommended limit (FAO/WHO)
Cd	0.45±0.15	0.34±0.20	0.065±0.028	0.2
Cr	21.9±2.58	26.5±5.9	0.01	-
Cu	12.8±4.2	22.5±8.9	2.8±0.4	20
Pb	18.9±2.5	22.8±16.1	2.8±1.8	0.2
Zn	59.8±25.0	52.8±14.9	21.7±9.7	50
Hg	0.018±0.007	-	0.002	-

The average Pb concentration in LVB polished rice was 0.10 µg g^{-1}, which is higher than the worldwide mean (0.02 µg g^{-1}) reported by Watanabe et al. (1989) but within the range reported in Chinese rice (0.05 - 0.11 µg g^{-1}) by Fangmin *et al.* (2006). Cadmium concentration was less than 0.2 µg g^{-1} in all rice samples, which is the maximum allowable level in human consumable food material (FAO/WHO, 2002). The results indicated that LVB rice had acceptable concentrations of Cd, however, rice from Mwanza City paddy fields need attention because the concentration is close to the limit of allowable concentration (FAO/WHO, 2002). Chino (1981) reported that the concentration of Cd in *O. sativa* grown in uncontaminated, normal soil was 0.05 µg g^{-1}. Cadmium in rice is of great concern because of its severe public health impact (Tschiya 1978). In Asia a number of studies have been conducted to establish the levels of Cd in *O. sativa*. For example, Herawati *et al.* (2000) and Nogawa *et al*. (2004) reported high Cd content (0.02 – 1.06 µg g^{-1}) in Japanese rice. Rice from other countries like Indonesia, the Cd content was 0.07 µg

g^{-1}, and in China it ranged from 0.05 to 1.86 µg g^{-1} (Suzuki *et al*. 1980; Watanabe *et al.* 1996; Zhang *et al*. 1996; Fangmin *et al*. 2006). The lowest Cd concentration (0.04 µg g^{-1}) in Asian rice was reported in rice from Java (Suzuki *et al*.1980), the worldwide average is 0.02 µg g^{-1} (Watanabe *et al*. 1989). The concentration of Cd in Asian rice is generally higher than rice from Australia, North America and the European countries (Schuhmacher *et al*. 1994; Merry *et al*. 1983; Wahid *et al*. 1995; James *et al*. 2000; Shimbo *et al*. 2001).

Previous heavy metal pollution studies in LVB paid great attention to mercury because of the artisanal gold mining activities in the basin. The Hg content of polished rice ranged from <0.1 to 6.2 ng g^{-1}, similar to the concentration values (from below 4 ng g^{-1} to 13 ng g^{-1}) reported by Machiwa (2005) and Taylor *et al*. (2005). However, higher concentration of Hg was found in the husks than in polished rice, suggesting the significance of atmospheric dispersal of mercury and other pollutants in the basin (Ikingura and Akagi 2002, Tamatamah *et al*. 2005).

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