CONCENTRATIONS OF METALS IN RIVER SEDIMENT AND WETLAND VEGETATION IN MINING SITES, LAKE VICTORIA BASIN, TANZANIA.

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ABSTRACT

Levels of metals were determined in river sediment, rice and sugarcane juice from Lake Victoria basin where small-scale gold processing activities are carried out to assess levels of contamination. Concentrations of metals in river sediments were generally high in areas that were closest to gold ore processing sites. For instance, mercury was highest (36.3 ±12.8 µg/g dw) in river sediments of Tigiti River in Mugumu District. Other heavy metals (Cd, Pb, Zn and Cu) had highest concentrations (2.20±0.71, 208±19.3, 412±20.1 and 132.7±11.9µg/g dw, respectively) in sediment samples from Kagota. The concentration of arsenic was highest (985.0±67.2 µg/g dw) in Mugusu River sediment. Mercury concentration in rice was highest (378.5±15.1µg/kg dw) in samples from Lwamgasa wetland and lowest (47.9±2.9 µg/kg dw) in samples from Saragurwa wetland. Cadmium concentrations in rice ranged from 2.3-5.5µg/kg dw, Zn and Cu ranged from 16340-27280µg/kg dw and 1150-2240µg/kg respectively. Arsenic was not detected in any rice sample. Lead was only detected in rice from Sengerema (150±12µg/kg dw), in a wetland that is close to the main road. Mercury concentrations in sugarcane juice were below the limit of detection (0.01µg/l) in all samples even those that were harvested closest to the gold ore-washing site at Samina. It is concluded that small-scale gold mining activities contaminate watercourses close to ore washing sites

INTRODUCTION

A small-scale mining site essentially means an area that is used for gold ore processing or reprocessing of mine tailings. Currently, the information on the contribution of gold mining activities in Lake Victoria basin to concentrations of metals in the lake has not been adequately construed. In most cases, insufficient environmental materials are sampled, hence giving inconclusive results.

Lake Victoria Gold Fields (LVGF) consists of auriferous ores that are won from primary and secondary gold deposits. Primary gold deposits are those where gold is found in quartz veins especially in shear zones within the greenstone belts (Condie 1981; Bell and Dodson 1981; van Straaten 1983; Borg *et al* 1992). Secondary gold deposits consist of gold that was liberated from original rock type and re-deposited in several secondary environments. Gold deposits of LVGF are chiefly auriferous quartz veins containing free milling gold or refractory gold hosted in sulphides such as pyrite, chalcopyrite, pyrrhotite, arsenopyrite or even in traces of galena and sphalerite (Kahatano and Mnali, 1997). Therefore, depending on the mineralogy, gold mining can release a variety of heavy metals (e.g. Cu, Zn, Pb and As) in the environment. Metallic mercury is used for purification of gold ores by small-scale miners, therefore, is also released to the environment. Mercury is mixed with the concentrate in a pan to form a Hg-Au amalgam. Finally Au is recovered through the process of amalgam roasting in open air (or by the use of a retort), a process that is likely to cause atmospheric contamination of Hg (Stevens et al. 1982; Campbell 2001;

Tamatamah 2002; Ikingura and Akagi, 2002).

Laterite soils found in LVGF have excellent metal adsorption capacity. Metals are strongly adsorbed onto both goethite (a major component of lateritic crusts) and humic acids present in the top few centimeters of the LVGF soils. For instance, DHV consultants (1998) observed in the dry season that the dispersion of heavy metals was characterized by a steep gradient from the source, indicating that Hg did not move far from the source. This report presents concentrations of metals in river sediment and soil samples from small-scale gold ore processing sites in Lake Victoria basin.

MATERIALS AND METHODS

Study sites

The sampling stations on rivers (numbers prefixed with T) were proximal to small-scale gold ore processing sites. The rivers directly or indirectly discharge into Lake Victoria at station numbers prefixed with L (Fig. 1). Sampling in areas that are currently being mined or have been abandoned was conducted in May and June 2002.

T1: Sirorisimba, Mugumu District (01°44'30.3"S, 034°13'56.4"E)
Gold ores at Sirorisimba are present in surface deposits that are now being worked on to a limited degree. No gold ore processing site was located.

T2: Ring'wani, Mugumu District (01°43'13.9"S, 034°26'33.6"E)
This area was once worked for some period of time, currently is not being actively mined. Sediment samples were collected in the river about 1 km from the former mine and soil samples were collected 20 m from the river bank in the direction away from the former mine.

T3: Nyigoti, Mugumu District (01°58'41.8"S, 034°38'45.4"E)
This area was once worked for some period of time, currently is not being actively mined. Maruru River drains this mineralized area via Fort Ikoma and discharges into Grumeti/Rubana River. Sediment samples were collected in Maruru River adjacent to the mine and soil samples were collected about 15 m from the riverbank.

T4: Tigiti, Mugumu District (1°29'29.2"S, 034°33'25.9"E)
This mining area was active in the past, currently is not being actively mined by artisanal gold miners. Sediment samples were collected from Tigiti River at Nyamongo and soil samples were collected at about 15 m from Tigiti River bank.

T5: Kagota (Kibaga village), Tarime District (01°22'39.9"S, 034°23'16.0"E)
This is an emerging area that is currently being mined. Rivers draining Tarime town are tributaries of Mori River which discharges in Lake Victoria. Sediment samples were collected in Nyangwe River adjacent to Kibaga village and soil samples were collected 20 m from the River bank.

T6: Samina, Geita District (02°54'01.9"S, 032°09'06.00"E)
This area is actively used for gold ore processing. Sediment samples were collected about 1 km downstream of the gold ore washing/sluicing area and upstream of the washing site.

T7: Nungwe/Nyakabale, Geita District (02°50'14.0"S, 032°09'16.2"E)
Large scale mining is operated at Nungwe, gold processing is by use of cyanide method.

T8: Nungwe, Geita District (02°47'55.0"S, 032°01'24.9"E)
This area (Nungwe wetlands) is used extensively for rice cultivation, it is a flood plain which is close to the large and small-scale gold mines of Geita.

T9: Saragurwa, Geita District (02°50'38.2"S, 032°02'06.7"E)
This wetland is used for paddy cultivation, it is located within the flood plain of Mugusu River.

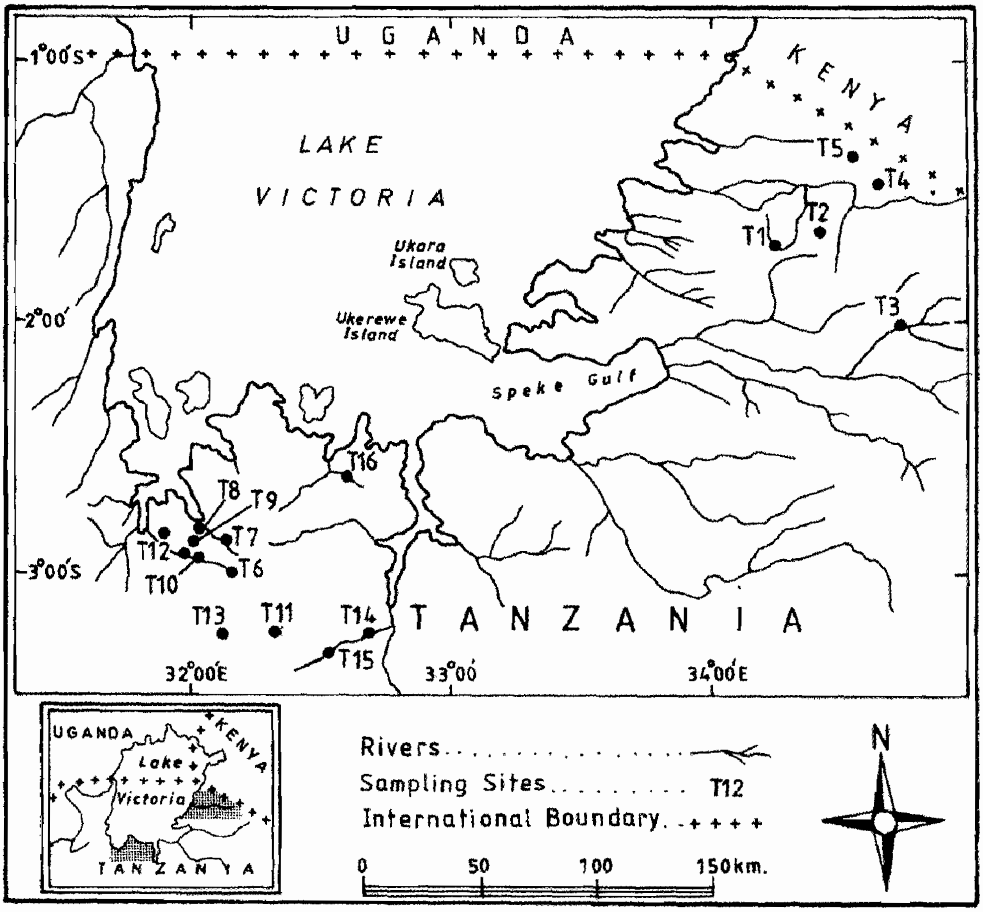

Figure 1 Map of Lake Victoria basin on the Tanzanian side showing locations of sampling stations on some rivers (numbers prefixed with T. Latitudes are in °S and longitudes are in °S

T10: Mugusu, Geita District (02°51'28.2"S, 032°03'26.4"E)
In this area gold processing is conducted in a mining village. River sediment samples were collected about 10 m downstream of gold ore washing site and about 50 m upstream of gold ore washing site.

T11: Nyarugusu, Geita District (03°06'49.7"S, 032°14'54.8"E)
This is an active gold processing site. River sediment samples were collected downstream at about 200 m from the sluice area.

T12: Buseresere, Geita District (02°53'42.5" S, 031°53'37.7"E)
Gold ore processing is being actively conducted in this area. Sediment samples were collected in Nyamasenge River at Imwero village, about 0.5 km downstream of ball mill grinding area.

T13: Lwamgasa, Geita District (03°06'55.9"S, 032°02'18.9"E)
This is an active gold ore processing site. Sediment samples were collected in a tributary of Nyikonga River, about 50 m downstream of the ball mill rock crushing

site. The Nyikonga River discharges into Lake Victoria.

T14: Nyangalamila, Geita District (03°07'27.1"S, 032°43'44.6"E)

This wetland is used for paddy cultivation, it is located within the flood plain of Ligembe River. Currently there is no active gold mining in the Ligembe River catchment.

T15: Nyakagwe, Geita District (03°12'51.9"S, 032°25'00.00"E)

This is an area where gold ore processing is being actively conducted. Sediment samples from Nyakagwe River were collected upstream and downstream adjacent to the gold ore washing site.

T16: Sengerema, Sengerema District (02°39'26.9"S, 032°38'55.0"E)

The wetland is located near Sengerema secondary school, close to the main road. This site is used for rice cultivation and is remote from gold processing sites.

Sampling

Sediment samples were collected upstream and downstream, close to gold ore processing areas for comparison purposes. In few cases, for comparison purposes soil samples were taken from adjacent areas that were presumed to have low influence from mining activities. Surface sediment was collected using a plastic scoop. An auger was used in locations where a subsurface soil sample was required. Sediment and soil samples were kept frozen (- 20°C) in clean wide mouth glass bottles until analysis.

Mature rice and sugarcane samples were collected from wetlands that are close to mining areas or adjacent to rivers that drain gold ore processing sites. Rice samples were kept in plastic bags. Sugarcanes were immediately squeezed to extract the juice that was kept frozen in high-density polyethylene bottles until analysis within two weeks.

Analysis of sediment and soil

Moisture and organic matter content in sediment samples were determined by oven drying to constant weight at 105°C followed by combustion in a muffle furnace at 550°C. Sediment and soil samples for metal analysis were freeze-dried and homogenized using agate mortar and pestle. Approximately 5g of soil or sediment sample was weighed out accurately, 7g Boric acid was added to the sample and scanned by Sequential X-Ray Fluorescence (XRF) Spectrometer Siemens SRS 3000 for analysis of total Hg and As. Atomic Absorption Spectrophotometer (AAS) model SpectrA A55 was used in the flame mode, for analysis of Cd, Pb, Zn and Cu. Certified Reference Materials PACS-2 (marine sediment) and BCR-143R (sewage sludge amended soil) were used for quality assurance and quality control purposes.

Analysis of rice and sugarcane

Rice grains were dried to constant weight in the laboratory at room temperature. Husks were removed from dried rice grains that were ground using agate mortar and pestle. Rice samples were digested using sulphuric acid, nitric acid and perchloric acid. Total Hg and As were analysed by XRF and Cd, Pb, Zn and Cu by AAS. Certified Reference Material, BCR-060 (Aquatic plant, *Lagarosiphon major*) was used for quality control and quality assurance purposes. Sugarcane juice was analysed for total Hg using flameless AAS equipped with a hydride generator.

Student t test (Zar, 1999) was invoked to decipher differences in concentrations of heavy metals in targeted sediment, rice and sugarcane samples and the respective reference samples.

RESULTS AND DISCUSSION

Heavy metals in river sediment

Sampling locations downstream of gold processing sites in Geita, Mugumu and Tarime Districts had slightly higher levels of mercury compared with reference samples that were assumed to represent background levels. The differences were statistically significant ($P < 0.05$) for all sites with the exception of Ring'wani, where the downstream sediment had low Hg content (<0.01 μg/g) and at Nyigoti, where the reference soil sample had higher Hg content than downstream sediment (Tables 1 and 2). Generally, river sediment samples that were collected downstream of gold processing sites in Tarime and Mugumu Districts had elevated concentration of mercury (Table 1). The high level of Hg suggests that artisanal miners in Tarime and Mugumu Districts process the gold ores in or very close to the rivers. At Kagota in Tarime, an artisanal gold processing area, Hg was fourfold higher in sediment compared to the adjacent soil samples. At Tigiti, Hg was elevated in downstream sediment (36 times higher) relative to adjacent soil samples, suggesting input from gold ore washing. Noteworthy, the concentrations of Hg in reference soil samples from Kagota and Tigiti were also high, indicating that these soils are also contaminated by gold processing activities. At Mugusu, one of the active small-scale gold processing areas in Geita District, mercury was 100 times higher in downstream sediment samples. At Samina, also an active gold processing site, Hg content was higher in downstream relative to upstream sediments (Table 1). All sediment samples were collected less than 1 km upstream and downstream of gold processing sites.

Other heavy metals (As, Cd, Pb, Zn and Cu) were also significantly higher ($P < 0.05$) in downstream sediment samples compared with reference sediment and soil samples as shown in Table 2. For instance at Kagota, Cd was twofold higher, Pb, Zn and Cu were about three times higher and As was more than fivefold higher. At Mugusu, As and Pb were significantly higher (Table 2) in river sediment downstream of the washing area compared with upstream sediment, As was 75 times higher and Pb was six-fold higher. The concentrations of Cd, Zn and Cu in downstream sediment samples were not significantly different ($P > 0.05$) from upstream samples. At Samina, Cd, Zn and Cu had significantly higher concentrations in downstream relative to upstream sediments ($P < 0.05$). These observations suggest that in addition to Hg, other metals are also mobilized by gold ore processing activities.

These results show that generally small-scale gold mining activities in Lake Victoria basin contaminate watercourses with mercury. Similar observations have been made by Lindberg et al., 1987, Lacerda et al., 1989 and Lindqvist at al, 1991, Other heavy metals are also released and are mobilized during gold processing. For instance, at Kagota As, Pb, Zn and Cu concentrations are also mobilized suggesting that gold ores at Kagota are probably associated with minerals such as arsenopyrite, galena, sphalerite and chalcopyrite (Kahatano and Mnali, 1997). At Samina, gold ore is also associated with other heavy metals (e.g. Cd, Pb, Zn and Cu). At Mugusu, Au is associated with As and Pb and at Nyakagwe gold exists mainly with Cu. Previous reports, however, have concluded that the mobilized heavy metals are not transported far from the source (DHV Consultants, 1998; van Straaten, 2000a; 2000b). In fact, a high proportion of metals are retained by "natural means" before reaching Lake Victoria (Machiwa, in press). Lateritic, clayey and organic matter rich soils in the LV basin possibly adsorb most of the metals on the way towards the Lake. It has also been reported that a large proportion of suspended particulate matter that is generated in some locations in the lake basin settles down in watercourses, therefore is not discharged into Lake Victoria (Yanda *et al.* 2001).

Heavy metals in rice and sugarcane

The concentration of some metals in rice from some wetlands in Lake Victoria basin is given in Table 3. The concentration of Hg in sugarcane was below detection limit (0.01 μg/l) in any of the analysed samples suggesting low uptake of Hg by the sugarcanes. However, the speciation of Hg in the soils to determine its availability to plants was not ascertained.

Mercury was highest (378.5±15.1 μg/kg, dry weight) in rice samples from Lwamgasa and lowest (47.9±2.9 μg/kg) in samples of Saragurwa, located in Mugusu River catchment about 10 km from Mgusu mining village. Rice samples that were collected in Sengerema for reference purposes (an area with no mining activities), had low Hg content (103.5±6.2 μg/kg) compared to samples collected in wetland that are within 0.5 km from gold ore washing areas, such as Lwamgasa, Nyangalamila and Nyarugusu (Table 3). It is not certain why Hg level in Sengerema rice was higher than that of Saragurwa. Rice samples from Nungwe flood plains had relatively high Hg content (167.7±25.2 μg/kg), the area is located downstream of Samina and other small-scale gold processing sites in Geita. This reflects the extent of lateral mobilization of Hg probably by surface runoff or atmospheric transport from adjacent mining areas. Appropriate measures should be taken to reduce input of Hg to wetlands used for agriculture and grazing (St Louis, 1994; DHV Consultants 1997; JPHA 2001). The concentrations of other metals (Cd, Zn and Cu) were also significantly different ($P < 0.05$) between Sengerema rice samples and that of the other sampling sites (Table 4). Apart from mobilization by gold ore processing activities, also it is possible that soils in Geita naturally have higher concentrations of metals than soils of Sengerema. Metal concentration in Sengerema soils was not determined. Arsenic was not detected (< 0.01 μg/kg) in any of the rice samples. Lead was also not detected (< 0.01 μg/kg) in all rice samples except those of Sengerema wetland (150±12 μg/kg) located close (< 0.5 km) to the main road. This probably indicates Pb contamination of rice grown at roadsides. Apart from Pb, all of the analysed metals had lowest concentrations in Sengerema rice samples.

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