

ASSESSMENT OF HEAVY METAL POLLUTION IN THE LUPA GOLD FIELD, SW TANZANIA

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ABSTRACT

The concentrations of As, Cd, Cr, Cu, Hg and Pb were determined in water, stream sediments, soil, and mine tailings from Lupa Gold Field (LGF), SW Tanzania, in order to assess their pollution levels. As, Cd and Cr were determined by automated Graphite Furnace Absorption Spectrophotometry. Cu and Pb were analysed by Air-Acetylene Flame, while Hg was analysed by Cold Vapour Atomic Absorption Spectrophotometry. The mean concentrations obtained were: As: 0.44 ppb (water), 1.2 ppm (sediments), 0.44 ppm (soil) and 5.2 ppm (tailings); Cd: 0.03 ppb (water), 0.03 ppm (sediments), 0.03 ppm (soil) and 0.50 ppm (tailings); Cr: 1.4 ppb (water), 70 ppm (stream sediments), 250 ppm (soil) and 270 ppm (tailings); Cu: 30 ppb (water), 68 ppm (sediments), 66 ppm (soil) and 455 ppm (tailings); Hg: 0.25 ppb (water), 1.1 ppm (sediments), 0.10 ppm (soil) and 8.70 ppm (tailings) and Pb: 0.50 ppb (water), 85 ppm (sediments), 22 ppm (soil) and 275 ppm (tailings). Leaching of As-based mineral flotation reagents as well as the decomposition of accessory As minerals such as arsenopyrite (FeAsS), enargite (Cu_3AsS_4) and tennantite ($\text{Cu}_{12}\text{As}_4\text{S}_{13}$) most likely contributed to some high As concentrations in the mine tailings. The low Cd content in all samples reflects the low content of sphalerite (in which Cd replaces Zn) typical of the LGF ores. Chromium was low in water, most likely because of its low mobility; it was high in soils and tailings derived from mafic-ultramafic rocks. High Cu levels in tailings came from dissolution of chalcopyrite and bornite. Neutral to alkaline pH conditions (6.5-8.5) of water was most likely responsible for its low Cu levels. Amalgamation of Au concentrate likely introduced Hg into the environment. Dissolution of galena and anglesite was likely the source of Pb into the soils, sediments and tailings. The range of concentrations of the six heavy metals recorded in the Lupa gold field is of great concern to the human health.

INTRODUCTION

The Lupa Gold Field (LGF) is the second largest gold producing area in Tanzania after the Lake Victoria Gold fields (Fig. 1). It occupies a total area of about 3,000 km². It has produced more than 30 tonnes of gold and 8 tonnes of silver since its discovery in 1922. These precious metals have been produced from artisanal, small- and large-scale surface and underground workings of the gold-quartz reefs that were emplaced in the shear zones that crosscut the gneisses, metamafic rocks and granitoids of the Palaeoproterozoic Ubendian Belt (Fig. 2). Gold and silver were also won from working of alluvial, eluvial and deluvial placer deposits. The ore minerals in the gold-quartz veins comprise principally sulphides (pyrite, chalcopyrite, galena, and traces of sphalerite, molybdenite, pyrrhotite and pentlandite). Other ore minerals include tellurides (altaite, hessite, calaverite, petzite, montanite and melonite), magnetite, tetrahedrite-tennantite, arsenopyrite, electrum and native gold (Mnali 1999).

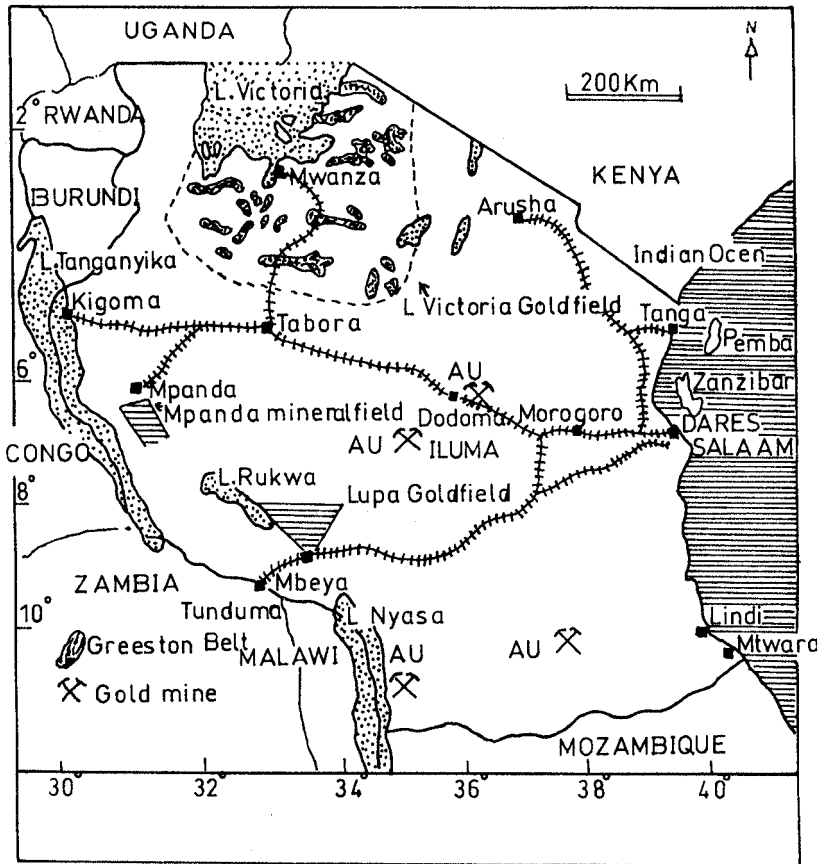


Fig. 1: Map of Tanzania showing major gold producing areas

The concentrations of As, Cd, Cr, Cu, Hg and Pb were determined in water (45 samples), stream sediments (50 samples), soil (40 samples) and mine tailings (35 samples) from the LGF. These elements were of interest because Cu, Pb, and As are found in gold-quartz veins in the study area. Therefore their dissolution could lead to significant anomalies in soils, stream sediments, tailings and water within the Lupa gold field. Cr could originate from weathering of mafic-ultramafic rocks (amphibolites, gabbro and pyroxenites) that constitute the wall rocks for gold-quartz veins. Cd is commonly associated with sphalerite (ZnS) in which it replaces Zn. The sphalerite occurs in trace amounts in several mines in the study area. Small-scale and artisanal miners use Hg for the recovery of gold from ore concentrate. The Hg could therefore enter the environment during amalgamation process and firing of Au-Hg amalgam in order to expel Hg.

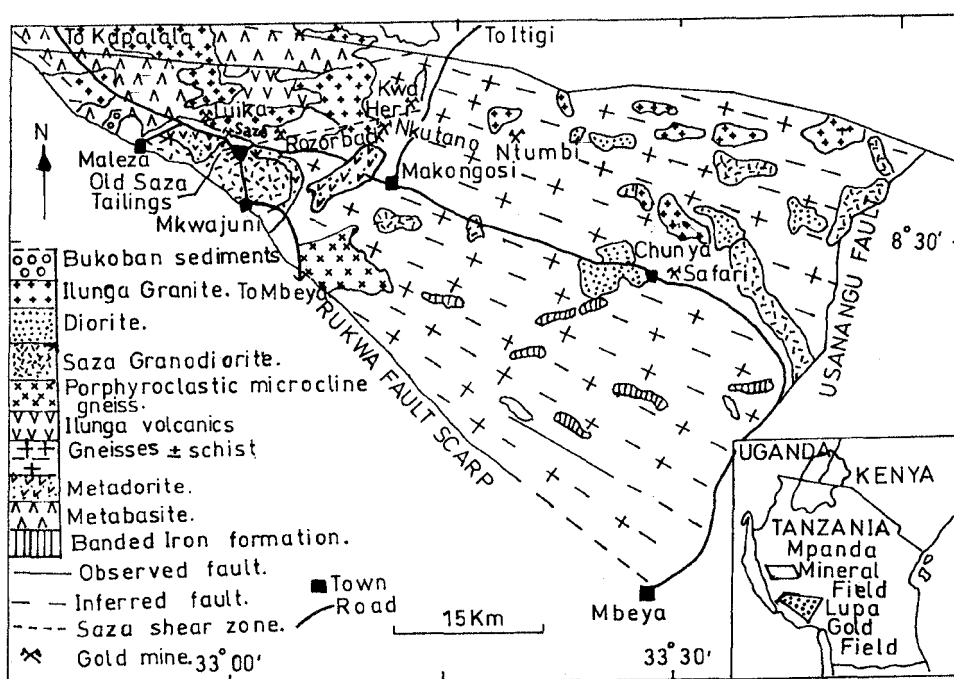


Fig. 2: Geological Map of Lupa gold field, Tanzania, showing gold mines

Health hazards caused by heavy metal pollution have been discussed by Aswathanarayana (1995), Kauranne and Silanpää (1992), Nakamura *et al.* (1988), Anon. (1993), Berkman and Ryall (1982), and Hopps *et al.* (1974). Arsenic compounds are toxic and possibly carcinogenic, but the element may also be a nutrient (Kauranne & Silanpää 1992). Health effects caused by arsenic may include peripheral neuropathy, tubular dysfunction, cirrhosis, anaemia, ulcers, emphysema and fibrosis, skin and lung cancer and chromosomal aberrations (Aswathanarayana 1995). Cadmium is harmful to

animals because it becomes incorporated in certain low molecular weight proteins of the blood plasma. Cadmium intake might cause tubular, glomerular damage, proteinuria, slight anaemia, emphysema, osteomalacia, cardiovascular diseases, cancer of the prostate gland and lung and chromosomal aberrations. Excessive intake of cadmium has been associated with *itai-itai* disease in Japan (Kolyjonen 1992), and degeneration of kidney and bones (Aswathanarayana 1995). Chromium is an essential trace nutrient that takes part in the metabolism of glucose. It is poisonous when in hexavalent (Cr^{6+}) state. It induces skin sensitisation (Berkman & Ryall 1982). Impaired glucose tolerance in some human beings can be caused by Cr^{3+} . Copper is an essential micronutrient for all organisms but toxic when in excess. It is responsible for fungal and bacterial resistance in plants. However it may cause staining of laundry and sanitary ware if its concentration in water is above 2 mg/l (Anon. 1993).

This paper evaluates heavy metal concentrations in various secondary dispersion media (in order to determine pollution levels) resulting from eight decades of uncontrolled gold mining in the LGF.

METHODS

Soil, stream sediment, water samples and mine tailings were collected during the fieldwork in April 1996. Soil samples were collected from gold mining and amalgamation sites and areas away from mining and processing sites in order to get background concentrations of heavy metals. Stream sediments were collected from streams with flowing water upstream and downstream of gold washing areas, and from small dry streams and tributaries that provided samples for the determination of background concentrations of the heavy metals. Mine tailings were taken from old tailing mounds at Saza, Kwa Heri, and Ntumbi mines; and from current small-scale mines including Safari, Razorback, Nkutano and other artisanal workings within the LGF. Water samples were taken from rivers and streams upstream and downstream of gold washing and amalgamation sites.

Soil, stream sediment and tailing samples were dried and sieved through a clean 250- μm -mesh size. Two hundred to three hundred milligrams of the resultant fine-fraction were leached with 3 ml of concentrated HNO_3 under pressure and temperature of 160°C for four hours in a special bomb (Uhrberg 1982), before the solution was made up to 10 ml on cooling. As, Cd and Cr were analysed using automated Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS). Cu and Pb were analysed by direct aspiration into an Air-Acetylene Flame (FAAS) using titrisol standards. Analytical precision was determined by carrying out duplicate analysis after every 10 samples. Reagent blanks and standard samples were included in each analytical batch to check the analytical error. Hg was analysed by Cold

Vapour Atomic Absorption Spectrophotometry (CVAAS) after aspiration with 2% SnCl₂ using the method of standard addition.

The water samples were filtered through 0.45 µm membrane filter immediately after collection. The filtered water was divided into two aliquots each containing 100 ml. The first aliquot was poured into an acid-washed plastic bottle and 1 ml of super-pure concentrated nitric acid was added. The bottle was then tightly stoppered and labelled. This sample was used for the analysis of As, Cd, Cr, Cu and Pb. The second aliquot of the sample was poured into the acid-washed clear plastic bottle and 1 ml of concentrated nitric acid and 1 ml of 5% potassium dichromate solution were added for preservation purposes (Hamlin 1989). The sample bottle was also stoppered and labelled and used for the analysis of total mercury. The water samples were aspirated directly from the sample bottles and analysed for the heavy metals following the methods described above.

RESULTS

Very few soil samples contain high concentrations of the heavy metals than the permissible WHO (1993) levels (Table 1). Some stream sediments and mine tailings contained high concentrations of heavy metals above WHO (1993) permissible levels. Water samples contained very low concentrations of the heavy metals.

Table 1. Concentration range (1), arithmetic mean (2), and standard deviation (3) of heavy metals in the various sampling media from the Lupa gold field, Tanzania. The WHO (1993) permissible levels are given as (4)

SAMPLE TYPE	As	Cd	Cr	Cu	Pb	Hg
Soil (ppm) N = 40	1) 0.38-0.70	0.01-0.10	70-900	15-200	10-80	0.05-0.11
	2) 0.44	0.03	250	66	22	0.10
	3) 0.5	0.02	180	60	16	0.02
	4) 20	3	100	100	50	2
Stream sediments (ppm) N = 50	1) 0.40-2.40	0.01-1.0	10-160	15-600	10-590	0.01-10
	2) 1.2	0.03	70	68	85	1.10
	3) 0.8	0.02	35	120	200	2.5
	4) No data	No data	No data	No data	No data	No data
Mine tailings (ppm) N = 35	1) 1-70	0.03-1.40	15-660	10-1500	10-570	0.3-31
	2) 5.2	0.26	270	455	275	8.7
	3) 6.5	0.5	246	600	235	13
	4) 20	No data	No data	No data	No data	No data
Water (ppb) N = 45	1) 0.03-2.1	0.01-0.12	0.14-3.40	10-60	0.3-1.2	0.12-0.60
	2) 0.44	0.03	1.4	30	0.5	0.25
	3) 0.45	0.30	1.6	33	0.3	0.11
	4) 10	3	30	50	10	1

N = Number of samples analysed

DISCUSSION

The high concentrations of arsenic (As) were encountered only in the mine tailing samples from Ntumbi (70 ppm As *versus* WHO (1993) permissible level of 20 ppm As), Saza (47 ppm As) and Luika (36 ppm As). The high content of As in the mine tailings might have originated from the decomposition of accessory As-bearing minerals such as arsenopyrite (FeAsS), enargite (Cu₃AsS₄) and tennantite (Cu₁₂As₄S₁₃) that are found in trace amounts in the gold ores. Some As could have been introduced through As-based mineral flotation reagents during concentration of sulphide-hosted gold ore. The low content of As in water and stream sediments was due to the low mobility of the element in natural water systems since the element is readily scavenged by iron oxides after being released from the host ore minerals during weathering processes. Besides mining activities other anthropogenic sources of As might include alloys, storage batteries, agricultural herbicides and wood preservatives.

The concentration of cadmium in all sampled media was very low, reflecting the low content of sphalerite (in which Cd replaces Zn) in the gold ores. This implies that derivation of Cd from other sources including electroplating, anticorrosive coating, PVC stabilizers, Ni-Cd batteries and alloys in the LGF was minimal.

The concentration of chromium in some soils, stream sediments and mine tailings was higher possibly owing to the Cr released from weathering of mafic-ultramafic wall-rocks (gabbro, basalts and pyroxenites) that host gold-quartz veins in the LGF. In weathering regimes, Cr follows Fe and Al and is enriched in residual sediments like laterites and clays. Anthropogenic sources of Cr such as decomposition of alloys, refractories, paints and textile dyes, could be responsible for the observed high Cr concentrations in some media.

Few stream sediments and mine tailing samples have high concentrations of copper (up to 600 ppm and 1500 ppm, respectively) that appear to have been derived from the breakdown of chalcopyrite and bornite found in the gold-quartz veins. It is important to note that chalcopyrite was the second most abundant ore mineral in the gold-quartz veins in the LGF after pyrite. The low content of Cu in waters (mean = 30 ppb Cu *versus* WHO (1993) permissible level of 50 ppb Cu) can be explained by the low mobility of the element in near neutral to alkaline pH conditions (6.5-8.5) prevailing in the waters of the LGF. In weathering conditions, Cu is highly mobile at pH below 5.5 but has low mobility at neutral or alkaline conditions (Reedman 1979).

The high concentration of total mercury in the stream sediments and mine tailings was mostly caused by anthropogenic Hg introduced to the environment by artisanal and small-scale miners during amalgamation and firing of Au-Hg amalgam. Mercury is extensively used during gold extraction in the LGF. On average one gram of gold would require 2-3 grams of

mercury during amalgamation. After amalgamation, mercury is evaporated to the atmosphere during amalgam burning to recover gold. Mercury spillage into the stream water is common during amalgamation. Water contains low concentrations of Hg owing the low Hg solubility and high density that makes it sink into the stream sediments.

Mine tailings and few stream sediments contained high concentrations of Pb. The Pb was probably derived from weathering of accessory galena, which was third most abundant ore mineral in the gold bearing quartz-veins in the LGF. Pb could also have arisen from leaching of anglesite and cerussite. Other anthropogenic sources of Pb such as weathering of battery scraps, lead pipes, lead pigments and dispersion from gasoline emissions as well as applications of phosphate and sulphate fertilizers probably contributed to the observed high Pb concentrations in some soil samples (up to 80 ppm *versus* WHO (1993) permissible level of 20 ppm Pb), stream sediments (up to 590 ppm Pb) and tailings (up to 570 ppm Pb).

Mercury occurs in the ecosystem in different compound forms that have different solubility and different degrees of toxicity to organisms. Methylmercury (CH_3Hg^+), which can form in aquatic environments, is an extremely toxic compound (Nakamura *et al.* 1988, Meili 1991). Health effects related to the intake of methylmercury include brain damage, abnormal movement and reflexes, tubular nephrosis, stomatites, bronchial effects, spontaneous abortion and deformed brain and body. It has been related to *minamata* disease in Japan. Lead has no known biological role and is toxic, teratogenic and carcinogenic. In biological processes it has a detrimental effect through replacing calcium and iron in organisms (Koljonen 1992). Intake of Pb in human beings causes anaemia, neurological dysfunction, renal impairment and irreversible brain damage especially in foetuses, infants and children.

CONCLUSION

The levels of heavy metal concentrations in soils, stream sediments and mine tailings obtained during this study are of interest with respect to the health of people living in the LGF and the surrounding areas. Further studies that involve sampling and analysis of biological samples such as human hair and urine, fish, meat, vegetation and fruits for the determination of speciation of Hg, As, and Pb will be required to determine possible health risks and their bio-availability through the food chain.

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