MERCURY AND MINING IN AFRICA WITH SPECIAL REFERENCE TO TANZANIA

J.R. IKINGURA, M.K.D. MUTAKYAHWA AND J.M.J. KAHATANO
University of Dar es Salaam, Department of Geology
P.O. Box 35052, Dar es Salaam, Tanzania.

Abstract. A study of gold (Au) mining areas in Tanzania is being undertaken to assess environmental impacts arising from the use of mercury (Hg) in gold extraction. Initial results already indicated the presence of elevated Hg concentrations in environmental samples from the mining areas. The mean Hg concentration in river sediments is 4.19 μg/l, soils within gold mining and processing centres exhibit high Hg content (mean 3.39 μg/g) that decreases rapidly to background regional values within a distance of a few kilometres. A review of published Hg data for sediments, fish and aquatic plants from African inland and coastal waters revealed, with a few exceptions, low Hg concentrations close to natural background levels.

1. Introduction

For several decades gold has been an important export commodity, providing foreign currency for a number of African countries. In the period 1976-1985, African countries produced more than 200 million troy ounces of gold (see Table I). The Republic of South Africa alone accounted for 96% of the gold production. Zimbabwe ranked second to South Africa in gold production followed by Ghana, Zaire, Zambia and Ethiopia. Gold production in other African countries was less than a few hundreds of kilogrammes. Although statistics for total gold production in African countries over the last 10 years (i.e. 1985-1994) are not available, it is expected that the ranking of various African countries in terms of gold production in that period will not differ substantially from that shown in Table I.

TABLE I
Gold production in Africa for the period 1976-1985*

1. South Africa	220,081,000 Troy Oz.
2. Zimbabwe	4,145,000
3. Ghana	3,664,000
4. Zaire	856,512
5. Zambia	103,409
6. Ethiopia	101,078
7. Mali	79,447
8. Liberia	62,255
9. Gabon	39,923
10. Congo	35,549
11. Central Africa Republic	11,292
12. Rwanda	7,878
13. Tanzania	6,990
14. Sudan	4,200
15. Burundi	4,005
16. Cameroon	2,108
17. Kenya	1,965
18. Madagascar	1,190

*Reported gold production for the period 1981/1985 (Source: Minerals, Year Books 1980 and 1985, Vol. III, US Bureau of Mines, Department of the Interior).

Water, Air and Soil Pollution **97**: 223-232, 1997.
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Gold mining in Africa varies from large and medium-scale mining to low-technology small-scale mining such as labour-intensive peasantry or artisanal mining. Large-to medium-scale gold mining is conducted by well-established and licensed private companies or state-owned mining corporations. Mining operations of such companies are guided and controlled by mining policies and laws of individual countries. In this case the mining is regulated and obliged to implement environmental protection and restoration measures. More efficient gold extraction methods involving one or a combination of (i) gravity separation (ii) amalgamation (iii) floatation and (iv) leaching followed by adsorption or precipitation of the dissolved gold are employed in medium and large-scale gold mining. The extraction is supposed to be followed by treatment and safe disposal of solid waste and slurry from processing plants according to acceptable environmental protection standards or guidelines.

Small-scale gold mining including artisanal mining is commonly conducted by self-employed individuals, peasant families, small groups of workers and small companies. Many African countries lack clear policies for small-scale mining, despite the fact that this type of mining provides means of subsistence to a larger number of people than the formal large and medium-scale mining. As a result, with a few exceptions, small-scale gold mining in many African countries is haphazard, unregulated, and environmentally unsound. Gold recovery methods employed in most artisanal workings involve either gravity separation or gravity separation followed by Hg amalgamation depending on the type of ore being processed. Gold recovery by Hg amalgamation is preferred by artisanal miners because it is simple, does not require sophisticated tools, and can be used to recover gold from small volumes of ore. Because of the unregulated nature of the artisanal gold mining and poor handling of Hg by the miners a considerable amount of Hg is released to the environment during gold extraction. In this paper gold mining and use of Hg in gold extraction in Tanzania is discussed and published Hg data from other African countries are reviewed.

2. Gold mining in Tanzania.

Gold mining in Tanzania has a history of over 100 years. Available records on gold mining date as far back as 1884 during Germany colonial rule. Over 100,000 kg of gold have been produced officially in Tanzania since 1935. Whereas most of the gold produced in the country during colonial administration (Pre-1961) and shortly after 1961 came from a few medium-size mechanized mines, post-independence gold production has resulted from small-scale workings and artisanal mining. The bulk of gold production in Tanzania has come mainly from three principal goldfields namely the Lake Victoria Goldfield in northern Tanzania, the Mpanda mineral field and the Lupa goldfield in western and southwestern Tanzania. The Lake Victoria goldfield (Fig. 1) contributed about 75% of the gold production while the Lupa and Mpanda goldfields together contributed about 25%

Bad weather conditions coupled with poor crop yields and low crop prices in recent years have forced many people in rural areas to engage in gold mining as an

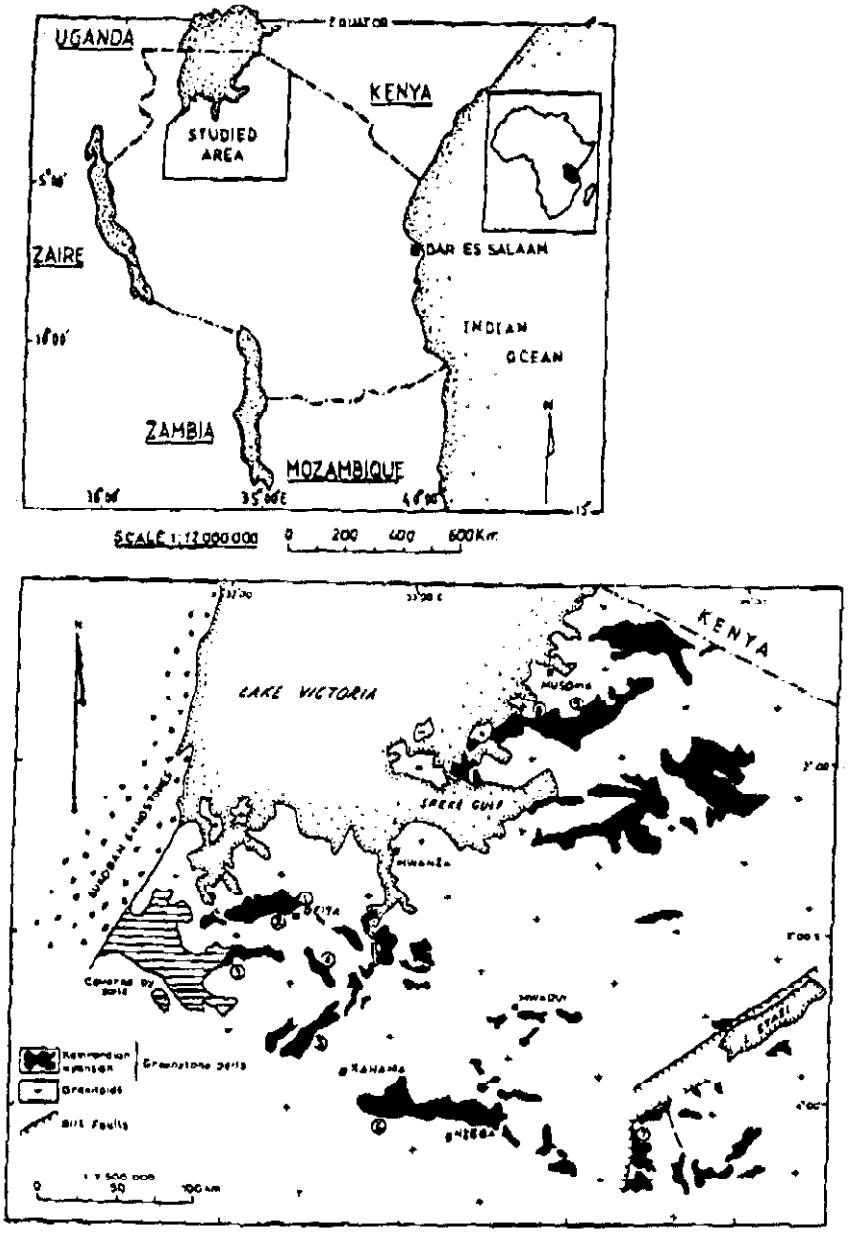


Figure 1. Geological sketch map of the Lake Victoria Goldfields showing the major gold occurences (modified after Van Straaten, 1982)

alternative means for subsistence. It is estimated that between 150,000 and 200,000 people are currently engaged in artisanal gold mining activities in different parts of the country. Artisanal gold mining is at present the only source of Tanzania's gold production estimated to be about 4 t annually.

2.1. ARTISANAL GOLD MINING AND PROCESSING

Artisanal gold mining and processing in Tanzania is generally labour intensive. The mining involves opening of pits and adits through gold-bearing rocks using simple tools such as picks, chisels, and hammers, hoes and shovels. Dynamite is used rarely to break hard rocks and facilitate the mining. Wood is used to support pit walls. Deep pits can extend down to a depth of 70 m.

Beyond this depth the miners encounter air ventilation problems and are forced to abandon the pits. Occasionally air compressors are used to facilitate ventilation and allow mining at deeper depth. Hoisting of mine waste and gold ore from pits is done by using a simple wooden pulley system

Gold ore processing involves crushing and grinding of the ore in locally fabricated ball mills or in wooden mortars using old motor vehicle axle as pestles. This is followed by gravity separation involving simple panning or washing or powdered ore on inclined sluice boxes to produce a gold rich concentrate. Gold is recovered from the concentrate by adding mercury to produce a gold-mercury amalgam. Amalgamation is done at processing sites along river banks or in residential compounds. The gold is finally recovered from the amalgam by wrapping the amalgam in aluminium foil or aluminium coated cigarette paper and firing in open air. Firing of the amalgam is conducted at the gold ore processing sites, in residential compounds and inside the houses.

Recovery Hg and gold from the amalgams using retorts is practised only by a few organized workers. Further treatment and purification of the gold is done in the national commercial bank branches before the bank buys the gold from the miners.

2.2. INTRODUCTION OF MERCURY INTO THE ENVIRONMENT.

Mercury is released to the environment by artisanal miners during amalgamation process and during firing of amalgams. Washing of gold ore and amalgamation with mercury are done along river banks or near domestic water wells and ponds. This causes direct contamination of water sources by Hg spilled from gold pans during mixing of the ore concentrate with Hg. Mercury which remains in the tailings at the processing sites is also eventually leached and dispersed into the environment. Firing of amalgams in open air causes Hg to evaporate directly into the air. These processes by which Hg is released to the environment by gold mining activities are not unique to Tanzania but common elsewhere in Africa and other parts of the world were Hg is used in gold extraction without proper handling measures. This has been documented for example in Garimpeiro gold mining in Brazil (Lacerda

and Salomons 1991, Malm et al., 1990) and in small-scale mining in Venezuela (Shrestha et al., 1989).

2.3. ENVIRONMENTAL STUDY OF THE MINING AREAS.

A study of gold mining areas in Tanzania is being conducted in order to assess the environmental impacts arising from gold mining activities and use of Hg in gold extraction . The initial phase of the study has concentrated on gold mining areas within the Lake Victoria goldfields (Fig.1). The first task has been to determine the concentration of heavy metals including mercury in water, soil, river sediments and mine tailings, and to compare the concentrations with various environmental standards and published data from other parts of the worlds. In addition, the extent of mercury dispersion from gold mining centres was evaluated as part of the study.

3. Sampling and analytical methods.

Samples of water, soil, river sediments and mine tailings were collected from both active and abandoned gold mining areas for geochemical study. Water samples were collected from rivers, streams and domestic water ponds. The samples were filtered through a 0.45 μm membrane and preserved in 100 ml clear plastic bottles. They were conserved by a addition of 1 ml super pure nitric acid (HNO_3) and 0.5 ml 5% potassium dichromate ($K_2Cr_2O_7$) solution per sample. A distilled-de-ionized water blank was similarly preserved and conserved in the field for every ten samples collected. The upper surface of the soils was collected for analysis. River sediments and mine tailings were collected using a plastic mug. These samples were preserved in thick polyethylene bags and allowed to dry at room temperature before sieving. <200 μ m fraction of the sieved samples was used for heavy metal analysis. Heavy metals were extracted from soil and sediment samples using a hot aqua regia leach. Metal contents in water sample and leach solutions were determined by a flame atomic absorption spectrometric (AAS) method using a Perkin Elmer model 2380 atomic absorption spectrophotometer. Mercury was analyzed by AAS using the cold vapor technique. Analyses were performed in the geochemical laboratory at the University of Dar es Salaam, Tanzania, and at McAua-Konsult heavy metal laboratory in Uppsala, Sweden. Result for Samples analyzed at both laboratories showed good agreement.

4. Results.

Results of Hg analysis in water, river sediments and mine tailings from gold mining areas in the Lake Victoria goldfield are summarized in Table II. Dissolved Hg concentration in water from rivers and domestic water ponds is in the range 0.01-6.78 μg/l. The average Hg concentration in 71 samples analyzed is 0.68 $\mu g/l^{-1}$. Although the average Hg concentration in the water is below WHO maximum permissible level of 1 $\mu g/l^{-1}$ in drinking water (WHO, 1971), there are several areas where Hg level already exceeds the permissible level. In fact 25% of the water samples analyzed had Hg concentration above the WHO permissible level. This suggests the presence

already of significant levels of Hg contamination in water sources in the gold mining areas in the Lake Victoria goldfields.

TABLE II

Summary of mercury concentration in water, sediments, soils and mine tailings in the Lake Victoria goldfields, Tanzania shown are- Number of observation (N) range of values, mean and standard deviation (std).

Water	(N 71)	Range Mean Std.	0.01-6.78 µg/l 0.68 0.99
Sediments	(N 40)	Range Mean Std.	0.02-136 µg/l 4.91 21.60
Soils	(N 15)	Range Mean Std.	0.05/28/17 µg/g 3.39 7.52
Tailings	(N 7)	Range Mean Std	0.28/31/15 µg/g 10.27 12.74

Mercury concentration in the river sediments is in the range 0.02-136 µg/g. The average Hg concentration in the sediments is 4.91 µg/g. Higher Hg concentrations occur in sample collected from gold ore processing site.

Soil samples collected within and around mining centres exhibited Hg concentrations elevated above the regional background concentration. The mean Hg concentration in the soil was 3.39 µg/g compared with the background concentration of 0.05-0.06 µg/g. Highest Hg concentrations were found in soils samples collected from places of Hg-gold amalgam firing. The Hg concentration in the soil decreased markedly to background levels within a distance of a few kilometres from the mining centres.

Analysis of gold ore tailings revealed Hg concentrations in the range 0.28-31.15 µg/g and an average concentration of 10.27 µg/g (Table II). The high Hg content in the tailings indicates that significant amount of Hg are left in the tailings during amalgamation. This Hg is likely to eventually be leached from the tailings by percolating water and cause contamination of soil and nearby water sources.

5. Mercury data from other African countries.

Published Hg data from gold mining areas in African countries are generally scarce. This is probably because not many conducted in Africa regarding the use of Hg in gold extraction and its environmental impact on various ecosystems. Most studies on the levels and distribution of heavy metals in Africa have concentrated on urban and industrialized areas (Biney et al., 1994). The most comprehensive review of heavy

metals including Hg in African aquatic environment has been recently published by Biney et al. (1994). Biney et al concluded that with the exception of a few areas the concentration of heavy metals in African aquatic systems were low and close to natural background levels. Heavy metal studies incorporating Hg which are cited by Biney et al. (1994) include the study of Hg in fish in Ghana by Ntow and Khwaja (1989) and the study of metals in fish and sediments from the River Wiwi in Kumasi by Biney and Beeko (1991). Biney and Beeko (op cit.) found a positive correlation between Hg concentration and fish body weight. Higher levels of Hg were also found in fish than in sediment. The study by Ntow and Khwaja (1989) revealed that total Hg concentrations in commercial fish from different coastal areas of Ghana were significantly below the 0.5 ug/g permissible level adopted in many countries in the world. Remarkably high Hg concentration in fish (1.0-2 ug/g) and in blood and hair in Seychelles inhabitants whose diet involves a lot of fish consumption have been found by Methews (1981).

Analyses of Hg in fish and fish-eating birds from Hartbeesport dam in South Africa by Greichus et al. (1977) indicated that Hg concentration in birds were 2- to 5-fold higher than in fish. The dam is essentially a reservoir of industrial and municipal waters from Johannesburg.

A review of levels of contamination in the marine environment of the west central African region including Cameroon, Ghana, Cote d'Ivoire and Senegal by Portman et al. (1989) indicated that there was little input of Hg and other metals into the coastal zone from the hinterland (Biney et al., 1994). Published Hg data from various African sub-regions are summarized in Table III, IV and V.

TABLE III

Mercury concentrations in sediments from various African sub-regions (μg/g dry weight)*

Sub-region	Hg
Inland water	
Western and Central Africa	0.21-0.33
Eastern Africa	<0.05
Southern Africa	0.02-0.28
Coastal Water	
Northern Africa	0.12
Western and Central Africa	0.10-0.35
Southern Africa	0.019

* (Source: Biney et. al. 1994)

TABLE IV

Mercury concentrations in fish from various African subregions (μg/g fresh weight)*

Subregion	Hg
Finfish	
Inland Waters	
Northern Africa	0.010
Western and Central Africa	0.034-0.053
Eastern Africa	0.044
Coastal Waters	
Northern Africa	0.077
Western and Central Africa	0.06-17
Shellfish	
Western and Central Africa	
Penaeus sp.	0.033-017
Crassostrea gasar	0.072-013

(Source: Biney et al., 1994)*

TABLE V

Mercury concentration in aquatic plants from various African subregions (μg/g dry weight)*

Subregion	Hg
Inland Waters	
Western and Central Africa	0.13-0.37
Southern Africa	0.26-1.60
Coastal Waters	
Western and Central Africa	<0.10

(Source: Biney et al., 1994)*

6. Discussion

Most of the published studies concerning Hg contamination arising from gold mining activities have focused on Latin America, particularly Garimpo mining in the Brazilian Amazon. As a result there is already a good data base in the literature on Hg concentrations in various environmental media in contaminated and uncontaminated areas of the Amazon. It is therefore essential to make reference to the existing data from Latin America in discussing or evaluating Hg data obtained from a few studies done in gold mining areas in other parts of the world. A comprehensive study of Hg distribution in the Amazon ecosystems was conducted by Larceda and Salomons (1991). They indicate the Hg concentration in water in contaminated Amazon rivers to be in the range <0.04-8.60 $\mu g/l^{-1}$ whereas in the bottom sediments concentrations are in the range 0.04-19.8 $\mu g/g^{-1}$. Mercury concentrations in fish muscle tissue for fish

from the Amazon were found to be in the order of 0.01 to 2.7 $\mu g/g^{-1}$ (wet weight). The survey of Amazon aquatic plants from the Madeira river in areas affected by gold mining activities indicated Hg concentrations of up to 1.04 $\mu g/g^{-1}$ in the floating microphyte species and up to 0.08 $\mu g/g^{-1}$ in rooted species.

The concentrations of Hg in sediment (0.02-0.33 ug/g, dry weight) and finfish (0.010-0.053 µg/g, wet weight) from African inland waters (Tables III and IV) are much lower than those reported from the Amazon region. The Hg concentrations in the sediments are generally low and close to natural background levels found in non-contaminated world rivers (<0.3 $\mu g/g^{-1}$, Biney et al., 1994). Mercury levels in aquatic plants (0.13-1.60 $\mu g/g^{-1}$) from African inland waters (Table V) are however significantly higher than those from the Amazon Madeira river. These hg data comparisons are however difficult to interpret because the Amazon data are derived mainly from areas affected by gold mining activities whereas the African data presented in Table III to V are derived mostly from urban and industrialized areas not affected by mining. A more appropriate comparison with the Amazon data can however be made using Hg data from the study of gold mining areas in Tanzania.

Mercury concentrations found in water, sediments and soils in the studied gold mining areas in Tanzania already indicate the presence of significant Hg contamination in those areas. For example, mercury concentration in the range 0.01-6.78 $\mu g/l^{-1}$ in water from the mining areas is very high in comparison with the value of <0.01 $\mu g/l^{-1}$ for non-contaminated world rivers but is within the range of concentrations found in contaminated Amazon rivers. The Hg concentration of up to 136 $\mu g/g^{-1}$ (mean 4.91 $\mu g/g^{-1}$) in the sediments from Tanzania rivers affected by gold mining activities is remarkably high in comparison with published data from contaminated rivers in the Amazon region. This may be attributed to the small size of the Tanzanian rivers and low water flow and discharge rates that allow Hg to accumulate in the sediments instead of being rapidly flushed out. Even in the Amazon, high Hg concentrations in sediments have been found in the tributaries instead of the main rivers that are characterized by high water flow and suspended load, which may give rise to a high dilution rate and hence decrease in both dissolved and particulate-bound Hg in the main river (Malm et al., 1990). Now that high concentrations of Hg have been confirmed in water and sediments in rivers affected by gold mining activities in Tanzania, there is a necessity to investigate the distribution of the Hg in the biota and gold miners in the affected areas.

In summary there is still a scarcity of research information regarding mercury distribution in African inland and aquatic environments. Concerted research efforts are needed in order to understand the behaviour of the Hg in African tropical ecosystems. African researchers along can not be left to address the problem of increased Hg input in the environment in view of the limited financial resources and limited research facilities in African countries. Collaborative research between African researcher and scientists from developed countries appears to be the most viable alternative towards understanding the magnitude of Hg problems in Africa and the behaviour of Hg in African ecosystems. The research data presented here from Tanzania already indicate

that there is remarkable Hg contamination in the gold mining areas investigated. To what extent Tanzania's experience of elevated Hg concentrations in the gold mining areas is replicated in other African countries where Hg is used in small-scale gold mining activities is not known. The answer can only be obtained through interactive research among African researchers and other scientists.

Acknowledgments

This study forms a part of the research project on the environmental aspects of mining and industrialization in Tanzania supported by the Swedish Agency for Research Cooperation with Developing Countries (SAREC). We are thankful to Dr. Lars Landner of MFG Environmental Research Group, Sweden, for technical assistance in the execution of the project.

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