Human exposure to mercury due to small scale gold mining in northern Tanzania

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Received 27 September 1999; accepted 4 March 2000

Abstract

In northern Tanzania large numbers of small scale miners use mercury in the gold extraction process causing contamination of the environment and risks to human health. Human exposure to Hg was assessed in populations in and around small scale gold mining camps by means of human hair and urine surveys. We also determined Hg concentration in fish in aquatic bodies close to these camps. Urinary Hg testing in three communities showed that 36% of the gold miners working with amalgam exceeded the WHO guideline concentration of 50 μg Hg/g creatinine. Data from a hair survey of fishermen and farmers confirm that at present, the fish-eating population close to the southern tip of Lake Victoria is at low risk with regard to Hg exposure. Concentrations in fish were low and >90% of the hair samples from the fish-eating population were below 2 μg/g T-Hg. Highest Hg concentrations in fish caught along the southern shores of Lake Victoria and in rivers draining from gold processing sites were detected in lungfish species (Protopterus aethiopicus), and lowest Hg concentrations in tilapia (Oreochromis niloticus and Tilapia zilli). © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Mercury; Gold mining; Tanzania; Lake Victoria; Urine; Hair; Fish; Occupational risks

1. Introduction

Gold mining and subsequent processing of gold ores using amalgamation techniques are known for their potential contamination to the environment and risks to human health. Many reports have been published on the health risks associated with small scale gold mining in Brazil and other gold mining areas (Malm et al., 1990, 1995; Pfeiffer et al., 1991, 1993; Cleary et al., 1994; Hylander et al., 1994; Akagi et al., 1995a,b; Lebel et al., 1997; Lacerda and Salomons, 1998). Relatively few data have been published from surveys in Africa (Ntow and Khwaja, 1989; Biney et al., 1994; Ikingura and Akagi, 1996; Kahatano and Mnali, 1997; Ikingura et al., in press).
More than 25,000 people are living and working in small scale gold mining camps in the Shinyanga, Kahama, and Bukombe Districts of northern Tanzania. The miners make extensive use of Hg in the gold recovery process. There is a potential risk of human exposure to inorganic Hg, not only to those persons directly handling the Hg but also families, in whose homes the Hg from the amalgam nodule is volatilized and also to those persons eating fish with elevated concentrations of methyl-mercury (MeHg).

Each year a total of approximately 3–4 tonnes of Hg are released from the processing of gold ores from small scale gold mining operations in the Tanzanian portion of the Lake Victoria Goldfields (van Straaten, this issue). In the gold extraction process between 20 and 30% of the anthropogenically introduced Hg is lost to soils, tailings, stream sediments and water close to the processing sites. Some of the Hg reaches aquatic environments, through either direct discharge and transport into the waterways, or indirectly through deposition from the air or through rain. Inorganic mercury released to the environment can be transported in the river system and through air transport ending up in the aquatic system. Potentially the inorganic Hg can be transformed into the toxic form of methyl-mercury.

The purpose of the present study was to assess the risks of Hg contamination to populations in and around small scale gold mining camps in northern Tanzania, and in fish-eating populations around the southern shores of Lake Victoria.

2. Materials and methods

2.1. Study area

The study area is located in the Bukombe, Kahama and Shinyanga Districts in northern Tanzania and aquatic areas at the southern tip of Lake Victoria (Fig. 1). The small scale gold mining areas are located in the Lake Victoria Goldfields of northern Tanzania (van Straaten, 1983; Ikingura and Akagi, 1996).

To assess the extent of Hg exposure of small scale gold miners and farming communities around the small scale gold mining camps in northern Tanzania we carried out a human exposure study including urine surveys. The indirect Hg exposure through the consumption of MeHg-contaminated fish was assessed as part of a fish survey and through hair analyses.

2.2. Human health survey

To better understand the processes involved in small scale gold mining and gold processing and to evaluate the losses of metals including the losses of the anthropogenically introduced Hg, we developed a schematic mining/processing flow-sheet (Fig. 2). The processes involved are similar in many areas of small scale gold mining in Tanzania. Mining and processing techniques are divided into at least two separate phases. The first phase includes activities related to the actual mining of gold deposits, in this case shallow underground mining of primary reef gold and near surface mining of eluvial and supergene gold accumulations. During this phase the miners crush and grind the extracted gold bearing ores. The second phase includes all activities associated with the processing of the crushed and ground ores, resulting in the recovery of heavy concentrates using gravity separation techniques. The last step involves the use of metallic Hg. Mercury is mixed into the concentrate forming a Hg-Au amalgam. ‘Raw gold’ is recovered through the process of amalgam roasting. The final refinement of the gold is normally carried out away from the small scale gold mining sites, at dealers places in towns and in goldsmiths’ shops.

The different activities have different impacts on the environment and human health. While phase one activities have a high potential for the immediate and direct impacts on human health (for instance accidents in underground workings), and the environment (waste rock placement, erosion, dust, etc.), phase two activities involve the use of water and the use of anthropogenically introduced Hg as well as the disposal of process contaminated wastes. Physical contact with metallic Hg occurs when the miners mix the mercury with the concentrate with bare hands. Long-term damage to human health through Hg inhalation.
can be caused during the second phase when miners roast the amalgam without protection at close distance to the volatilized Hg.

To assess the human exposure to metallic Hg in the vapour phase we measured total Hg in urine. MeHg exposure was assessed by means of analysis of total Hg (and in some cases inorganic Hg) in hair samples. We collected the urine of 107 individuals from two gold mining camps (Mwakitolyo and Katente) and from control groups, mainly from farming and fishing communities away from gold mining areas, and from four goldsmiths. Hair samples were taken from 67 fish-eating persons in the Smith Sound area of Lake Victoria and from small scale gold miners.

2.3. Fish survey

To assess potential MeHg exposure in fish-eating populations we conducted a fish survey in 1997 in the Isanga river system of northern Tanzania which drains from a highly contaminated gold processing site (Mwakitolyo) into Smith Sound and Lake Victoria (Fig. 1). During the dry season the river stops flowing in the area around Mwakitolyo and fish become trapped in isolated pools or swamps, e.g. the Mahiga swamp (Fig. 1). Some of these swampy areas are used during the dry season for gold ore processing.

We selected five sampling sites in the Isanga drainage system from Mwakitolyo downstream
into Lake Victoria, and an additional sampling site at a tailings pond in the Katente mining area.

The fish survey included: active fish capture, informal interviews with local people, and observation of the general conditions of the physical environment (e.g. riparian and in-stream vegetation and basic water quality parameters). Beach seine net (30 feet long by 5 feet wide with 2-inch stretch mesh) was the principal fishing gear used to collect fish samples.

2.4. Analytical methods

The human health survey included the sampling of urine and hair of directly and indirectly exposed persons as well as persons in areas far away from the gold mining activities. Urine samples were collected in sterile, metal-free polystyrene flasks treated with diluted nitric acid and Ultrapure water. The selected person (male and female) thoroughly washed their hands and genitals and deposited a ‘mid-stream’ urine sample into the sample flask. The urine samples were frozen at −20°C the same day and delivered in a frozen state to the laboratory of TNO in Zeist, the Netherlands, where they were analysed for both total Hg and creatinine, using the cold vapour atomic absorption spectrophotometry (CVAAS) technique. The results were normalized to their creatinine-adjusted Hg content.

Human hair samples were collected by cutting approximately 50 mg of hair close to the scalp.
The strand of hair was tied together with a string, stapled onto cardboard and the root end of the hair was indicated. Each sample was preserved in a labelled paper envelope and kept at room temperature and delivered to the ‘Laboratoire de Toxicologie’ Sainte-Foy, Quebec, Canada. The samples were analysed for total mercury (T-Hg) with a few check samples also for inorganic Hg. For T-Hg analyses 10 mg of hair was digested in concentrated nitric acid for 1 h at 80°C, for inorganic Hg 10 mg of hair was digested with a 45% sodium hydroxide solution at room temperature for 72 h. The digest was introduced to the reaction chamber, Hg vapour was generated and Hg detected by cold vapour AAS (Pharmacia Mercury monitor 100).

Apart from sampling of urine and hair, the medical personnel under the supervision of Dr Mwandu Kolandatu Hospital conducted a short interview of the participating persons about medical and occupational history. At the end of the study, all persons involved in this survey were informed of their individual Hg analysis in hair and/or urine.

The fish survey included identification, measurement and sex and gonad inspection. Liver and dorsal muscle samples were collected using stainless steel tools and wearing surgical gloves. Tissue samples, collected from 35 medium and larger specimen fish belonging to 8 different genera, were kept in sterile polypropylene tubes with tight caps, preserved in ice containing coolers and transported deep frozen to the Laboratory Services Division of the University of Guelph, Canada. The freeze dried, microwave-digested tissue samples were analysed for T-Hg by cold vapour atomic absorption spectrometry using a Cetac M6000A Mercury Analyser.

3. Results

From the 107 human urine samples collected, 45 were from small scale gold miners involved in processing gold ore using mercury recovery techniques (occupationally exposed), 14 samples were from miners who worked in the mining camps but did not engage in gold processing using mercury (indirectly exposed), 43 were control samples from businessmen, housewives, farmers, cooks, fishermen, etc., four samples came from goldsmiths in Shinyanga, and one sample was invalid. Fig. 3 illustrates the distribution of creatinine-adjusted Hg levels in urine from occupationally exposed individuals, from miners indirectly exposed, and from the control group. Urinary Hg in the control group (n = 43) was low, with a mean of 5.14 μg Hg/g creatinine. The mean urinary Hg concentration of the indirectly exposed group was 11.97 μg Hg/g creatinine. The urinary Hg concentra-

Fig. 3. Urinary mercury concentrations in three occupational groups in and around two small scale gold mining camps: Mwakitolyo and Katente, northern Tanzania.
tions of the four goldsmiths from Shinyanga were surprisingly low. With a mean of 5.86 μg Hg/g creatinine their urinary Hg concentrations were close to that of the control group.

High Hg concentrations were found in urine from those persons who carry out amalgamation and amalgam burning at the Mwakitolyo camp (mean urinary Hg of 20 amalgamating persons = 39.11 μg Hg/g creatinine). Urinary Hg concentrations of 25 persons amalgamating at the Katente mining camp was similarly high, with a mean of 39.78 μg/g creatinine. The highest concentration of 172.08 μg/g creatinine was from the urine of a 29-year-old male, who started amalgamating and amalgam roasting in 1991 and who claimed to roast amalgam every day up to 10 times!

From the 45 occupationally exposed persons, 12 persons had urinary Hg concentrations between 50 and 100 μg/g creatinine, and four persons had urinary Hg concentrations exceeding 100 μg/g creatinine. All 16 persons were involved in amalgamation and amalgam roasting.

Gold miners who worked with amalgam in the mining camps of Mwakitolyo and Katente had significantly higher Hg in their urine than the unexposed group:

- 36% exceeded the WHO guideline (WHO, 1980) concentration of 50 μg Hg/g creatinine;
- 44% exceeded the American government (ACGIH) guideline of 35 μg/g creatinine.

The mean T-Hg concentrations in hair samples from 36 fishermen and farmers (part of the control group) ranged from 0.1 to 0.6 μg/g, reflecting a low level of Hg exposure. Hair samples from two other persons of the control group outside the mining area, a female cook and a female farmer, showed very high Hg concentrations in hair (18.5 and 288 μg/g wet wt., respectively). We re-analysed both samples for total and inorganic Hg and found that all the Hg was in the inorganic form, probably reflecting contamination with banned hair and skin cosmetics. Although illegal in Tanzania, the skin bleaching soaps ‘Jaribu’, ‘Mekako’, ‘Rico’ and ‘Jambo’ containing 2% mercuric iodide (according to the label) are widely available on the market in Tanzania.

Results of the fish survey indicate that Hg concentrations in fish from the Isanga drainage system are generally low (0.02–0.63, mean: 0.12 μg Hg/g wet wt.), similar or even lower than most published Hg concentrations in fish from non-polluted areas of the world. Different fish species had different Hg concentrations: lowest Hg concentrations were recorded in phytoplankton feeding tilapia (Oreochromis niloticus and Tilapia zillii) (mean from muscle and liver = 0.07 μg/g), highest concentration in lungfish (Protoperus aethiopicus) (0.24 μg Hg/g in muscle, 0.58 μg Hg/g in liver). Mercury concentrations in Nile perch (Lates niloticus), which was caught in open water of Smith Sound were generally low (0.05–0.25 μg Hg/g). There are indications of site-specific Hg contamination in fish, e.g. Hg concentration in mudcatfish (clarias sp.) caught close to amalgamation sites (Mwakitolyo) was 0.14 μg/g in muscle, the Hg concentration in mudcatfish furthest away from the source of contamination (Sotta) was < 0.4 μg/g. The same pattern could be observed in muscle samples of tilapia (Oreochromis sp.): at Mwakitolyo the Hg concentration was 0.08–0.16 μg/g, at Sotta 0.02 μg/g.

One fish specimen (clarias sp.) collected from a tailings pond at Katente in Kahama District had extremely high total mercury (T-Hg) concentrations (4.53 μg/g in liver and 2.55 μg/g in muscle).

4. Discussion

4.1. Human health survey — urine analyses

The urinary Hg measurements differentiated into three occupational groups including a control group. The survey clearly demonstrated the high occupational exposure risks of those persons handling Hg. Small scale gold miners handling Hg and amalgam in the two studied mining camps of Mwakitolyo and Katente had significantly higher Hg in their urine than the unexposed group. These data are consistent to the findings of other researchers in the Lake Victoria area and in South America (Ikingura and Akagi, 1996; Lac-
erda and Salomons, 1998). Ikingura and Akagi (1996) analysed the urine of 31 people in selected gold mining areas of the Lake Victoria area on total mercury (T-Hg). Urinary mercury levels in five persons frequently exposed to mercury vapour during amalgamation and amalgam roasting were very high, 129–411 ng/ml (mean 241.3 ng/ml), as compared with the WHO guidelines of 50 ng/ml and to urinary Hg concentration of five mine workers from the same mining area not directly exposed to mercury vapour (1.8–103 ng/ml, mean 40.3 ng/ml). Background levels in the area were 1.2–1.6 ng/ml (Ikingura and Akagi, 1996). All samples collected by Ikingura and Akagi (1996) were analysed for total Hg only and not creatinine adjusted.

Kahtatano et al. (Presentation, Intern. Conference on Small Scale Mining in African Countries, Dar es Salaam, September 29–October 1, 1997), in a similar survey analysed urinary levels in miners who amalgamated and carried out amalgam roasting at the Mwakitolyo mine site, and in a control group in town (Mwanza). Again, only T-Hg was analysed and not creatinine adjusted. In the town of Mwanza the mean urinary mercury level in the eight males sampled was 0.56 ng/ml (range 0.3–1.0 ng/ml), the urinary mercury concentration in eight females, however, was higher, ranging from 0.4 to 101.4 ng/ml (mean 35.3 ng/ml). The elevated Hg concentrations were from women using (officially banned) skin-lightening soaps and hair curling cosmetics. In the mining camp of Mwakitolyo the researchers analysed urinary levels from eight males and four females, T-Hg concentrations ranging from 1.3 to 157.6 ng/ml (mean 56.7 ng/ml) in the urine of men, and 0.8 and 6.5 ng/ml in urine from females.

4.2. Human health survey — hair analyses

Hair samples collected and analysed in the present study confirm the low T-Hg concentrations in the population of this area. The mean of hair samples from 36 fishermen and farmers away from the gold mining area, in the Smith Sound area, reflected a low level of exposure to MeHg. The low Hg concentrations in hair of the fishing village population was consistent with the findings of very low Hg concentrations of fish consumed by the inhabitants of these villages.

The data of the hair survey are consistent with the findings of Ikingura and Akagi (1996) who analysed 24 human hair samples from individuals in the Lake Victoria Goldfields on total mercury (T-Hg) and methylmercury (MeHg). T-Hg concentrations in 22 of the 24 samples were in the range 0.16–5.43 µg/g, with a mean of 0.95 µg/g. The mean T-Hg concentrations in hair samples from fishermen and farmers away from the gold mining area was 0.30 µg/g (range 0.16–0.44 µg/g), reflecting a low level of exposure to mercury. They also found low Hg concentrations in hair of the fishing village population.

In a similar study, Kahtatano et al. (presentation, Intern. Conference on Small Scale Mining in African Countries, Dar es Salaam, September 29–October 1, 1997) report from the Hg analyses of 26 individuals from Mwanza town and the Mwakitolyo mine with T-Hg concentrations in human hair in the range of 0.7–7.30 µg/g (mean = 2.30 µg/g).

Based on these three surveys it seems that there is a very low risk of Hg contamination for the general population who consume locally caught, small fish at the southern tip of Lake Victoria.

4.3. Fish survey

An unknown quantity of Hg lost from anthropogenic sources reaches aquatic environments, through either direct discharge and transport into the waterways, or indirectly through wet and dry deposition from the air or through rain. The generally low Hg concentrations in fish reported in the present study are comparable with results of fish surveys of other research teams which collected fish samples over the last 5 years in the southern part of Lake Victoria. Four independent research groups (from four countries) using different analytical laboratories analysed altogether 127 samples of fish muscle for T-Hg and came to similar conclusions.

Ikingura and Akagi (1996) report on the analyses of 15 samples from fish caught by local fishermen in the Nungwe Bay area of Lake Victoria.
located approximately 10 km away from a local gold mine. The researchers concluded that there is no increased exposure of T-Hg and MeHg to the local fish-eating population in the Nungwe Bay area. Their results indicate extremely low Hg concentrations in fish in this area in comparison with most published Hg levels in fish from non-polluted areas of the world. The very low net methylation rates of mercury in this area are possibly due to ‘strong binding of MeHg in soils, sediments and biota such that little of the total MeHg budget is released to water bodies and available for bioaccumulation in fish or aquatic food chains’.

In an internal, report Migiro et al. (unpublished) presented new analytical data from a survey on fish, sediment and water in the Mwanza area. A total of 50 samples from muscles of three species of fish were analysed for their mercury content: Tilapia (*Oreochromis niloticus* and *Tilapia zillii*), Nile Perch (*Lates niloticus*) and lung fish (*Protopterus aethiopicus*). The conclusion of the preliminary investigations was that it is unlikely that the general population consuming locally caught, small fish in the vicinity of Lake Victoria and contaminated rivers draining from gold mining areas is overexposed to Hg.

5. Conclusion

The main conclusions from the health and fish studies in and around small scale gold mining camps in northern Tanzania are:

- the risks of Hg contamination to persons handling Hg (occupational exposure) mainly small scale gold miners in northern Tanzania, are very high;
- Hg concentrations in fish in the southern part of Lake Victoria/Tanzania are generally low which is consistent with the low T-Hg concentration analysed in hair of fishermen in this area.

Except for the unknown fate and impacts of large volumes of Hg released from the mining camps and goldsmiths shops in a volatile form, the impacts of small scale gold mining on the environment and human health in the Shinyanga, Kahama and Bukombe Districts in Tanzania are at present largely localized and affect mainly the population of the small scale mining communities. If not contained and improved, however, the impacts of the small scale mining activities will be long lasting and threaten economic development, essential ecological processes and human health of future generations.

At present the main concern is that of human health, specifically for those directly and indirectly involved in handling Hg and amalgam roasting. Participatory research with small scale miners will have to be initiated to develop practical solutions for the reduction of unacceptable occupational exposure to Hg vapours and Hg losses to the environment.

Acknowledgements

This study was financially supported by the Government of the Netherlands. Many thanks are due to my colleagues in the field: Ms Choudry, Messrs A. Nkulo, G. Wiatzka, R. Van Lissa, G. Spoor, J. Shayo, D. Binamungu, R. Tamatamah, L. Mwasumbi, W. Temu, J. Baker, Dr B. Kiwambo and Dr E. Mwandu. Special thanks go to Tom van Miert and the ‘mara mbili team’. Thanks are also due to my colleagues at the Geology Department of the University of Dar es Salaam, especially Dr J. Ikingura, and Dr G. Steenbergen, Ms K. Kramer and Mr A. Rwechengura from the Royal Netherlands Embassy, Dar es Salaam. Technical and scientific assistance was also provided by Dr G. Spiers, Sudbury, Dr Les Evans, University of Guelph and Dr Kim Bolton, University of Toronto. By far the greatest gratitude is extended to all the small scale gold miners who demonstrated the various mining and processing activities, and who generously provided urine and hair for this study. I thank the reviewers for their constructive comments and suggestions.
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