ELSEVIER

The Science of the Total Environment 191 (1996) 59–68

the Science of the Total Environment
An International Journal for Scientific Research into the Environment and its Relationship with Man

Monitoring of fish and human exposure to mercury due to gold mining in the Lake Victoria goldfields, Tanzania

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Received 12 March 1996; accepted 7 June 1996

Abstract

Monitoring of environmental and human exposure to mercury in the Nungwe Bay area of the Lake Victoria goldfields, Tanzania, has revealed low mercury concentrations in fish (range: 1.8–16.9 ppb, mean: 7.0 ppb) and human hair (range: 156–5433 ppb, mean: 947 ppb) that represent background levels. Gold mining has not produced a significant increase in environmental methylmercury that is available for bioaccummulation in aquatic food chains. Urinary mercury levels in gold mine workers frequently exposed to Hg vapour in amalgamation and burning of amalgam were significantly higher (mean: 241 ng/ml) than those in the general mine population not occupational exposed to Hg (mean: 2.6 ng/ml). Rotation of mine duties reduced Hg exposure levels and hence the risk of intoxication in the gold mine workers. The lowest urinary and hair mercury levels were found in the Nungwe Bay fishing village population. This was consistent with the low mercury content of fish consumed by the inhabitants of the Nungwe Bay.

Keywords: Mercury; Gold mining; Lake Victoria; Fish; Tanzania

1. Introduction

Increased use of mercury in gold recovery in mining operations in many developing countries in recent years has raised world concern over the release of this toxic metal into the environment. Previous experiences of human mercury poisoning in Minamata Bay (1956) in Japan [1] and in Iraq (1970s) [2] indicate the dangers associated with mercury contamination. Recent research activities on the environmental impact of mercury from gold mining have concentrated mainly on Latin America, particularly the Brazilian Amazon. As a result, several research papers and scientific reports have been published on mercury contamination and health effects in the Amazon [3,4,5,6]. Little work, however, has been undertaken to study environmental mercury contamination in African countries were an increasing large number of people are engaged in so called 'artisanal' small scale gold mining using mercury amalgamation technique. In Tanzania, for example, it is esti-

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PII S0048-9697(96)05178-9

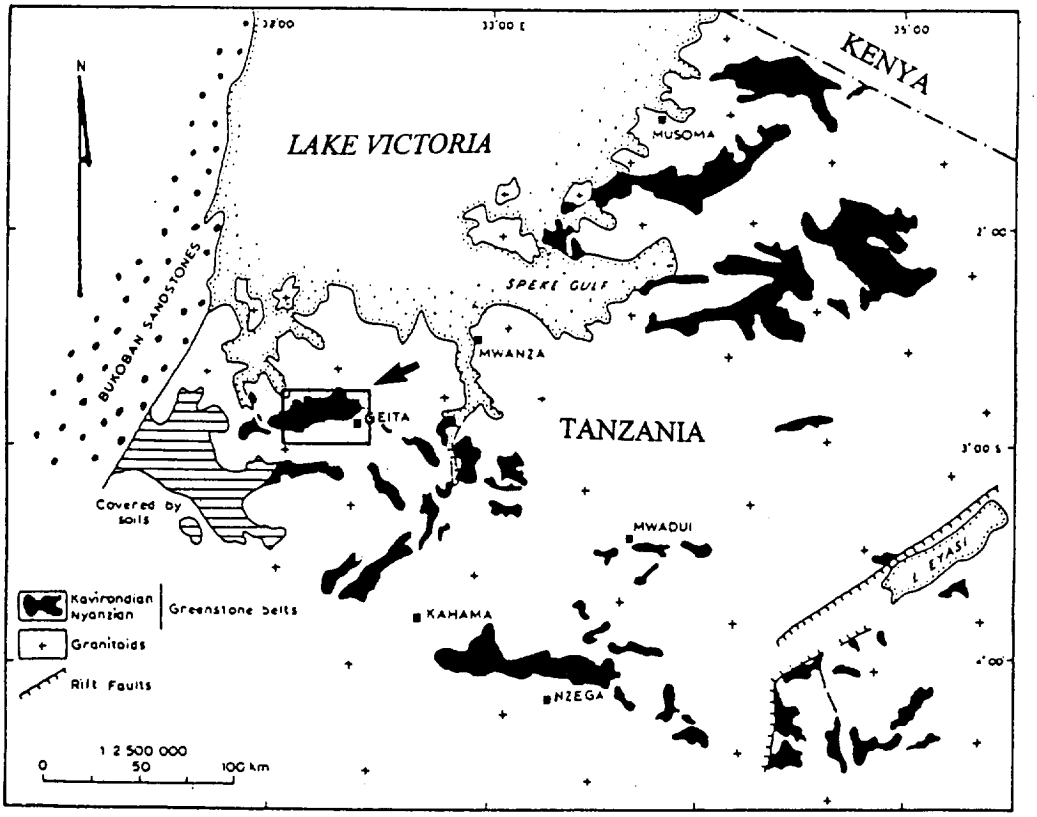


Fig. 1. Sketch map of the Lake Victoria goldfields (black) showing the location of the study area (modified after [8]).

mated that ~250 000 people are involved in small scale gold mining in three principal goldfields namely the Lake Victoria goldfields, around Lake Victoria; the Lupa goldfield in the southern part of the country and the Mpanda mineral field in the western part [7].

There is a potential risk of human exposure to inorganic mercury because of the extensive use of mercury in gold recovery in the Tanzania goldfields. Furthermore, inorganic mercury released into river systems during gold ore-processing is likely to be gradually transformed into the highly toxic form of methylmercury and become concentrated through biomagnification in aquatic food chains, particularly in fish consumed by local populations. The purpose of the present study was to determine mercury levels in fish and human hair and urine in order to assess environmental and human exposure to mercury in the Lake Victoria goldfields. This study is the first that has dealt with biological monitoring of mercury contamination due to gold mining in Tanzania.

2. Materials and methods

2.1. Study area

The Lake Victoria goldfields (LVGF) refer to a number of goldfields located to the east and south of Lake Victoria in northern Tanzania (Fig. 1) [8]. Unprecedented levels of 'gold rush' involving a large number of the local population in the LVGF and other parts of the country began in the late 1980s and reached a peak around 1993. The gold rush was partly stimulated by the relaxation of mining regulations in the country following the liberalization of the state controlled economy. The gold rush resulted for the first time in haphazard gold mining and the extensive use of

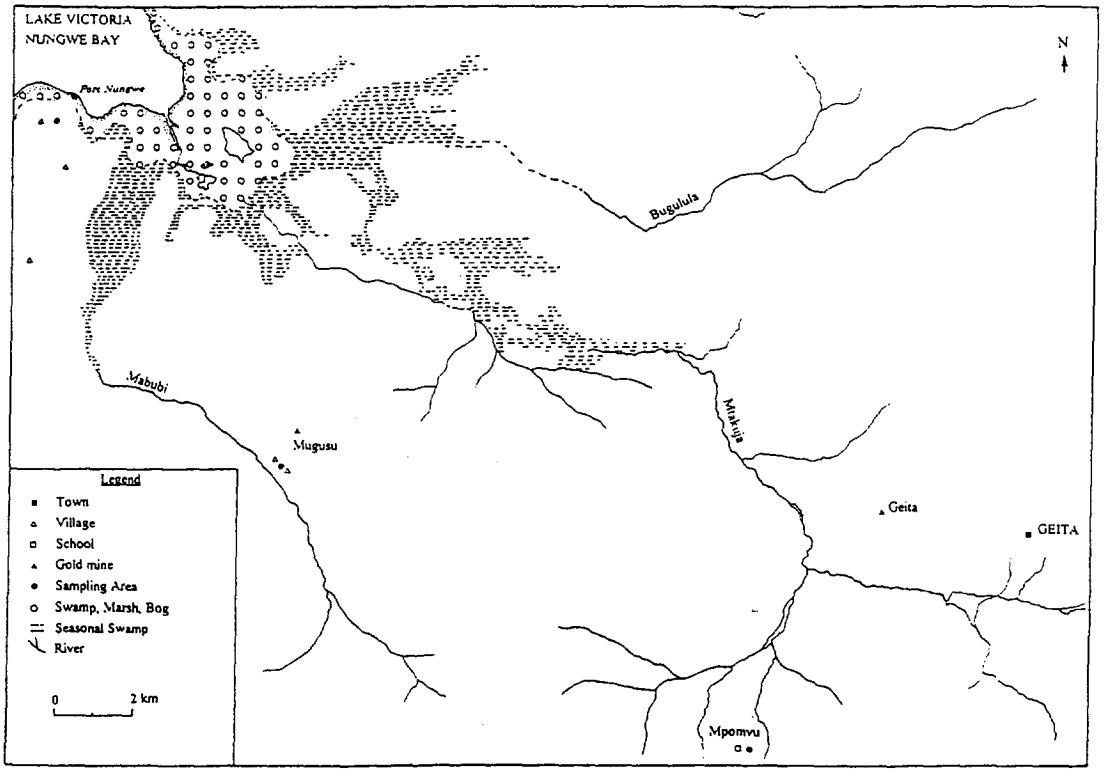


Fig. 2. Map showing the sampling areas and drainage pattern for Nungwe Bay (see inset in Fig. 1).

mercury in gold recovery by local miners. At least 6 tonnes of mercury are released into the environment annually from the production of ~4 tonnes of gold from small scale mining in various parts of the country [7]. Approximately 75% of the gold production and hence of the mercury used is in the LVGF. This means that ~4.5 tonnes of mercury are released annually in the LVGF alone by gold mining activities. Initial studies of mercury contamination in the LVGF have indicated the presence of elevated mercury concentrations in various environmental media. The mercury concentration in river water and domestic water ponds is in the range 0.01–6.78 μg/l whereas in river sediment the concentration is in the range 0.02–136 μg/g. Soil around the Au-Hg amalgam burning areas has an average mercury concentration of 3.4 μg/g in contrast with the regional background concentration of 0.05–0.06 μg/g [9]. These data, although still preliminary, indicate environmental Hg contamination in the LVGF due to gold mining activities.

Two study areas, Mugusu and Nungwe Bay (Fig. 2), were chosen for biological monitoring of mercury contamination. Mugusu has been an active small scale gold mining area for ~8 years since 1988. Inhabitants of the Mugusu mine were chosen for monitoring of inorganic Hg exposure from amalgam burning. Nungwe Bay on the southwestern part of Lake Victoria is located ~10 km from the Mugusu gold mine. The bay is essentially a drainage area for the Mugusu (Mabubi) river and other rivers contaminated with Hg due to gold mining activities. The bay is surrounded by a village (Nyamwilolelwa) whose inhabitants are engaged both in fishing and farming, and fish is a major item in their diet. These inhabitants were thought to be suited for monitoring of organic mercury exposure through fish consumption. Fish from Nungwe Bay was consid-

ered to be ideal for monitoring of environmental mercury contamination in that area as fish could not be obtained from the contaminated rivers.

2.2. Sampling

Sampling was conducted during the first week of November 1995. Hair and urine samples were collected mainly from inhabitants of the Mugusu gold mine and Nungwe Bay fishing village. In addition, samples were collected from a teacher and student, and one child at a primary school (Mpomvu) located ~15 km from the Mugusu mine. The latter group including one of the authors (JRI) was a control group. Although the sampling was initially targeted to specific groups considered to be at high risk of Hg exposure in the gold mine and fishing village, it turned out to be somewhat random because samples could only be obtained from a few people who volunteered. The majority of the people in the mine and the village were reluctant to donate hair or urine samples because of strong superstitious beliefs. Hair samples were collected by cutting ~30–50 mg of hair close to the scalp. Each sample was preserved in a labelled paper envelope and kept in an air tight plastic bag. Spot urine samples were collected in clean glass bottles with tight plastic caps. Both hair and urine samples were kept at room temperature (25°C) for 4 days before the samples were transported from the field to the Geochemical Laboratory at the University of Dar es Salaam where they were kept in a freezer until the time of shipment to Japan for analysis. Fish samples were collected from different types of fish caught from Nungwe Bay by fishermen during the day of sampling. Each fish sample consisted a rectangular piece (2 × 4 cm) of fish muscle. The samples were collected in thick polyethelyne bottles with tight caps and kept in a cooler box until brought to the nearby town where the samples were frozen. All fish samples were transported and kept frozen until analyzed.

2.3. Mercury analysis

Samples were analysed for total mercury (T-Hg) and methlymercury (MeHg) at the National Institute for Minamata Disease (NIMD) in Japan, using reliable and sensitive speciation techniques developed by Akagi and Nishimura [10] and modified recently as described by Akagi et al. [3]. The precision and accuracy of these techniques have been repeatedly verified by inter-laboratory calibration exercises [11,12] including the analysis of reference standards (e.g. IAEA 085 and 086). The techniques are applicable to a wide range of biological samples with Hg concentrations down to background levels. An overview of the analytical procedures is given here. For T-Hg analysis, ~0.5 g of finely chopped fish muscle, 10 mg of finely cut hair or 5 ml of urine were placed separately in a 50-ml volumetric flask with a long neck and digested with a mixture of 2 ml HNO_3-$HClO_3$ (1:1), 5 ml H_2SO_4 and 1 ml distilled H_2O at 230–250°C for 20 min. After cooling, each digested sample was made up to 50 ml by adding distilled water to the sample bottle and shaking to homogenize the sample. Internal laboratory standards were carried through the digestion procedure along with the samples. T-Hg in the sample solution was determined by cold vapour atomic absorption spectrometry using a semi-automated mercury analyzer (Model Hg-4000) developed at NIMD. For MeHg analysis in fish, ~0.5 g of finely chopped fish muscle was placed in a Pyrex glass test tube with an air-tight screw cap and digested with 10 ml of 1 N KOH in ethanol at 100°C in a water bath for 1 h. MeHg in the digested sample was extracted with 0.05% dithizone solution in benzene and then purified and concentrated following the procedure described by Akagi et al. [3]. Internal MeHg standards were carried through the digestion, extraction and purification procedure along with the samples. MeHg content in the final purified benzene extract was determined by electron capture detector (ECD)-gas liquid chromatography (GLC). All fish samples were analyzed in duplicate for T-Hg and MeHg. In hair MeHg analysis, ~20 mg of finely cut hair samples were placed in a 10-ml Pyrex glass test tube and 2 drops of ethanol added to reduce surface tension. MeHg was extracted from the sample by adding 5 ml of 2 N HCl to the sample and heating at 100°C in a water bath for 5 min. One ml of the HCl extract was extracted

with 4 ml benzene. MeHg in the benzene extract was determined by GLC.

3. Results

Results of T-Hg and MeHg analysis in fish and human hair are given in Tables 1 and 2. T-Hg concentration in fish was in the range 1.8–16.9 ppb (mean: 7.0 ppb or ng/g wet weight). Lower mercury concentrations were found in Tilapia (Sato) and Kamongo than in other fish species. Mean T-Hg concentrations in five Tilapia samples was 2.4 ppb (2.4 ng/g wet weight) whereas six replicate analyses of one Kamongo had a mean concentration of 2.2 ppb. Relatively high mercury concentrations were found in Soga (mean: 13.7 ppb), followed by Nile perch (mean: 9.7 ppb) and Furu (6.7 ppb). It is interesting to note that Soga and Furu, the smallest fish species in terms of maximum growth size or body weight, exhibited significantly higher T-Hg concentration than large fish such as Sato, Kamongo or Nile perch. The proportion of MeHg to T-Hg in all fish samples was in the range 62.5–97.4% (mean: 87.8%), which indicated that most of the mercury in the fish was in the form of methylmercury.

Table 1
Total mercury (T-Hg) and methylmercury (MeHg) contents in fish from Nungwe Bay, Lake Victoria

Sample no	Fish wt. (g)	Fish L. (cm)	Fish W. (cm)	Fish type[a]	T-Hg (ppb)	MeHg (%)
F1	650	30	12.5	I	2.4	83.3
F2	650	30	12	I	2.7	92.6
F3	350	26	10	I	2.4	95.8
F4	150	18.5	7.5	I	2.9	89.7
F5	150	19	7	I	1.8	94.4
Mean	390	24.7	9.8	I	2.4	91.0
F6	700	37.5	11	II	11.7	97.4
F7	200	25	7.5	II	6.9	85.5
F8	150	23	6.5	II	10.5	101.9
Mean	350	28.5	8.3	II	9.7	94.9
F9	125	20	6	III	16.9	74.0
F10	75	18	5	III	16.4	97.0
F11	50	16	4	III	7.8	92.3
Mean	83.3	18	5	III	13.7	87.8
F12	600	54	8	IV	2.2	72.7
Mean[b]				IV	2.2	72.7
F13	75	16	5	V	8.3	90.4
F14	45	12.5	4	V	5.4	87.0
F15	25	10	2.5	V	6.4	62.5
Mean	48.3	12.8	3.8	V	6.7	80.0

[a]Type: I, tilapia (sato); II, Nile perch (sangara); III, soga; IV, catfish (kamongo); V, furu.
[b]Six replicate analyses.

T-Hg concentration in 22 out of 24 human hair samples were in the range 156–5433 ppb (mean: 947 ppb) whereas in the remaining two samples the concentration was much higher at 34 212 ppb and 214 188 ppb. The latter samples were from female adults with long hair for 24 and 15 months, respectively, since their last hair cut. The age of hair was < 15 months in the rest of the population. Those two anomalous hair samples will not be considered in the following discussion because they probably represent extreme cases of external contamination as indicated by their extremely low MeHg content (Table 2). Mean T-Hg concentration among nine male gold miners whose occupation ranged from gold mining and panning to amalgamation and amalgam burning at Mugusu mine was 1725 ppb (range: 421–5433 ppb). Among the three females at the Mugusu mine whose hair was analyzed, one female engaged in mercury amalgamation and petty trade of general goods while the remaining were housewives. The housewives had low hair T-Hg concentrations (365 to 416 ppb) in comparison with the female who engaged in amalgamation (sample Mu-09, Table 2). One hair sample from a 13-year-old school student at the Mugusu gold mining area had a T-Hg concentration of 1500 ppb, which was within the range of concentrations found in samples from the gold miners. A hair sample from a female teacher at a primary school located ~ 15 km from the Mugusu mine had surprisingly high T-Hg concentration (34 212 ppb) in comparison with the people who lived full-time in the mine (sample Mu-09 excepted). The teacher, however, had visited the the Mugusu mine on official duties 2 days before the hair sampling was undertaken. A hair sample taken from one of the authors (JRI) as part of the control group during sampling had a T-Hg concentration (1318 ppb) that was within the range of concentrations found in the inhabitants of the gold mine.

Table 2
Total mercury (T-Hg) and methyhnercury (MeHg) concentrations in hair and urine (T-Hg) from inhabitants of the Lake Victoria goldfields, Tanzania

Sample no.[b]	Sex (M/F)	Age (years)	Duration mine/village (years)	Occupation[a]	Hair T-Hg (ppb)	Hair MeHg (%)	Urine T-Hg (ng/ml)
Mu-01	M	30	3	b	1115	28.4	318.5
Mu-02	M	34	6	m, a	1025	27.3	90.1
Mu-03	M	22	6	p, b	2988	9.7	201.6
Mu-04	M	53	6	m, p, b	715	ND	1.8
Mu-05	M	50	6	m, p, b	421	69.1	4.2
Mu-06	M	25	10	p, a, b	2209	17.2	145.4
Mu-07	M	22	5	p, a, b	1114	17.4	129.4
Mu-08	M	21	3	p, a, b	5433	7.3	411.4
Mu-09	F	28	2	a, c	214 188	0.1	8.8
Mu-10	F	27	1	w	365	63.3	1.9
Mu-11	F	32	7	w	416	30.7	1.3
Mu-12	M	13	6	s	1500	21.0	4.5
Mu-13	M	23	5	m, a, b	505	34.2	102.6
Mu-14	M	20	5	m	ND	ND	3.1
Pr-15	F	6	6	—	ND	ND	2.0
Pr-16	F	13	13	s	ND	ND	21.7
Pr-17	F	35	11	t	34 212	0.5	27.3
Nu-20	M	55	9	f, g	442	20.5	0.9
Nu-21	M	42	2	d	383	44.6	2.7
Nu-22	M	54	25	d, f	ND	ND	1.0
Nu-23	M	65	10	g	271	33.4	14.1
Nu-24	M	44	2	f, g	260	32.7	1.1
Nu-25	M	48	7	f, g	ND	ND	1.1
Nu-26	M	41	3	f, g	156	59.0	1.2
Nu-27	F	17	17	g	216	61.3	0.7
Nu-28	F	19	19	g	318	54.8	ND
Nu-29	F	17	17	g	197	ND	ND
Nu-30	F	15	15	g	375	82.1	ND
Nu-31	F	6	6	—	419	47.0	ND

[a]Occupation: a, amalgamation; b, amalgam burning; c, commerce; d, administration; f, fishing; g, agriculture; m, mining; p, panning; s, student, t, teacher; w, housewife.
[b]Sample locality: Mu, Mugusu gold mine; Pr, primary school; Nu, Nungwe Bay village.
ND, not determined.

T-Hg concentration in hair samples from inhabitants of the Nungwe Bay fishing village was in the range of 156–442 ppb (mean: 304 ppb). There was not much difference in the average hair Hg concentration between males and females in the fishing village. Average T-Hg concentration in five hair samples from the males was 302 ppb whereas in five samples from the females the average was 304 ppb.

The proportion of MeHg to T-Hg in hair from the inhabitants of the Mugusu mine was in the range of 7.3–69.1% (mean: 27.1%; sample MU-09 excluded) whereas in the inhabitants of the Nungwe Bay fishing village the proportion was in the range of 20.5–82.1% (mean: 48.4%). These data suggest that on average a large proportion of Hg in the hair was inorganic both in the mine population and the fishing village population. The

proportion of MeHg to T-Hg in the hair was, however, much higher in the fishing village population than in the mine population. The higher proportion of MeHg in the fishing village population was consistent with the fact that the population is exposed to Hg mainly through fish consumption. The high proportion of inorganic Hg in the Mugusu mine population could be attributed to external contamination as in the case of gold miners and dealers in the Amazon in Brazil [3].

Data for T-Hg analysis in urine are given in Table 2. Urine T-Hg concentration in five male mine workers whose main occupation was amalgam burning and/or amalgamation and gold panning was in the range of 129–411 ng/ml (mean: 241.3 ng/ml) whereas in five workers who engaged mainly in gold mining but also took part in amalgamation or amalgam burning the concentration was in the range of 1.8–103 ng/ml (mean: 40.3 ng/ml). Housewives not engaged in amalgamation or amalgam burning exhibited the lowest urine T-Hg concentration (mean: 1.6 pbb, for two pregnant females). Urine samples from a school teacher and a student at a primary school located 15 km from the Mugusu mine had a T-Hg concentration of 27.3 ng/ml and 21.7 ng/ml, respectively. Relatively high urinary Hg levels in these two non-gold mine subjects suggest that the subjects frequently visited the gold mine villages where they were probably exposed to elevated air Hg levels. In fact the primary school teacher was at the Mugusu gold mine as 'national elections returning officer' 3 days before urine sampling. The teacher was one of the female adults with high inorganic hair Hg concentrations that probably suggested external contamination. A urine sample from a 6-year-old child at the primary school had a T-Hg concentration of 2.0 ng/ml whereas the sample from one of the authors (JRI) collected during sampling had a concentration of 2.5 ng/ml.

Average T-Hg concentration in seven out of eight urine samples collected from inhabitants of the Nungwe Bay fishing village was 1.2 ng/ml while in the remaining sample the concentration was 14.1 ng/ml. With the exception of the latter sample, inhabitants of the fishing village had lower urine T-Hg concentrations than the inhabitants of the gold mine.

4. Discussion

Mercury content in fish and human hair is considered to be a good indicator of environmental and human exposure, respectively, to organic or methylmercury (MeHg) contamination whereas urine is considered a good biomonitor for inorganic Hg exposure [13,14]. Diet, consisting particularly of fish, is the main source of exposure to MeHg in the general population. Exposure to inorganic Hg is mainly associated with certain occupational environments such as dentistry, chloralkali plants and industries for the production of batteries, thermometers and fluorescent tubes [14]. Gold extraction using mercury amalgamation also increases human exposure to Hg as has been demonstrated in Garimpeiro gold mining in Brazil [3]. The results of the present study provide a basis for assessment of environmental and human exposure to MeHg and inorganic Hg in the Lake Victoria goldfields (LVGF).

Extremely low Hg levels found in fish (range: 1.8–16.9, mean: 7.0 ppb) suggest that there is very little input or production of MeHg in the Nungwe Bay area of Lake Victoria. The levels reflect background mercury concentrations that are even much lower than most published Hg levels in fish from non-polluted areas of the world. For example, published Hg concentrations in finfish from African inland waters are in the range of 10–53 ppb (mean: 35 ppb) [15]. Fish from Lake Nakuru, one of the East African rift valley lakes in Kenya, has a mean Hg concentration of 44 ppb [16]. According to WHO environmental health criteria [17] Hg concentrations in fresh-water fish from non-polluted areas are commonly in the range of 100–200 ppb (0.1–0.2 μg/g). Judging from these data, fish analyzed in the present study have surprisingly low Hg levels.

In contrast to fish from the LVGF, fish from gold mining areas in the Amazon region exhibit high mercury levels. Mercury concentration in fish from the Tapajós river basin in Brazil is in the range of 0.04–3.8 ppm (mean: 0.7 ppm); higher concentrations being reached in top trophic level carnivorous fish species [12]. The proportion of MeHg to T-Hg in the fish from the Tapajós basin was mostly in the range of 65–98%, which

indicates that the fish accumulated much more MeHg than inorganic Hg. Our results from LVGF are also consistent with this observation. The proportion of MeHg in LVGF fish was in the range of 62.5–97.4% (mean: 87.8%). Differences in mercury concentrations in five fish species analyzed in this study could be partly attributed to different feeding habits in the individual fish species. High trophic level fish, such as carnivorous fish, tend to have a higher Hg concentration than low trophic level herbivorous fish because of bioaccumulation of Hg in the aquatic food chain [18]. It is, however, still surprising to observe that the smaller fish species (e.g. Soga and Furu), that are also probably lower in the food chain, exhibited relatively higher Hg concentrations than the larger fish including the Nile perch which is known to be carnivorous and a top predator in Lake Victoria. One explanation could be the small number of samples (3–5) analyzed for each fish type. However, because the samples were carefully selected to represent a range of size or age in each fish category, it is possible that the differences in Hg concentrations among the fish types are valid and reflect not only feeding habits but also the sub-environments (e.g. shallow or deep water, estuary, etc.) in which the fish live. The smaller fish in this case probably spend more time in a shallow water, organic-rich sub-environment that is favourable to Hg methylation and bioaccumulation of MeHg.

Hair Hg concentrations in the inhabitants of the Mugusu gold mine (mean: 1484 ppb) and the Nungwe Bay fishing village (mean: 304 ppb) are generally low in comparison with published data from other parts of the world. The reference value for total mercury in hair is considered to be ~ 2000 pbb (2 μg/g; WHO [19]). This means that hair Hg concentrations in the LVGF inhabitants are on average 2–6.5 times lower than the WHO reference value. Abe [20] reported hair Hg levels of 3.7–71.9 ppm (μg/g) in fish-eating subjects of the Lake Murray area and an average of 0.75 ppm in non-fish eating subjects of the upper Strickland area, Papua New Guinea. High Hg levels in fish-eating subjects corresponded with high Hg content in fish that was attributed to natural ecological processes in the Lake Murray area. Much higher hair Hg levels (range: 4.7–151 ppm, mean: 25 ppm) have been found in human populations living in areas contaminated by gold mining in the Tapajós river basin, Brazil [12]. Fish from the contaminated areas also exhibited a high Hg content (mean: 0.69 ppm). In these and other studies, human hair was considered a good indicator of MeHg exposure through fish consumption. In the present study, low hair Hg levels in the subjects from the LVGF are consistent with low Hg levels in fish consumed in that area.

Mean urinary Hg concentration in male gold mine workers who were engaged mainly in amalgamation or amalgam burning was significantly higher (mean: 241 ng/ml) than that in the workers who spend most time in the mine than in the amalgamation area (mean: 40 ng/ml). The former group was on average 5 times more occupationally exposed to Hg vapour than the mine workers or part-time workers in amalgamation. Much lower urinary Hg levels (range: 1.3–4.5 ng/ml, mean: 2.6 ng/ml) were found in the general mine population (e.g. housewives, children) not directly exposed to Hg vapour. These data suggest that air Hg levels in the mine area were on average low with the exception of amalgam burning areas where high air Hg concentrations could be locally attained. The urinary Hg level that increases the incidence of Hg toxic effects is considered to be > 50 ng/ml [21]. Judging from this urinary Hg value, it is only the mine workers who are engaged mainly in amalgamation and amalgam burning that are at high risk of adverse effects due to Hg poisoning. Rotation of mine duties (e.g. amalgamation vs. gold mining) could lower Hg exposure levels and reduce the risks of Hg intoxication. All inhabitants of the Nungwe Bay fishing village investigated in this study, with one exception, had lower urinary mercury levels (mean: 1.2 ng/ml). This is consistent with urinary Hg levels of up to 4 μg/l [19] found in the general population not occupational exposed to Hg.

5. Conclusions

Biological monitoring of environmental and human exposure to Hg contamination in the Lake

Victoria goldfields (LVGF) has revealed low Hg concentrations in fish and human hair that are thought to represent background levels. Mean T-Hg concentration in 15 fish samples was 7.0 ppb (range: 1.8–16.9 ppb) whereas in 22 hair samples the concentration was 947 ppb (range: 156–5433 ppb). Extremely low mercury levels in the fish in comparison with published data from other parts of the world suggest the presence of low background MeHg levels in the Nungwe Bay area of Lake Victoria and its catchment areas. Gold mining activities seem, so far, not to have produced any significant increase in MeHg concentration in the environment that could be reflected in high fish Hg content. This could be because of very low net methylation rates of inorganic Hg released into the environment or because of strong binding of MeHg in soils, sediments and biota such that very little of the total MeHg budget is released to water bodies and available for bioaccumulation in fish or aquatic food chains. It is necessary to understand the dynamics of Hg cycling in the Lake Victoria goldfields in order to elucidate the fate of the Hg used in the gold extraction.

Urinary Hg levels in the Mugusu gold mine workers who are frequently exposed to Hg vapour during amalgamation and burning of amalgams were significantly higher (mean: 241 ng/ml) than the WHO 50 ng/ml limit, above which there is increase in incidences of inorganic Hg intoxication. Rotation of mine duties (e.g. amalgamation or amalgam burning vs. mining) reduced urinary Hg levels in the mine workers and hence the risk of mercury intoxication. The lowest urinary and hair T-Hg concentrations were found in the inhabitants of the Nungwe Bay fishing area. Low hair T-Hg concentrations in the fishing village inhabitants (mean: 304 ppb; range: 156–442 ppb) were consistent with the low Hg content of fish consumed in that area.

Acknowledgements

Fieldwork was made possible through the University of Dar es Salaam research project on 'Environmental aspects of Mining and Industrialization in Tanzania' financed by the SAREC (Swedish Agency for Research Cooperation with Developing Countries) Department of the Swedish International Development Authority (SIDA). Laboratory analyses were performed at NIMD under a research fellowship granted to JRI by Japan Science and Technology Agency (STA). We would like to thank Mr. K. Haraguchi of NIMD for technical assistance.

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