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ENVIRONMENTAL TRANSFORMATION AND DISTRIBUTION OF MERCURY RELEASED FROM GOLD MINING AND ITS IMPLICATIONS ON HUMAN HEALTH IN TANZANIA, STUDIED BY NUCLEAR TECHNIQUES

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Abstract

The dispersion and transformation of mercury in the southwest Lake Victoria goldfields was investigated through field and laboratory studies in order to evaluate the environmental impact and human health risks due to mercury pollution from small-scale gold mining in Tanzania. River sediment, gold-ore tailings, fish, and lichens were analyzed for their mercury content to determine mercury contamination levels. Mercury concentrations in the tailings from Rwamagaza mine were in the range of 165 to 232 mg/kg while at the Mugusu mine the maximum concentration was 6 mg/kg in the river sediment contaminated by the tailings. The dispersion of mercury along the Mabubi River downstream of the gold-ore processing site at the Mugusu mine decreased rapidly to less than 0.5 mg/kg at a distance of 4 km, and less than 0.1 mg/kg at 9 km. Granulometrical analysis of mercury distribution indicated highest mercury concentrations to be associated with the grain size fraction <212 mm in the sediment.

Total mercury concentrations in eight fish species from the Lake Victoria at Nungwe Bay were generally very low and varied from 2 to 34 µg/kg (w.w). The lowest concentrations were found in Tilapia and the highest in Nile perch. The percentage of methylmercury in the fish muscle ranged from 65 to 97%. These results suggest that mercury contamination from gold mining operations in the southwest Lake Victoria goldfields has not led to any significant increase in environmental methylmercury levels that could be reflected in high mercury concentrations in the fish. Based on these results, fish consumption from the Nungwe Bay area of the Lake Victoria does not pose any human health risks on account of very low mercury levels in the fish at present.

Mercury concentrations in two lichen species, Parmelia and Usnea, in the Geita Forest Reserve around the Mugusu mine ranged from 0.10 to 3.10 µg/g (d.w.). The mercury concentration in the lichens decreased away from the mine village, indicating the fall of mercury levels in the air away from the source of emission. The presence of the mercury gradient in the lichens around the mine, make the lichens suitable as a bioindicator for the assessment of air mercury pollution from gold-ore processing operations.

Results of the laboratory experiments on mercury adsorption by laterite and bauxite and mercury transformation and uptake by fish in an aquatic system contaminated by gold-ore tailings are also discussed.

1. INTRODUCTION

This project deals with the study of the dispersion patterns and the environmental transformation of mercury released from small-scale gold mining operations in the southwest Lake Victoria goldfields in northwestern Tanzania (Fig. 1), and its impact on human health. The project involves field studies and laboratory investigations. Laboratory studies are conducted in collaboration with the scientists at National Institute for Minamata Disease (NIMD) in Japan. One field study and two laboratory experiments have been completed since the project started.

The research activities accomplished include:

- Field study and collection of samples (sediment, tailings, lichens, fish) from the southwest Lake Victoria goldfields.
- Mercury analysis in fish, sediment, tailings, and lichens collected from the study areas.
- One laboratory experiment on the transformation and uptake of mercury by fish in a sediment-water system contaminated by metallic mercury from gold-ore tailings.
- Preliminary laboratory investigations of the mobility and adsorption of mercury in laterite and bauxitic soils.
- Synthesis of the fieldwork and laboratory data and preparation of a manuscript for publication of the research results from the lichen study.

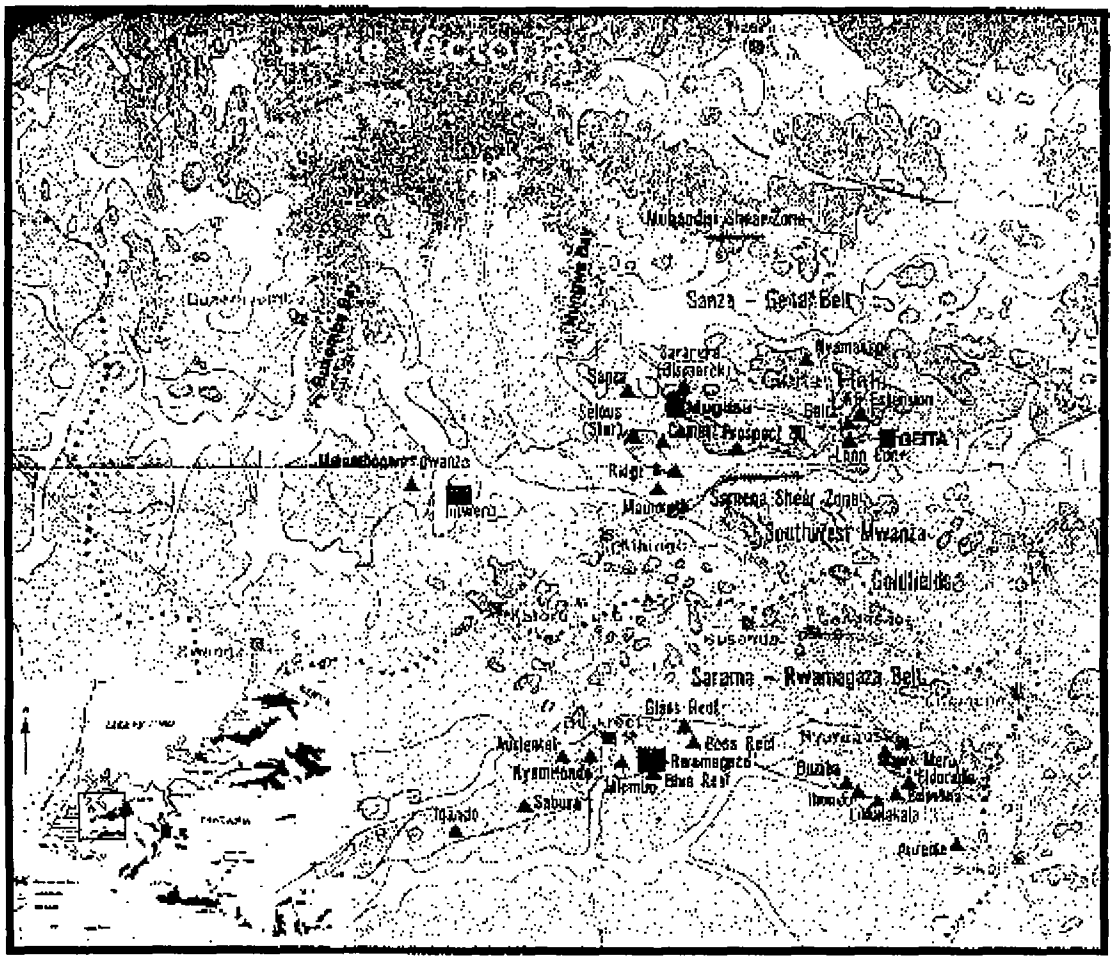

FIG 1: Map of Lake Victoria gold fields (black insert) and the study area

2. METHODS

2.1. Collection of Samples

River sediment and/or gold ore tailings were collected from three gold mining areas namely, Imweru, Rwamagaza and Mugusu in the southwest Lake Victoria goldfields (Fig. 1). Lichens were collected from the Geita Forest Reserve around the Mugusu mine, and from the woodland around the Imweru mine. Fish sampling was carried out at the Nungwe Bay Port in the southwestern part of Lake Victoria. The Nungwe Bay receives storm and river water from several gold mining areas including the Mugusu mine. Elaborate field sampling procedures and sample handling were followed to avoid mercury contamination during collection, transportation and storage of the samples.

2.2. Mercury Analysis in Sediment, Tailings, Fish and Lichens

Gold-ore tailings and sediment samples were analyzed for total mercury at the University of Dar es Salaam (UDSM) geochemical laboratory in Tanzania and at the National Institute for Minamata Disease (NIMD) in Japan. Total mercury and methylmercury analysis in fish and lichens was accomplished at NIMD, where highly sensitive analytical equipment was used for the measurement of very low mercury concentrations (<0.5 μg/kg) in the samples.

For total mercury analysis in sediment and soil at UDSM, 0.2-0.3 g of a dry sample are weighed in a quartz glass tube and digested with 3 ml of concentrated HNO_3 at 160°C for 2 hours in an oven. After adding HNO_3 to the sample, the quartz tube is normally sealed immediately with a Teflon cap and then loaded and closed tightly in steel digestion bomb. The bomb is then placed in the pre-heated oven at 160°C. After digestion, the bomb is removed from the oven and allowed to cool to room temperature. The quartz tube is then unloaded from the bomb and 7 ml of distilled, de-ionized, mercury free water added to the digested sample. Internal reference standard materials and reagent blanks are prepared in the same way as the samples. The measurement of mercury concentration in the sample solution is carried out by cold vapour atomic absorption spectrometry (CVAAS) using the Perkin Elmer AAS (Model 2380). The accuracy and precision of total mercury analyses were ensured using an internal reference standard, analyzing sample blanks and duplicate samples, and by carrying out inter-laboratory comparison of results between UDSM and NIMD.

The analytical procedures for total mercury and methylmercury at NIMD are well described in several publications [1], [2], [3]. The accuracy and precision of the analytical methods at NIMD have been verified through inter-laboratory comparison exercises and by participating in the analysis of standard reference materials produced by the International Atomic Energy Agency (IAEA), such as IAEA-0140 [4].

For total mercury analysis, 0.5 g of fish, 0.2 g of sediment or lichen sample were placed into a 50 ml Pyrex glass flask and then digested with 1ml of Hg-free water, 2 ml of HNO_3-$HClO_4$ (1:1), and 5 ml of H_2SO_4 at 200 ± 5°C for 30 minutes on a hotplate. After cooling, the sample solution was made up to 50 ml with dionized Hg-free water. The mercury content in the final solution was determined by Cold Vapour Atomic Absorption Spectrometry using Sanso Automatic Mercury Analyzer (HG-5000)

In the analysis of methylmercury in fish samples, 0.5 g of fish muscle were placed into 50 ml conical Pyrex glass test tube, to which 10 ml of 1 N potassium hydroxide solution in ethanol (KOH-Et) were added. The test tube was closed tightly with a screw cup containing Teflon lining, and then placed into ethylene glycol hot bath at 100°C. The sample was digested in the hot bath for 30 minutes and then allowed to cool to room temperature. After cooling, mercury in the sample solution was extracted with 5 ml 0.01% dithizone solution in toluene (Dz-Toul). The Dz-Toul extract was washed twice with 3 ml 1N NaOH to remove excess dithizone and obtain a clear solution of methylmercury dithizonate in toluene. After washing, methylmercury was back-extracted into the aqueous phase using 5 ppm Na_2S alkaline solution. The aqueous solution was washed with 2 ml of toluene to remove organic impurities. Thereafter, the aqueous solution was slightly acidified with 4 to 5 drops of 1N HCl and bubbled with N_2 gas (50 ml/min.) to purge excess sulfide ions as H_2S gas. After bubbling, 2 ml of Walpole Buffer (pH 3) were added to the aqueous solution, before methylmercury was re-extracted with 0.5 ml of 0.01% Dz-Toul. The Dz-Toul extract was washed with 3 ml 1N NaOH, and then acidified with 2 drops of 1N HCl. Methylmercury concentration in the acidified Dz-Toul extract was finally determined by ECD Gas Chromatography.

2.3. Investigation of Mercury uptake by Fish

An aquarium experiment to investigate the transformation of metallic mercury and the uptake of mercury by fish was conducted in the Department of Geology at the University of Dar es Salaam for eight weeks from October to December 2000. The purpose of the experiment was to determine and evaluate the rate and levels of mercury accumulation in fish from tropical water-sediment systems contaminated by metallic mercury from gold-ore tailings. The tailings, sediment and water used for the experiment were collected from Rwamagaza and Mugusu gold mining centers (Fig. 1). It was envisaged that the results of the experiment would provide better understanding of the environmental conditions in which metallic mercury pollution poses greater health risk to local communities through enhanced geochemical and biochemical transformation and accumulation in fish and other aquatic organisms consumed in those communities. Fish samples collected from the experiment were kept frozen and finally air freighted to Japan for mercury analysis at the National Institute for Minamata Disease (NIMD). Analytical facilities at NIMD offered better detection limits for mercury than those achieved in the geochemical laboratory at the University of Dar es Salaam (UDSM). Also methylmercury analysis could not be done at UDSM. The research collaboration with NIMD offered good opportunity for accomplishing research tasks that could not be done in Tanzania.

2.3.1. Experimental Setup

Four glass aquariums (60 x 45 x 30 cm) were used for the experiment. River sediment and gold-ore tailings contaminated with metallic mercury from gold ore processing operations at the Mugusu and Rwamagaza mines were sieved (<2 mm), weighed and then placed into three aquariums labeled AQ1, AQ2, and AQ3. Aquariums AQ1 and AQ2 consisted the same type of sediment from Mabubi river, at the Mugusu mine. Aquarium AQ3 contained marsh soil-sediment from a seasonal stream channel north of the Rwamagaza mine. Water from the same localities was added to each aquarium. The sediment/tailings were allowed to settle and equilibrate with the water for two weeks. The fourth aquarium was kept as a sediment-free control (AQC). The aquariums were rapped with an opaque paper to permit light only from the top of the aquarium. After settling, 10 small tropical gold fish were introduced into each aquarium. A nylon fiber screen was placed above the sediment in each aquarium before the fish were introduced, in order to avoid the stirring of the sediment by the fish. The water in the aquariums was kept oxygenated by bubbling air through the water using air pumps. Freshwater weed was added into AQC and AQ2 also to oxygenate the water. The fish were fed once per day during the experiment. Two to three fish samples were collected from each aquarium at the end of the 2nd, 4th and 6th weeks for aquariums AQ1, AQ2 and AQ3, and the 8th week for aquarium AQ2. Fish samples from the control aquarium (AQC) were collected during the 1st week and the 6th week of the experiment. All fish samples were kept frozen until the time of analysis.

During the course of the experiment, freshwater snails, which came accidentally in the weed, flourished in the aquarium AQ2. Since the snails were feeding largely on the weed, the weed in the aquarium AQ2 was finally wiped out by the end of the 3rd week of the experiment. The rate of regeneration of the weed in the aquarium was basically outweighed by the consumption rate by the snails and probably the fish. A composite sample of the snails was collected for mercury analysis at the end the 8th week of the experiment. Table 1 below shows the summary of the experimental conditions.

TABLE I: WATER-SEDIMENT INCUBATION SETUP

Aquarium No.	Dry sediment ± tailings (kg)	Sediment (d.w.) T-Hg (mg/kg)	Sediment organic matter content	Water added (Litres)	Water/Sediment Ratio	Water Temperature	Water pH 2nd Week* 6th Week*	Conductivity µS/cm 6th Week*
AQ1	3.84	6	10%	17.28	4.5	28±0.5°C	7.8; 8.2	570
AQ2	3.88	6	10%	17.46	4.5	28±0.5°C	7.7; 8.2	500
AQ3	2.07	0.08	>10%	13.46	6.5	28±0.5°C	7.3; 7.2	104

*Since the fish were introduced into the aquarium.

2.4. Investigation of Mercury Adsorption in Bauxite and Laterite

A preliminary experiment to evaluate the adsorption of mercury from gold ore tailings by laterite soils was also conducted during the year under review. The objective of the experiment was to determine whether there were any significant differences in mercury adsorption capacity between iron-rich and aluminium-rich soils and the implication of the adsorption in the mobility of mercury in contaminated areas. Studies in the Amazon region have shown that soils of contrasting composition have different affinities for mercury [5]. In Tanzania, different soil types reflecting bedrock geology and geomorphological position underlie various terrains in the goldfields impacted by mercury contamination. The mobility of mercury in such areas would probably vary depending on the soil characteristics. Among the different soil types, laterite soils (i.e. Fe- or Al-rich) are considered more effective in mercury absorption due to the presence of suitable adsorption sites on Fe-Al oxyhydroxides. It is, however, not known which type of laterite has higher adsorptive properties for mercury and hence more effective in reducing mercury mobility and cycling in contaminated areas. The present experiment attempted to elucidate the adsorption capacity of the two types of laterite for mercury from mine tailings via a water interface.

2.4.1. Experimental Setup

Gold-ore tailings contaminated with metallic mercury from gold mining operations at Rwamagaza mine were used for the experiment. The tailings, containing mercury concentration of 165-170 mg/kg, were introduced into a glass aquarium and 14.25 liters of fresh water from the same locality were added. The tailings and water were allowed to settle and equilibrate for 21 days. After equilibration, about 2.5 g of iron-rich laterite soil of different of grain sizes (<2-0.2, <0.2-0.063, <0.063 mm) were weighed separately onto porcelain dishes (experiment cells) and then suspended in water in the aquarium. The dishes were suspended such that they were about 10 cm above the tailings-water interface. Two dishes each containing 2.5 g of powered bauxite ore (<0.063 mm) were also suspended in the water. The experimental cells were allowed to equilibrate with the water for 14 days, before the cells were retrieved from the water and dried in the oven at 40°C. Dry laterite and bauxite from the cells was then analyzed for total mercury. Untreated laterite and bauxite were also analyzed for mercury to determine their initial mercury content. The mercury analysis was carried out at the University of Dar es Salaam in Tanzania and the National Institute for Minamata Diseases in Japan. The results for the experiment are discussed in Section 3.3.0 of the report.

3. RESULTS AND DISCUSSION

3.1. Mercury Distribution in Mugusu River Sediments

A summary of granulometrical analysis of mercury distribution in Mugusu (Mabubi) river sediments is given in Figures 2 and 3. Highest mercury concentrations were associated with the grain size fraction <212 μm. The coarse sediment fraction (>300 μm) had the lowest concentrations. Mercury concentrations in the fine-grained sediment (<212 μm) decreased from 5,228 ng/g within one kilometre from the gold-ore processing site to as low as 415 ng/g about 4 km downstream. The mercury concentrations decreased almost to background levels (<100 ng/g) about 9 km downstream, close to the Nungwe Bay of the Lake Victoria.

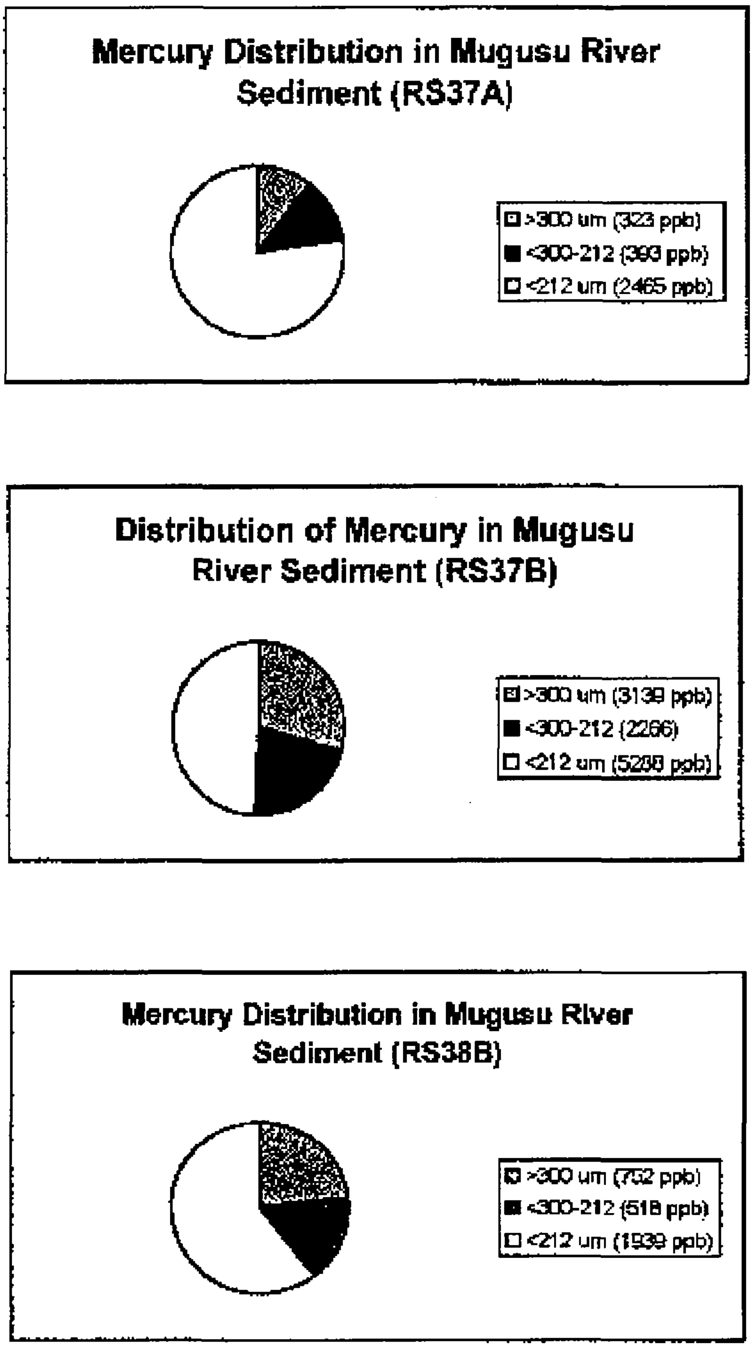

FIG 2: Mercury distribution in different grainsize fractions of river sediments downstream (1-2.5 km) of gold processing site

These data suggested that mercury transport along the Mugusu River drainage channel from the gold-ore processing site is generally very low, especially during the dry season when he river flow is lowest. Samples collected in the middle of the riverbed or drainage channel generally had lower mercury concentrations those from the edge of the riverbed at the same sampling location.

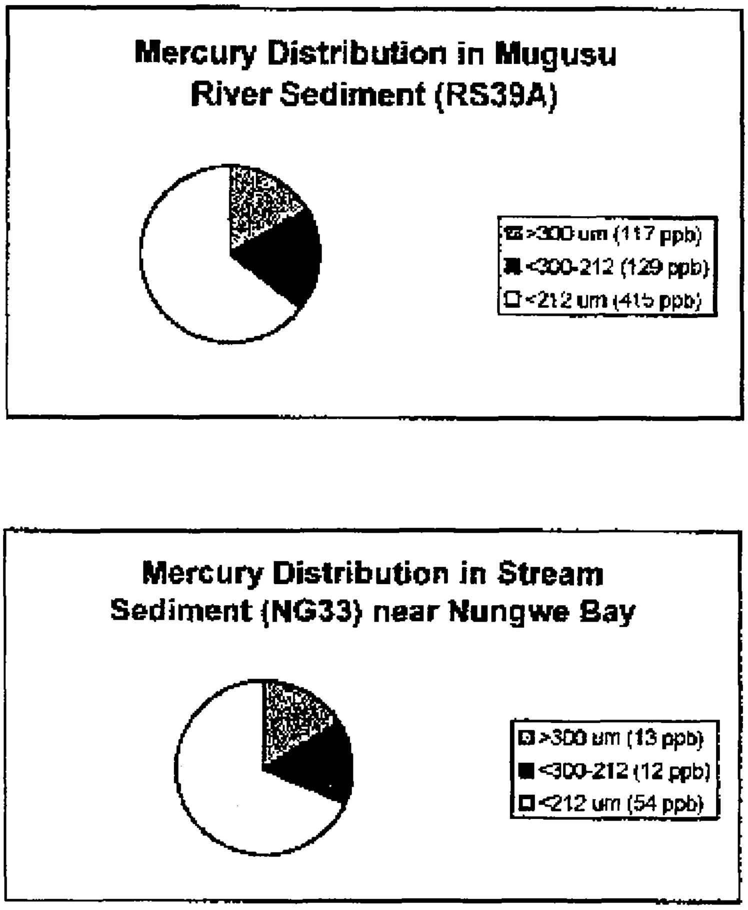

FIG 3: Distribution of mercury in different grainsize fractions of sediments about 4 km downstream of gold processing site (RS39), and 9 km further downstream (NG33) just before Lake Victoria Nungwe Bay

3.2. Mercury Levels in Lichens

Mercury concentrations in two lichen species, *Parmelia sp.* and *Usnea sp.*, around the Mugusu gold mine in the Geita Forest Reserve ranged from 0.10 to 3.10 µg/g (Table 2). The highest mercury concentration was recorded in the *Parmelia* lichen (LC-3) collected from a tree near the gold-ore processing site in the mine village. Mercury levels in the *Parmelia* decreased from 3 µg/g in the mine village to 0.4 µg/g about 3 km northwest of the mine. A more rapid decrease of the mercury levels in the lichens was recorded in the eastward direction from the mine. Lichens collected about 1.5 km SE of the mine village had mercury concentration of 0.2 µg/g, while in a composite sample collected 6 km NE of the mine, the concentration was 0.1µg/g. The latter sample was collected to determine mercury background levels in the *Parmelia*. The mercury gradients in the lichens west and east of the mine were consistent with the westerly prevailing wind direction.

TABLE II: THg ANALYSES FOR LICHENS FROM IMWERU AND MUGUSU MINE AREAS

Sample No.	Locality/ Mine	Distance* (km)	Lichen Type	THg (μg/g)
LC-1B	Imweru	1.8 NE	I	0.13
LC-2A	Imweru	1.6 S	I	0.08
LC-2B	Imweru	1.6 S	II	0.44
LC-3	Mugusu	0	I	3.10
LC-4A	Mugusu	1.5 SE	I	0.21
LC-4B	Mugusu	1.5 SE	II	0.16
LC-5	Mugusu	1 NW	I	1.09
LC-6	Mugusu	2 NW	I	0.47
LC-7A	Mugusu	2 NW	I	0.54
LC-8	Mugusu	3 NW	I	0.42
LC-9	Mugusu	6 NE	I	0.10

Lichen Type I: *Parmelia sp*; Type II: *Usnea sp.*
*Sampling distance from the mine village

Lichens are considered useful bio-indicators of air quality since they obtain most of their nutrients directly from the atmosphere; they are good metal accumulators and usually have wide geographical distribution [6], [7]. Trace metal contents in lichens have been used worldwide in the assessment and evaluation of air quality [8], [9], [10], especially in areas affected by air pollution from industrial or volcanic gaseous emissions. Biomonitoring studies have demonstrated that the metal concentrations in lichens reflect to the large extent atmospheric trace element levels and/or deposition [11]. A successful biomonitoring program is feasible when contaminant burden is readily distinguished from background levels in the lichens being investigated.

The results from the study indicate that the *Parmelia* lichen could be used successfully in the biomonitoring of air pollution by mercury in the Lake Victoria goldfields. The biomonitoring would help to identify areas and villages that are impacted by airborne mercury pollution apart from the mining centers. The present results indicate that villages at a distance of 3 km from the gold mine in the windward direction experienced elevated air mercury concentrations that are 4 times higher than the local background level. It is important to extend the biomonitoring further away from the Mugusu mine in order to determine the locations where mercury gradient falls to background levels in the westerly direction. It is also necessary to extend similar biomonitoring to other mining areas so as to determine areas and villages that are affected by airborne mercury pollution. Impacted areas would need short- and long-term air pollution management and mitigation measures to offset potential human health risk from airborne mercury exposure.

3.3. Mercury Levels in Fish from Nungwe Bay

Table 3 shows the results for total mercury and monomethylmercury analysis in fish samples from the Nungwe Bay. Mercury levels in 8 fish species ranged from 2 to 34 ng/g. The percentage of methylmercury in the fish was in the order of 65 to 97%. The lowest mercury concentrations were found in Tilapia, which is an herbivore, and the highest in Nile perch, which is a piscivore. These fish mercury levels are among the lowest to be reported in fresh water fish. Since fish tend to accumulate monomethylmercury than inorganic mercury, these results indicate that methylmercury levels in the Lake Victoria environment are still extremely low. The results also suggest that the discharge of metallic mercury from gold mining activities in the southwest Lake Victoria goldfields (Geita District) has not led to any significant increase in environmental methylmercury levels that could be reflected in high fish mercury levels.

The mercury levels in the Nungwe Bay fish from the present study are similar to those found in the previous mercury monitoring study by [12]. They are also within the range of mercury concentrations reported by Kahatano et al. [13] in the fish collected from Mwanza and Smith Sound areas of the Lake Victoria.

The dynamics of metallic mercury transformation and cycling in the Lake Victoria goldfields remain poorly understood. The present results, however, suggest that methylmercury production and bioaccumulation in the Lake Victoria environment is probably still low.

TABLE III: TOTAL MERCURY (THg) AND METHYLMERCURY (MeHg) ANALYSES FOR LAKE VICTORIA FISH FROM NUNGWE BAY.

Sp. No.	Fish Name	Fish Body wt (g)	Length (cm)	THg ng/g	MeHg ng/g	MeHg %
FS-1	Tilapia	925	36	3.9	3.3	84.61
FS-2	Tilapia	525	29.5	2.4	2.2	91.67
FS-3	Nile Perch	950	44	34.1	32	93.84
FS-4	Nile Perch	350	33	11.8	11.5	97.46
FS-5A:C	Kamongo	6750	119	30.5	27.6	90.49
FS-5B:T	Kamongo	6750	119	29.3	22.7	77.47
FS-6	Mumi	1250	56	12.9	11.9	92.25
FS-7	Kambale	114	24	8.3	7.8	93.98
FS-8	Kambale	57	19.5	7.0	6.8	97.14
FS-9	Shilonge	43	30	3.0	2.4	80.00
FS-10	Fulu	57	15	5.1	4.4	86.27
FS-11	Fulu	28	12.5	4.3	3.5	81.40
FS-12	Fulu	20	10	3.5	2.7	77.14
FS-13	Salari	28	11.5	25.9	16.7	64.48
FS-14	Salari	23	10.5	7.3	5.3	72.60
FS-15	Salari	14	10	14.3	13.4	93.71

3.4. Adsorption of Mercury in Laterite and Bauxite

The results of mercury adsorption experiment are given in Table 4. For Fe-rich laterite soil, mercury adsorption factors (expressed as a ratio of total mercury concentration in the sample after [A] and before [B] the experiment) were in the order of 8.5 to 9.5. There were no marked differences in the adsorption of mercury in the Fe-laterite soil with grain size <0.063 mm and <0.2 to 0.063 mm; the clay-silt and fine sand fractions. The adsorption was somewhat low in the medium- to coarse-grained laterite (<2 – 0.2 mm).

TABLE IV: MERCURY ADSORPTION FACTORS FOR Fe-LATERITE AND Al-BAUXITE

Exp. Cell No.	Material Type	Material Wt. (g)	Grain Size (mm)	Av. THg* Before: B	Av. THg* After: A	Hg Sorption Factor: A/B
RZ51	Bauxite	2.500	<0.063	804	924	1.1
RZ52	Qtz sand	2.500	<0.2-0.063	ND	75	ND
RZ53	Bauxite	2.500	<0.063	804	969	1.2
RZ54	Fe-laterite	2.502	<2-0.200	16	138	8.6
RZ55	Fe-laterite	2.502	<0.2-0.063	16	150	9.4
RZ56	Fe-laterite	2.501	<0.063	16	150	9.4
RZ57	Fe-laterite	2.500	<0.063	16	147	9.2

*Total mercury (ng/g); ND: Not Determined

Fine-grained bauxite material (<0.063 mm) used for the experiment was obtained by crushing bauxite ore. The ore turned out to have elevated mercury concentration (>860 ng/g) either due to contamination during pulverization or because of original high mercury background. The adsorption of mercury in the clay-silt size fraction (<0.063 mm) of the powdered bauxite ore was not clearly discernable because of the initial high mercury concentration. The adsorption factors for two samples of bauxite were 1.1 and 1.2, indicating very little sorption of mercury in the experiment cell. The adsorption sites for mercury in the bauxite were probably already saturated with mercury. It will be important to repeat the experiment using bauxitic laterite with low background mercury concentration, in order to clarify the effect of Al-rich soils in the mobility of mercury in tropical environments.

TABLE V: TOTAL MERCURY (THg) AND METHYLMERCURY (MeHg) CONCENTRATIONS IN THE FISH FROM THE AQUARIUM EXPERIMENT

Aquarium No.	*1st Week*	*2nd Week*	*4th Week*	*6th Week*	*8th Week*
AQC	N = 4 W = 1.58 **THg = 53.7**			N = 3 W = 1.82 **THg = 30.0**	
AQ1		N = 2 W = 2.54 **THg = 37.5** MeHg = 41.3 (n=1) (82.93%)	N = 2 W = 2.13 **THg = 66.5** MeHg = 58.4 (87.82%)	N = 3 W = 2.32 **THg = 36.1** MeHg = 36.7 (n=2) (89.09%)	
AQ2		N = 2 W = 4.82 **THg = 68.4** MeHg = 57.6 (84.21%)	N = 2 W = 3.93 **THg = 89.9**	N = 3 W = 2.09 **THg = 45.0** MeHg = 50.2 (n=2) (102.87%)	N = 2 W = 2.09 **THg = 91.0** MeHg = 73.6 (80.88%)
AQ3		N = 1 W = 4.16 **THg = 65.4** MeHg = 54.1 (82.71%)	N = 1 W = 5.98 **THg = 83.8** MeHg = 57.0 (68.02%)	N = 3 W = 2.52 **THg = 32.6** MeHg = 23.6 (n=2) (91.47%)	
AQ2/Snail*					**THg = 233.9** MeHg = 30.2 (12.90%)

AQC: Control aquarium; N: number of fish samples; W: Fish average weight (g);
THg: Weighted average total mercury concentration (ng/g); MeHg: Methylmercury (%); n: number of MeHg analyses if different from N.
* Composite sample of freshwater snail from aquarium 2.

3.5. Results for Aquarium Fish Experiment

The results for the fish experiment are summarized in Table 5. In the control aquarium, average mercury levels in the fish decreased almost by 45% from 54 ng/g to 30 ng/g during the 6 weeks of the experiment. This suggested that the fish food did not contribute to any increase in the fish mercury levels. It is worthwhile to note that while the mercury concentration decreased by almost 45%, the average fish weight increased only by 15%. If the decline of mercury level in the fish is attributed to mass dilution as a result of the fish growth, then it seems that the decline rate was nearly 3 times higher than the gain in fish body weight. The reason for this decrease in the fish mercury concentration is not understood.

The average fish mercury levels in the aquarium 1 declined during the first two weeks of the experiment in comparison with the control. The decline was, however, reversed between the

3rd and 4th weeks, when the fish mercury levels increased to 67 ng/g (w.w.). In the aquariums 2 and 3, mercury concentration increased progressively in the fish during the first four weeks of the experiment, reaching the level of about 90 ng/g and 84 ng/g, respectively, at the end of the 4th week.

Between the 5th and 6th weeks, mercury levels in the fish declined in all the aquariums, reaching similar levels as the control at the end of the 6th week. In the aquarium 2, where the experiment continued to the 8th week, the mercury levels in the fish increased again between the 7th and 8th week, attaining same levels as those in the 4th week (90 ng/g).

Mercury patterns in the aquarium fish described above are quite abnormal in comparison with the patterns reported from previous fish experiments [14], [15]. In the previous experiments, mercury concentrations commonly showed a progressive increase in the fish at least during the first three weeks of the experiment, following the contamination of the aquarium sediments with mercury. The obvious fundamental difference between the present and previous experiments lies in the form of mercury contamination in the aquarium sediment. Whereas in this experiment the sediments were contaminated by metallic mercury in the other experiments mercury chloride was the contaminant. In contrast to the mercury chloride, the transformation of metallic mercury to methylmercury is probably slow since it requires the oxidation step before the mercury is available for methylation and accumulation in fish and other aquatic organisms. The oxidation of elemental mercury is probably the rate-limiting step for the methylation and bioaccumulation of mercury in aquatic systems contaminated by mercury-bearing gold-ore tailings.

While the results presented here are subject to reconfirmation by further studies, they point to unusual mercury uptake and release behavior by the tropical fish in a model of an aquatic system contaminated by metallic mercury.

4. RESEARCH PROGRESS AND PLANS

4.1. Progress

Research activities are progressing well and yielding useful results. One field study and two laboratory experiments have been completed. One manuscript of the results from the lichen study has been submitted for publication in the Bulletin of Environmental Contamination and Toxicology journal.

4.2. Plans

We are planning to carry out the following activities:

- To conduct further laboratory studies on the oxidation and methylation of mercury in tailings in order to evaluate the environmental factors that are important for mercury cycling in areas impacted by metallic mercury pollution from gold mining operations. The studies will be done in collaboration with scientists at the National Institute for Minamata Diseases (NIMD, Japan);

- To determine the mineralogical and chemical characteristics of iron-laterite and bauxitic laterite and bauxite in relation with Hg mobility and adsorption in tropical soils using XRD/XRF techniques;

- To carry out a follow up field work study in selected areas of the Lake Victoria goldfields for testing and validating results obtained from the laboratory experiments; and

- To prepare a final technical report for the project and process the research results for publication.

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REFERENCES

[1] AKAGI, H., NISHIMURA, H., Speciation of mercury in the environment, in T. Suzuki, N. Imura and T.W. Clarkson (eds.), Advances in Mercury Toxicology; Plenum Press, USA, (1991) 53-76.

[2] AKAGI, H., Analytical methods for evaluating human exposure to mercury due to gold mining. Proceedings, Intern. Workshop: Health and Environmental effects of Mercury due to Mining operations. Manila, Philippines; National Institute for Minamata Disease, Japan, (1997) 131-141.

[3] AKAGI, H., IKINGURA, J.R., Analytical technique for the evaluation of the environmental factors influencing the dynamics of mercury in aquatic systems with particular emphasis on tropical areas. Proceedings, NIMD Forum 2001 – Mercury Research: Today and Tomorrow, Nation. Inst. for Minamata Disease, Japan, (2001) 1-11.

[4] COQUERY, M., CARVALHO, F.P., HORVAT, M., AZEMARD, S., World-wide intercomparison exercise for the determination of trace elements in Fucus sample IAEA-140. IAEA, MEL, Report No. 64 (1997), 93 p.

[5] ROULET, M.I., FORSBERG, B.R., GUIMARAES, J.R.D., MAURICE-BOURGOIN, L., LUCOTTE, M., ZEIDEMANN, V.K., The geochemical relationship between mercury and oxyhydroxides in Amazonian soils and sediments; Abstracts 6th ICMGP, Minamata, Japan, (2001).

[6] MULGREW, A., WILLIAM, P., Biomonitoring of air quality using plants: Lichens. Air Hygiene Report No. 10, WHO Collaborating Centre for Air Quality Management and Air Pollution Control; Berlin,(2000) 13-29.

[7] QUEVAUVILLER, PH., HERZIG, R., MUNTAU, H. Certified reference material of lichen (CRM 482) for the quality control of trace element biomonitoring. Sci. Tot. Environ. 187 (1996)143-152.

[8] NIMIS, P.L., ANDREUSSI, S., PITTAO, E., The performance of two lichen species as bioaccumulators of trace metals. Sci. Tot. Environ. 275 (2001) 43-51.

[9] NASH III, T.H., GRIES, C. The use of lichens in atmospheric deposition studies with emphasis on the Arctic. Sci. Tot. Environ. 160/161 (1995) 729-736.

[10] NYANGABABO, J.T., Lichens as monitors of aerial heavy metal pollutants in and around Kampala. Bull. Environ. Contamin. Toxicol. 38 (1987) 91-95.

[11] WOLTERBEEK, H. TH., BODE, P., VERBURG, T.G., Assessing the quality of biomonitoring via signal-to-noise ratio analysis. Sci. Tot. Environ. 180 (1996) 107-116.

[12] IKINGURA, J.R., AKAGI, H., Monitoring of fish and human exposure to mercury due to gold mining in the Lake Victoria goldfields, Tanzania, Sci. Tot. Environ. 191 (1996) 59-68.

[13] KAHATANO, J.M.J., MNALI, S.R., AKAGI, H., A study of mercury levels in fish and humans in Mwakitolyo mine and Mwanza town in the Lake Victoria goldfields, Tanzania; in Landner L. (Ed.) Proceedings of Intern. Confer. on Small-scale Mining in African Countries: Prospects, Policy, and Environmental Impacts; CM Gruppen, AB, Bromma, Sweden; (1997) 159-170.

[14] SHIN, E-B., KRENKEL, P.A., Mercury uptake by fish and biomethylation mechanisms, J WPCF 48/3 (1976) 473-501.

[15] IKINGURA, J.R., AKAGI, H., Methylmercury production and distribution in aquatic systems, Sci. Tot. Environ. 234 (1999) 109-118.