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Final Report for an Assessment of the Environment and Health in the Rwamagasa area, Tanzania. UNIDO Project EG/GLO/01/G34

Environmental Protection Programme

Commissioned Report CR/04/129

BRITISH GEOLOGICAL SURVEY

COMMISSIONED REPORT CR/04/129

Final Report for an Assessment of the Environment and Health in the Rwamagasa area, Tanzania. UNIDO Project EG/GLO/01/G34

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Key words

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Front cover

Cover picture Covered amalgamation pond and sluices at tailings reprocessing site adjacent to the *mbuga* of the River Isingile.

Bibliographical reference

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Foreword

This final report is a published product of a study by the British Geological Survey (BGS) and the Institute of Forensic Medicine, Ludwig-Maximilians-University, Munich carried out on behalf of UNIDO as part of Project No. EG/GLO/01/G34 "Removal of Barriers to the Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies.

The report comprises (1) an Executive Summary jointly compiled by the BGS and the Institute of Forensic Medicine, Ludwig-Maximilians-University, Munich; (2) an Assessment of the Environment in the Rwamagasa area (BGS Commissioned Report CR/04/014R); and (3) a Medical Investigation of 250 people living in the Rwamagasa area (compiled by the Institute of Forensic Medicine, Ludwig-Maximilians-University, Munich)

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Executive Summary

Introduction

Artisanal gold mining is one of the major sources of mercury contamination, especially in developing countries. Whilst the gold extraction process (known as amalgamation) is a simple technology, it is potentially very harmful to the environment and can contaminate air, soil, rivers and lakes with mercury. The health of the miners and other people living within the area affected by mercury contamination may be negatively affected through inhalation of mercury vapour or contaminated dusts, direct contact with mercury, through eating fish and other food, and through the ingestion of waters and soils affected by the mercury contamination.

In response to this problem, the Global Environmental Facility (GEF) of the UN approved funding for the project *Removal of Barriers to the Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies* (also referred to as the *Global Mercury Project (GMP)*) in March 2002. The Global Mercury Project was started to help demonstrate ways of overcoming barriers to the adoption of best practices, waste minimization strategies and pollution prevention measures that limit contamination of international waters and their associated environments.

In August 2003, the British Geological Survey (BGS), acting under the Natural Environment Research Council, signed a contract (No. 03/088) with the United Nations Industrial Development Organization (UNIDO) to carry out limited Environmental and Health surveys and assessments in the Rwamagasa artisanal gold mining area in the Republic of Tanzania. Rwamagasa was selected by UNIDO as the demonstration site for Tanzania. The environmental assessment was executed by the BGS whilst the medical and toxicological investigations were subcontracted to the Institut für Rechtsmedizin der Ludwig-Maximilians-Universität München, Germany. The regional health authorities in Geita supported the medical investigations, whilst the environmental assessment was carried out in collaboration with staff from the Geita Mines Office and from the Kigoma and Mwanza offices of the Tanzania Fisheries Research Institute (TAFIRI), with the enthusiastic assistance of Mr Aloyce Tesha, Assistant to the UNIDO Country Focal Point.

Rwamagasa is located in Geita District, which has an area of 7,825 km², 185 villages, and a population around 712,000 (census of 2002). The number of artisanal miners in the Geita District is unknown by it is estimated to be as many as 150,000, most of whom are illegal panners. Primary artisanal workings in the Rwamagasa area are centred on quartz veins in sheared, ferruginous, chlorite mica schists. Grab samples of vein and wall rock grade 6-62 g/t Au. The only legal mining in the Rwamagasa area is carried out within the boundaries of the Primary Mining Licence held by Blue Reef Mines where approximately 150 people are involved in mining and mineral processing activities. This is the only site in the Rwamagasa

area where primary ore is being mined underground. All other mineral processing activity of any significance is concentrated at the northern margin of Rwamagasa, especially on the land sloping down to the Isingile River. In this area, there are about 30 groups of historic and active tailings dumps and about ten localities where small (200 litre) ball mills are operating. The number of people actively involved, at one particular time, in ball milling, sluicing and amalgamation is probably no more than 300.

Amalgam is burned in a small charcoal fire, which releases Hg to the atmosphere. Retorts are not used. Amalgamation mainly takes place adjacent to amalgamation ponds, which are usually formed of concrete, but sometimes have only wood walls even though environmental legislation dictates that the Hg contaminated mineral concentrates and tailings should be stored in concrete lined structures.

The Blue Reef Mine is reported to produce about 1 kg Au per month whereas artisanal miners re-working tailings produce about 0.5 kg per month. On this basis, approximately 27 kg of Hg will be released to the environment from the Rwamagasa area each year. Of this, atmospheric emissions from amalgam burning will be about 14 kg from the Blue Reef mine site and 7 kg from the other amalgamation sites. About 2 to 3 kg Hg will remain in heavy mineral tailings in the amalgamation ponds, which are frequently reprocessed. It is reported that the number of miners working in the Rwamagasa area was much larger in the past, so the historical release of mercury would probably have been higher than at present.

The young and strong men, so called healthy workers, are mainly found in the bigger and more technically equipped properties. Older people, women of all ages and children mainly work in the smaller artisanal mining properties. Retorts are not used, neither is there any other protection, such as ventilation, against any kind of mercury contamination. Housing areas, food stalls and the schools are located close to the sites where amalgamation and burning of the amalgam is carried out. Mineral processing tailings containing mercury are found within the village adjacent to cultivated land or near local water wells. Mercury is usually stored in the miner's houses in small soft-drink bottles, near to where they and their families sleep. The mercury is mainly obtained from Nairobi in Kenya and the gold is either used for jewellery in Tanzania or sold to Dubai.

Hygiene standards are extremely low and are a reason for many infectious diseases such as diarrhoea, typhoid and parasitism. There is no effective waste disposal system for either mercury, sanitary or other domestic waste.

Road accidents, accidents in insecure tunnels and amalgamation plants, malaria, tuberculosis, and sexually transmitted diseases including AIDS are the dominant causes of morbidity and mortality. No special health service exists for the mining community – the nearest dispensary is about 10 km away. A local dispensary is under construction, but the construction has been stopped due to lack of money. The village lacks social welfare services and a police post for security. The nearest district hospital is in Geita. All non-minor illnesses have to be transferred to Geita hospital, which is adequately equipped for a district hospital.

Environmental assessment field programme

The objective of the environmental assessment was to (i) identify hotspots in the project demonstration sites, (ii) conduct specified geochemical and toxicological studies and other field investigations in order to assess the extent of environmental pollution in surrounding water bodies and (iii) devise intervention measures. Although Rwamagasa is located only 37 km to the south of Lake Victoria, streams draining the Rwamagasa 'mining hotspot' actually drain SW into the Nikonga River, and then for a further 430 km via the Moyowosi swamps and the River Malagarasi before reaching Lake Tanganyika near Ilagala, about 50 km to the SSE of Kigoma. One of the major objectives of the project is to assess the impact of mercury contamination on international waters as well as in the vicinity of the 'mining hotspot', so the field programme was carried out in two areas: (a) the Rwamagasa 'mining hotspot' sub-area and (b) the Lake Tanganyika – River Malagarasi sub-area (see Figure ES-1). Dispersion of Hg from Rwamagasa to Lake Tanganyika is probably relatively unlikely because contaminant Hg will be adsorbed by organic material in the extensive Moyowozi and Njingwe Swamps and flooded grassland area, located from 120 km to 350 km downstream of Rwamagasa. Whereas the swamps will act as a potential biomethylation zone, they will also act as an environmental sink for Hg contamination, which is likely to inhibit migration of Hg into the lower reaches of the Malagarasi River and Lake Tanganyika. The swamp area was inaccessible within the logistical and budgetary constraints of the current project.

The environmental field programme was carried out during the dry season at which time there was little evidence that large quantities of contaminated tailings were being washed into the Isingile River. However, waste water and tailings from amalgamation 'ponds' were observed at one site to be overflowing onto an area where vegetables were being grown. If large quantities of Hg contaminated tailings are dispersed onto the seasonal swamp (*mbuga*) area adjacent to the Isingile River during the wet season, then this may lead to the significant dispersion of Hg both into the aquatic system and onto agricultural sites being used for rice, maize, and vegetable cultivation.

Previous studies in the Lake Victoria Goldfields area indicate that dispersion of Hg from tailings is relatively restricted, not least because Fe-rich laterites and seasonal swamps (*mbugas*) act as natural barriers or sinks attenuating the widespread dispersion of Hg in sediments and soils.

A field programme was carried out in September–October 2003 leading to the collection of a total of 38 water, 26 drainage sediment, 151 soil, 66 tailings, 21 vegetable and 285 fish samples. Preparation and analysis of the samples was carried out in the UK and Canada. Analytical data for duplicate field samples, replicate analyses and recovery data for Certified Reference Materials indicate a level of analytical precision and accuracy that is appropriate for this type of environmental survey. Cd, Cu, Pb and Zn were determined in drainage sediment, tailings and soil samples, in addition to Hg and As (which were specified in the ToR and BGS's proposal) on the basis that these could be useful indicators of mineralization and/or anthropogenic contamination. The range of chemical substances determined in the samples collected, and the range of media sampled should not be considered to represent a comprehensive environmental survey. In addition, the results reported here refer only to the sites sampled at the time of

the survey and should not be extrapolated to infer that elevated levels of contamination are not present at other sites or elsewhere in the district or region. The results presented reflect the level of resources available for the environmental assessment.

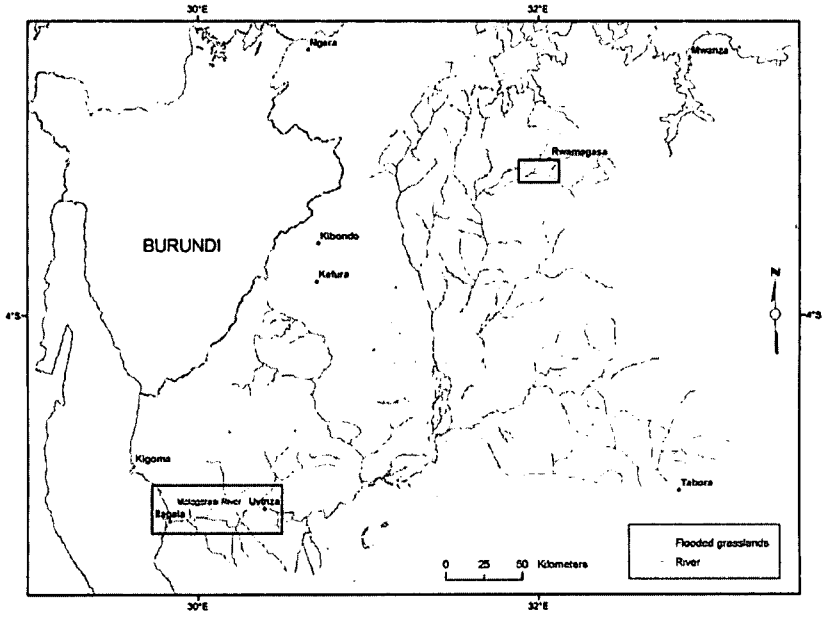

Figure ES-1. Location of the River Malagarasi and Rwamagasa sub-areas in northwest Tanzania.

Nature and extent of the mercury pollution in the river system adjacent to the hot spot area

At the time of sampling, mercury in filtered drainage water samples ranged from 0.01 to 0.03 µg/L in the R. Malagarasi and from 0.01 to 0.07 µg/L in the Rwamagasa area. None of the filtered water samples exceeded any of the Tanzanian Water Quality Standards or other national and international water quality standards, or criteria, for drinking water, protection of aquatic biota or the protection of human health. Arsenic in filtered water ranged from 0.1 to 2.4 µg/L and none of the samples collected exceeded any water quality standards or criteria.

Hg concentrations in the fine fraction of streams sediments from the River Malagarasi at Ilagala range up to 0.65 mg/kg, which is rather high for an area that does not appear to be unduly affected by anthropogenic contamination. Concentration of Hg in the fine fraction, together with adsorption of Hg onto Fe and organic material, may in part explain these relatively enhanced Hg concentrations, but these hypotheses need to be verified by further studies. Other possible sources include the geothermal springs at Uvinza or contamination of sediment by mercuric soap, which may be used by some people for skin lightening.

In the Rwamagasa area, Hg in the fine fraction of drainage sediments ranges from 0.08 to 2.84 mg/kg, although Hg does not exceed the Toxic Effects Threshold (1 mg Hg/kg) of the Canadian Sediment Quality Criteria for the Protection of Aquatic Life for more than 2 km downstream from the major

mineral processing centre located to the south of the Isingile River. Toxic Effects Thresholds for As, Cd, Cu, Pb and Zn are not exceeded in drainage sediments from the Rwamagasa area.

Environmental assessment of the "hot spot" area based on sampling of mineral processing wastes and soils

There is little difference between mercury concentrations in samples taken from historic (dry) primary tailings piles (mean 5 mg/kg) and samples taken from recent sluice box tailings (mean 3 mg/kg). Hg in tailings samples from the amalgamation ponds and amalgamation pond tailings (mean 86 mg/kg) are on average about 20 times higher. The high level of Hg in the primary and sluice box tailings is the result of recycling/reprocessing of amalgamation pond tailings. An association between Cd-Cu-Hg-Zn probably reflects contamination from mercury used in amalgamation combined with metals that are possibly derived from the ball mills and galvanised roof sheets. Correlations between arsenic and iron probably reflect the influence of trace quantities of arsenopyrite and pyrite in the gold ore. Both these hypotheses need to be verified.

At the time of the survey, generally low concentrations of Hg occurred in most of the analyzed soils used for cassava, maize, and rice cultivation, as well as *mbuga* and unclassified soils located away from the urban centre of Rwamagasa and associated mineral processing areas. Higher concentrations are found in urban soils and also in *mbuga* and vegetable plot soils adjacent to the Isingile River, close to the mineral processing areas. Hg in the urban soils is probably mainly derived from air borne transport and deposition of Hg released during the burning of amalgam, although this has not been verified. High Hg appears to occur in the *mbuga* and vegetable plot soils where these are impacted by Hg-contaminated water and sediment derived from mineral processing activities located on the southern side of the Isingile River. In these soils there is a clear association between Cd-Cu-Zn, which reflects contamination from metals that are possibly derived from the ball mills and/or galvanized roof sheets. An association between As, Cu and Fe probably reflects the influence of the weathering products of arsenopyrite and pyrite found in the gold ore, although this needs to be verified.

Mercury exceeds (1) the maximum permissible concentration of Hg in agricultural soil in the UK (1 mg/kg) in 12 soil samples; (2) the Canadian Soil Quality Guideline for agricultural soils (6.6 mg/kg) in three samples; and (3) the UK soil guideline value for inorganic Hg for allotments (8 mg/kg) in two samples.

Cadmium and zinc exceed the maximum permissible concentrations for agricultural soil in the UK (3 mg Cd/kg and 200 mg Zn/kg) in only a few soil samples. Arsenic exceeds the Canadian Soil Quality Guideline for agricultural soils (12 mg/kg) in nine agricultural and urban soils.

Soil profile data demonstrate that surface contamination by mineral processing waste in some agricultural soils affects the root zone. Hoeing of the soils is likely to result in mixing of surface Hg contamination throughout the root zone, although this has not been verified.

Nature and extent of the mercury pollution in agricultural produce, especially in those being part of the main diet

Hg in vegetable and grains samples collected from the agricultural areas potentially impacted by mercury contamination are mainly below the detection limit of 0.004 mg/kg Hg with concentrations of 0.007 and 0.092 mg/kg Hg recorded in two yam samples and 0.035 mg/kg Hg in one rice sample. A positive correlation between Hg in agricultural crops and soil was not detected during the present survey. Hg in beans, onions and maize samples purchased at Rwamagasa market are below the detection limit (<0.004 mg Hg/kg) whilst two dehusked rice samples contain 0.011 and 0.131 mg/kg Hg. The concentrations of Hg in rice are similar to those recorded in rice grown on the highly contaminated soils of the Naboc irrigation system on the island of Mindanao in the Philippines.

Mercury in fish: biomarkers for mercury methylation and potential food sources

The main fish species used as bioindicators of mercury contamination included perch (*Lates spp*), tigerfish (*Brycinus spp*), tilapia (*Oreochromis spp*), catfish (*Clarias spp*). Fish tissue THg data indicates that the sites sampled in the immediate area of mining activities at Rwamagasa, are the worst affected (Figure ES-2) and should be considered environmental 'hotspots' and sites of biomethylation. Many fish tissue samples from these sites fail export market standards (0.5 mg/kg) and also exceed the WHO recommended standard for the protection of health of vulnerable groups (0.2 mg/kg). Mercury in fish collected from the Nikonga River, approximately 25 km downstream from Rwamagasa, have low Hg concentrations. This suggests that the impact of mercury contamination on aquatic biota is relatively restricted, which is confirmed by the generally low mercury concentrations in drainage sediment and *mbuga* soils at distances more than about 6 km downstream of the main mineral processing area (or 'hotspot'). However, this observation will need to be verified by more detailed studies. Fish length vs. mercury concentration plots for fish from the River Malagarasi and Malagarasi delta area of Lake Tanganyika (collected from Uvinza and Ilagala) confirm generally low mercury concentrations that are similar to levels found in similar species in Lake Victoria (Figure ES-3). All fish samples collected from the Malagarasi River area are below the WHO threshold for vulnerable groups (0.2 mg/kg). This suggests that mercury contamination from the Rwamagasa artisanal gold mining centre does not have a significant impact on fish stocks in either the lower reaches of the River Malagarasi or the International Waters of Lake Tanzania.

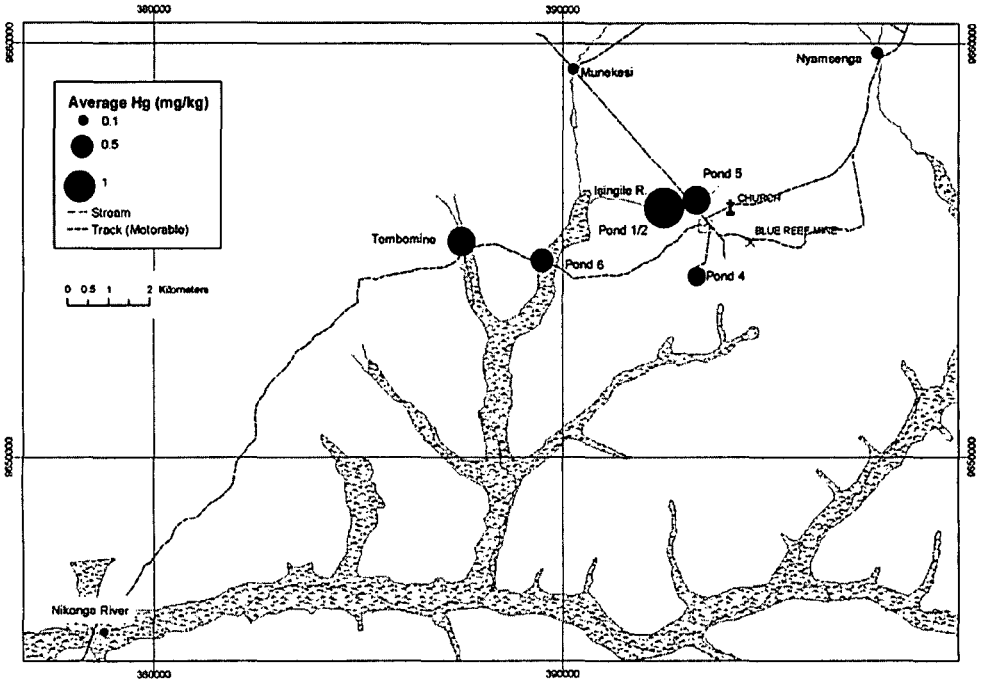

Figure ES-2. Average mercury concentration (mg/kg) in catfish (*Clarias spp.*), Rwamagasa area.

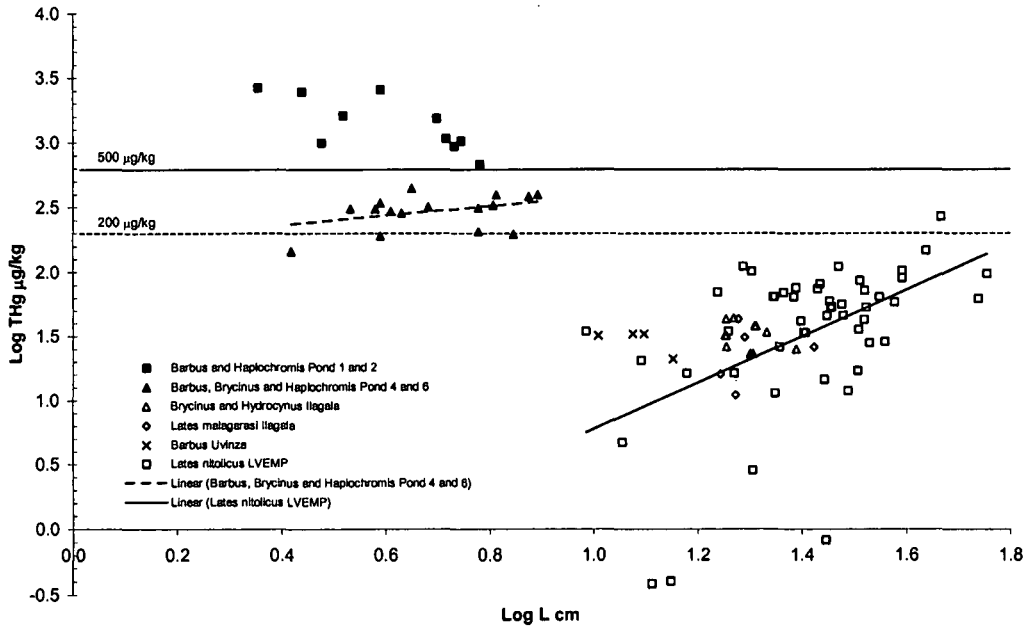

Figure ES-3 Hg (µg/kg) related to length (cm) in piscivorous, insectivorous and planktivorous fish from (a) the Rwamagasa area, (b) River Malagarasi – Lake Tanganyika (Ilagala, Uvinza) and (c) Lake Victoria (Lake Victoria Environmental Management Project, Machiwa *et al.* 2003).

Exposure to environmental mercury

None of the water samples collected from the river network, or associated drainage ponds exceeded the WHO or local Tanzanian guideline values of 1 μg Hg/l for drinking water. Whilst this suggests that mineral processing operations have not contaminated local surface waters and shallow groundwaters it does not indicate whether drinking water used by the local people has been contaminated with Hg or other non-related substances. More extensive monitoring of drinking water sources (which was not the focus of the current investigations) should be considered as a component of any subsequent follow up work.

The only samples of filtered water collected during the survey that contained relatively high Hg concentrations (max. 0.45 μg Hg/l) were from amalgamation ponds. This highlights the need for careful management of waste-waters from these ponds and monitoring of any nearby drinking water supplies.

The average mercury concentration recorded for samples of rice grain grown on soils potentially impacted by mercury contamination was 0.026 μg/g (dry wt.). Consequently, the amount of mercury entering the body, assuming an average consumption of 300g rice/day is 0.055 mg THg/week (equivalent to 0.46 μg MeHg/kg bw/week), which is much lower than the Provisional Tolerable Weekly Intake (PTWI) of 0.3 mg for total mercury and 1.6 μg/kg bw/week for methyl mercury in the diet set by the WHO and the FAO. These are likely to maximum inputs because most people in the Rwamagasa area will consume less than 300 g rice/day because they will also consume cassava and maize, which are generally grown on soils with low Hg. This observation needs to be verified by more detailed studies.

The vast majority of people in the Rwamagasa area principally eat Tilapia (*Oreochromis spp.*), Perch (*Lates spp.)* and dagaa (dagan; *Rastrineobola spp.* and equivalents) from Lake Victoria. Catfish (*Clarias spp;* kamare, mumi) is eaten by less than 10% of those people. Consumption of 250g perch, 500g tilapia and 250g of catfish each week would result in an intake of 27 μg THg/week (equivalent to 0.35 μg MeHg/kg bw/week) for residents of Ilagala-Uvinza area, 44 μg THg/week (equivalent to 0.58 μg MeHg/kg bw/week) for Rwamagasa residents consuming only fish from Lake Victoria, 56 μg THg/week (equivalent to 0.75 μg MeHg/kg bw/week) for people in the Rwamagasa background area consuming tilapia and perch from Lake Victoria and catfish from the local streams, and 259 μg THg/week (equivalent to 3.45 μg MeHg/kg bw/week) for people in the Rwamagasa area consuming tilapia and perch from Lake Victoria and catfish from mining impacted streams. Apart from the latter group, these inputs related to fish consumption are well below the WHO/FAO Provisional Tolerable Weekly Intake (PTWI) of 300 μg for total mercury and 1.6 μg MeHg/kg bw/week in the diet. It appears that only those people consuming catfish from the Isingile River, and other mining contaminated locations such as Tembomine, are likely to be at risk of exceeding the PTWI for mercury.

People consuming 300g/day of rice grown on the mercury contaminated Isingile *mbuga* soils and 1kg of fish from Lake Victoria would have a combined estimated MeHg input of 1.04 μg MeHg kg bw/week, which is two thirds of the methyl mercury PTWI.

Whereas it is not known whether individuals practice geophagia in the Rwamagasa area, elevated exposures to Hg could result from the occasional deliberate and habitual consumption of contaminated soils and dusts. For example, the Provisional Tolerable Weekly Intake (PTWI) of 0.3 mg for total mercury in the diet set by the WHO and the FAO, which is equivalent to 26 μg THg/day for a 30kg child would be exceeded by an individual practising geophagia (central estimate and worst-case) or on a case by case basis by an individual occasionally consuming soil/dust (worst-case). The practice of geophagy by pregnant females would be of particular concern in this regard given the sensitivity of the foetus to mercury.

The inadvertent ingestion of dusts and soils even those having Hg concentrations significantly above the regional background, and hence considered to be moderately contaminated, does not appear to lead to a significant excess exposure to mercury. For example comparison of exposures due to inadvertent ingestion of soils and/or dusts (0.72 to 1.8 μg THg/day or 5 to 13 μg THg/week) is typically less than individual exposure via other dietary sources water, rice and fish.

However, given the uncertainties involved in estimating inadvertent dust and soil intake in the rural Rwamagasa environment, exposure via this route, in addition to more classical geophagic behaviour, should be considered when planning remedial/intervention measures. Such measures could include the marking and fencing off of waste tips and areas of enhanced contamination and improvements in hygiene (washing of hands and food preparation such as the drying of cassava and other crops directly on the ground and the use of soil as a desiccant to aid the storage of groundnuts and beans). Whilst geophagy does have an important cultural and possibly nutritional benefit, the resulting levels of potential exposure to young adults and pregnant woman are high enough to suggest that this practice should be positively discouraged within the mining districts. If it was demonstrated that geophagy is practiced in the Rwamagasa area, the importation of geophagic materials into local markets from outside the contaminated region should be encouraged and the negative effects of using local soils conveyed though local woman's groups and childhood development officers.

Medical investigation methodology

The extraction of the gold with liquid mercury releases serious amounts of mercury, especially high toxic mercury fumes into the local environment. The health status of 211 volunteers in Rwamagasa artisanal gold mining area and 41 non-exposed people from a nearby control area in Katoro, located 30 km distant from Rwamagasa was assessed with a standardised health assessment protocol from UNIDO (UNIDO 2003) by an expert team from the University of Munich, Germany in October/November 2003. The health assessment protocol was developed by UNIDO in collaboration with the Institut für Rechtsmedizin der Ludwig-Maximilians-Universität München, Germany and other international experts. The "Health Assessment Questionnaire" was partly translated in Swahili to be used to examine the general health condition of members of the mining community and to indicate symptoms of mercury poisoning. State of

the art anamnestic, clinical, neurological, neuro-psychological and toxicological tests were used. All participants were examined to identify neurological disturbances, like ataxia, tremor and coordination problems. The data was compiled for statistical purposes and confidentiality regarding all health related issues was maintained.

Results of the medical investigation

Mercury concentrations in the bio-monitors urine, blood and hair were significantly higher statistically in the exposed population from Rwamagasa compared with the Katoro control group, but only some amalgam burners showed mercury levels above the toxicological threshold limit HBM II in urine (Figure ES-4), blood and hair. A speciation of mercury in hair demonstrates that mainly inorganic mercury (including mercury vapour) contributes to the high body burden of the artisanal miners. Low mercury concentrations in all bio-monitors (especially: blood) of volunteers not occupationally exposed to mercury in Rwamagasa indicate that there is no relevant secondary exposure of humans to mercury in this area by air, drinking water or food, especially locally caught fish.

Only a few statistically significant correlations were detected between Hg concentrations in bio-monitors (urine, blood and hair) and anamnestic/clinical data for the amalgam-burners sub-group. Significant correlations included those between the anamnestic data (i) "tremor at work" with Hg in urine, blood and total Hg in hair and (ii) Hg in blood with tiredness, lack of energy, weakness, and problems with concentration and clear thinking. The only significant correlation between a classical clinical indicator and Hg in biomonitors was "Heel to knee tremor" with Total Hg in hair whilst significant correlations with the "Matchbox test" were found with Hg in urine and blood. Whereas on a group basis Hg in the target tissue (i.e. brain) correlates well with Hg in urine, blood and hair of people with significantly different levels of occupational or environmental exposure, the poor correlations between classical clinical indicators of mercury intoxication and Hg in bio-indicators within the group of amalgam-burners in the present study probably reflects large inter-individual differences (i.e. an individual's biomonitor Hg level may not directly indicate their target tissue (brain) Hg burden). In an individual who has suffered from chronic exposure to Hg, damage to the central nervous system may have occurred months or years before the biomonitor samples were analysed. Biomonitor data indicate an individual's recent body-burden whereas the clinical indicators probably indicate an individual's past or cumulative Hg burden. This would explain why the former occupationally exposed group shows a high median medical score whilst the group's biomonitor Hg levels are only slightly elevated. When the results of individual anamnestic, clinical and neurological tests are summed together, significant correlations exist (i) between Hg in urine and blood with the anamnestic score and (ii) between Hg in urine and the sum of all the anamnestic, clinical and neurological tests. It was shown that for the Rwamagasa amalgam-burner group, which is predominantly exposed to inorganic Hg (including Hg vapour), the Hg concentration in urine is a sound predictor for a Hg intoxication.

Typical symptoms of mercury intoxication were prevalent in the exposed group. For example, combining the medical score with the bio-monitoring results made it possible to diagnose chronic mercury intoxication in 25 out of 99 amalgam burners, and in 3 out of 15 former amalgam burners (Figure ES-5). Table ES-1 shows the mercury concentrations in biomonitors for the group of intoxicated amalgam burners.

	Hg-blood (µg/l)	Hg-Urine (µg/g crea.)	T-Hg-Hair (µg/g)	MeHg-Hair (µg/g)
N	25	25	20	18
median	8.6	13.2	4.1	0.77
maximum	33.3	36.8	48.7	5.25

Table ES-1: Mercury concentrations in biomonitors of the 25 intoxicated amalgam burners (in some cases hair samples were not available)

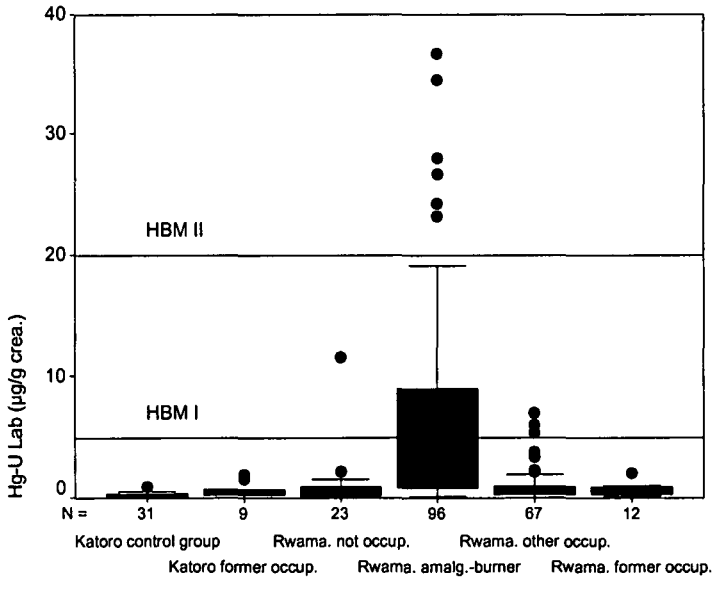

Figure ES-4: Total mercury concentration in urine (µg Hg/g creatinine), determined in laboratory (expanded y-axis; occup. = occupational)

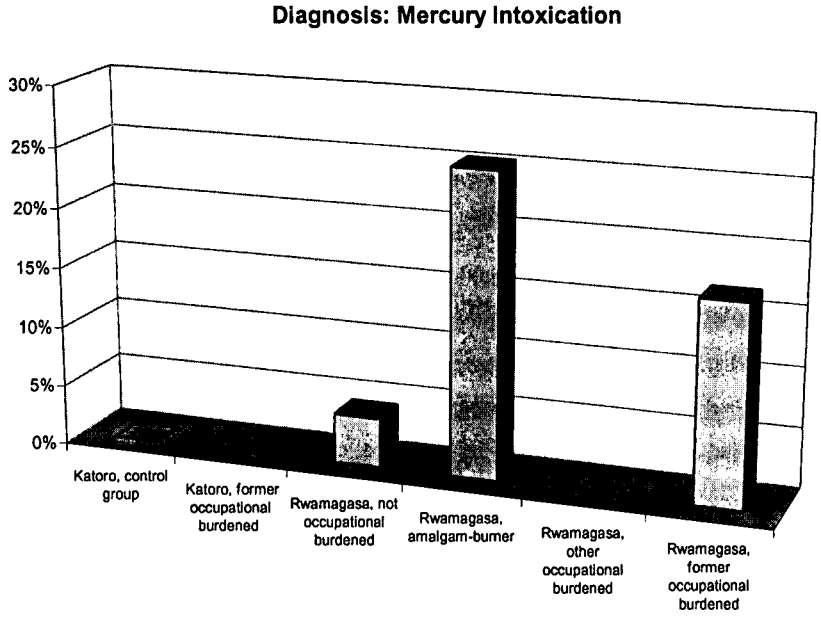

Figure ES-5: Frequency of the diagnosis of mercury intoxication in the different sub-groups.

Within the other population groups in Rwamagasa (i.e. people not occupationally exposed to mercury) and in the Katoro control group no cases of mercury intoxication were diagnosed. The percentage of cases diagnosed with mercury intoxication within the amalgam burners was lower in Rwamagasa than in the comparable small-scale gold mining area of Mt. Diwata in the Philippines, for example, where 85% of the amalgam burners were intoxicated (Drasch 2001). The difference in the level of intoxication cannot be explained by a different (i.e. a safer) amalgam burning technique in Rwamagasa. Moreover, it must kept in mind, that the maximal burden (as expressed in the top mercury concentrations found in the bio-monitors) was comparable to Mt. Diwata. The impression gained during the field programme was that this difference might be explained just by a lower amount of mercury used for gold extraction in the Rwamagasa area, reflecting the lower level of gold production. This results in a lower number people exhibiting high levels of mercury intoxication.

Child labour in the Rwamagasa mining sites is very common from the age of 10. The children work and play with their bare hands with toxic mercury. This is very important because mercury can cause severe damage to the developing brain.

Nursed babies of amalgam burning mothers are at special risk. Extremely high mercury concentrations were detected in two out of five breast-milk samples from nursing mothers who worked as amalgam burners. In addition to a placental transfer of mercury during pregnancy from the mother to the foetus (as has been proved in other studies) this high mercury burden of nursed babies should be a cause of great concern.

Poverty is the main reason for the poor health status of the small-scale mining communities. Struggling for survival frequently makes gold mining a necessity in order to obtain financial resources. The daily fight for survival makes the miners put their own health and the health of their children at risk.

A reduction of the release of mercury vapours from small-scale gold mining like in Tanzania into the atmosphere should not only reduce the number of mercury intoxicated people in the mining area but it will also reduce global atmospheric pollution, because a significant proportion of mercury vapours formed by burning of amalgam in the open-air may be transported long-range distances (Lamborg, 2002). The total release of mercury vapour from artisanal gold mining is currently estimated to be up to 1,000 metric tons per year (MMSD, 2002), while approximately 1.900 tons of mercury from all other anthropogenic sources were released into the atmosphere (Pirrone, 2001).

Mercury is undoubtedly a serious health hazard in the small-scale gold mining area of Rwamagasa. Working for many years in the amalgamation process, especially amalgam burning has resulted in severe symptoms of mercury intoxication. The exposure of the whole community to mercury is reflected in raised mercury levels in the urine, and the detection of the first symptoms of brain damage such as ataxia, tremor and movement disorders. Mercury intoxication (according to the definition of UNIDO (UNIDO 2003)) was diagnosed in 25% of the amalgam burners from Rwamagasa. In addition, intoxication was also detected in some people that had formerly worked with mercury and amalgam. People from Rwamagasa who are not directly involved in amalgam burning, have a higher mercury burden than the control group, although the majority of these people are not intoxicated. The background mercury burden in the Katoro control group is the same order of magnitude as in western industrial countries.

Recommendations for monitoring water quality and biota

Monitoring is expensive and costs can be reduced if the main exposure routes are known. Hence there is a need for a more intensive study to link exposures from various pathways to mercury levels in blood prior to the development of monitoring or remediation strategies.

Monitoring in the environmental survey followed, as closely as was practicable, the internationally accepted protocols recommended by UNIDO (2003). It is recommended that water monitoring be carried out in the Rwamagasa drainage system during the wet season in order to test for mercury dispersion in solution and in the suspended sediment. The short term and medium term temporal variation in these pollution indicators should also be investigated.

Continuous monitoring equipment capable of determining Hg at low concentrations in drainage systems is, as far as the authors of this report are aware, not available commercially. So any monitoring system would be periodic rather than continuous. Quarterly monitoring will probably be adequate for the Isingile and Nikonga Rivers for a period of two years. If no significant Hg concentrations are detected during that period, and there are no significant changes in the amount of mineral processing and associated factors, then annual monitoring, following the USEPA recommendations, will probably be adequate.

The only effective option to prevent continuing Hg pollution of the Isingile River and surrounding agricultural areas is to require (a) the removal of all the existing mineral processing waste currently located close to the Isingile River and (b) the termination of all mineral processing activities in the vicinity.

Monitoring of drinking water from wells in the Rwamagasa area was not carried out during the current survey, but should be considered when designing any future water quality monitoring systems.

Monitoring of biota (fish and agricultural crops) has been carried out as part of the current study and could be carried out periodically using the UNIDO sampling protocols (UNIDO, 2003), which document procedures for the periodic monitoring of aquatic biota. Periodic monitoring of agricultural crops could also be carried out, although the results of this study indicate that little Hg is present in most of the crops. Due to time and funding constraints, the current study was able to sample only a relatively limited number of sites. For this reason it is recommended that a more comprehensive survey should be carried out, in order to verify the results presented in this study.

Recommendations for the remediation and possible rehabilitation of mercury 'hot spots'

The present survey did not detect any concentrations of Hg in solution that would require remediation, as they did not exceed water quality standards. Should future water quality monitoring detect concentrations that require remediation, then a number of remediation technologies may be appropriate.

From a practical point of view, there would be little justification in trying to remediate and rehabilitate the Hg contaminated bottom sediments of the Isingile River until (a) the releases of Hg contaminated mineral processing tailings from the Rwamagasa area have been terminated, (2) the risk of future contamination of the drainage system by progressive or catastrophic releases of Hg contaminated processing waste has been eradicated. It is, however, relatively unlikely that the tailings piles located adjacent and to the south of the Isingile are a potential source of catastrophic contamination as the waste piles are relatively small and the slopes are relatively gentle. However, both (i) the highly contaminated amalgamation pond tailings and (ii) the primary and sluice box tailings that have been contaminated with mercury as a result of reprocessing the amalgamation pond tailings are probably the main source of potential mercury contamination in the Rwamagasa area and dispersal of these tailings needs to be avoided. Removal of the tailings to a safe containment facility, underlain and covered with lateritic material (hydrous ferric oxides) should be considered. As far as the authors are aware, no clean-up goals for mercury have been set in Tanzania, although this needs to be verified.

The principal remediation-rehabilitation options for Hg-contaminated soils and sediments in the Isingile River – Rwamagasa area include (i) excavation of Hg-contaminated soil and disposal to an off-site secure landfill or depository, (ii) electroleaching, comprising wet extraction followed by electrolytic preparation of the leachate is an emerging and potential alternative cleanup method that is reported to offer a cheaper

and more environmentally friendly alternative to thermal treatment or the acid leaching process. The cost of these potential remediation options has not been estimated.

Specific practical remediation measures cannot be recommended until a much more detailed assessment has been made of Hg concentrations in the agricultural soils, their uptake by crops and transfer into the human food chain. On the basis of evidence collected during this survey, it appears that significant amounts of mercury are not adsorbed into the grain of the agricultural plants. If this can be confirmed by more detailed site specific studies (involving further collection and analysis of soil and rice grain samples from exactly the same sites, for example) it may be possible to confirm that there is little or no potential for a direct negative impact on human health caused by the consumption of rice and other crops grown on these relatively high Hg soils. Mercury uptake by other crops (such as maize or cassava) grown on soils that are currently used for rice should also be evaluated in case such a change in agricultural practices would increase the potential exposure of the local population.

Recommendations for reduction of the release of mercury into the environment

The exposure to mercury for the miners and the community has to be drastically decreased. Proper mining techniques to reduce the accidents and mercury exposure are essential. Small-scale miners need all possible support to introduce cleaner and safer gold mining and extraction technologies.

The Local Mines Office in Geita needs to ensure that the small scale miners follow relevant mining and environmental regulations and approved practices, such as making sure that all amalgamation is carried out in cemented ponds and that all tailings from these amalgamation ponds are stored in appropriate cemented storage areas that prevent dispersal of mercury contamination onto adjacent land and into water courses.

Exposure to mercury vapour is avoidable with the application of simple technological improvements such as retorts. Technical solutions need to go hand in hand with awareness raising campaigns.

An alliance of local, regional, governmental and intergovernmental bodies is needed to improve the social, health and environmental situation of artisanal small-scale gold miners. Cooperation between health and environmental sectors is needed on local, regional, national and intergovernmental level; for example, UNIDO and WHO in Dar es Salaam could form a nucleus of a national mercury task force.

Recommendations for reduction of mercury as a health hazard

The clinical testing and laboratory results indicate that mercury is a major health hazard in the Rwamagasa area especially for those artisanal miners who burn amalgam. A lower, but significant, level of Hg intoxication is observed in those residents of Rwamagasa who have no occupational exposure.

In order to reduce the level of risk from mercury it is suggested that:

1. Child labour with highly toxic substances must be stopped immediately. Legal restrictions on child labour need to be implemented immediately.
2. Women of childbearing age need special information campaigns on the risk of mercury to the foetus and the nursed baby and advice on how to avoid, or at least reduce, exposure.
3. Participants in the medical assessment diagnosed with mercury intoxication need medical treatment. A system is required for the diagnosis and treatment of mercury related health-problems. Capacity building, including establishing laboratory facilities to analyse mercury in human specimens is required. The financial aspect of treatment and the legal problem of importing drugs (such as chelating agents like DMPS or DMSA, required to remove mercury from the body) need to be solved. Funding of preventive campaigns and for treatment facilities is now needed.
4. Training programs for the health care providers in the district in Geita and other health centres in mining areas is required to raise awareness of mercury as a health hazard and advise people how they can reduce their own and their children's environmental and occupational exposure to mercury.
5. Clinical training of local health workers, including the use of a standardised questionnaire and examination flow scheme (MES = mercury examination score). Particular attention needs to be paid to collecting information on individual's environmental and occupational exposure as this will aid the detailed assessment of exposure routes and the design of strategies that will help to reduce mercury exposure.
6. A mobile "mercury ambulance" might ensure that small-scale miners can be reached more efficiently than from a permanent local health office. A "mercury ambulance" equipped with the necessary medical and laboratory utensils bus could be driven into the artisanal mining areas. Two or three specially trained doctors or nurses could perform the examinations, and begin to carry out treatment. The ambulance could also be used for health awareness programs (e.g. video equipment). Miners in remote areas might welcome evening entertainment and soccer videos might attract more miners to the "mercury ambulance", than much other information material. Sponsors could be sought for a "mercury ambulance", which could be based on a truck or bus chassis.

Recommendations to increase awareness of the risks of mercury

(a) Assess in a different study design the possibility of mercury related birth and growth defects, increased abortion/miscarriage rates, infertility problems, learning difficulties in childhood or other neuro-psychological problems related to occupational and/or environmental mercury exposure.

(b) Assess in a more detailed study the possible transfer of mercury from the environment to, mother to child via breast-milk and related possible adverse health effects. Females at childbearing age and before urgently require more awareness to refrain from amalgam burning, at least during pregnancy and nursing. If this is not possible, a discussion whether to provide them with milk powder and high purity drinking water together with training them to prepare hygienically appropriate formula food for their babies needs to be based on a larger data base and a different epidemiological approach.

(c) Assess the relative importance of the main potential sources of exposure for people in Rwamagasa who are not occupationally exposed to mercury (i.e. airborne Hg-vapour; ingestion of Hg-contaminated dust through hand-to-mouth contact or on unwashed or inadequately washed food; ingestion of locally grown Hg-contaminated crops; Hg-contaminated fish from local streams; deliberate occasional or habitual consumption of soil (geophagia)). This has not been evaluated adequately and requires further integrated investigation by a team of environmental, public health, medical and toxicological specialists.

Recommendations for improvement of general health.

Poverty is considered to be the main reason for most of the health and environmental problems in the Rwamagasa area. At the moment it does not seem to be acceptable that children live in Rwamagasa because of inadequate sanitary standards and high exposure to mercury. The improvement of sanitary standards is needed urgently.

The relative occupational health risks of mining should be assessed in more detail (accidents, malaria, drinking water quality, sexually transmitted diseases, tuberculosis, HIV / AIDS). One option to reduce the health hazards in Rwamagasa might be a proper zoning into industrial areas, commercial areas and housing areas. The imposition of basic hygienic standards, such as proper drinking water and reduction of *Anopheles* mosquitoes would also lead to an improvement in the health of the local people. Raising safety awareness and the introduction of appropriate mining techniques (such as better tunnel safety) will help to reduce the risk of accidents at mining sites. The risk of sexually transmitted diseases could be reduced if campaigns for safer sex were more effective. An appropriate health service is urgently required to improve the health status of the Rwamagasa community.

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Part 1

Assessment of the Environment in the Rwamagasa area, Tanzania

by

British Geological Survey

BGS Report CR/04/129 (Issue 1.0) for UNIDO Contract 03/088

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Final Report for Assessment of Environment in the Rwamagasa area, Tanzania. UNIDO Project EG/GLO/01/G34.

Environmental Protection Programme

Commissioned Report CR/04/014R

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BRITISH GEOLOGICAL SURVEY

COMMISSIONED REPORT CR/04/014R

Final Report for Assessment of Environment in the Rwamagasa area, Tanzania. UNIDO Project EG/GLO/01/G34.

J D Appleton, H Taylor, T R Lister & B Smith

Key words

Mercury, Tanzania, Rwamagasa, Artisanal, Gold, Mining.

Front cover

Cover picture Sluicing & amalgamation site in the centre of Rwamagasa village.

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Foreword

This draft final report is an interim published product of a study by the British Geological Survey (BGS) carried out on behalf of UNIDO as part of Project No. EG/GLO/01/G34 "Removal of Barriers to the Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies.

Acknowledgements

A large number of individuals contributed to the planning and execution of the field programme. In addition to the collection of data, many individuals have freely given their advice, and provided the local knowledge so important to the effective execution of the field programme.

The assistance of the UNIDO (Vienna) Coordinating Unit staff, Dr Christian Beinhoff, Dr Marcello Veiga, Ludovic Bernaudat, and M. Latrech is gratefully acknowledged. The completion of the field programme in Tanzania would not have been possible without the assistance of Felix Ugbor (UNIDO Country Representative), Victor Akim (National Programme Officer), William Smith (UNIDO driver). Fish sampling in the Kigoma area was greatly assisted by the Tanzania Fisheries Institute (TAFIRI) Centre Director Mr D Chitamweba and technician Mr Kashushu. Fish sampling in the Rwamagasa area was carried out with the assistance and advice of Dr Oliva Mkumbo, technician Wabeya and driver Miko. TAFIRI (Mwanza) loaned the project a Land Rover to assist with the fish-sampling programme. Geita Mines Officer Mr John Nayopa provided advice and assistance with obtaining an export permit for the environmental samples whilst technicians Kulwa Kabadi and Joseph Manaku assisted with the field-sampling programme. Rwamagasa Village Executive Officer, Mr Doto Kaparatus ensured good collaboration from the miners and farmers.

Advice on mercury contamination and artisanal gold mining was kindly provided by the following individuals during a series of meetings held in Dar es Salaam and Mwanza: Mr Gray L Mwakalukwa (Commissioner for Minerals and UNIDO Country Focal Point); Mr M Z Mraba (Zonal Mines Officer, Mwanza); Professor Yunus D Mgaya and Dr John F Machiwa (Faculty of Aquatic Sciences and Technology, University of Dar es Salaam); Dr Ben Ngatunga (Deputy Director, Tanzania Fisheries Research Institute, TAFIRI, Kyela); Dr Diamantino P Azevedo, John Bomani and Manfred Akstinat (Southern and Eastern Africa Mineral Centre – SEAMIC); Samuel Msangi (Principal Environmental Management Officer) and Mr Mwaipopo (Directorate of Environmental Compliance & Enforcement, National Environment Management Council, NEMC); Ms Kisanga (Department of the Environment, Vice Presidents Office) and Emmanuel W Jengo (Executive secretary, Tanzania Chamber of Mines). Professor Mruma (Head of the Geology Department, University of Dar es Salaam) kindly provided nitric acid and deionised water as well as advice on past and current research activities carried out by staff in his

Department. Dr F K Mwanisi, District Medical Officer, Geita kindly agreed to collaborate with the Medical assessment being carried out by sub-contractors led by Prof Gustav Drasch, University of Munich, Germany. Mr Korodias Shoo (Environment Officer) and Mr Graeme McIlveen (Manager, Safety, health & Environment) at Geita Mine are thanked for permitting project staff to store fish, water, and sediment samples in the Environment Dept. fridge and freezer.

Last, but not least, the BGS would like to acknowledge with gratitude the enthusiastic assistance, advice and cooperation of Mr Aloyce Tesha, Assistant to the Country Focal Point, before, during and after the field programme. The project driver, Omar S Makulu, is thanked for his skilful and careful driving.

The advice and assistance of Mark Allen and colleagues, BGS (sediment, soil and tailings sample preparation), Barbara Vickers, BGS (water analysis), Andrew Scott, Laboratory Manager – Environment, Direct Laboratory Services Ltd., Wolverhampton, UK (fish and vegetable analysis), Rick McCaffrey, Clarence Leong and Wai Szeto, ACME Analytical Laboratories, Vancouver, Canada (soil, sediment and tailings analysis) is gratefully acknowledged. The report was edited by Professor Barry Smith (BGS, Environment Protection Programme Manager) and Dave Holmes (BGS, Head of Environment and Hazards Directorate).

Contents

Summary

Introduction

Artisanal gold mining is one of the major sources of mercury contamination, especially in developing countries. Whereas the gold extraction process (known as amalgamation) is a simple technology, it is potentially very dangerous and contaminates the air, soil, rivers and lakes with mercury. The health of the miners and other people living within the area affected by mercury contamination may be negatively affected through inhalation of mercury vapour, direct contact with mercury and through eating fish and other food affected by the mercury contamination.

In response to this problem, the Global Environmental Facility (GEF) of the UN approved funding for the project *Removal of Barriers to the Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies*[1] (also referred to as the *Global Mercury Project (GMP)*) in March 2002. The Global Mercury Project was started to help demonstrate ways of overcoming barriers to the adoption of best practices, waste minimization strategies and pollution prevention measures that limit contamination of the international waters environment.

In August 2003, the British Geological Survey (BGS), acting under the Natural Environment Research Council, signed a contract (No. 03/088) with the United Nations Industrial Development Organization (UNIDO) to carry out limited Environmental and Health surveys and assessments in the Rwamagasa artisanal gold mining area in the Republic of Tanzania. Rwamagasa[2] was selected by UNIDO as the demonstration site for Tanzania. The environmental assessment, to which this report refers, was executed by the BGS whilst the medical assessment was subcontracted to the Institut für Rechtsmedizin der Ludwig-Maximilians-Universität München, and is the subject of separate reports.

The Environmental Assessment reported here is part fulfilment of the project's objectives to (i) identify hotspots in the project demonstration sites, (ii) conduct specified geochemical and toxicological studies and other field investigations in order to assess the extent of environmental pollution in surrounding water bodies and (iii) devise intervention measures. The general scope of the Environmental Assessment is given in the Terms of Reference (Appendix 1). The methodology, approach and work plan are detailed in the BGS Proposal dated 25 February 2003, as clarified by e-mail messages of 7 April 2003, which the

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[1] http://www.gefweb.org/Documents/Project_Proposals_for_Endorsem/PP_Archives/Global_-_Gold_Mining_project.pdf

[2] printed as Lwamgasa on the 1:50,000 scale Busanda (Sheet 46/1) topographic map; also named elsewhere as Ruamagaza and Rwamagaza.

BGS submitted to UNIDO in response to UNIDO's Request for Proposal No. P.2003/007 of 23 January 2003. Although Rwamagasa is located only 37 km to the south of Lake Victoria, streams draining the Rwamagasa 'mining hotspot' actually drain SW into the Nikonga[3] River, and then for a further 430 km via the Moyowosi swamps and the River Malagarasi before reaching Lake Tanganyika near Ilagala, about 50 km to the SSE of Kigoma. One of the major objectives of the project is to assess the impact of mercury contamination on International waters as well as in the vicinity of the 'mining hotspot', so the field programme was carried out in two areas: (a) the Rwamagasa 'mining hotspot' sub-area and (b) the Lake Tanganyika – River Malagarasi sub-area.

This final report is the second report for a study by the British Geological Survey (BGS) carried out on behalf of UNIDO as part of Project No. EG/GLO/01/G34 "Removal of Barriers to the Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies".

Field programme

A field programme was carried out in September–October 2003 leading to the collection of a total of 38 water, 26 drainage sediment, 151 soil, 66 tailings, 21 vegetable and 285 fish samples. Preparation and analysis of the samples was carried out in the UK and Canada. Analytical data for duplicate field samples, replicate analyses and recovery data for Certified Reference Materials indicate a level of analytical precision and accuracy that is appropriate for this type of environmental survey. Cd, Cu, Pb and Zn were determined in drainage sediment, tailings and soil samples, in addition to Hg and As (which were specified in the ToR and BGS's proposal) on the basis that these could be useful indicators of mineralization and/or anthropogenic contamination. The elements determined in the samples collected should not be considered to represent a comprehensive environmental survey. In addition, the results reported here refer only to the sites sampled at the time of the survey and should not be extrapolated to infer that elevated levels of contamination are not present at other sites or elsewhere in the district or region. The results presented reflect the level of resources available for the environmental assessment.

Nature and extent of the mercury pollution in the river system adjacent to the hot spot area

At the time of sampling, mercury in filtered drainage water samples ranged from 0.01 to 0.03 µg/L in the R. Malagarasi and from 0.01 to 0.07 µg/L in the Rwamagasa area. None of the filtered water samples exceeded any of the Tanzanian Water Quality Standards or other national and international water quality standards, or criteria, for drinking water, protection of aquatic biota or the protection of human health.

[3] printed as Nyikonga on the 1:50,000 scale Busanda (Sheet 46/1) topographic map; Nikonga was the spelling verified for the geological maps printed by the Mineral Resources Division, Tanzania.

Arsenic in filtered water ranged from 0.1 to 2.4 μg/L and none of the samples collected exceeded any water quality standards or criteria.

Hg concentrations in the fine fraction of streams sediments from the River Malagarasi at Ilagala range up to 0.65 ppm, which is rather high for an area that does not appear to be unduly affected by anthropogenic contamination. Concentration of Hg in the fine fraction, together with adsorption of Hg onto Fe and organic material, may in part explain these relatively enhanced Hg concentrations, but these hypotheses need to be verified by further studies. Other possible sources include the geothermal springs at Uvinza or contamination of sediment by mercuric soap used for skin lightening.

In the Rwamagasa area, Hg in the fine fraction of drainage sediments ranges from 0.08 to 2.84 ppm, although Hg does not exceed the Toxic Effects Threshold (1 ppm) of the Canadian sediment Quality Criteria for the Protection of Aquatic Life for more than 2 km downstream from the major mineral processing centre located to the south of the Isingile River. Toxic Effects Thresholds for As, Cd, Cu, Pb and Zn are not exceeded in drainage sediments from the Rwamagasa area.

Environmental assessment of the "hot spot" area based on sampling of mineral processing waste and soils

There is little difference between mercury concentrations in samples taken from historic (dry) tailings piles (mean 5 ppm) and samples taken from recent sluice box tailings (mean 3 ppm). Hg in tailings samples from the amalgamation ponds and amalgamation pond tailings (mean 86 ppm) are on average about 20 times higher. An association between Cd-Cu-Hg-Zn probably reflects contamination from mercury used in amalgamation combined with metals that are possibly derived from the ball mills and galvanised roof sheets. Correlations between arsenic and iron probably reflect the influence of trace quantities of arsenopyrite and pyrite in the gold ore. Both these hypotheses need to be verified.

At the time of the survey, generally low concentrations of Hg occurred in most of the analyzed soils used for cassava, maize, and rice cultivation, as well as *mbuga* and unclassified soils located away from the urban centre of Rwamagasa and associated mineral processing areas. Higher concentrations are found in urban soils and also in *mbuga* and vegetable plot soils adjacent to the Isingile River, close to the mineral processing areas. Hg in the urban soils is probably mainly derived from air borne transport and deposition of Hg released during the burning of amalgam, although this has not been verified. High Hg appears to occur in the *mbuga* and vegetable plot soils where these are impacted by Hg-contaminated water and sediment derived from mineral processing activities located on the southern side of the Isingile River. In these soils there is a clear association between Cd-Cu-Zn, which reflects contamination from metals that are possibly derived from the ball mills and/or galvanized roof sheets. An association between As, Cu and Fe probably reflects the influence of the weathering products of arsenopyrite and pyrite found in the gold ore, although this needs to be verified.

Mercury exceeds (1) the maximum permissible concentration of Hg in agricultural soil in the UK (1 mg/kg) in 12 soil samples; (2) the Canadian Soil Quality Guideline for agricultural soils (6.6 mg/kg) in three samples; and (3) the UK soil guideline value for inorganic Hg for allotments (8 mg/kg; Environment Agency, 2002) in two samples.

Cadmium and zinc exceed the maximum permissible concentrations for agricultural soil in the UK (3 mg Cd/kg and 200 mg Zn/kg) in only a few soil samples. Arsenic exceeds the Canadian Soil Quality Guideline for agricultural soils (12 mg/kg) in nine agricultural and urban soils.

Soil profile data demonstrate that surface contamination by mineral processing waste in some agricultural soils affects the root zone. Hoeing of the soils is likely to result in mixing of surface Hg contamination throughout the root zone, although this has not been verified.

Evaluate the nature and extent of the mercury pollution in agricultural produce, especially in those being part of the main diet

Hg in vegetable and grains samples collected from the agricultural areas potentially impacted by mercury contamination are mainly below the detection limit of 0.004 ppm Hg with concentrations of 0.007 and 0.092 ppm Hg recorded in two yam samples and 0.035 ppm Hg in one rice sample. A positive correlation between Hg in agricultural crops and soil was not detected during the present survey. Hg in beans, onions and maize samples purchased at Rwamagasa market are below the detection limit (<0.004 mg Hg/kg) whilst two dehusked rice samples contain 0.011 and 0.131 ppm Hg. The concentrations of Hg in rice are similar to those recorded in rice grown on the highly contaminated soils of the Naboc irrigation system, Mindanao.

Mercury in fish: biomarkers for mercury methylation and potential food sources

The fish tissue THg data indicates that the sites sampled in the immediate area of mining activities at Rwamagasa, are the worst affected and should be considered environmental 'hotspots' and sites of biomethylation. Many fish tissue samples from these sites fail export market standards (0.5 ppm) and also exceed the WHO recommended standard for the protection of health of vulnerable groups (0.2 ppm). Mercury in fish collected from the Nikonga River, approximately 25 km downstream from Rwamagasa, have low Hg concentrations. This suggests that the impact of mercury contamination on aquatic biota is relatively restricted, which is confirmed by the generally low mercury concentrations in drainage sediment and mbuga soils at distances more than about 6 km downstream of the main mineral processing area (or 'hotspot'). However, this observation will need to be verified by more detailed studies. Fish from the River Malagarasi and Malagarasi delta area of Lake Tanganyika collected from Uvinza and Ilagala are generally low and similar to mercury concentrations found in similar species in Lake Victoria. All fish samples collected from the Malagarasi are below the WHO threshold for vulnerable groups (0.2 ppm).

Exposure to environmental mercury

None of the water samples collected from the river network, or associated drainage ponds exceeded the WHO or local Tanzanian guideline values of 1 μg/l Hg for drinking water. Whilst this suggests that mineral processing operations have not contaminated local surface waters and shallow groundwaters it does not indicate whether drinking water used by the local people has been contaminated. More extensive monitoring of drinking water sources (which was not the focus of the current investigations) should be considered as a component of any subsequent follow up work.

The only samples of water collected during the survey that contained relatively high Hg concentrations (max. 0.45 μg Hg/l) were from amalgamation ponds. This highlights the need for careful management of waste waters from these ponds and monitoring of any nearby drinking water supplies.

The average mercury concentration recorded for samples of rice grain grown on soils potentially impacted by mercury contamination was 0.026 μg/g (dry wt.). Consequently, the amount of mercury entering the body, assuming an average consumption of 300g rice/day is 0.055 mg THg/week (equivalent to 0.46 μg MeHg/kg bw/week), which is much lower than the Provisional Tolerable Weekly Intake (PTWI) of 0.3 mg for total mercury and 1.6 μg/kg bw/week for methyl mercury in the diet set by the WHO and the FAO. These are likely to maximum inputs because most people in the Rwamagasa area will consume less than 300 g rice/day because they will also consume cassava and maize, which are generally grown on soils with low Hg. This observation needs to be verified by more detailed studies.

The vast majority of people in the Rwamagasa area principally eat Tilapia (*Oreochromis spp.*), Perch (*Lates spp.)* and dagaa (dagan; *Rastrineobola spp.* and equivalents) from Lake Victoria. Catfish (*Clarias spp;* kamare, mumi) is eaten by less than 10% of those people. Consumption of 250g perch, 500g tilapia and 250g of catfish each week would result in an intake of 27 μg THg/week (equivalent to 0.35 μg MeHg/kg bw/week) for residents of Ilagala-Uvinza area, 44 μg THg/week (equivalent to 0.58 μg MeHg/kg bw/week) for Rwamagasa residents consuming only fish from Lake Victoria, 56 μg THg/week (equivalent to 0.75 μg MeHg/kg bw/week) for people in the Rwamagasa background area consuming tilapia and perch from Lake Victoria and catfish from the local streams, and 259 μg THg/week (equivalent to 3.45 μg MeHg/kg bw/week) for people in the Rwamagasa area consuming tilapia and perch from Lake Victoria and catfish from mining impacted streams. Apart from the latter group, these inputs related to fish consumption are well below the WHO/FAO Provisional Tolerable Weekly Intake (PTWI) of 300 μg for total mercury and 1.6 μg MeHg/kg bw/week in the diet. It appears that only those people consuming catfish from the Isingile River, and other mining contaminated locations such as Tembomine, are likely to be at risk of exceeding the PTWI for mercury.

People consuming 300g/day of rice grown on the mercury contaminated Isingile *mbuga* soils and 1kg of fish from Lake Victoria would have a combined estimated MeHg input of 1.04 μg MeHg kg bw/week, which is two thirds of the methyl mercury PTWI.

Elevated exposures to Hg can result from the occasional deliberate and habitual consumption of contaminated soils and dusts. For example, the Provisional Tolerable Weekly Intake (PTWI) of 0.3 mg for total mercury in the diet set by the WHO and the FAO, which is equivalent to 26 μg THg/day for a 30kg child is exceeded by an individual practising geophagia (central estimate and worst-case) or on a case by case basis by an individual occasionally consuming soil/dust (worst-case). The practice of geophagy by pregnant females is of particular concern in this regard given the sensitivity of the foetus to mercury.

The inadvertent ingestion of dusts and soils even those having Hg concentrations significantly above the regional background, and hence considered to be moderately contaminated, does not appear to lead to a significant excess exposure to mercury. For example comparison of exposures due to inadvertent ingestion of soils and/or dusts (0.72 to 1.8 μg THg/day or 5 to 13 μg THg/week) is typically less than individual exposure via other dietary sources water, rice and fish.

However, given the uncertainties involved in estimating inadvertent dust and soil intake in the rural Rwamagasa environment, exposure via this route, in addition to more classical geophagic behaviour, should be considered when planning remedial/intervention measures. Such measures could include the marking and fencing off of waste tips and areas of enhanced contamination and improvements in hygiene (washing of hands and food preparation such as the drying of cassava and other crops directly on the ground and the use of soil as a desiccant to aid the storage of groundnuts and beans). Whilst geophagy does have an important cultural and possibly nutritional benefit, the resulting levels of potential exposure to young adults and pregnant woman are high enough to suggest that this practice should be positively discouraged within the mining districts. To this end the importation of geophagic materials into local markets from outside the contaminated region should be encouraged and the negatives effects of using local soils conveyed though local woman's groups and childhood development officers.

Monitoring systems for water quality and biota

Monitoring in the current survey followed, as closely as was practicable, the internationally accepted protocols recommended by Veiga and Baker (2003). It is recommended that water monitoring be carried out in the Rwamagasa drainage system during the wet season in order to test for mercury dispersion in solution and in the suspended sediment. The short term and medium term temporal variation in these pollution indicators should also be investigated.

Continuous monitoring equipment capable of determining Hg at low concentrations in drainage systems is, as far as the authors of this report are aware, not available commercially. So any monitoring system would be periodic rather than continuous. Quarterly monitoring will probably be adequate for the Isingile and Nikonga Rivers for a period of two years. If no significant Hg concentrations are detected during that period, and there are no significant changes in the amount of mineral processing and associated factors, then annual monitoring, following the USEPA recommendations, will probably be adequate.

The only effective option to prevent continuing Hg pollution of the Isingile River and surrounding agricultural areas is to require (a) the removal of all the existing mineral processing waste currently located close to the Isingile River and (b) the termination of all mineral processing activities in the vicinity.

Monitoring of drinking water from wells in the Rwamagasa area was carried out during the current survey, but should be considered when designing any future water quality monitoring systems.

Monitoring of biota (fish and agricultural crops) has been carried out as part of the current study and could be carried out periodically using the UNIDO sampling protocols (Veiga and Baker, 2003), which document procedures for the periodic monitoring of aquatic biota. Periodic monitoring of agricultural crops could also be carried out, although the results of this study indicate that little Hg is present in most of the crops. Due to time and finding constraints, the current study was able to sample only a relatively limited number of sites. For this reason it is recommended that a more comprehensive survey should be carried out, in order to verify the results presented in this study.

Measures for the remediation and possible rehabilitation of mercury 'hot spots'

The present survey did not detect any concentrations of Hg in solution that would require remediation as they did not exceed water quality standards. Should future water quality monitoring detect concentrations that require remediation, then a number of remediation technologies may be appropriate.

From a practical point of view, there would be little justification in trying to remediate and rehabilitate the Hg contaminated bottom sediments of the Isingile River until (a) the releases of Hg contaminated mineral processing tailings from the Rwamagasa area have been terminated, (2) the risk of future contamination of the drainage system by progressive or catastrophic releases of Hg contaminated processing waste has been eradicated. It is, however, relatively unlikely that the tailings piles located adjacent and to the south of the Isingile are a potential source of catastrophic contamination as the waste piles are small and the slopes are relatively gentle. As far as the authors are aware, no clean-up goals for mercury have been set in Tanzania, although this needs to be verified.

The principal remediation-rehabilitation options for Hg-contaminated soils and sediments in the Isingile River – Rwamagasa area include (i) excavation of Hg-contaminated soil and disposal to an off-site secure landfill or depository, (ii) electroleaching, comprising wet extraction followed by electrolytic preparation of the leachate is an emerging and potential alternative cleanup method that is reported to offer a cheaper and more environmentally friendly alternative to thermal treatment or the acid leaching process. The cost of these potential remediation options has not been estimated.

Specific practical remediation measures cannot be recommended until a much more detailed assessment has been made of Hg concentrations in the agricultural soils. On the basis of evidence collected during this survey, it appears that significant amounts of mercury are not adsorbed into the grain of the

agricultural plants. If this can be confirmed by more detailed surveys (involving further collection and analysis of soil and rice grain samples from exactly the same areas, for example) it may be possible to confirm that there is little or no potential for a direct negative impact on human health caused by the consumption of rice and other crops grown on these relatively high Hg soils. Should this be the case, there would be no compelling reason to prevent the continued cultivation of rice and other agricultural crops on the Hg-contaminated soils.

Interactions between government departments, mining industry and research institutions

The report outlines the responsibilities of the various government departments in relation to artisanal gold mining, the setting of environmental standards and environmental monitoring. Responsibility for administration, implementation and enforcement of regulations under the Mining Act (1998) and Minerals Regulations (1999) in the Geita – Rwamagasa area is delegated to the Ministry's Local Mines Office which is responsible for the extremely difficult task of ensuring that the small scale miners follow relevant mining and environmental regulations and approved practices, such as ensuring that all amalgamation is carried out in cemented ponds and that all tailings from these amalgamation ponds are stored in appropriate cemented storage areas that prevent dispersal of mercury contamination onto adjacent land and into water courses. Observations during the field project indicated that many small-scale miners in the Rwamagasa area do not follow these regulations. Most of the research on the impact of mercury contamination related to artisanal gold mining in Tanzania has been funded by UNIDO and JICA. The World Bank-GEF funded Lake Victoria Environmental Monitoring Project is executed principally by staff from the Tanzania Fisheries Research Institute (TAFIRI) and the University of Dar es Salaam. The analytical laboratories of the Southern and Eastern African Mineral Centre (SEAMIC) also contributes to these research activities.

1 Introduction

Artisanal gold mining provides income to some of the world's poorest people, many of whom are women and children, but it is also one of the major sources of mercury contamination, especially in developing countries. It is estimated that 2 kilograms of mercury are released into the environment for every kilogram of gold produced by artisanal and small-scale miners. Whereas the gold extraction process (known as amalgamation) is a simple technology, it is potentially very dangerous and contaminates the air, soil, rivers and lakes with mercury. The health of the miners and other people living within the area affected by mercury contamination is negatively affected through inhalation of mercury vapour, direct contact with mercury and through eating fish and other food affected by the mercury contamination.

UNIDO has provided technical assistance to the small-scale gold mining sector in developing countries since 1985. Projects dealing with the introduction of cleaner technologies and mercury pollution abatement have assessed the environmental and health impacts of mercury pollution caused by artisanal gold miners in Venezuela, Ghana and the Philippines. It is now accepted that the environmental and health impacts resulting from the use of mercury in the processing of gold within the artisanal mining sector and their effects on International Water bodies are similar in nature in most developing countries and that solutions to these problems require concerted and coordinated global responses.

In response to this requirement, the Global Environmental Facility (GEF) of the UN approved funding for the project *Removal of Barriers to the Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies*[4] (also referred to as the *Global Mercury Project (GMP)*) in March 2002. UNDP acts as the Implementing Agency while UNIDO is responsible for project execution. The Global Mercury Project was started to help demonstrate ways of overcoming barriers to the adoption of best practices, waste minimization strategies and pollution prevention measures that limit contamination of the international waters environment. The project is funded by GEF, UNDP and UNIDO and is complemented by a suite of ongoing activities, which are financed through either the participating countries' own resources and/or bilateral programs. The project aims to help remove barriers that inhibit artisanal miners from applying cleaner and efficient technology. The project also aims to demonstrate the application of cleaner technology and train miners in order to enhance the application of cleaner technology and thus reduce pollution and minimize waste resulting from the currently applied poor practices.

UNIDO selected a pilot suite of six developing countries (Brazil, Indonesia, Laos, Sudan, Tanzania and Zimbabwe) located in several key trans-boundary river/lake basins. It is estimated that nearly 2.0 million people are directly involved in artisanal mining activities in the six pilot countries whilst the livelihoods of more than 10 million depend on these activities. UNIDO conducted preliminary investigations in the

[4] http://www.gefweb.org/Documents/Project_Proposals_for_Endorsem/PP_Archives/Global_-_Gold_Mining_project.pdf

six pilot countries to establish the intensity of the artisanal mining activities and their impacts on the international water bodies. A demonstration site was selected in each country.

The ultimate goals of the GEF/UNDP/UNIDO Global Mercury Project are:

1. to reduce mercury pollution of international waters by emissions emanating from small-scale gold mining,
2. to introduce cleaner technologies for gold extraction and to train people in their application,
3. to develop capacity and regulatory mechanisms that will enable the sector to minimize mercury pollution,
4. to introduce environmental and health monitoring programmes,
5. to build capacity of local laboratories to assess the extent and impact of mercury pollution.

The objective of the GEF/UNDP/UNIDO GMP is to replace mercury amalgamation in the project demonstration sites to the extent possible with new technology while improving the income of the miners through more efficient gold recovery, increasing knowledge and awareness and providing policy advice on the regulation of artisanal gold mining with due consideration of gender policies. Beneficiaries will be the miners, governments, local institutions and people living in areas impacted by mercury contamination.

The project is organised to fulfil seven major objectives:

1. Project coordination and support; establish country program management structures and Task Forces
2. Increase artisanal mining knowledge and awareness
3. Establish human exposure to mercury and pollution impacts of the affected areas
4. Establish technological requirements
5. Introduce efficient and clean technology
6. Assist Governments to develop implementable policies and legislation
7. Self-financing and donor conferences.

In August 2003, the British Geological Survey (BGS), acting under the Natural Environment Research Council, signed a contract (No. 03/088) with the United Nations Industrial Development Organization (UNIDO) to carry out Environmental and Health surveys and assessments in the Rwamagasa artisanal gold mining area in the Republic of Tanzania (see Terms of Reference in Appendix 1). Rwamagasa[5] was selected by UNIDO as the demonstration site for Tanzania. The environmental assessment, to which this report refers, was executed by the BGS whilst the medical assessment was subcontracted to the Institut

[5] printed as Lwamagasa on the 1:50,000 scale Busanda (Sheet 46/1) topographic map; also named elsewhere as Ruamagaza and Rwamagaza.

für Rechtsmedizin der Ludwig-Maximilians-Universität München, and will be the subject of separate reports.

The Environmental Assessment is part fulfilment of the project's objectives to (i) identify hotspots in the project demonstration sites, (ii) conduct geochemical and toxicological studies and other field investigations in order to assess the extent of environmental pollution in surrounding water bodies and (iii) devise intervention measures.

BGS Staff involved in the execution of the field programme were Dr J D Appleton (Project Manager & Geochemist), Mr T R Lister (Geochemist), Dr Helen Taylor (Aquatic Ecologist/Chemist). This report was prepared by Don Appleton and Helen Taylor, with contributions from Bob Lister.

2 Background

2.1 INTRODUCTION

The project proposal and work schedule was based initially on information on the Rwamagasa small-scale mining site in Geita district provided by UNIDO (L. Bernaudat) and from other readily accessible sources. This information indicated that there would be two main potential sources of mercury contamination. The first was from the main amalgamating area at the small-scale Blue Reef Mine, which is separately fenced and totally cemented. The second, and possibly more important source of contamination was from independent artisanal miners reported to sluice and amalgamate on the banks of the River Isingile, to the north of Rwamagasa.

Although Rwamagasa is located only 37 km to the south of Lake Victoria, streams draining the Rwamagasa 'mining hotspot' actually drain SW into the Nikonga River, and then for a further 430 km via the Moyowosi swamps and the River Malagarasi before reaching Lake Tanganyika near Ilagala, about 50 km to the SSE of Kigoma (Figure 1). One of the major objectives of the project is to assess the impact of mercury contamination on International waters as well as in the vicinity of the 'mining hotspot', so the field programme was carried out in two areas: (a) the Rwamagasa 'mining hotspot' sub-area and (b) the Lake Tanganyika – River Malagarasi sub-area (see Figure 2).

The Rwamagasa 'hotspot' is located about 3 km to the SE of the Buckreef Mine camp (Figure 3) and within the Buckreef/Rwamagasa gold prospect, which is currently being evaluated by the Perth-based Spinifex Gold (now named East Africa Mines). Nearby, Geita Mines has reserves of 6.4 Moz Au and production was 540,000 in 2001. Barrick's Bulyanhulu mine, which contains one of the largest gold reserves in East Africa, began commercial production in 2001. Bulyanhulu mine has resources of over 10 Moz with production forecast to start at 450,000 oz/year at cash costs of $130/oz and a life of mine of 15 years.

According to the Spinifex Gold Annual Report for 2002, an exploration program in the Buckreef/ Rwamagasa area commenced in September 2002 involving 60,000 m of drilling and collection of over 10,000 soil samples. Artisanal workings in the Rwamagasa area were reported to be focussed on quartz veins in sheared, ferruginous, chlorite mica schists. Grab samples of vein and wall rock grade 6-62 g/t Au (Spinifex Ltd 2002 Annual Report). Gold-bearing shear zones are reported to trend NW-SE and E-W. As would be expected, some conflict between the large-scale and artisanal mining activities has been reported in this area. Spinifex is actively promoting the prospect and apparently looking for prospective purchasers.

Background information on mercury contamination associated with artisanal gold mining in Tanzania is available in a number of published reports and scientific papers (Appel et al., 2000; Asanao et al., 2000;

Campbell et al., 2003a,b; Harada et al., 1999; Ikingura and Akagi, 1996; Ikingura and Akagi, 2002; Kinabo, 1996; Kinabo, 2002a,b; Kinabo and Lyimo, 2002; Kishe and Machiwa, 2003; Machiwa et al., 2003; Mutakyhwa, 2002; Semu et al., 1989; Sindayigaya, 1994; University of Dar es Salaam, 1994; van Straaten 2000a,b). For background information on the geology and mineralization, see van Straaten (1984), Barth (1990) and Borg (1994).

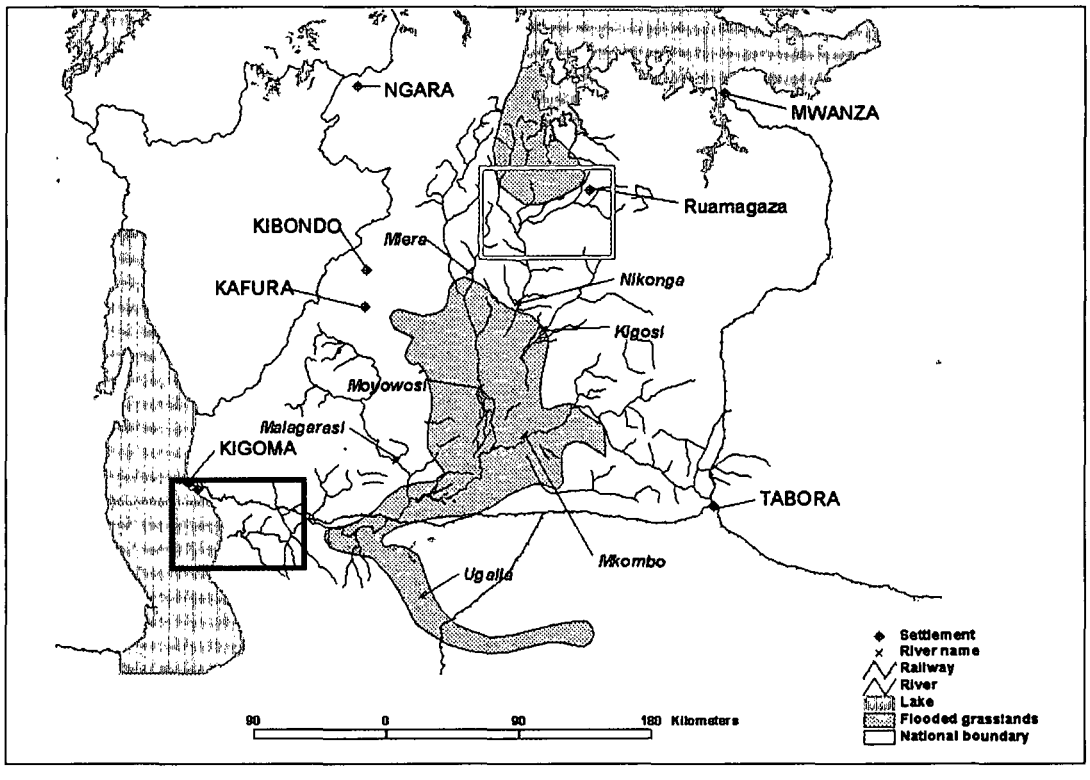

Figure 1. Sub-areas for environmental assessment. BLUE BOX = Lake Tanganyika - River Malagarasi sub-area: Lower section of River Malagarasi and International waters of Lake Tanganyika; RED BOX Rwamagasa sub-area: Upper section of Nikonga River downstream of Ruamagaza (Rwamagasa)

2.2 RIVER MALAGARASI

The principle objective of water, sediment and fish sampling in the lower reaches of the River Malagarasi and obtaining fish samples from the delta zone in Lake Tanganyika was to evaluate whether mercury contamination from the Rwamagasa and adjoining mining areas is dispersed as far as Lake Tanganyika. The GEF Global Mercury Project focuses on the impact of mercury contamination on International water bodies so it was essential that samples were collected from the above-mentioned locations.

Dispersion of mercury from the Rwamagasa area to Lake Tanganyika may be unlikely because contaminant mercury would expected to be adsorbed by organic material in the extensive Moyowozi and Njingwe Swamps and flooded grassland area, located from 120 km to 350 km downstream of Rwamagasa. The Malagarasi-Moyowozi-Sagara-Ugalla swamps cover an area of approximately 25,000 km^2 (see Figure 1). Whereas the swamps will act as a potential methylation zone, they will also act as an environmental sink for mercury contamination and this is likely to prevent migration of Hg into the lower reaches of the Malagarasi River and Lake Tanganyika, some 430 km downstream from Rwamagasa. The swamp area was inaccessible within the logistical and budgetary constraints of the current project. It should be noted that if elevated mercury concentrations occur in the river sediment, water and fish samples collected from the lower reaches of the Malagarasi River and Lake Tanganyika, this will not prove that artisanal gold mining is the source of the Hg. A much more rigorous, time-consuming and expensive field programme would be required to assess the source of elevated mercury levels, should these be found.

Stream sediment, water, and fish were collected from the lower reaches of the Malagarasi River near where it enters Lake Tanganyika (Ilagala, Figure 2) and also from near Uvinza, approximately 60 km upstream. Fish samples were collected in close collaboration with national fisheries experts from the Kigoma offices of the Tanzania Fisheries Research Institute (TAFIRI).

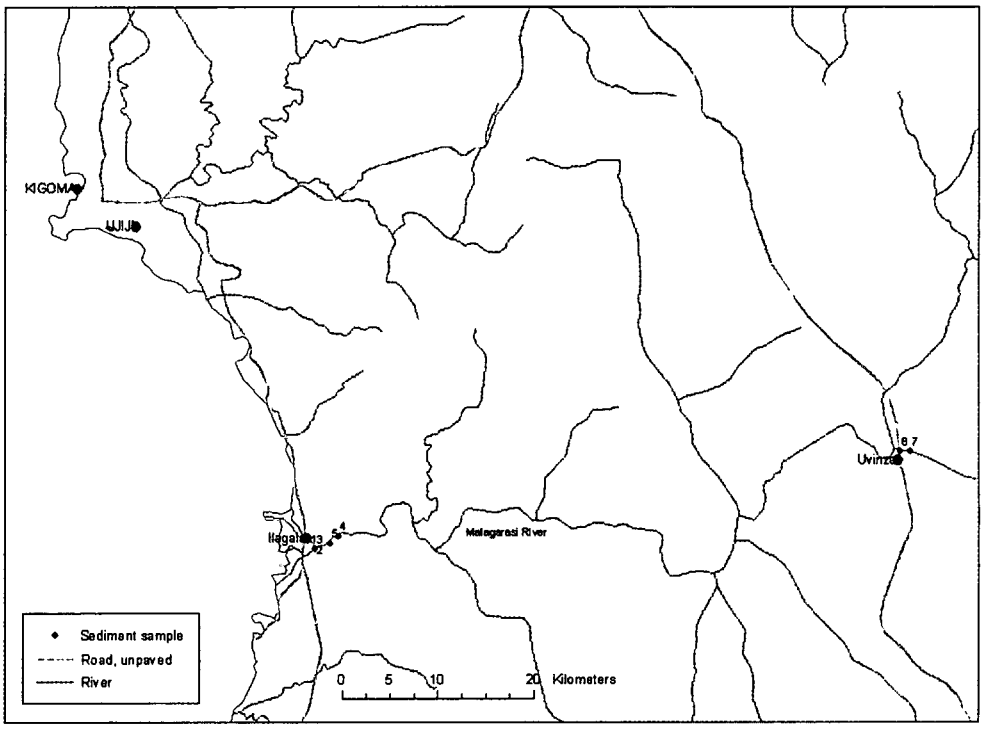

Figure 2. Location of sediment and water samples sites on the River Malagarasi

2.3 RWAMAGASA

A description of the Rwamagasa small-scale mining site in Geita district was provided to the BGS team by L. Bernaudat (UNIDO). "*The site is important in size; shops of all kind can be found. The mining area is away from the residential part and fenced. A roof covers every pit. The miners have stopped grinding the ore themselves because the machines to do it properly are far too expensive. The service of grinding the ore is provided by Merameta, a joint venture between the Government and private investors from South Africa. The miners call the company, when they have enough ore in stock. Meremata provides the ball mills and takes the machinery back when the ore has been crushed. In exchange, the miners have to sell the gold to Merameta. This company provides also generators for the water pumps. The processing area is fenced and equipped with cemented ponds. The amalgamating area itself is separately fenced and totally cemented. Unfortunately, no processing activity could be observed during the visit. The only existing retort was broken. On this site, only men seem to work for the mine. Women hold the shops in the village and provide the miners with food. Surprisingly, the cooking takes place in the processing area where amalgam is burned as well. In the village, a few ball mills have been seen in operation. A young boy was observed when crushing the ore with a hammer, but he was stopped and replaced by an adult when the UNIDO group was noticed by the villagers. These independent miners cause serious pollution. During the visit, some miners were seen when sluicing/amalgamating directly at the shore of the river. At this huge site, the best as well as the worst artisanal methods could be observed only a few hundreds of meters apart. It seems that the awareness campaign initiated by UNIDO has not reached everyone.*"

The situation found in the area is now somewhat different. The *Meremata* organisation no longer functions in Rwamagasa. The only legal mining is carried out within the boundaries of the PML held by Blue Reef Mines (Plates 1 to 6) where it is reported that approximately 150 people are involved in the mining and mineral processing activities. This is the only site in the Rwamagasa area where primary ore is being mined underground[6]. All other mineral processing activity of any significance is concentrated at the northern margin of Rwamagasa, especially on the land sloping down to the Isingile River. In this area, there are estimated to be about 30 groups of historic and active tailings dumps and up to ten localities where ball mills are operating. The number of people actively involved, *at one particular time*, in ball milling, sluicing and amalgamation (assuming about 5-10 people work at each of 10 ball milling sites; 5 people work at each of 20 active sluicing sites; and 5 people work at each of about 10 active amalgamation sites) is probably no more than 300. This observation needs to be verified by more detailed studies.

At Blue Reef mine and other amalgamation ponds, miners were seen to mix the mercury used for amalgamation with their bare hands (see Plates 7 to 12 for sequence of photos illustrating amalgamation process). Amalgam is burned in the open air, usually in a small charcoal fire, which releases the mercury

[6] This report does not include artisanal mining in the Iseni area, which lies approximately 5 km to the east of Rwamagaza village.

to the atmosphere (Plate 13). Amalgamation mainly takes place adjacent to amalgamation ponds, which are usually formed of concrete, but sometimes have only wood walls. According to environmental legislation, the mercury contaminated mineral concentrates and tailings should be stored in a concrete lined structure. However, it was seen and reported that mercury contaminated tailings are frequently reprocessed by digging out tailings from the amalgamation ponds (see, for example, Plate 14). These are dried, re-ground in a ball mill and sluiced prior to amalgamation. Re-processing the amalgamation tailings will result in dispersion of mercury into the local vicinity of the mineral processing areas where this activity is carried out (i.e. mainly on the slopes going N. down to the R. Isingile *mbuga*). It is reported that reprocessing of amalgamation tailings is carried out within the confines of the mineral-processing centre at the Blue Reef mine.

The socio-economic report states that "Usually the ore is taken home to be manually crushed either by the members of family or labourers. After the ore is crushed to a certain size, the ore is taken to the ball mill, which is usually a modified tractor with a wheel hub connected to the ball mill. The ball mills are set up in the residential areas and the owner of the crusher provides mercury for amalgamation." BGS staff observed that ball mills driven by small petrol engines are now crushing most of the ore and re-processed tailings. Crushers based on modified tractors are rare. Most of the ball mills seen are located on the northern margin of Rwamagasa, on the slopes leading down to the Isingile River. There are also similar ball mills located within the confines of the Blue Reef Mine processing centre (Plates 5 and 6). No "gold shops", where gold is re-heated to remove excess mercury, were found or reported in the Rwamagasa area. In addition, it appears that mercury is not added to rock being crushed in ball mills so this will tend to reduce the potential for contamination. The only retort seen was in the mine office at the Blue reef mine and this was not being used because the glass bowl was broken.

Apart from Hg vapour released when the amalgam is burned, the main potential source of contamination to the aquatic environment is from mercury-contaminated tailings being reprocessed by the artisanal miners operating in the area immediately to the north of Rwamagasa (Plates 15 to 17). The field programme was carried out during the dry season so there was little evidence that large quantities of contaminated tailings are being washed into the Isingile River. This is in strong contrast to many other artisanal mining sites, such as the Naboc River, in the Philippines, for example (Appleton, 2000). Wastewater and tailings from amalgamation 'ponds' was observed at one site to be overflowing onto an area where vegetables are being grown (see Plate 14).

Previous studies in the Lake Victoria Goldfields area indicate that dispersion of mercury from tailings is low, not least because Fe-rich laterites and seasonal swamps (*mbugas*) will act as natural barriers or sinks preventing the widespread dispersion of Hg in sediments and soils. Dispersion of Hg in ground and surface water during the dry season is reported to be very restricted (van Straaten, 2000). There were few visible signs that indicate extensive dispersion of Hg-contaminated tailings into the drainage system of the Rwamagasa area (Figure 3). Contamination of drainage sediment solely from operations in the Rwamagasa area will impact the Isingile drainage system down to the confluence with the stream

draining south from Buck Reef mine. Downstream of this point, contamination may be derived from other sources as well as artisanal mining in the Tembomine area.

If large quantities of contaminated sediment are dispersed onto the *mbuga* area adjacent to the Isingile River during the wet season then this may lead to the significant dispersion of contaminant mercury both into the aquatic system and onto agricultural sites being used for rice, maize, and vegetable cultivation. The results of the sediment and soil sampling programme should reveal the extent and magnitude of this dispersion.

The only evidence that mercury may be impacting animals was seen at one site where ducks were seen swimming in water that had overflown from an amalgamation pond (Plate 19).

The socio-economic survey did not provide an adequate reconstruction of the mining history of the area so it was not possible to use this source to identify the likely extent and magnitude of metallic Hg contamination in the mining hotspot area. A semi-quantitative estimation of this was achieved by using the presence of tailings to indicate the locations of historic and present mineral processing sites and thus the likely sources of Hg contamination. In particular, the main Hg amalgamation ponds were located and sampled. Whereas collection of information on gold production in the area was outside the terms of reference of this environmental project, discussions with Geita Mines Officer Mr John Nayopa revealed that the Blue Reef Mine produces about 1 kg per month whilst the artisanal miners re-working tailings (mainly in the area along the northern border of Rwamagasa, adjacent to the Isingile River) produce about 0.5 kg per month. If these figures are correct, approximately 27 kg of mercury will be released to the environment from the Rwamagasa area each year. Of this, approximately 14 kg will be emitted to the atmosphere from amalgam burning within the Blue Reef mine site. Because the Blue Reef mine is located well away from surface drainage, it is estimated that very little Hg from this source will enter the river system through water-born dispersion of Hg-contaminated tailings. Approximately 7 kg of mercury will be released to the atmosphere from the other amalgamation sites and 2 to 3 kg to heavy mineral tailings in the amalgamation ponds (which are often reprocessed).

3 Sampling and analytical methods

Project and field work planning was based on (i) an evaluation of the sociological survey report on the Rwamagasa mining community produced by a National Expert (Wagner, 2003) and (ii) all other readily available sources of information. The operational plan for the field programme was designed to fulfil the ToR (Appendix 1) and is described in the Field Report (Appleton, Lister and Taylor, 2003).

3.1 SAMPLING

3.1.1 Drainage sediment and water

In the River Malagarasi near Ilagala, sediment samples were collected using a Van Veen grab sampler deployed from a boat (Plate 20) and the fixed-cable ferry. Sub-samples were placed in a pan (Plate 21) and thoroughly mixed prior to wet sieving through 2mm and 150μm mesh. At the second site on the Malagarasi River, near Uvinza, it was not practical to use the Van Veen sampler so sediment was obtained from appropriate sites along the bank of the river and wet sieved (Plate 22). The sample sites were well away from the influence of the salt mines, Uvinza town and the Lugufu Refugee Centre

The streams in the Rwamagasa area were either completely dry or ponded (Plates 23 to 26) so there was no active dispersion of potentially contaminated sediment in suspension. For this reason no suspended particulate samples were collected.

Bottom sediment samples, each of 150-200 grams, were collected by wet screening up to 5 kg of river or stream-bed sediment through 2mm and <150 μm sieves, using a minimal amount of water to avoid the loss of fine silt and clay fractions. Samples were sealed in plastic securitainers to avoid evaporative losses and oxidation. The approximate weight percentages of the >2mm, 2mm to >150μm, and <150μm size fractions were noted at each site.

Duplicate sediment samples were collected at four sites (A69/70; A-82/203; A85/106; and A86/216). Background samples from areas known to be well away from artisanal gold mining were collected from streams in the Munekesi area (A-87) and from the Nyamsenga (A-104) (se Figure 3). Sample site A-69/70 is located about 300 m upstream from the nearest processing site so should not be impacted by tailings contamination. There could, of course, be contamination by airborne mercury vapour at this site.

Stream water pH, temperature, Eh and conductivity were determined in the field using a series of temperature-compensated electrodes and meters (Plate 27). Most of the water samples for analysis at the BGS were collected using 25 mm diameter, 0.45 μm Millipore™ cellulose acetate membranes into 30 ml HPDE bottles (*Nalgene™*). Coarse prefilters were used in conjunction with the 0.45 mm cellulose disks on all obviously turbid samples. A few samples were filtered through 50 mm diameter *Sartorius Sartolab* P 0.45 μm disposable SFCA membranes using 50 ml disposable syringes and collected into 30 ml LPDE

bottles (*Nalgene*^{TM}). At each site, two 30 ml samples, filtered and preserved with 0.3 ml conc. HNO_3 + 0.3 ml 0.2 vol.% K_2CrO_7 were collected for total Hg analysis.

In the Rwamagasa area, where there is some possibility of arsenopyrite being associated with the gold mineralization, one or two 30 ml samples of filtered water preserved with 1% v/v HNO_3 were collected for the determination of arsenic.

A number of "Blank" water samples were made using deionised water from the BGS laboratories mixed with the nitric acid used to preserve the water samples. Data for these Blanks was used to correct the Hg and As data as it was demonstrated that the nitric acid provided by the University of Dar es Salaam was not totally free of As and Hg. It was not practicable to transport concentrated nitric acid from the UK as transportation is prohibited in passenger aircraft. Water samples were kept cool after collection and preserved with acid within 8 hours after collection. The samples were then stored in a refrigerator before being transported back to the UK for analysis.

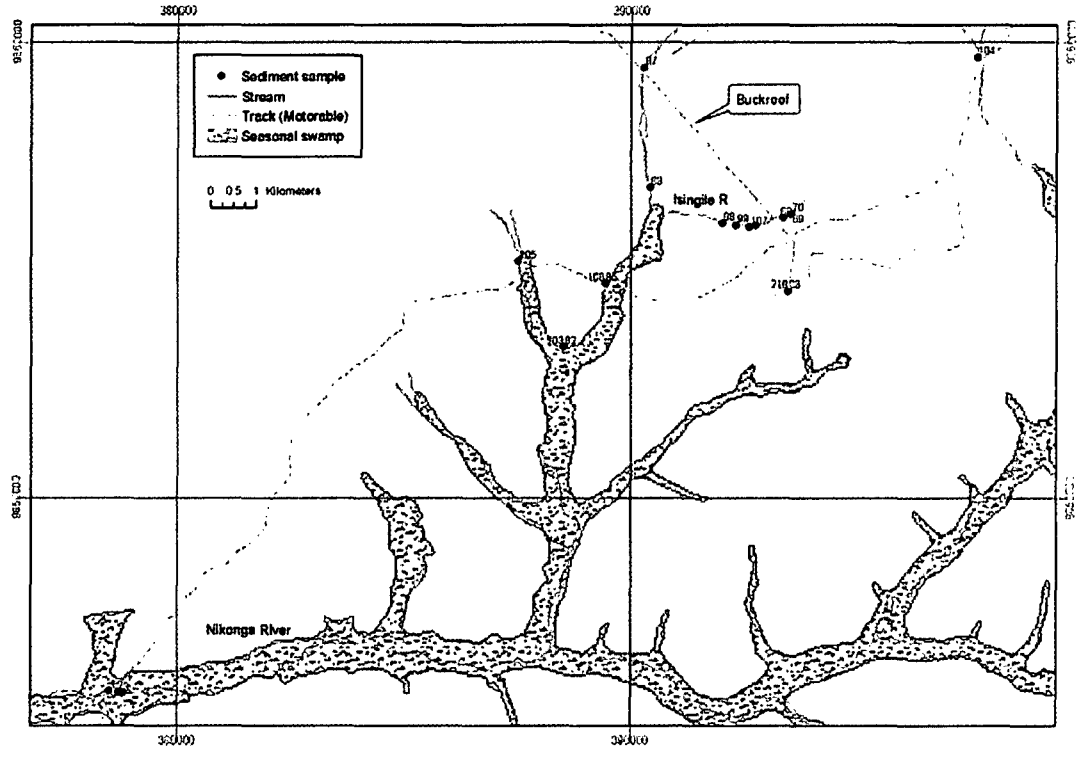

Figure 3. Distribution of wet-sieved (<150μm) stream sediment samples collected from the Rwamagasa area

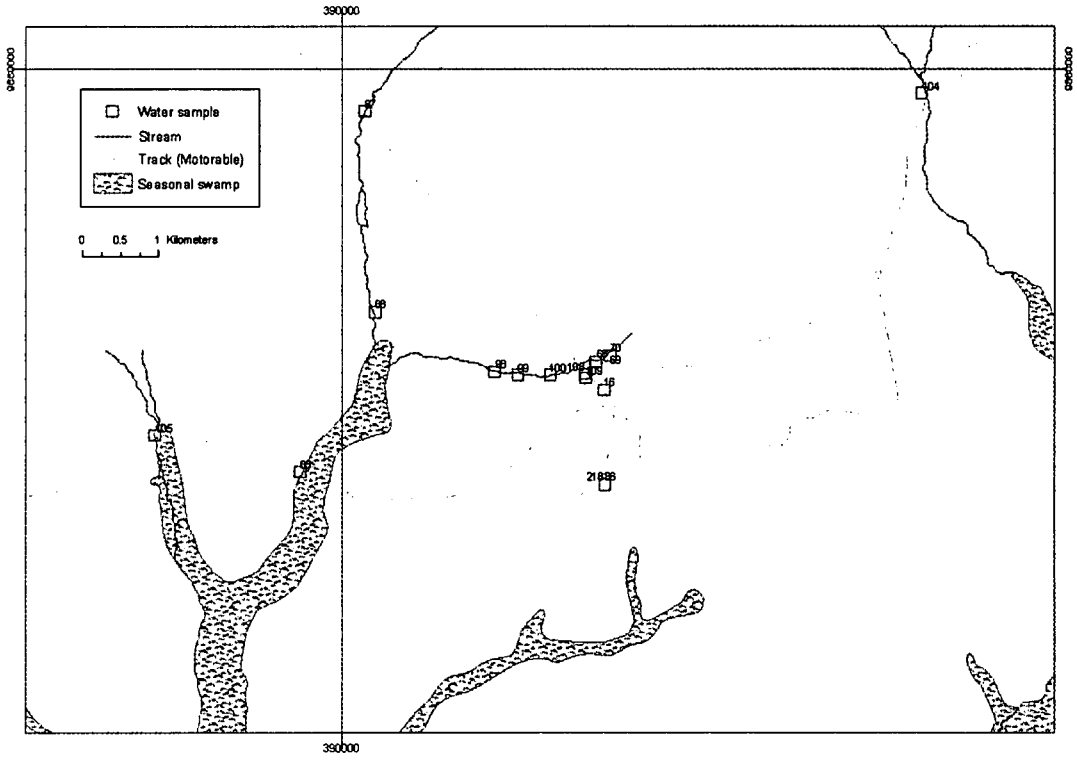

Figure 4. Distribution of filtered water samples collected from the Rwamagasa area

3.1.2 Mineral processing waste (Tailings)

One of the major objectives of the environmental assessment is to Determine the level and extent of metallic Hg contamination in the mining/mineral processing/amalgamation 'hotspot' area. An assessment of the potential environmental impact and 'hazard' associated with mineral processing tailings, especially in the area located immediately south of the River Isingile and within the built-up area of Rwamagasa, was based on a representative selection of channel (Plate 28) and composite samples collected from the numerous tailings piles and a selection of the mercury amalgamation 'ponds' (Plates 29 to 38). Tailings samples were collected by thoroughly mixing a 2-3 kg composite of sub-samples in a large fibreglass pan, before obtaining a 250g split by cone-and-quartering. Samples were sealed in plastic securitainers to avoid evaporative losses and oxidation.

Locations of the different types of tailings samples are illustrated in Figures 5 and 6. The volume (m^{-3}) of each tailings pile (or group of piles) at a sample site was estimated (see Figures 7 and 8).

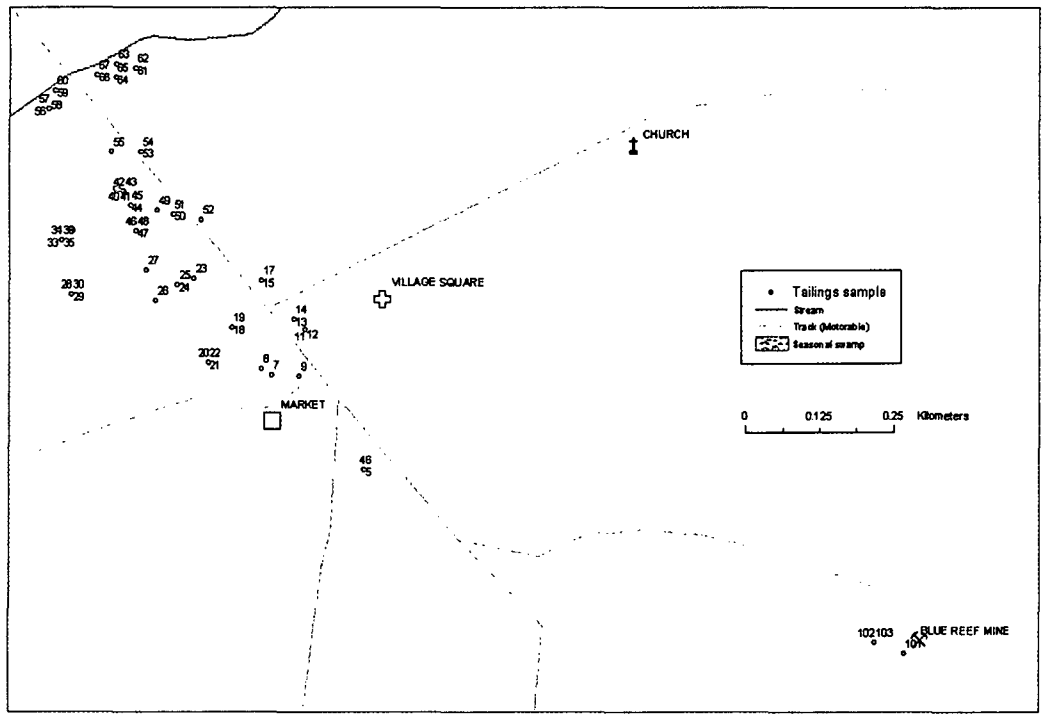

Figure 5. Location of tailings samples in the Rwamagasa area.

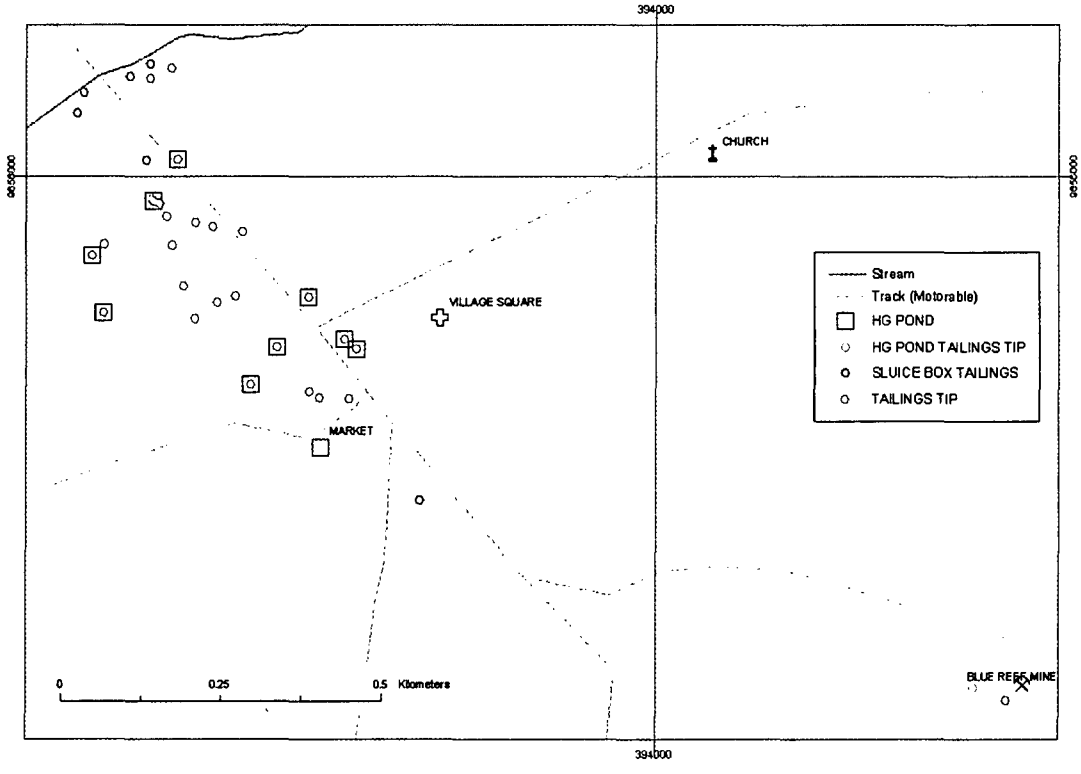

Figure 6. Distribution and classification of tailings sample types in the Rwamagasa area.

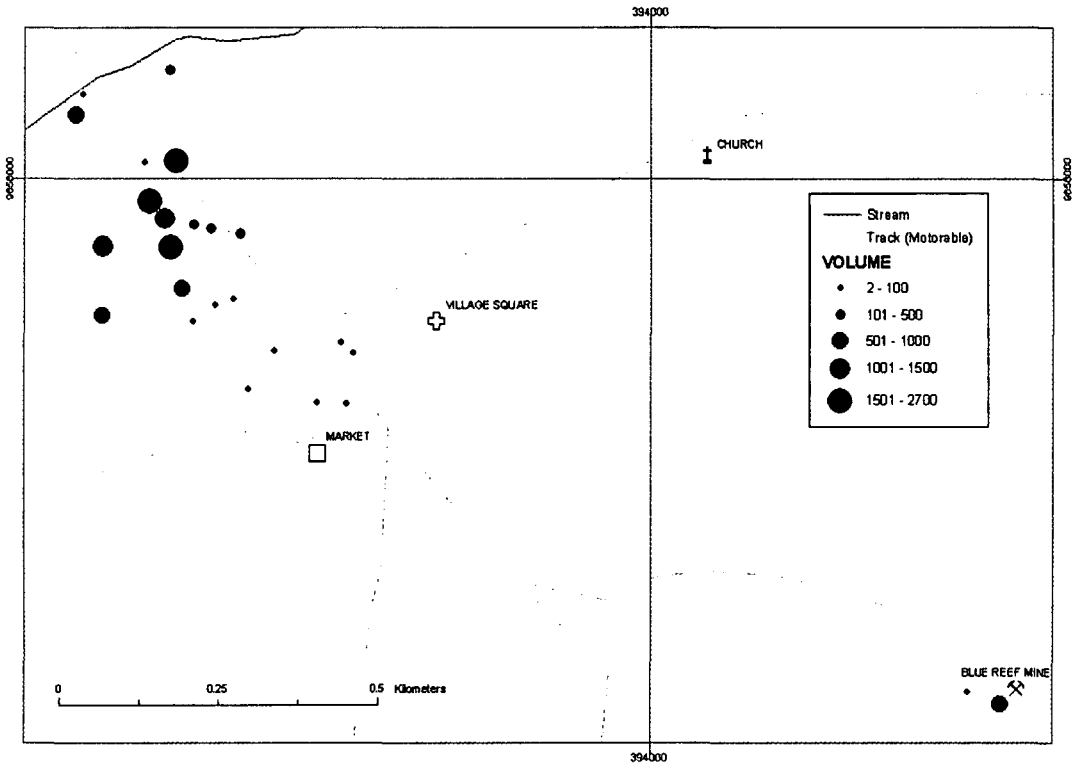

Figure 7. Approximate volumes (m^{-3}) of tailings tips in the Rwamagasa area.

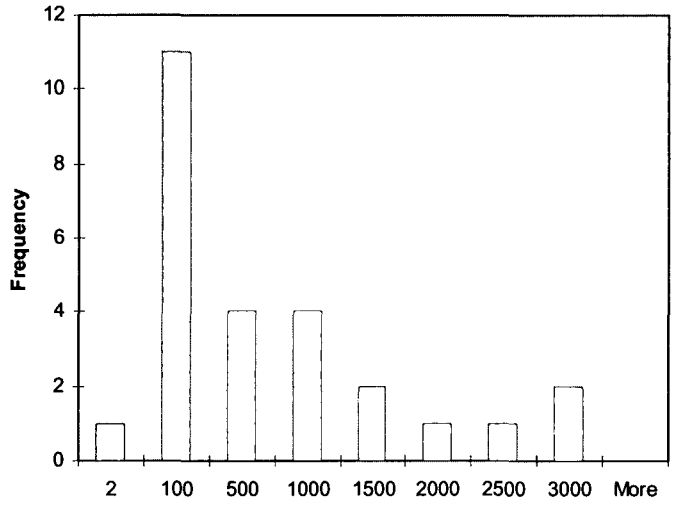

Figure 8. Histogram of approximate tailings tip volumes (m^{-3}) in the Rwamagasa area.

3.1.3 Soil

A representative number of topsoil samples (0-10 or 5-15 cm depth, depending on the situation) were collected in the Rwamagasa area and adjacent agricultural land (Figures 9 and 10). Hg analysis of these samples may help to indicate the level and extent of contamination caused by the airborne dispersion of Hg vapour as well as the dispersion of wind and water borne Hg-contaminated tailings. Hg results for soil samples may indicate whether Hg vapour is preferentially dispersed in relation to the predominant wind direction(s). The distribution of soil samples classified by land use is illustrated in Figure 11.

Soil samples were collected by mixing sub-samples taken from points within an area of about 100 m^2. In some cases the resultant bulk sample was relatively inhomogeneous (Plate 39) so careful disaggregation and mixing of the bulk sample was carried out prior to cone-and-quartering (Plate 40) to obtain a relatively homogeneous sample of 250-350g. Samples were sealed either in plastic securitainers or in a Kraft paper bag sealed within a plastic bag in order to avoid evaporative losses and oxidation. It was impractical and in most cases unnecessary to sieve the soil through a 2mm mesh in the field. Many soils were damp and very clayey so would not pass though a 2 mm sieve. Removal of the +2mm fraction will be carried out in the laboratory following drying and disaggregation. Duplicate samples were taken at a number of sites to estimate sampling precision.

Three profiles (A245-248; A267-271; A279-284; Figure 10) in the *mbuga* soils were sampled at 10 cm intervals to determine the vertical variation of Hg in agricultural land adjacent to the main mineral processing area. The profile A-279 to A-284 is illustrated in Plate 41.

In addition to the determination of Hg, the soil samples were also analysed for organic matter and *aqua regia* soluble Fe in order to assess the impact of adsorption onto organic matter in the organic-clay-rich vertisols (*mbuga*) and Fe-Al hydroxides in the ferrallitic soils (ferric luvisols and ferric acrisols; FAO classification) that characterise much of the Rwamagasa area. The *mbuga* soils are reported to be chemically rich; characterised by high content of smectite, shrink-swell clay; are very sticky and plastic when wet and very hard with a cracked surface when dry. They appear in some parts to have a high content of organic material. Medium to dark brown (sometimes orange brown) ferric soils (reported to be mainly ferric acrisols with argic B horizon, low nutrient retention properties, cation exchange capacity dominated by aluminium ions) characterise the interfluvial areas underlain by 'greenstone' belt rocks. Areas underlain by granite have much paler coloured, sandy and quartz-rich soils.

The final major objective of the environmental assessment was to Investigate the situation of the agricultural sites in the vicinity of the Rwamagasa small-scale mining activities and take samples. This was achieved by collecting composite surface soil samples (0-10 or 5-15 cm, depending on the situation) from (i) a detailed grid covering the area between the main artisanal mining mineral processing area at the northern edge of Rwamagasa and extending across the *mbuga* area of the River Isingile (Figures 10 and 11), (ii) along a profile crossing the R. Isingile *mbuga* about 1 km downstream (sites A-219-224), and (iii) along two profiles across *mbuga* areas (a) located further down the Isingile drainage system (sites A81-

84, A204-207) and (b) across the *mbuga* draining south from Tembomine (sites A76-80) (see Figures 9 and 11). Some of these samples were collected from dry rice paddies.

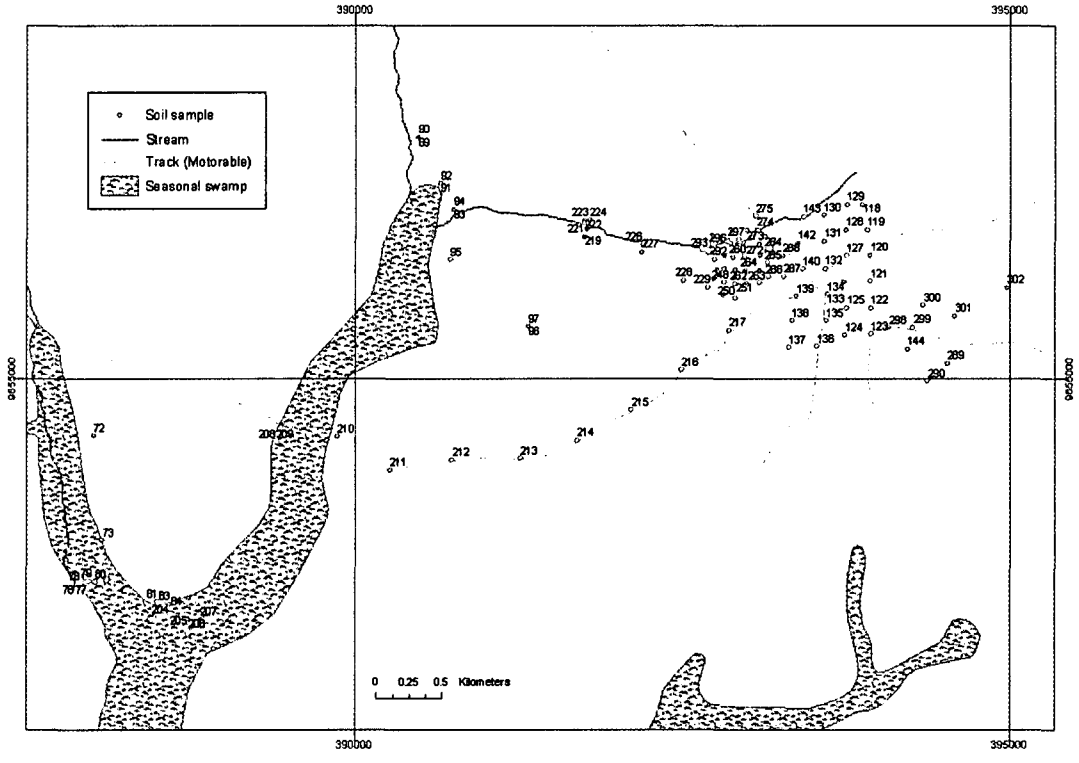

Figure 9. Distribution of soil samples collected in the Rwamagasa area (see Figure 8 below for detailed soil grid).

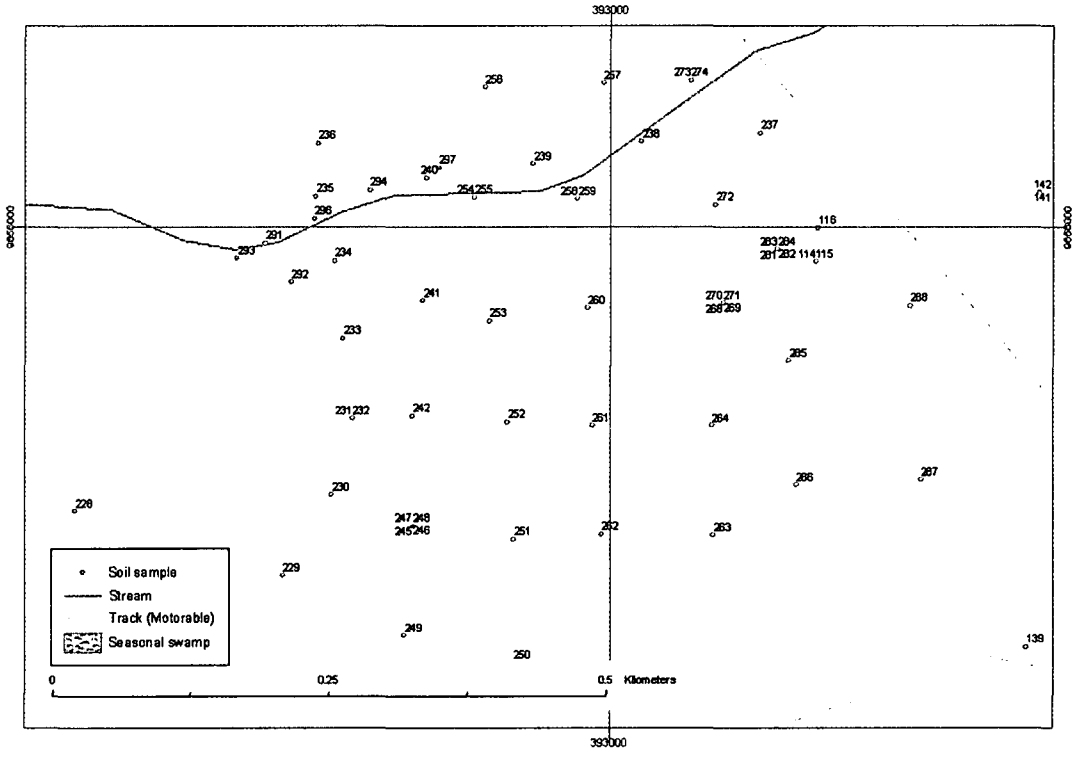

Figure 10. Distribution of high-density soil sampling grid (refer to Figure 7 above).

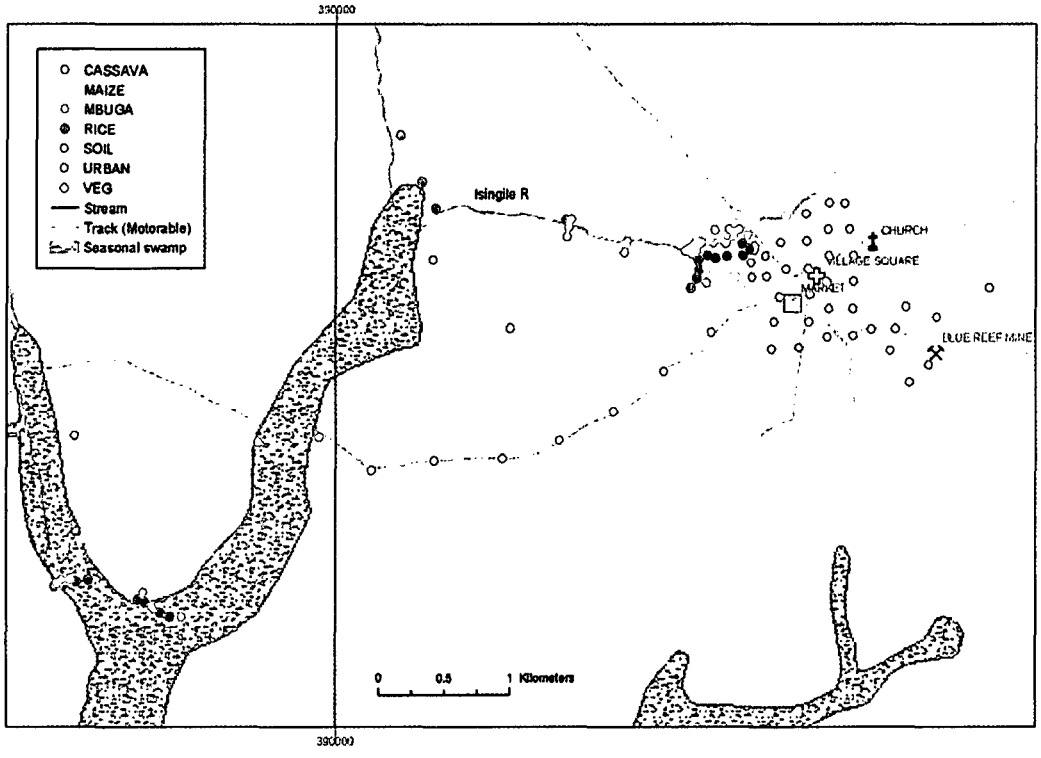

Figure 11. Soil samples classified by land use (legend self explanatory, except SOIL = unclassified)

3.1.4 Crops

The objective to Evaluate the nature and extent of the mercury pollution in agricultural produce, especially in those being part of the main diet was achieved by collecting for analysis vegetable and crop samples from two localities within the R. Isingile *mbuga* (Figure 12). Vegetable samples A110-113 were collected from a site within 5-10 m of an amalgamation pond where water, that is presumed to be Hg contaminated, was overflowing onto the cultivated ground (Plates 14 and 42). Other vegetable samples were obtained from vegetable gardens located on the northern side of the R. Isingile *mbuga* (sites 292-297, Figure 12; Plates 45 and 46) where potentially contaminated water from the R. Isingile was being used for irrigation. At most of these sites a soil sample was collected from the root zone in the immediate vicinity of where the vegetables sample was being grown. A number of rice samples reported to have been grown on the R. Isingile *mbuga* were also obtained and a range of vegetable samples reputed to be grown at the same location were purchased from the Rwamagasa market.

A potentially important pathway of mercury into the human food chain is linked to the cooking of food in processing areas where amalgam is burned. This was not observed during the field programme so could not be investigated.

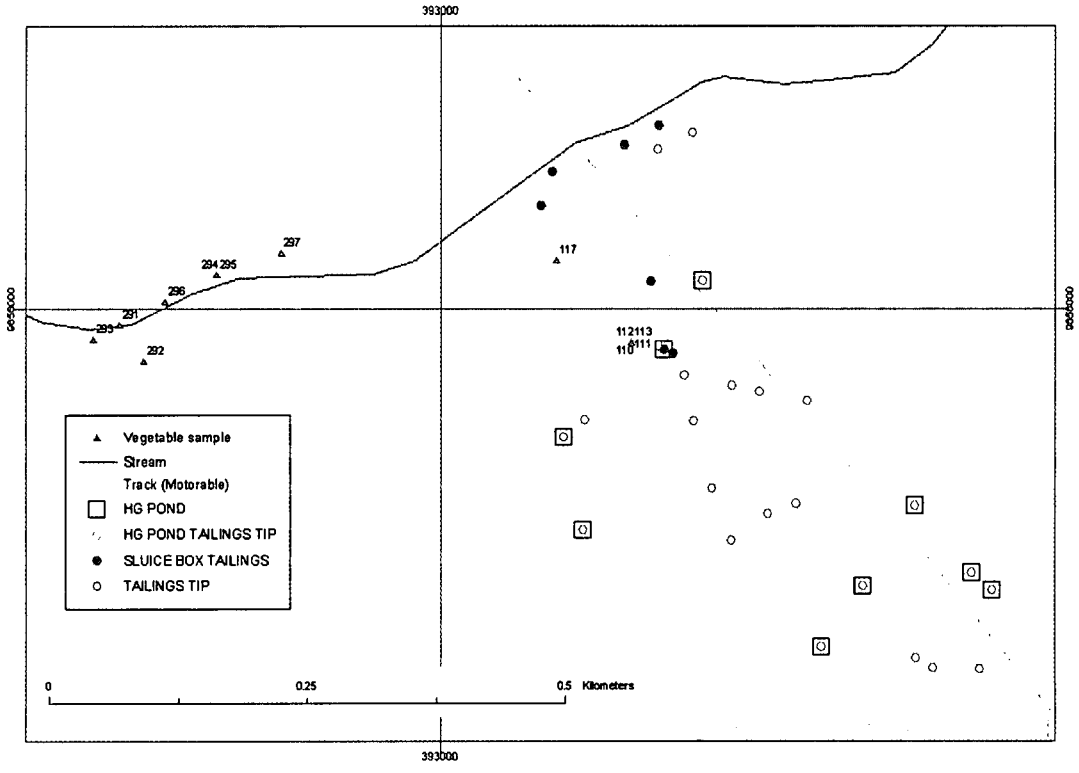

Figure 12. Location of vegetable samples compared with the distribution of tailings in the Rwamagasa area.

3.1.5 Fish

3.1.5.1 River Malagarasi

Identification of the most appropriate and practical species for monitoring was discussed with experts from TAFIRI[7] focussing on piscivores, species consumed by the local population, and food chain species with relatively restricted domains that should provide a good indication of the availability of methyl mercury in the food chain. An assessment of the levels of Hg in fish can allow the exposure of potentially affected human populations to be assessed and also act as bioindicators so that Hg contamination 'hotspots' may be identified.

Fish reported to originate from the delta area, at and close to the mouth of the Malagarasi River, and also from deeper water in Lake Tanganyika were purchased from Ilagala market (Table 1, Plates 47 and 48). The fish had been caught using nets. Lake Tanganyika is an important source of fish both internationally and locally[8].

[7] Identification of species was aided by TAFIRI staff with reference to Eccles (1992)

[8] See documentation from the Lake Tanganyika Biodiversity Project at http://www.ltbp.org/OVIEW.HTM

With assistance from Mr Kashushu, senior TAFIRI technician at Kigoma, 32 fish samples were purchased from Ilagala market. These comprised, from Lake Tanganyika, *Lates malagarasi* (n = 5) and *Oreochromis tanganicae* (n = 5) and from the Malagarasi River delta, *Hydrocyon vittatus* (n = 2), *Brycinus rhodopleura* (n = 6), *Auchenoglanis occidentalis* (n = 5) *and Clarias gariepinus* (n = 6). Examples of each species were photographed. Fish were processed in the field on the day of collection. The samples from both the Malagarasi River and Lake Tanganyika include a range omnivorous and piscivorous species (Table 1; Plates 49 to 55)

Attempts were made to (i) standardize sampling (especially the length of fish collected and analysed); and (ii) collect omnivorous fish to highlight mercury methylation and the potential health hazard to people consuming the fish. It transpired that it was neither logistically possible nor appropriate to collect benthic invertebrates for Hg determination in this area. The length and weight of each fish sample was recorded (Appendix 3).

At Uvinza, 9 fish samples (Table 2) were collected from the Malagarasi River by seine net by a local fisherman (Plate 56) under the supervision of TAFIRI and BGS staff. These comprised *Oreochromis tanganicae* (n = 4), *Barbus tropidolepsis* (n = 4, Plate 57) and *Ctenopharyngodon idella* (n = 1; Plate 58). Fish were sacrificed and processed in the field on the day of collection.

Table 1. Fish species from Ilagala market (fish caught by net)

Species	Common name	Origin	Eating Habits
Lates malagarasi	perch/lates	Lake Tanganyika	Piscivorous
Hydrocyon vittolus	tigerfish	Malagarasi River delta	Piscivorous
Brycinus rhodopleura	tigerfish	Malagarasi River delta	Piscivorous
Oreochromis tanganicae	tilapia	Lake Tanganyika	Omnivorous
Auchenoglanis occidentalis		Malagarasi River delta	Omnivorous
Clarias gariepinus	catfish	Malagarasi River delta	Omnivorous

Table 2. Fish species from the River Malagarasi near Uvinza

Species	Common name	Collection Method	Eating Habits
Oreochromis tanganicae	tilapia	seine net	Omnivorous
Barbus tropidolepsis		seine net	Omnivorous
Ctenopharyngodon idella	grass carp	rod & line	Omnivorous

3.1.5.2 RWAMAGASA

Whereas soil and sediment analysis will provide indications of the potential for methylation, only an assessment of the levels of Hg in fish/invertebrate samples, particularly fish, can indicate the extent and magnitude of biomethylation in the aquatic environment. Collection of a wide range of fish species in the Rwamagasa area was difficult due to the very dry conditions and restricted amount of water, which was generally confined to ponds. Fish samples were collected from the remaining small ponds by dam and drain, rod and line or by seine or gill net (Plates 24 and 25). The majority of the fish collected from the Rwamagasa area were the omnivorous catfish *Clarias* (Plate 59), *Haplochromis spp* (Plate 60) or *Barbus spp* (Plate 61) although some small specimens of the solely piscivorous *Brycinus* were collected from one site.

The distribution of fish sample sites is illustrated in Figure 13. Species collected from each site and their eating habits are summarised in Table 3.

Sixteen fish samples (*Clarias gariepinus* (n = 2) and *Barbus spp* (n = 14)) were collected from Rwamagasa Pond 1 (0392479/9656023) and a further 20 fish samples were collected from Pond 2 (located about 150 metres to the west of Pond 1). These included *C. gariepinus* (n = 3), *Barbus spp* (n = 2) and *Haplochromis spp* (n = 15).

C. gariepinus (n = 41) and *Haplochromis spp* (n = 11) were collected by dam/drain from Pond 4 (0393271/9654374), located to the south of Rwamagasa and potentially impacted by historic mineral processing activities and potentially contaminated acid (? mine) water.

Ten *C. gariepinus* were collected from Pond 5 (located about 150 m upstream of the main road from Rwamagasa to Buckreef Mine) by dam/drain and rod and line. This site is close to an area where tailings are being reprocessed by sluicing, but apparently not impacted by potential contamination from amalgamation ponds.

Pond 6 (0389192/9654784) samples comprise *Haplochromis spp* (n = 8), *Barbus spp* (n = 12), and *Brycinus* (n = 6) *and Clarias spp* (n = 20).

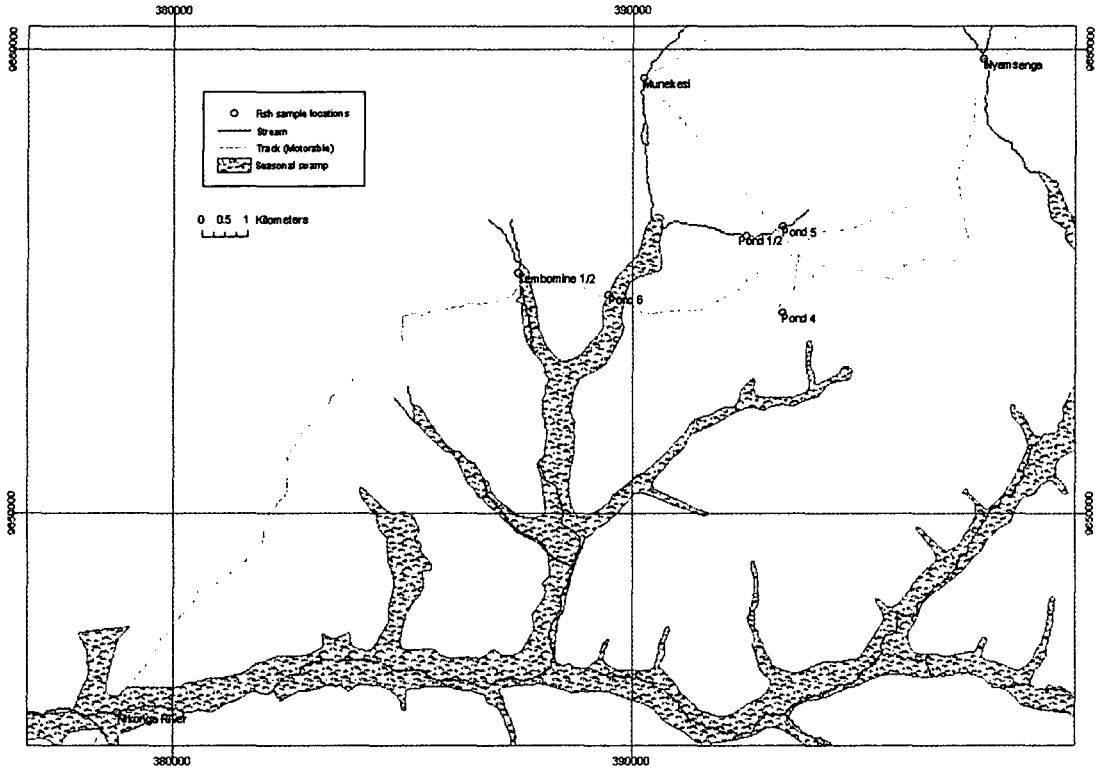

Figure 13. Distribution of fish sample sites in the Rwamagasa area.

The Nikonga River site will be impacted by potential contamination not only from the Rwamagasa, Iseni, Tembomine, Nyamtonde, Nyamalulu, and Nyamalimbe artisanal mining areas but also by contamination from the major historic artisanal mining activities at Nyarugusu. Very little water was present at this site (Plate 23) and all the fish were collected by damming and draining ponds. Samples from this site comprise *C alluadi (*n = 14), *Synodontis victoriae (*n = 1) and gastropods (n = 5).

Finally, fish samples were collected from two 'background' sites considered to be located well way from potential contamination by artisanal mining. Thirty seven *C. alluadi* were collected from the Nyamsenga 'background' site by dam/drain, and five samples of *C. gariepinus* were obtained from the Munekesi 'background' site (0390255/9659366).

For comparative purposes, twenty-five *C. gariepinus* were collected from the Tembomine site (0387526/9655219 to 0387538/9655215).

In addition, five *Oreochromis nitolicus* samples were purchased from Rwamagasa market. These originate from Lake Victoria and form a significant part of the diet for some of the local population.

Fish samples collected during the period 23 and 26 September were frozen whole on the day of collection and stored until they could be processed.

The recommendations for fish sampling made in the UNIDO Protocols (Veiga and Baker , 2003) were followed as closely as practicable, but this was constrained by two factors. The first factor is that funds

are available for the analysis of only about 180 fish samples. The second factor was that most of the streams in the immediate vicinity of the artisanal mining were ponded and not flowing. The only fish species available in significant numbers were *Haplochromis spp* (3-5 cm), *Barbus spp.* and *Clarias spp.* (5 to 42 cm) With very small fish, it is impractical to remove muscle tissue. In these cases, the fish were gutted, the head and tail removed and the fish washed with deionised water before freezing. Where individual fish are very small (3-7cm), composite samples comprising 2 to 5 individual fish of the same species, same length range and from the same site were submitted for analysis (see Appendix 2). The samples comprise muscle tissue, skin and bone. Analytical data for these samples will give an average Hg content for a site/length/species combination and reduce the number of samples for analysis from more than 250 to about 180. No published data has been encountered that describes the distribution of Hg in *Clarias* fish skin, muscle tissue, gills, and liver. Published data indicates that there is no significant difference in the bioaccumulation of Cu, Mn, Pb, Cr, Ni, Fe or Al in skin compared with muscle (of *Clarias*) but Zn appears to be 2 to 3 times higher in skin compared with muscle.

Fish of a few cm in size are usually analysed without any processing (removal of head, tail and guts) but Randy Baker (UNIDO consultant; personal communication) confirmed that it is acceptable to adopt the procedure used in the current field programme provided that all samples, now and in the future for the same species, are treated the same. Baker suggests that because a size-Hg relationship cannot be derived for small fish, they should be treated more like invertebrate samples. Baker considers that small fish are ideal biomonitors and suggested the fish should be stratified into say, three size categories: small (<3 cm), medium (3-5 cm) and larger (5 -8 cm; or whatever categories are appropriate) and pool groups of 3 to 5 fish per composite. He suggested that ideally a minimum of 5 composites per size and sampling area should be analysed for total Hg and compared to a reference area sample - which ideally, has the same species, size range and composites available. Simple statistics should then indicate whether the fish exposed to the impact of artisanal mining have consistently higher Hg than reference area fish, and whether there are any size related issues. Adopting this strategy should ensure that the most information is obtained within the constraints imposed by (i) the types and sizes of fish available and (ii) the available budget.

Table 3. Rwamagasa fish and invertebrate samples

Site	Species	Common name	Collection Method	Eating Habits
Pond1	*Clarias gariepinus*	catfish	seine net	Omnivorous
	Barbus spp		seine net	Omnivorous
Pond 2	*Clarias gariepinus*	catfish	dam/drain	Omnivorous
	Haplochromis spp		dam/drain	Omnivorous
Pond 4	*Clarias gariepinus*	catfish	dam/drain	Omnivorous
	Haplochromis spp		dam/drain	Omnivorous
Pond 5	*Clarias gariepinus*	catfish	dam/drain	Omnivorous
Pond 6	*Clarias spp*	catfish	rod & line	Omnivorous
	Haplochromis spp		rod & line	Omnivorous
	Barbus spp		rod & line	Omnivorous
	Brycinus spp (rhodopleura?)		rod & line	Piscivorous
Nikonga River	*Cynodontis victoriae*		dam/drain	Omnivorous
	Gastropoda spp		dam/drain	Herbivorous
	Clarias alluadi (see notes)	catfish	dam/drain	Omnivorous
Tembomine	*Clarias gariepinus*	catfish	dam/drain	Omnivorous
Munekesi	*Clarias gariepinus*	catfish	dam/drain	Omnivorous
Nyamsenga	*Clarias alluadi*	catfish	dam/drain	Omnivorous
Rwamagasa Market	*Oreochromis niloticus*	tilapia	Lake Victoria	Omnivorous

3.2 SAMPLE PREPARATION AND ANALYSIS

3.2.1 Water

Hg analysis was by cold vapour atomic fluorescence spectroscopy (CVAFS) to a practical detection limit of 20-30 ng/l. Water samples were subjected to a bromination stage, prior to analysis, to break down any organo-mercury compounds. Mercury was determined in four duplicate water samples and the second bottle from eight sample sites. The results indicate an acceptable level of reproducibility (Figure 14). Arsenic was determined by hydride generation AFS to a practical detection limit of 0.25 µ/L (ppb).

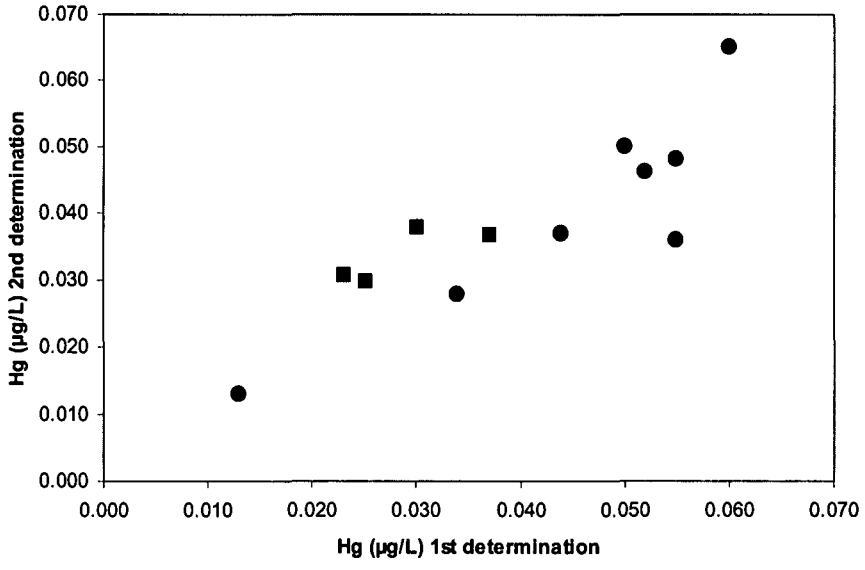

Figure 14. Hg is duplicate filtered water samples (■ duplicate sample; ● second bottle)

3.2.2 Sediments, tailings and soils

Bottom sediment, mineral processing tailings and soil samples were dried in a previously cleaned drying cabinet set at a temperature of 30°C. This is slightly below the temperature of 40°C recommended by the U.K. Standing Committee of Analysts (Mercury in waters, effluents, soils and sediments etc. additional methods 1985). The USEPA recommends that solid samples should be dried at less than 60°C in order to avoid Hg loss by volatilisation. Mercury loss by volatilisation during the drying process is always a potential problem, but drying at less than 40°C should have helped to minimise this loss. The only alternative is to digest and analyse samples and then recalculate Hg concentrations after determining loss of weight on drying. Unfortunately, this procedure prevents the adequate homogenisation of sediment and soil samples prior to analysis.

Dried bottom sediment, tailings and soil samples were disaggregated and ground in a *Tema* mill (agate) for a few seconds. The homogenised partly ground material was split by cone and quartering and approximately 30-50g was ground to <150 µm in an *Frisch* planetary ball mill (agate) for 30 minutes.

Samples (1g) for Hg determination were digested at room temp for 30 minutes in *aqua regia*, then placed in a hot water bath at 90 - 95°C for one hour, allowed to cool for 2 hours and made up to 10 ml with 5% HCl prior to determination by CV-AAS. When Hg exceeded the practical upper limit for CV-AAS (10 ppm), Hg was determined by ICP-ES.

Determination of As, Cd, Cu, Fe, Pb and Zn was by ICP-ES to practical detection limits of 2 ppm As, 0.5 ppm Cd, 1 ppm Cu, 0.01% Fe, 3 ppm Pb and 1 ppm Zn. 0.5 g of sample was leached in 3 ml 2-2-2- HCl-HNO_3-H_2O) at 95°C for one hour, diluted to 10 ml and analysed by ICP-ES.

Total Organic Carbon (Total C minus graphite C and carbonate) was determined by LECO analysis to a practical detection limit of 0.02%.

Replicate analytical determinations indicate a generally acceptable precision although this varies with concentration, as would be expected (Tables A-3-1, A-3-4, A-3-6). The precision data for field duplicate soil and tailings samples are also acceptable for this type of study (Figures 15 and 16; and Table A-3-2).

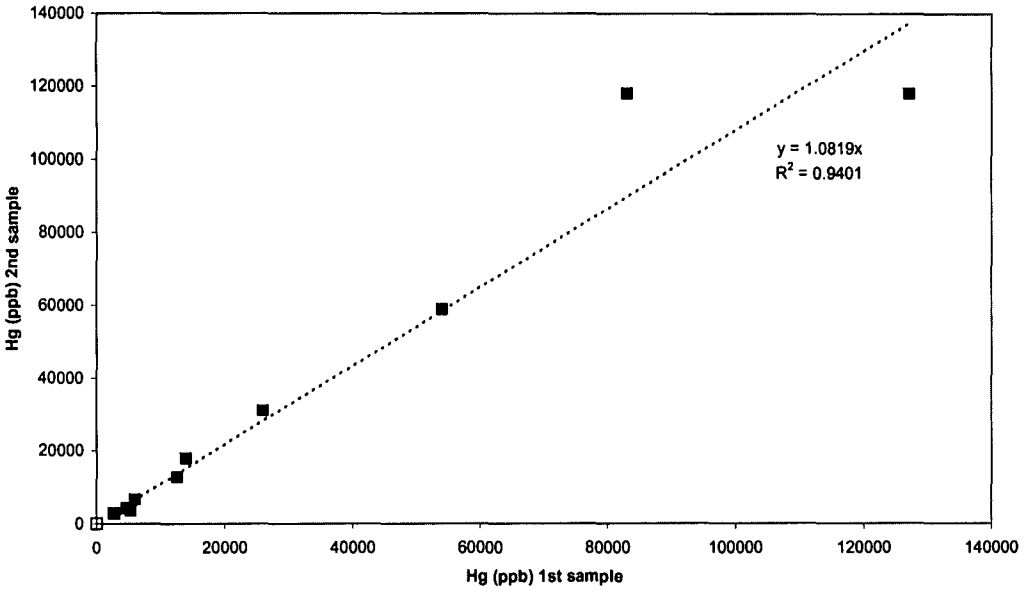

Figure 15. Hg (ppb) in duplicate tailings samples

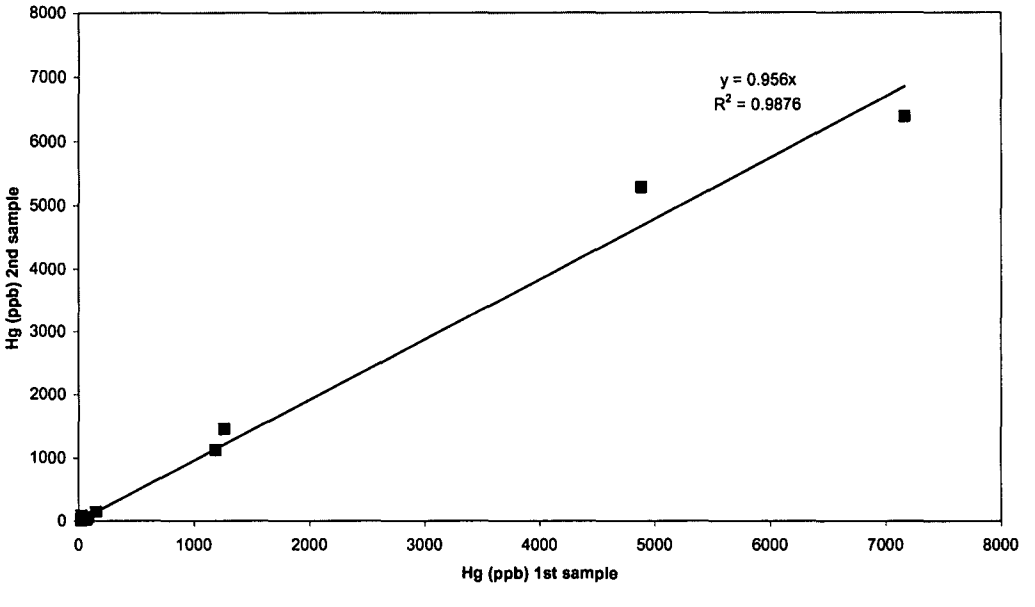

Figure 16. Hg (ppb) in duplicate soil samples

Some of the field duplicate sediment samples indicate significant variability in Zn and also Hg (Table A-3-3), which might reflect inhomogeneous particulate distribution in the sediments of anthropogenic Zn (from galvanised roof material, for example, and possibly also from ball mills) and Hg (from amalgamation). This inhomogeneity is to be expected and is also apparent in one pair of tailings duplicate samples (A011 and A012; Table A-3-2). More detailed investigations would be required to confirm these observations.

Accuracy of the ICP-ES and Organic Carbon (TOC) data is good, with recoveries of 96-102% (Table A-3-4). ACME Analytical Laboratories Ltd. recorded a recovery of 95% for CV-AAS determination of Hg based on CANMET-STSD-4 (Table A-3-5). Slightly higher Hg concentrations were determined by ICP-MS at the ACME Analytical Laboratories in six samples that had previously been analysed by CV-AAS (Table A-3-5).

Repeat determination of Hg in twelve sediment and soil samples from the Naboc area in Mindanao (Appleton, 2000) in which Hg had previously been determined by CV-AFS (BGS) confirm that the accuracy of the Hg analyses for the present study is adequate (Table A-3-5 and Figure 17). Mercury analyses at BGS were carried out by CV-AFS, using 1 g milled sub-samples, digested at <50oC in aqua regia. Mercury was then determined by CV-AFS to a practical detection limit for solid samples of 0.02 mg/kg.

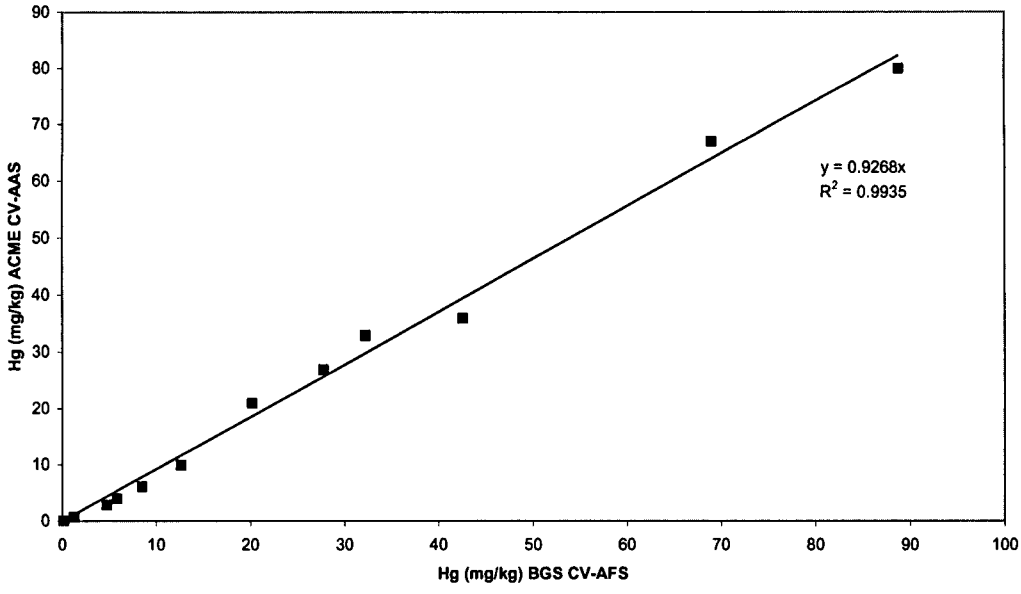

Figure 17. Comparison of Hg determined in a range of sediment and soil samples from the Naboc area, Mindanao (Appleton, 2000) by BGS (CV-AFS) and ACME Laboratories Ltd (CV-AAS <10 ppm Hg; ICP-AAS >10 ppm Hg).

3.2.3 Fish and vegetables

Homogenised fish samples were prepared using a food processor. Vegetables were macerated in the food processor to produce a fine pulp. In both cases, the whole sample was prepared in order to ensure a representative sub-sample for analysis. The freshly macerated material was analysed and a 50g subsample was frozen for possible future analysis. Mercury in 150 mg of prepared sample was measured directly using a Leco AMA 254 Advanced Mercury Analyser to a reporting limit is 0.004 mg/kg. In this method an aliquot of sample is combusted in pure oxygen and all evolved gasses are passed through a gold amalgamator, which collects and pre concentrates any mercury present. Mercury vapour released from the amalgamator by thermal decomposition is quantified by atomic absorption spectrophotometry.

The procedures adopted for control of analytical performance are compliant with standards described by IUPAC Guidelines on internal Quality Control, i.e. a minimum of 10% of all samples analysed for quality purposes; all analytical methods used are traceable, validated and controlled; continuous evaluation of analytical system performance; defined quality procedures for sample receipt, preparation and analysis; each sample is allocated unique laboratory reference and registered onto Laboratory Information Management System; rigorous result approval and reporting stages.

Analytical accuracy was monitored using Certified Reference Materials (BCR 422 Cod muscle and BCR-060 Aquatic plant) which were analysed on average once with every batch of 8 analytical samples. The Direct Laboratory Services Ltd working range for BCR-060 (0.300 - 0.380 mg/kg) is the same as the official BCR range. The laboratory working range for BCR-422 (0.525 - 0.603 mg/kg) is slightly wider than the official BCR range because the analytical method used has a slightly greater uncertainty for the sample type. These results (Table A-3-7) were used to calculate recovery figures which are in the range 94-103% for BCR-422 (cod muscle) and 90-93% for BCR-060 (Aquatic plant).

The Commission Regulation of the European Community No 466/2001 sets maximum levels for certain contaminates in foodstuffs. For mercury the levels set vary depending on the species of fish. For most predatory fish the allowed maximum concentration is 1.0 mg/kg (wet weight) and for non-predatory fish 0.50 mg/kg, although for vulnerable groups a limit of 0.20 mg/kg has been recommended (WHO, 1989). All samples that exceeded the 0.50 mg/kg limit were reanalysed and replicate values reported. The EC Directive sets a limit of 0.10 mg/kg for mercury in all vegetables except leafy vegetables, brassicas, fresh herbs and fungi for which the maximum allowed value is 0.30 mg/kg. Only one vegetable sample, which approached, but did not exceed, the 0.10 mg/kg threshold was re-analysed. Replicates were deemed to be acceptable if values fell within five percent of the mean value. The analytical precision (Relative Percent Difference) at concentrations greater than 0.5 mg/kg was +/- 2.6% and the average %RPD was 0.1% (Figure 18 and Table A-3-7).

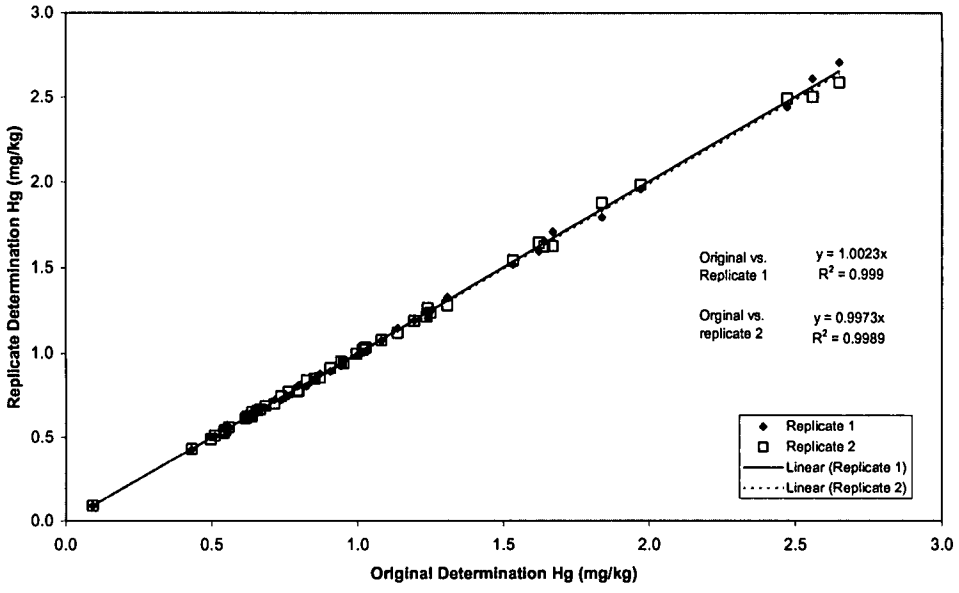

Figure 18. Original vs. First and Second Replicates determinations of Hg (mg/kg) in fish and vegetable samples

Duplicate samples of 20 fish were analysed for Hg. Whereas there is a broad agreement between determinations for duplicate samples (Figures 19 and 20) and the average combined sampling and analytical precision (%RPD) is ±15% for samples containing >0.1 mg/kg Hg, the precision at low concentrations (<0.1 mg/kg) is less satisfactory, ranging from –67% to +176% (Tables 4 and A-3-9). The reason for these relatively high RPD at low Hg concentrations is not known and would require further and more detailed investigation in future studies.

Table 4. Combined sampling and analytical precision (%RPD) for duplicate fish samples (n=20)

	%RPD*
Average	-13
Minimum	-67
Maximum	34
Average(>0.1)	-1
min (>0.1 mg/kg)	-12
max (>0.1 mg/kg)	15
Average (<0.1 mg/kg)	-4
min. (<0.1 mg/kg)	-67
max. (<0.1 mg/kg)	176

* %RPD = 100*(Original-Replicate)/((Original-Replicate)/2)

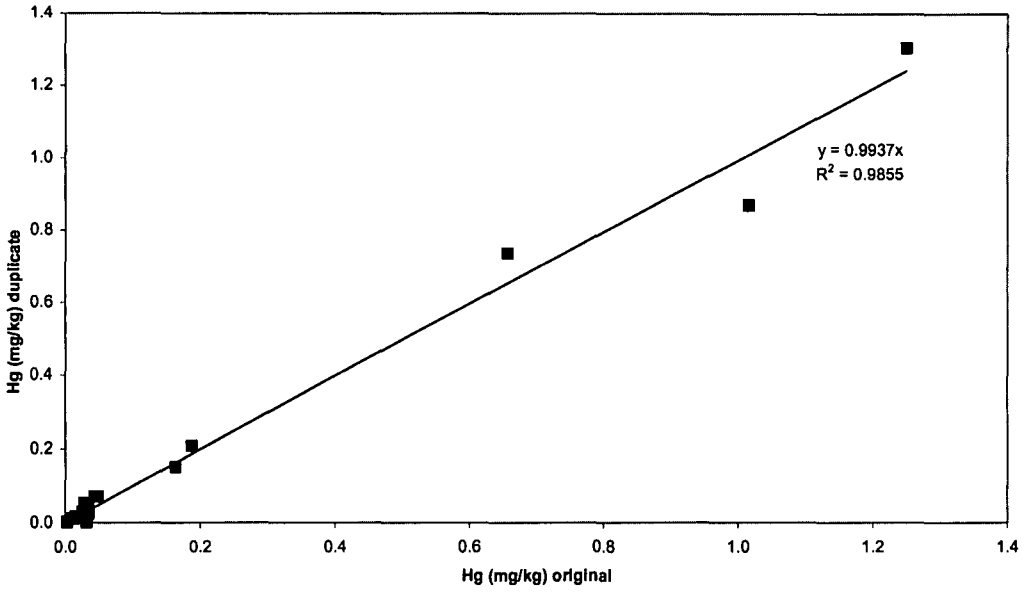

Figure 19. Hg data for duplicate fish samples

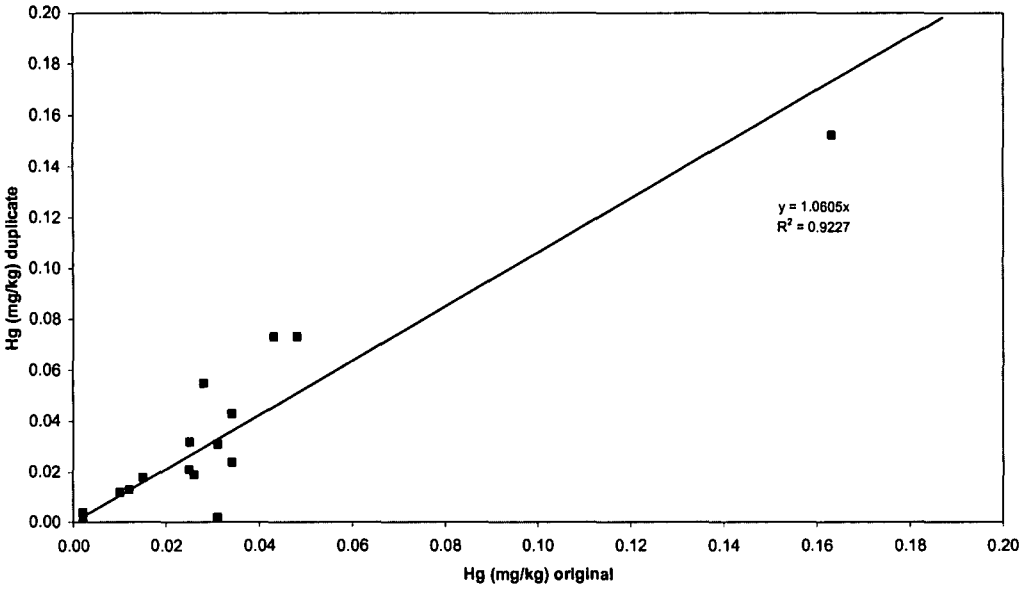

Figure 20. Hg data for duplicate fish samples with <0.2 mg/kg Hg

4 Mercury in water, sediment, tailings, soil, crops and fish

4.1 WATER

Hg in filtered water samples from Ilagala on the River Malagarasi ranges from 0.01 to 0.03 μg/L and from 0.02 to 0.03 μg/L at Uvinza. In the Rwamagasa area, Hg in filtered waters samples in ponds on the Isingile River and other drainage channels in the immediate vicinity of Rwamagasa (Figure 21) do not exceed concentrations detected at the two back ground sites (0.04-0.05 μg/L) apart from one sample with 0.07 μg/L (A100) located about 1 km downstream of the nearest Hg amalgamation ponds. A further 0.5 km downstream, Hg declined to 0.04 μg/L. Hg in one well located within Rwamagasa village, which was not used for the abstraction of drinking water, contained 0.01 μg/L Hg. Hg in filtered water from a Hg amalgamation pond (samples A108 and A109) contained 0.43 and 0.45 μg/L. These concentrations are lower than those recorded in drainage water samples from other artisanal gold mining areas, such as the Naboc River, Mindanao (Appleton, 20000.This reflects the smaller scale of mineral processing activities in the Rwamagasa area and the fact that Hg is not added to ball mills.

Hg in filtered stream and river water does not exceed any of the Tanzanian Water Quality Standards or other Water Quality Standards or Criteria for drinking water, protection of aquatic biota or protection of human health (Table 6). As would be expected, Hg in filtered water samples from the Hg amalgamation ponds exceeds all water quality standards (Table 6). Release of some of this mercury polluted water onto soils and into the River Isingile drainage system is inevitable, especially during the rainy season.

Arsenic in filtered water samples from the Rwamagasa area ranged from 0.1 to 0.5 in background areas to an average of 0.97 μg/L in the Isingile and associated drainage systems, rising to a maximum of 2.4 μg/L (Figure 22). Concentrations of 0.5-1.5 μg/L were recorded in the filtered Hg amalgamation pond water and 0.1 μg/L in a well. None of these arsenic concentrations exceed any water quality criteria (Table 6).

Mercury in filtered water correlates significantly with pH and arsenic in filtered water does not correlation significantly (95% CL) with pH, Eh or conductivity (Table 7).

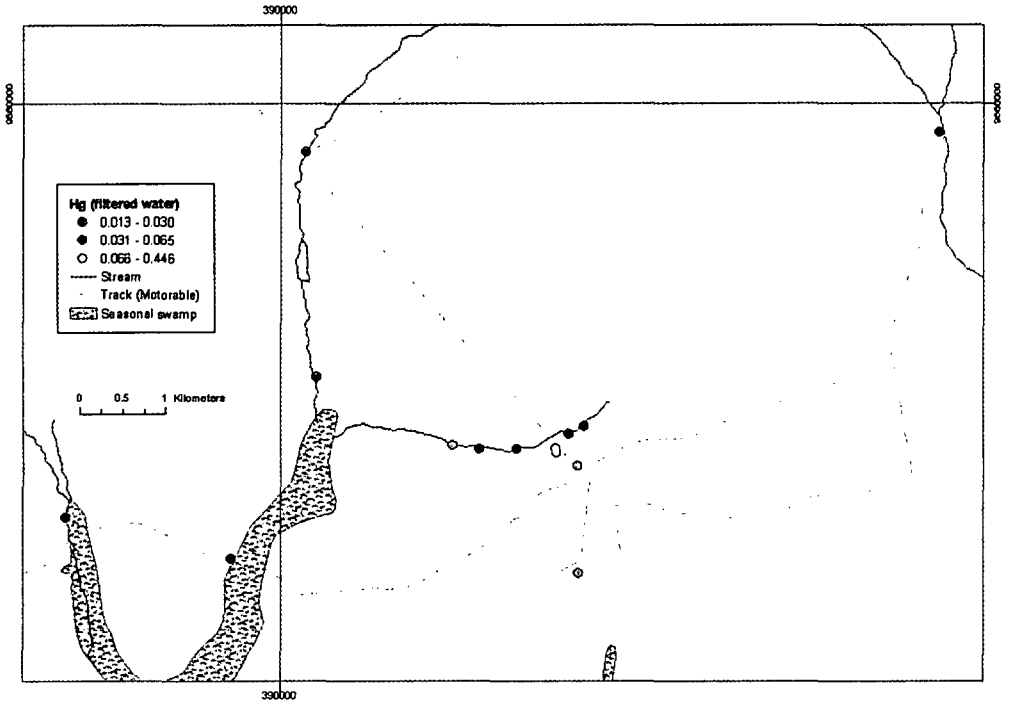

Figure 21 Mercury in filtered water (µg/L)

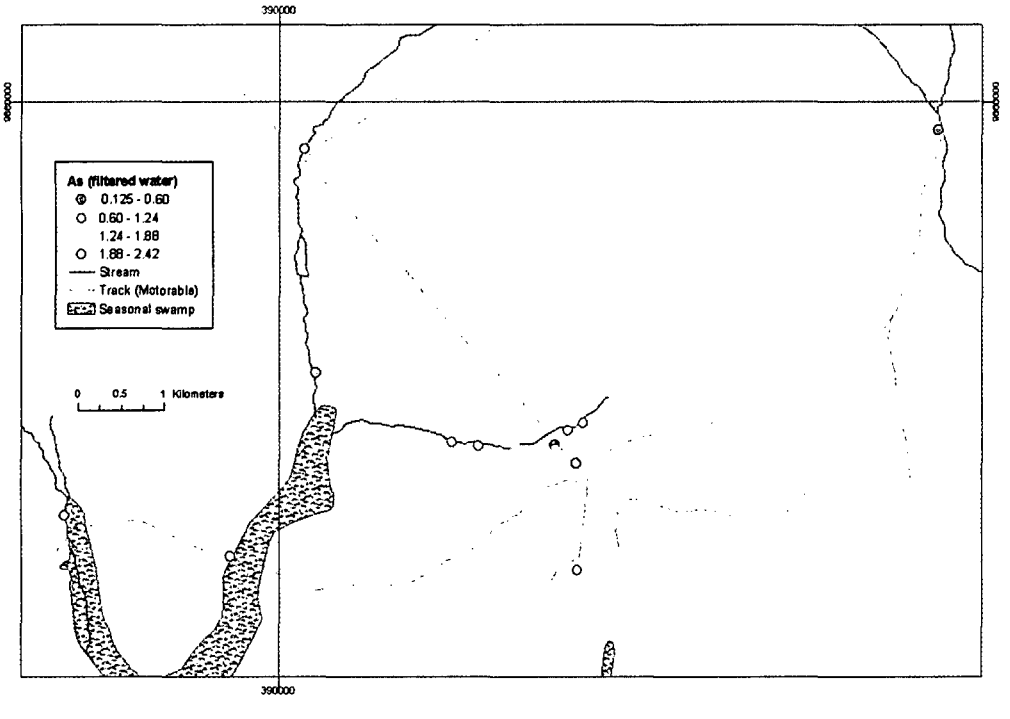

Figure 22. Arsenic in filtered water (µg/L)

Table 5 Summary statistics for filtered water samples from Rwamagasa drainage system

	Hg µg/l	*Conductivity*	*Eh*	*pH*	*As µg/l*
Mean	0.04	394	169	7.23	0.97
Median	0.04	380	172	7.37	0.77
Standard Deviation	0.01	124	75	0.74	0.67
Kurtosis	-0.12	-1	0	0.55	1.19
Skewness	0.57	0	0	0.46	1.31
Range	0.04	341	250	2.67	2.30
Minimum	0.03	242	41	6.18	0.13
Maximum	0.07	583	291	8.85	2.42

Table 6. Comparison of average (min.-max.) As and Hg concentrations in filtered water samples from the lower River Malagarasi (n=7) and the Rwamagasa area drainage system (n=13), Rwamagasa Hg amalgamation ponds (n=2) with Tanzania Water Quality Standards (upper section) and other Water Quality Criteria (lower section) (concentrations in µg/l)

				Tanzania Water Standards		
	Malagarasi River	Rwamagasa area-drainage	Rwamagasa area- Hg amalgamation ponds	Drinking water	Water for domestic animals, fisheries, shell-cultures, recreation	Irrigation water
As	nd	0.87 (0.13-2.42)	0.54-1.50	na	na	na
Hg	0.02 (0.01-0.03)	0.04 (0.01-0.07)	0.43-0.45	1	1	5

	Freshwater[1]		Salt water[1]		Human health[1,5]	Shellfish Directive (79/923/EEC)[4]	US EPA MCL[7]	WHO DW[8]	EEC DW MAC[9]
	Max. Conc.[2]	Cont. Conc.[3]	Max. Conc.[2]	Cont. Conc.[3]					
As	360	190	69	36	18	3000	10	10	50
Hg	1.4	0.77[6]	1.8	0.94	0.14	1 (0.4)	2	1	1

nd = not determined; na = not available

[1] EPA National recommended water quality criteria for protection of aquatic organisms and their uses - Correction USEPA Office of Water, EPA 822-Z-99-01 April 1999 (developed pursuant to section 304(a) of the US Clean Water Act). The criteria refer to the inorganic form only. Freshwater aquatic life criteria vary with total hardness and pollutant's water effect ratio (WER). Values quoted here correspond to total hardness of 100 mg/l and a WER of 1.0

[2] Criteria maximum concentration (CMC) = the highest concentration of a pollutant to which aquatic life can be exposed for a short period of time (1-hour average) without deleterious effects.

[3] Criteria continuous concentration (CCC) = the highest concentration of a pollutant to which aquatic life can be exposed for an extended period of time (4 days) without deleterious effects

[4] UK-DOE "I" (imperative) values recommended for compliance with EC Shellfish Waters Directive (79/923/EEC) (NRA, 1994; prop. revised imperative standards in brackets, DETR Consultation doc., 17/6/98)

[5] Human health (10^{-6} risk for carcinogens) for consumption of water and aquatic organism. For 10^{-5} risk, move decimal point one place to the right.

[6] If the CCC exceeds 0.012 µg/l more than once in a 3 year period in the ambient water, the edible portion of aquatic species of concern must be analysed to determine whether the concentration of methyl mercury exceeds the FDA action level of 1.0 mg/kg.

[7] EPA National Primary Drinking Water Regulations (40 CFR Parts 9, 141 and 142 [WH-FRL-6934-9] RIN 2040-AB75 National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring, January 2001)

[8] WHO, 1993.

[9] Council of European Union Directive (98/83/EC of 3/11/98) on the quality of water intended for human consumption

[10] value applies to a sample of water intended for human consumption obtained by an adequate sampling method at the tap and taken as to be representative of a weekly average value ingested by consumers.

Table 7. Pearson Correlation coefficients between Hg (µg/L), Conductivity, Eh, pH and A (µg/L) in Rwamagasa drainage water samples (n=13; $r_{95\%} = 0.48$)

Conductivity	0.20			
Eh	0.21	-0.04		
pH	0.70	0.55	0.15	
As µg/l	0.26	0.45	0.08	0.20
	Hg µg/l	Conductivity	Eh	pH

4.2 DRAINAGE SEDIMENT

In the absence of samples of suspended solids, the assessment of the extent and magnitude of dispersion of Hg from mineral processing activities into the drainage system and Hg mobility is based on (i) the determination of Hg in the fine (<150µm) fraction of river sediments collected from low energy, organic-rich sites; and (ii) the observation of indicators of river water organic (humic) substances. The potential bioavailability and mobility of Hg can be evaluated through characterization of the chemistry of drainage sediments, for example by determining Fe (to the assess likelihood that Hg is strongly adsorbed) and organic matter-TOC (to assess the potential for both adsorption and biomethylation).

The chemistry of the fine (<150µm) fraction of stream sediments from Ilagala and Uvinza is summarised in Table 8. Concentrations of As, Cd, Cu, Pb and Zn are generally low, apart from K002 in which high Zn (186 ppm) may indicate anthropogenic contamination. Hg concentrations range up to 0.655 ppm, which is rather high for an area that does not appear to be unduly affected by anthropogenic contamination. "Natural" background concentrations of Hg in the fine fraction of stream sediments reported in the literature generally range up to 0.5 ppm (Babut et al., 2001); the concentration upstream of gold processing in Ecuador range from 0.44 ppm in the Ponce Enriquez area (Appleton et al., 2001) to 0.5 ppm at Nambija (Ramirez Requelme et al., 2003); 0.6 ppm at Carson River (Gustin et al., 1994); <0.45 ppm at Red Devil Mine, Alaska (Gray et al., 1996); 0.5 ppm at Almaden, Spain (Berzas Nevado et al., 2003) and up to 1 ppm in Tuscany (Ferrara et al., 1991) although these are up to more than an order of magnitude above the level normally given for "global background" (0.01 to 0.05 ppm). Babut et al (2001) observed that sediment samples upstream of an artisanal gold mining area in Ghana contained 0.64 and 6.3 ppm, which the authors suggested were caused by atmospheric transport and deposition.

The sediment samples collected upstream of Uvinsa have relatively low Hg (0.17-0.24 ppm) compared with the samples from Ilagala which range from 0.10 to 0.66 ppm. The Ilagala samples contain higher Fe and TOC (Table 8 and Figure23) compared with the Uvinza samples, which would partially explain the higher Hg concentrations. Concentrations reported for the River Malagarasi will be enhanced due to the concentration effect of analysing the fine fraction, which comprises 15-50% of the bulk sediment at Ilagala and only about 3% at Uvinza. The enhanced Fe concentrations may in part reflect the impact of the Bukoban sedimentary rocks and andesitic basalts thought which the River Malagarasi passes in the

transect between Uvinza and Ilagala. Other possible sources of Hg include the geothermal springs at Uvinza (James, 1967; Tiercelin et al., 1993) and anthropogenic contamination related to the use of large quantities of charcoal in the salt plant at Uvinza, though this would be expected to impact on the Uvinza sediments as well. Contamination by mercuric soap used for skin-lightening may also be a factor at Ilagala. The Hg concentrations in the Ilagala sediments are below the Toxic Effects Threshold (1ppm, Table 9) although they are above the Minimal Effects Threshold (0.2 ppm).

Table 8. Stream sediment data for lower Malagarasi River (concentrations in ppm (mg/kg) except Fe (%) and TOC (%)

Sample	Area	<2mm (%)	2mm-150µm (%)	<150µm (%)	Cu	Pb	Zn	Fe	As	Hg	TOC	Cd
K 001	LM	0	50	50	49	10	42	4.14	1	0.455	2.90	<0.5
K 002	LM	0	60	40	49	11	186	4.17	1	0.655	3.62	<0.5
K 003	LM	0	80	20	44	10	50	3.95	1	0.160	2.70	<0.5
K 004	LM	0	70	30	55	10	49	4.40	1	0.615	3.00	<0.5
K 005	LM	5	80	15	42	12	37	3.96	3	0.095	3.31	<0.5
K 007	UV	2	95	3	9	6	11	1.11	1	0.165	0.86	<0.5
K 008	UV	15	82	3	7	7	11	1.04	1	0.240	0.80	<0.5
Ilagala												
Average	LM				48	11	73	4.12	1	0.396	3.11	<0.5
Minimum	LM				42	10	37	3.95	1	0.095	2.70	<0.5
Maximum	LM				55	12	186	4.40	3	0.655	3.62	<0.5
Geomean	LM				48	11	59	4.12	1	0.308	3.09	
Standard deviation	LM				5	1	64	0.18	1	0.257	0.36	
Uvinza												
Minimum	UV				7	6	11	1.04	1	0.165	0.80	<0.5
Maximum	UV				9	7	11	1.11	1	0.240	0.86	<0.5

Table 9. Comparison of heavy metals in bottom sediments from Background, Rwamagasa, and Nikonga R. areas compared with Sediment Quality Criteria for Protection of Aquatic Life (concentrations in mg/kg).

	Malagarasi River range	Background areas range	Rwamagasa area range	Rwamagasa area average	Nikonga River range	Sediment Quality Criteria[1]		
						No effects threshold	Minimal effects threshold	Toxic effects threshold
n.	7	2	11	11	3			
As	1-3	1	1-16	6	1	3	7	17
Cd	<0.5	<0.5	<0.5-0.7	<0.5	<0.5	0.2	0.9	3
Cu	7-55	5-13	20-108	64	2-12	28	28	86
Hg	0.10-0.66	0.08-0.09	0.04-2.84	0.84	0.09-0.19	0.05	0.2	1
Pb	6-12	8-18	9-38	15	3-11	23	53	170
Zn	11-186	12-20	29-325	88	5-13	100	150	540

Note: [1] Sediment Quality Criteria for Protection of Aquatic Life (Environment Canada, 1992 quoted in Haines et al., 1994).

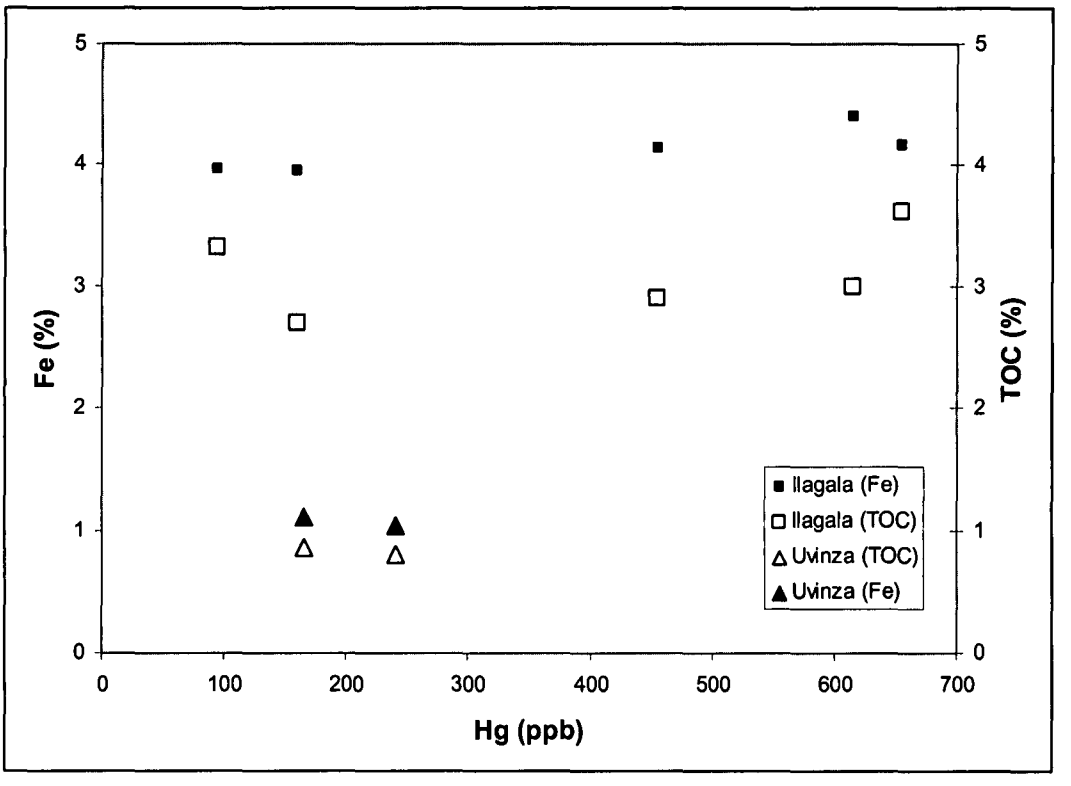

Figure 23. Variation of Hg (ppb) with Fe (%) and TOC (%) at Iligala and Uvinza, Malagarasi River

In the Rwamagasa area, Hg in the fine fraction of stream sediments ranges from 0.08 to 0.09 ppm at the two background sites. Sediments of the River Isingile impacted by Hg contamination from mineral processing and amalgamation range from 0.04 to 2.84 ppm with an average of 0.84 ppm (Table 10 and Figure 24). Hg in stream sediment declines to 0.09 to 0.19 ppm in the Nikonga River, about 23 km downstream of Rwamagasa. The Hg concentration at this site on the Nikonga River is surprisingly low considering that it could be impacted impacted by mercury contamination derived from the Rwamagasa, Iseni, Tembomine, Nyamtonde, Nyamalulu, and Nyamalimbe artisanal mining areas and also by contamination from the major historic artisanal mining activities at Nyarugusu.

Correlation coefficients for the Rwamagasa stream sediments (Table 11) indicate an association between Cu-Fe-As, which is probably a geochemical signature for the Au mineralization. Less strong correlations with Hg reflect the impact of amalgamation, and the association with TOC reflects adsorption of Cu and Hg onto organic material. Correlations with Zn appear to be influenced by the impact of metallic Zn contamination that could be derived from both galvanised roof sheets and also from either the lining or solder in ball mills. Further studies are required to confirm this.

Heavy metal concentrations are conventionally assessed with respect to the Toxic Effects Threshold for the Protection of Aquatic Life (Table 9). Hg exceeds the toxic effects threshold by a factor of up to 3 in bottom sediment, which is much lower than factors of 55 in bottom sediment and 166 in suspended sediment recorded for the Naboc River in Mindanao (Appleton, 2000). Hg does not exceed 1 ppm for

more than about 2 km downstream of the major mineral processing sites to the south if the Isingile River. This very restricted dispersion contrast sharply with that recorded in other areas such as Mindanao where Hg is still 2 ppm some 100 km downstream of the Diwalwal artisanal mining settlement (Appleton et al., 1999). The toxic effects thresholds for As, Cd, Cu, Pb and Zn are not exceeded in bottom sediments from the Rwamagasa area (Table 9).

Table 10. Stream sediment data for Rwamagasa area (concentrations in ppm except Fe (%) and TOC (%))

Sub-area and sample number	Statistic	+2mm (%)	2 mm – 150µm (%)	<150µm (%)	Cd	Cu	Pb	Zn	Fe	As	Hg	TOC
Background												
87		5	90	5	<0.5	5	8	12	0.6	1	0.09	1.3
104		2	50	48	<0.5	13	18	20	0.8	1	0.08	2.6
	average	4	70	27	<0.5	9	13	16	0.7	1	0.08	2.0
Rwamagasa area												
68		1	40	60	<0.5	82	13	59	4.8	4	3.02	4.5
69-70		1	50	50	<0.5	70	9	65	3.8	2	0.16	6.3
82-203		3	68	30	<0.5	20	12	175	1.3	2	0.19	2.1
85-106		5	73	25	<0.5	52	9	31	5.1	6	0.12	2.6
86-218		8	38	55	<0.5	59	26	325	3.4	1	0.58	3.7
88		5	90	5	<0.5	40	10	29	3.4	1	0.04	1.3
98		5	55	40	<0.5	77	14	44	6.4	9	0.39	3.8
99		5	40	55	<0.5	106	38	80	7.0	16	1.21	2.3
100		5	35	60	0.7	108	11	90	5.4	13	2.84	4.1
105		3	25	72	<0.5	40	15	35	3.1	6	0.67	3.2
107		5	40	55	<0.5	51	9	37	4.2	7	0.08	3.3
	average	4	50	46		64	15	88	4.4	6	0.84	3.4
	minimum	1	25	5	<0.5	20	9	29	1.3	1	0.04	1.3
	maximum	8	90	72	0.7	108	38	325	7.0	16	3.02	6.3
	geometric mean	3	47	39		58	13	64	4.0	4	0.36	3.1
	standard deviation	2	19	19		28	9	89	1.6	5	1.09	1.3
Nikonga												
1		0	15	85	<0.5	12	11	13	0.9	1	0.09	2.8
2		10	80	10	<0.5	5	5	5	0.3	1	0.19	1.1
3		10	60	30	<0.5	2	3	8	0.2	1	0.11	0.2
	average	7	52	42	<0.5	6	6	9	0.4	1	0.13	1.3

Table 11. Pearson correlation coefficients for Rwamagasa stream sediments (n=16; significance levels: $r_{95\%}$ 0.43; $r_{99\%}$ *0.57*)

Pb	0.52					
Zn	0.29	0.48				
Fe	*0.93*	0.49	0.18			
As	*0.79*	0.53	0.00	*0.80*		
Hg ppm	*0.69*	0.23	0.16	0.49	0.52	
TOC	*0.64*	0.18	0.29	0.54	0.23	0.41
	Cu	*Pb*	*Zn*	*Fe*	*As*	*Hg*

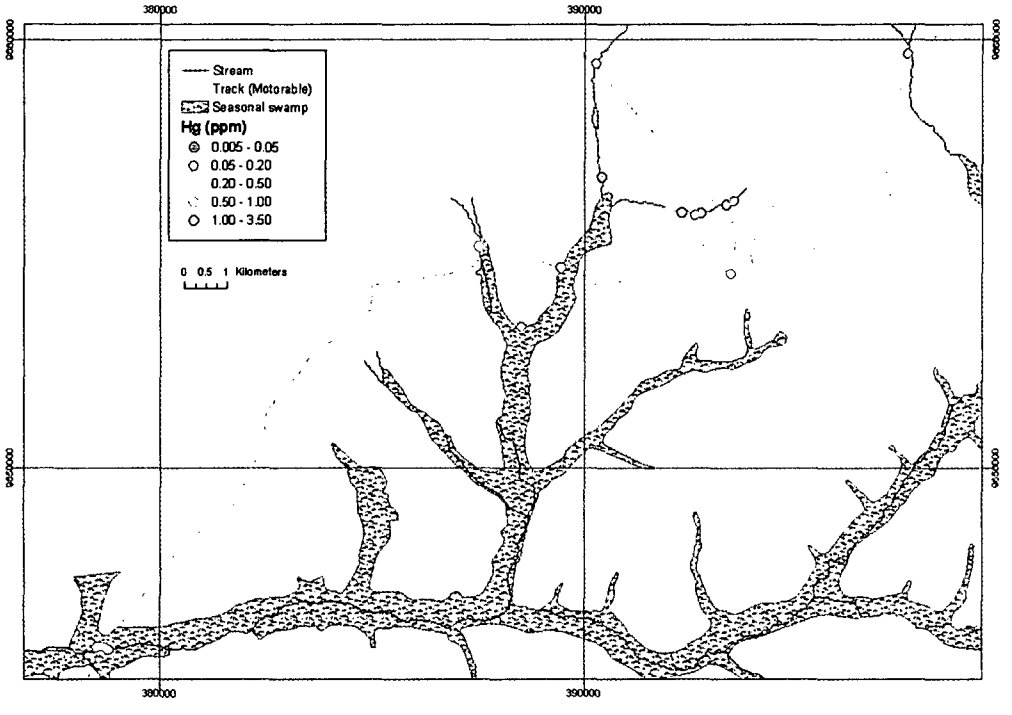

Figure 24. Mercury in stream sediment samples

It is assumed that methylation could take place during the dry season in the ponds that are found along the course of the River Isingile (see, for example, Plates 24 & 26); in the drainage channels that are used to channel irrigation water for vegetable cultivation; and, in the wet season, on the flooded seasonal swamp areas of the *mbugas* and rice paddy fields observed at various points as far downstream as site A-82 (Figure 3).

4.3 MINERAL PROCESSING WASTE MATERIAL (TAILINGS)

Summary statistics for grouped tailings samples indicate that there is little difference between Hg concentrations in samples taken from historic (dry) tailings piles (geometric mean, GM 5 ppm) and samples taken from recent sluice box tailings (GM 3 ppm; Table 12, Figure 25). Hg in tailings samples from the amalgamation ponds and amalgamation pond tailings (GM 86 ppm) are on average about 20 times higher. The distribution of Hg in historic tailings tips, recent sluice box tailings and amalgamation pond tailings is illustrated in Figures 26 and 27.

Correlation coefficients for the Rwamagasa tailings (historic and sluice box) indicate an association between Cd-Cu-Hg-Zn (Table 13), which reflects contamination from mercury used in amalgamation with metals that are possibly derived from the ball mills. Relatively high concentrations of Cd and Zn occur especially in the tailings samples collected from amalgamation ponds (Figures 28 - 29 and Table 12). Ball mills are typically made of soldered metal plates so there may be Cd and Zn in the solder would be expected to contaminate tailings. Cadmium is used extensively as a protective coating on iron and steel, and as an alloying agent with other metals. Cadmium is also used in batteries and occurs as a contaminant in zinc for galvanized roof sheets and steel piping. Correlations between As and Fe might indicate an influence of trace quantities of arsenopyrite and pyrite in the gold ore. This interpretation is confirmed by factor analysis results, which suggest Cd-Cu-Zn (ball mill contamination), As-Fe (mineralization) and Hg (amalgamation) associations (Table 14).

Table 12. Summary statistics for grouped tailings samples (concentrations ppm except Fe)

Sample	As	Cd	Cu	Fe (%)	Hg	Pb	Zn
Sluice box tailings (32)							
Average	24.4	0.7	106.5	4.6	6.9	21.4	110.5
Minimum	2.0	0.3	57.0	2.3	0.2	1.5	49.0
Maximum	46.0	6.1	353.0	7.5	39.0	101.0	513.0
Standard Deviation	9.2	1.1	52.1	1.2	9.9	17.6	82.7
Geometric mean	22.1	0.5	99.5	4.4	3.0	16.7	96.0
Tailings tips (13)							
Average	18.7	2.8	140.7	4.1	9.5	11.3	315.3
Minimum	6.0	0.3	61.0	2.7	0.7	1.5	38.0
Maximum	26.5	15.7	380.0	5.6	56.5	34.0	1588.0
Standard Deviation	6.0	5.4	108.9	0.7	14.8	7.6	544.3
Geometric mean	17.5	0.8	116.1	4.1	5.0	9.3	124.3
Hg pond tailings (10)							
Average	34.1	3.9	157.1	4.4	101.1	31.9	395.5
Minimum	8.5	0.3	76.0	2.6	28.5	2.3	42.0
Maximum	62.5	22.1	333.5	5.6	193.0	95.0	1971.0
Standard Deviation	17.3	6.8	75.2	0.8	53.7	26.6	593.8
Geometric mean	29.6	1.5	144.3	4.3	86.3	21.3	205.1

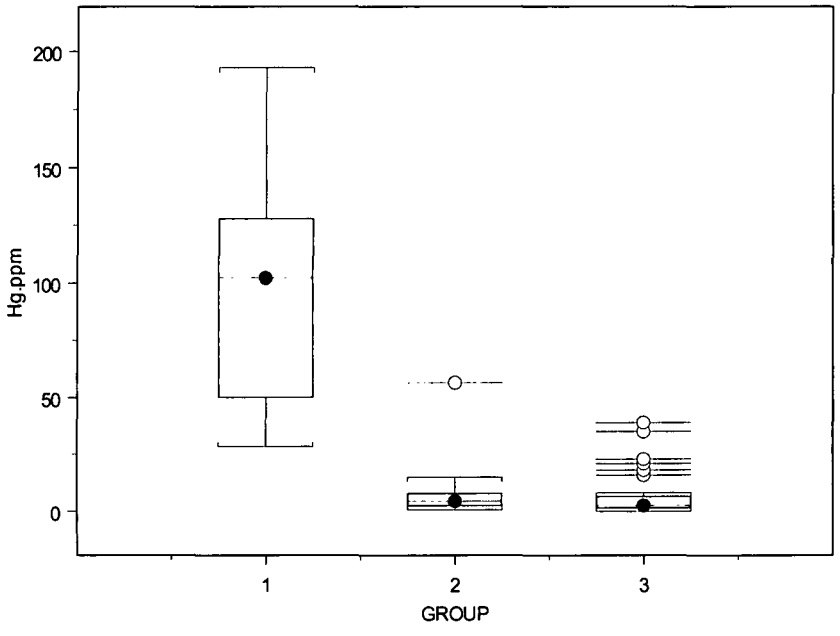

Figure 25. Box and whisker plot for Hg in tailings samples grouped by sample type [Groups: 1= Hg amalgamation pond tailings; 2= Sluice box tailings; 3= Historic tailings tip (mainly sluice box tailings). Box limits are 25th and 75th percentiles; Whiskers are drawn to the nearest value not beyond a standard span from the quartiles. Any points beyond this value (outliers) are drawn individually. The standard span is 1.5 * (Inter-quartile Range). Negative values are treated as if 0 was specified].

Table 13. Pearson correlation coefficients for Rwamagasa tailings samples not including amalgamation pond tailings (n=45; significance levels: 99% 0.35; *99.95% 0.48*)

Cd	*-0.48*					
Cu	-0.24	*0.82*				
Fe	*0.52*	*-0.41*	-0.11			
Hg	-0.07	*0.54*	*0.63*	-0.19		
Pb	*0.43*	-0.28	-0.09	*0.54*	-0.04	
Zn	*-0.48*	*1.00*	*0.84*	*-0.38*	*0.57*	-0.27
	As	*Cd*	*Cu*	*Fe*	*Hg*	*Pb*

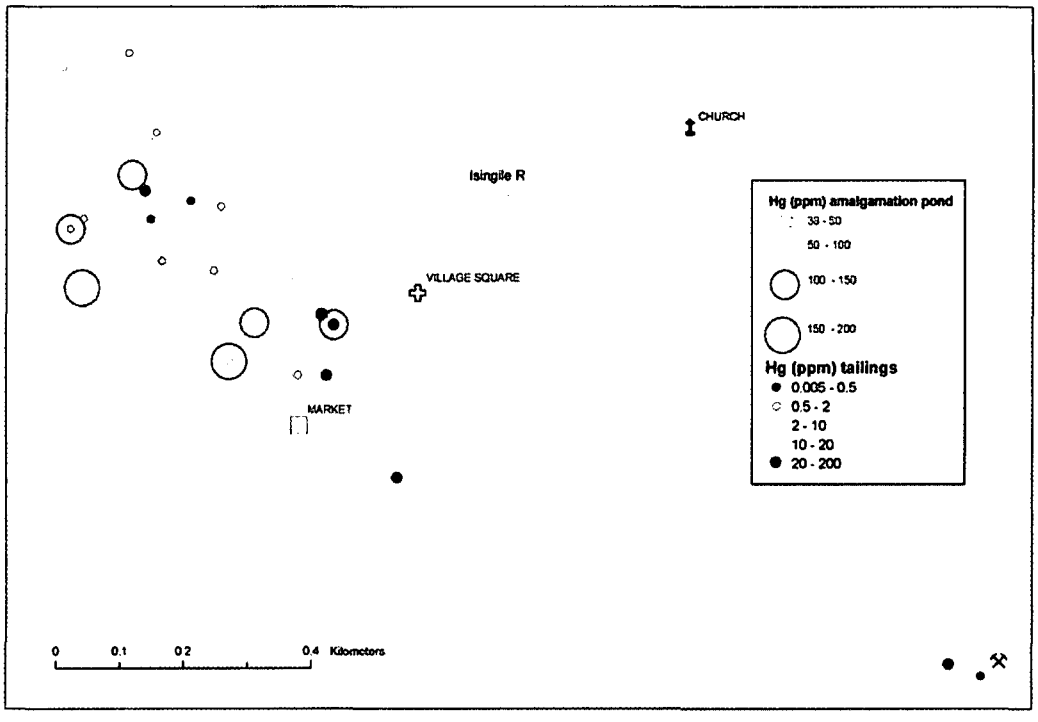

Figure 26. Hg (ppm) in tailings (filled coloured dots) and amalgamation ponds (open circles), Rwamagasa area.

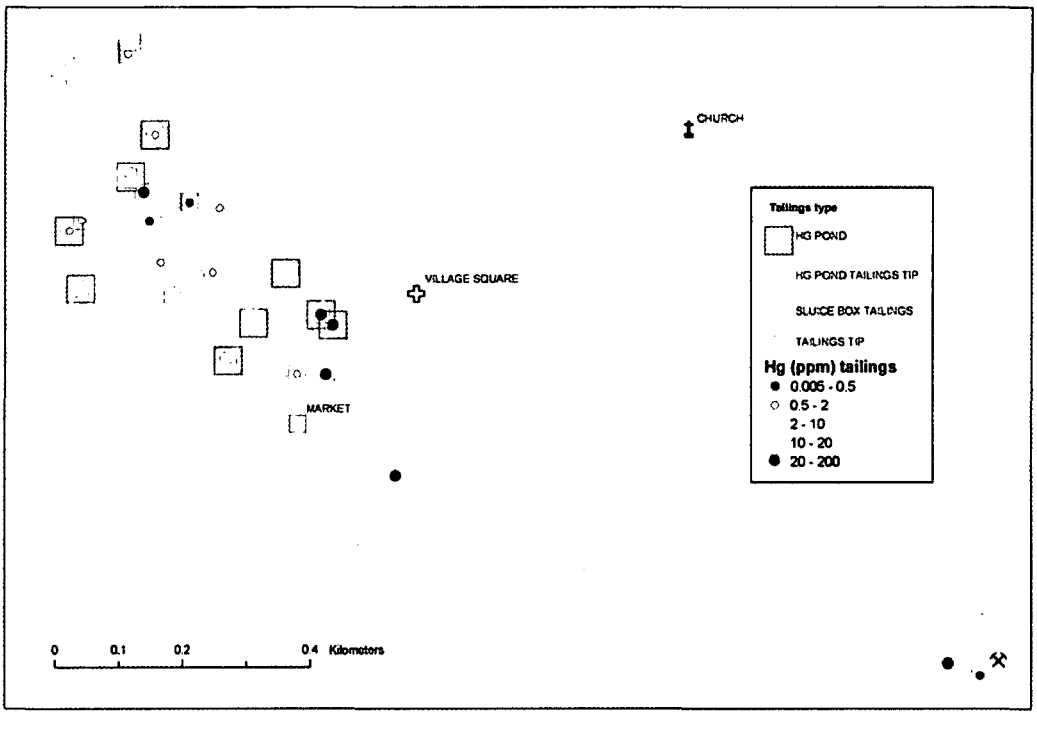

Figure 27. Hg (ppm) in tailings (coloured filled circles) and tailings sample types (open squares), Rwamagasa area.

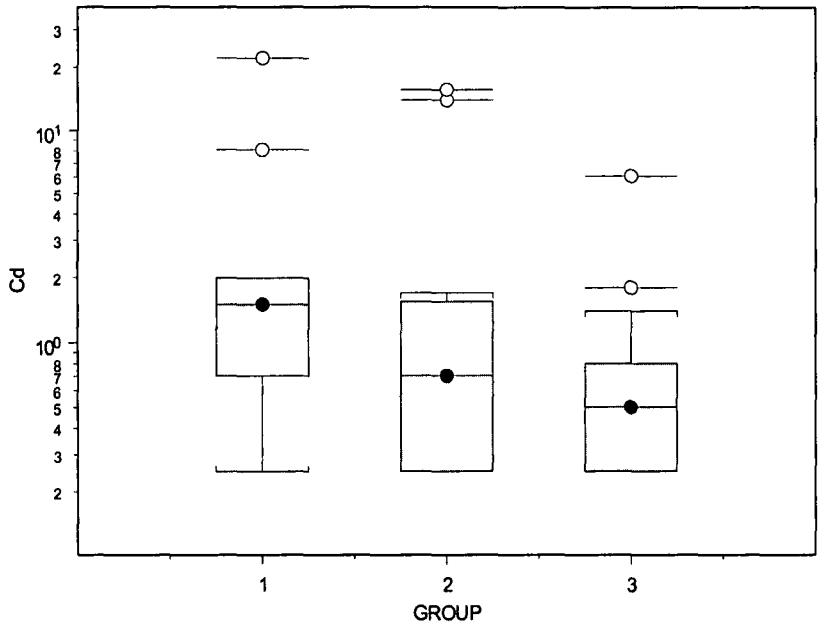

Figure 28. Box and whisker plot for Cd (ppm) in tailings samples grouped by sample type [Groups: 1= Hg amalgamation pond tailings; 2= Sluice box tailings; 3= Tailings tip (mainly sluice box tailings tip)]

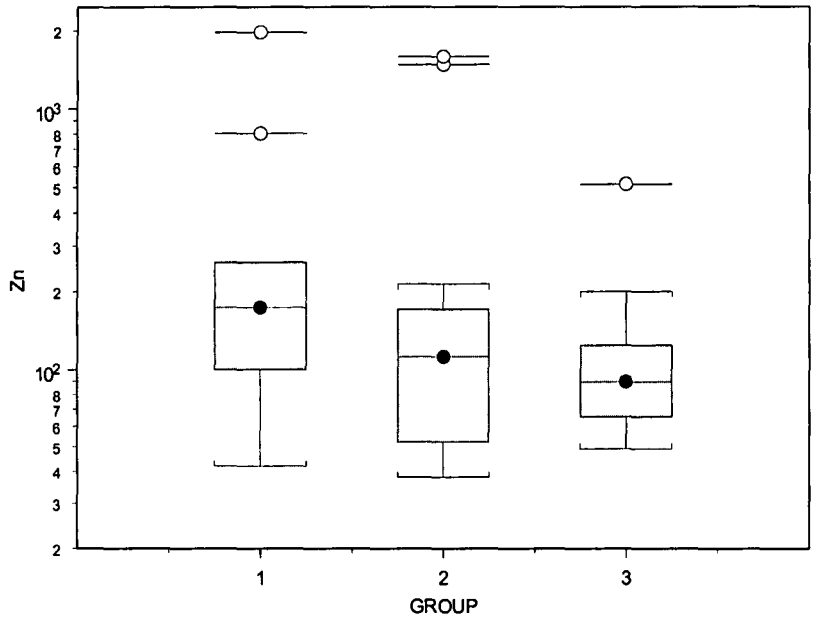

Figure 29. Box and whisker plot for Zn (ppm) in tailings samples grouped by sample type [Groups: 1= Hg amalgamation pond tailings; 2= Sluice box tailings; 3= Tailings tip (mainly sluice box tailings tip)]

Table 14: Factor scores for 3-Factor principal component model with varimax rotation for Rwamagasa tailings samples

	Factor 1	Factor 2	Factor 3
As	-0.245	**0.729**	0.392
Cd	**0.936**		-0.316
Cu	**0.868**		
Fe	-0.166	0.132	**0.774**
Hg	0.171	**0.814**	
Zn	**0.962**		-0.278
% of variance	45%	20%	16%

4.4 SOIL

Generally low concentrations of Hg occur in most of the cassava, maize, rice, mbuga, and unclassified soils whilst higher concentrations are found in the urban, mbuga and vegetable plot soils. In the former case, Hg is probably mainly derived from air borne transport and deposition of Hg released during the burning of amalgam, although this has not been verified. High Hg occurs in the *mbuga* and vegetable plot soils where these appear to be impacted by Hg-contaminated water and sediment derived from mineral processing activities located on the southern side of the Isingile River (Tables 15-16, Figures 30-31).

Correlation coefficients (Table 17) and factor scores (Table 18) for the Rwamagasa soil samples indicate an association between Cd-Cu-Zn, which reflects contamination from metals that are possibly derived from the ball mills. Relatively high concentrations of Cd and Zn occur especially in soils impacted by mineral processing waste (Figure 17 and 18) and it is assumed that these metals are derived principally from ball mills and galvanized roof sheets. Correlations and factor analysis associations between As, Cu and Fe may reflect the influence of trace quantities of arsenopyrite and pyrite in the gold ore in soils that have been impacted by mineral processing waste (Figure 19), although some of the higher As concentrations may reflect a higher background over the mineralised greenstone rocks. As-Cd-Fe-Hg-Zn would all be expected to be concentrated in similar situations as a result of contamination by mineral processing waste.

Hg exceeds (1) the maximum permissible concentration of Hg in agricultural soil in the UK (1 mg/kg) in 12 soil samples;(2) the Canadian Soil Quality Guideline for agricultural soils (6.6 mg/kg) in three samples; (3) the UK soil guideline value for inorganic Hg for allotments (8 mg/kg; Environment Agency, 2002) in two samples. The proposed Dutch Intervention value (SRC - "serious risk concentration") for inorganic Hg (36 mg/kg; RIVM, 2001); the USEPA soil ingestion Soil Screening Level (SSL) for inorganic Hg (23 mg/kg); and the USEPA SSL for inhalation of volatiles (10 mg/kg; USEPA, 1996); the Dutch proposed human health SRC of 210 mg/kg or the USEPA generic SSL for plant uptake (270 mg/kg), which implies that the plant uptake pathway is not regarded as a major contributor to exposure compared with soil ingestion (USEPA, 1996) are not exceeded in any soil samples collected during the

present survey from the Rwamagasa area. The level of contamination of agricultural and urban soils is therefore significantly less both in magnitude and extent than in other areas, such as the Naboc irrigation systems (Appleton, 2000).

Cd and Zn exceed the maximum permissible concentrations for agricultural soil in the UK (3 mg Cd/kg and 200 mg Zn/kg) in one urban soil; Cu (135 mg Cu/kg) in three urban and one mbuga soils; and Pb in no soil samples (300 mg Pb/kg). The Dutch SRCs for human health (24-28 mg Cd/kg) and the USEPA SSLs for soil uptake (400-622 mg Pb/kg; USEPA, 1996) are not exceeded in any of the samples collected. Arsenic exceeds the Canadian Soil Quality Guideline for agricultural soils (12 mg/kg) in nine agricultural and urban soils and exceeds the UK soil guideline value for inorganic As for allotments (20 mg/kg; Environment Agency, 2002) in five samples of maize, mbuga, vegetable plot and urban soils.

Table 15. Summary statistics for soils from the Rwamagasa area classified by soil use (concentrations ppm except Fe(%) and TOC(%))

	Cassava	Maize	Mbuga	Rice	Unclassified	Urban	Vegetable
Count	13	18	13	25	11	26	17
Min As	1	1	1	1	1	1	1
Max As	12	22	23	10	10	67	30.5
Avg As	5	4	7	4	4	9	8
Min Cd[1]	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Max Cd[1]	0.3	0.3	1.3	1.1	0.3	6.2	1.1
Avg Cd[1]	0.3	0.3	0.4	0.3	0.3	0.5	0.3
Min Cu	25	11	10	14	30	22	22.5
Max Cu	56	60	176	119.5	73	226	126
Avg Cu	42	36	51	40	47	60	59
Min Fe (%)	2.87	1.05	1.05	1.03	2.42	2.56	1.53
Max Fe (%)	7.47	8.70	8.88	6.57	7.13	10.39	6.89
Avg Fe (%)	5.18	3.55	3.83	3.35	5.57	5.57	4.58
Min Hg	0.005	0.005	0.005	0.005	0.010	0.010	0.005
Max Hg	0.065	0.085	9.205	5.078	0.055	8.855	6.770
Avg Hg	0.029	0.039	0.923	0.262	0.029	0.540	0.862
Min Pb	6	1.5	4	1.5	5	1.5	3.5
Max Pb	13	11	14	15	12	16	15
Avg Pb	10	6	9	9	9	8	9
Min Zn	13	8	10	12	13	11	17
Max Zn	33	65	161	138	28	651	116.5
Avg Zn	21	26	38	30	20	76	51
Min TOC (%)	1.33	1.07	1.62	0.78	1.21	0.31	1.60
Max TOC (%)	4.87	5.90	4.00	4.60	3.56	3.24	6.25
Avg TOC (%)	2.82	2.38	2.89	3.02	2.70	2.11	3.57

[1]Cd <0.5 given a value of 0.25 (0.3)

Table 16. Pearson correlation coefficients for Rwamagasa soils (n = 123; significance levels: 99% ***0.21***; 99.95% **0.30**)

As								
Cd	0.09							
Cu	**0.61**	**0.66**						
Fe	**0.40**	0.06	**0.52**					
Hg	**0.51**	***0.28***	**0.62**	0.15				
Pb	-0.02	-0.14	-0.01	0.18	0.18			
Zn	***0.25***	**0.93**	**0.77**	0.16	**0.36**	-0.12		
TOC	-0.21	-0.15	-0.07	-0.02	-0.11	***0.26***	-0.10	
	As	*Cd*	*Cu*	*Fe*	*Hg*	*Pb*	*Zn*	*TOC*

Table 17: Factor scores for 3-Factor principal component model with varimax rotation for Rwamagasa soil samples (n=123)

	Factor 1	Factor 2	Factor 3
As		**0.845**	-0.266
Cd	**0.968**		-0.147
Cu	**0.631**	**0.781**	
Fe		**0.495**	0.132
Hg	0.242	**0.570**	
Pb	-0.100	0.170	**0.614**
Zn	**0.914**	0.252	-0.111
TOC		-0.110	**0.452**
% of variance	28%	25%	9%

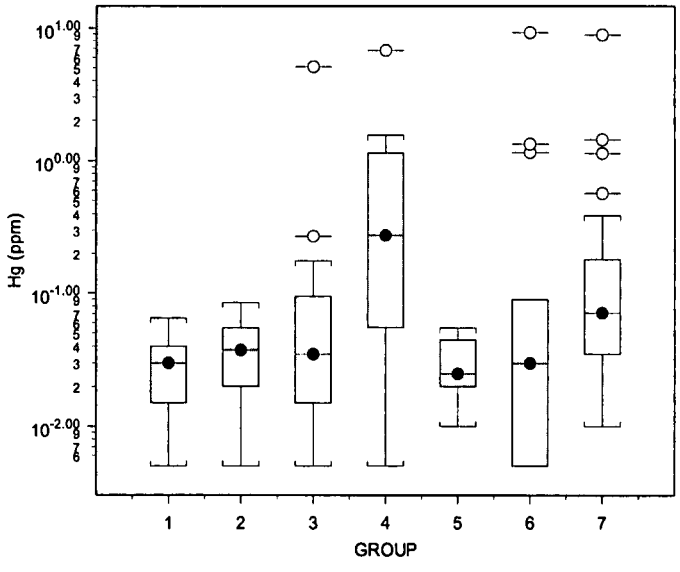

Figure 30. Hg is <2mm soil samples classified by land use [Group (no. of samples): 1 = cassava (13), 2 = maize (18); 3 = rice 25); 4 = vegetable (17); 5 = unclassified (11); 6 = mbuga (13); 7 = urban (26)]

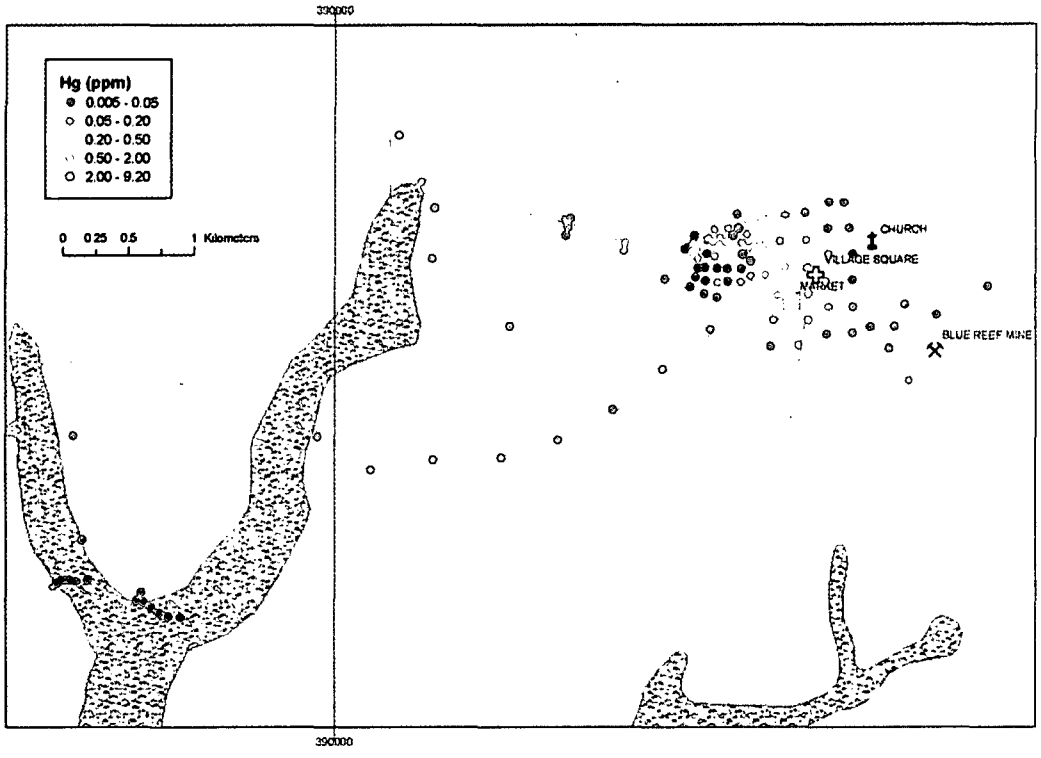

Figure 31. Hg (ppm) in soils, Rwamagasa area.

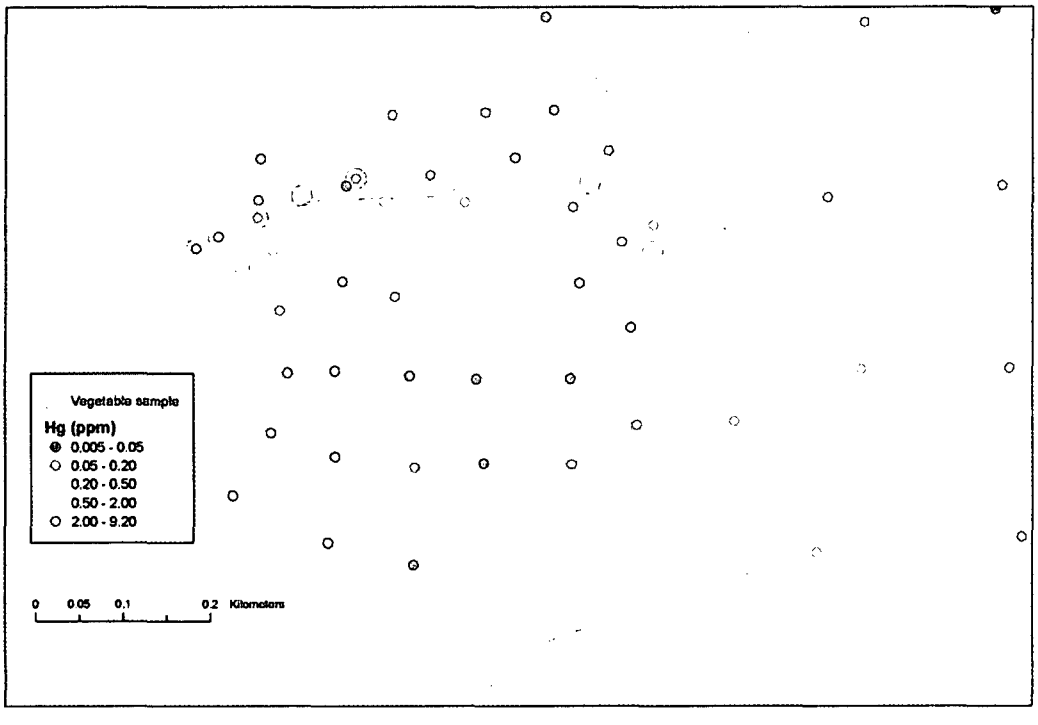

Figure 32. Hg (ppm) in soils, detailed sampling grid, Rwamagasa area.

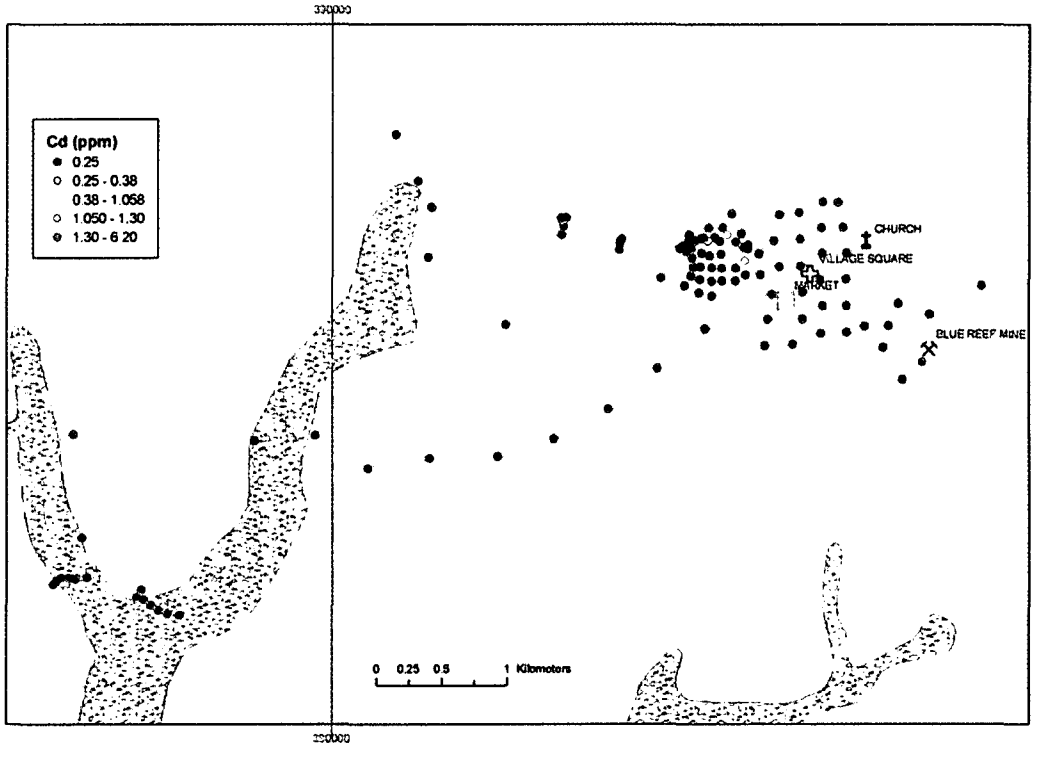

Figure 33. Cd (ppm) in soils, Rwamagasa area.

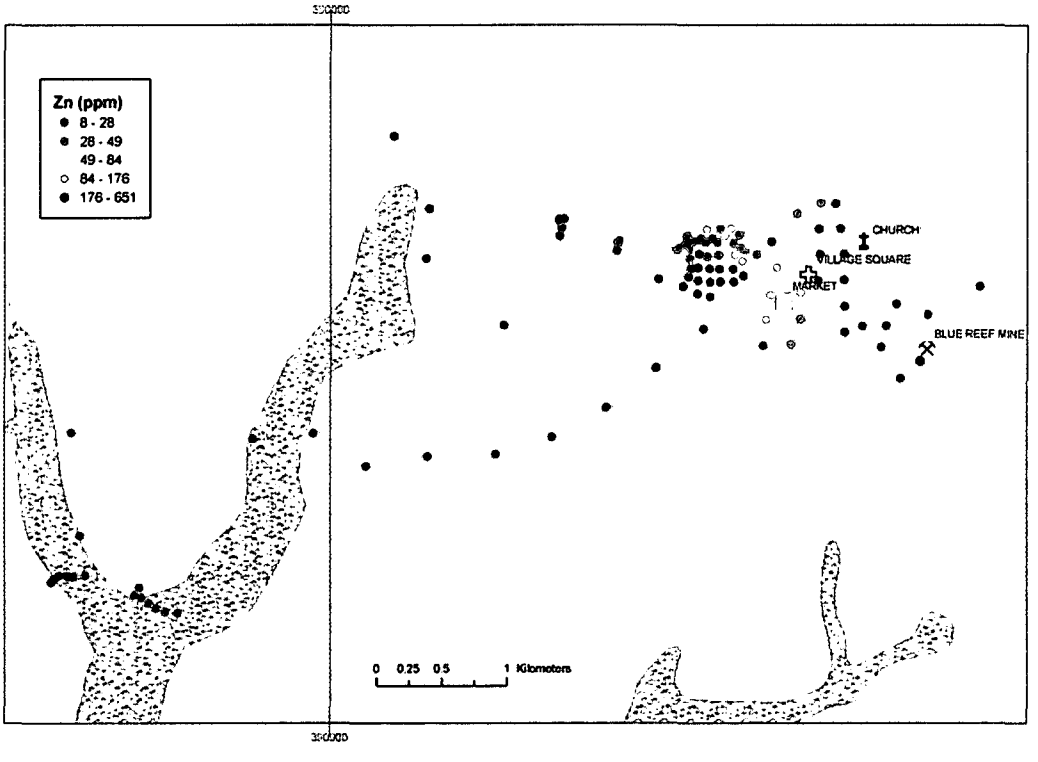

Figure 34. Zn (ppm) in soils, Rwamagasa area.

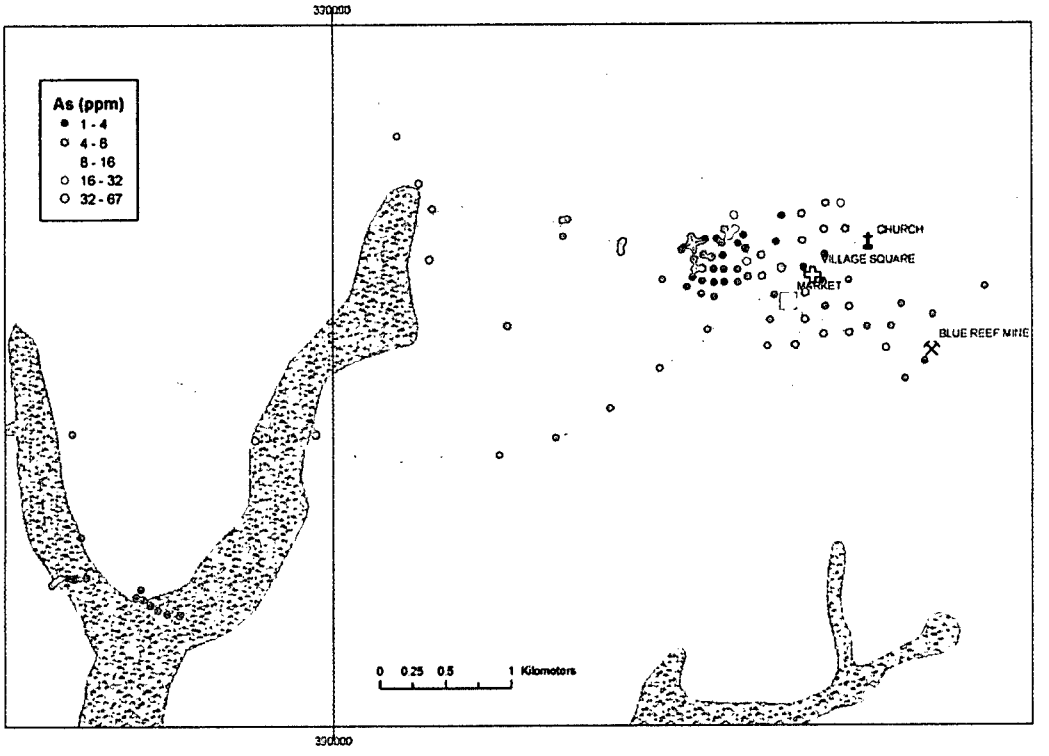

Figure 35. As (ppm) in soils, Rwamagasa area.

Table 18. As, Cd, Cu, Hg, Pb and Zn in surface soils from the Rwamagasa area (classified by land use) compared with soil quality guideline and limit values (concentrations in ppm (mg/kg)).

	Cassava	Maize	Mbuga	Rice	Soil	Urban	Vegetable
Count	13	18	13	25	11	26	17
As	1-12	1-22	1-23	1-10	1-10	1-67	1-31
Cd[1]	0.3	0.3	0.3-1.3	0.3-1.1	0.3	0.3-6.2	0.3-1.1
Cu	25-56	11-60	10-176	14-120	30-73	22-226	23-126
Hg	0.005-0.07	0.005-0.09	0.005-9.2	0.005-5.1	0.010-0.06	0.010-8.9	0.005-6.8
Pb	6-13	2-11	4-14	2-15	5-12	2-16	4-15
Zn	13-33	8-65	10-161	12-138	13-28	11-651	17-117

	Canadian Human Health Soil Quality Guidelines			UK Soil Guideline Values				EC (UK) Limit Values[1]
	Agricultural, residential/parkland	Commercial	Industrial	Residential with plant uptake	Residential without plant uptake	Allotments	Commercial /industrial	
As	12	12	12	20	20	20	500	na
Cd	14	49	2100	2[2]	30	2[2]	1400	1-3 (3)
Cu	na	na	na	na	na	na	na	50-140 (135)
Hg	6.6	24	50	8	15	8	480	1-1.5 (1)
Pb	140	260	740	450	450	450	750	50-300 (300)
Zn	na	na	na	na	na	na	Na	150-300 (200)

[1] Limit values for concentrations of heavy metals in soils (EC Directive 86/278/EEC on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture. Permitted range (value adopted by the UK in brackets)

[2] pH 7; 1 ppm (mg/kg) at pH6 and 8 ppm (mg/kg) at pH 8

na = not available.

Hg and other elements in soil profile 1 (A244-248, Table 19), which is located some distance from mining contaminated areas (Figure 10) exhibits generally low Hg concentrations which decline with depth in parallel with Cu, Zn, TOC and Fe. In this case the trace element concentrations are almost certainly controlled by Fe and TOC rather than surface contamination. Strong surface contamination by Cu, Pb, Zn, Cd, As and Hg is seen in the top 10 cm of Profile 2 (A267-271; location on Figure 10; data in Table 19). TOC declines with depth whereas Fe declines and then increases with depth, which probably explains why the trace elements do not decline below a depth of 10 cm as they will tend to increase as Fe increases and decline as TOC declines. Profile 3 (A279-284; location in Figure 10; data in Table 19) exhibits high Hg concentrations in the top 20 cm of the profile followed by a sharp decline to nearly background levels at greater depths (Figure 36). TOC mirrors the Hg distribution whereas Fe generally increases with depth. Cu, Pb, Zn and Cd are also enriched in the top 20 cm of the profile. Profiles 2 and 3 demonstrate that surface contamination by mineral processing waste affects the chemistry of the root zone, and hoeing of the soil will lead to the homogenisation of this contamination within the root zone.

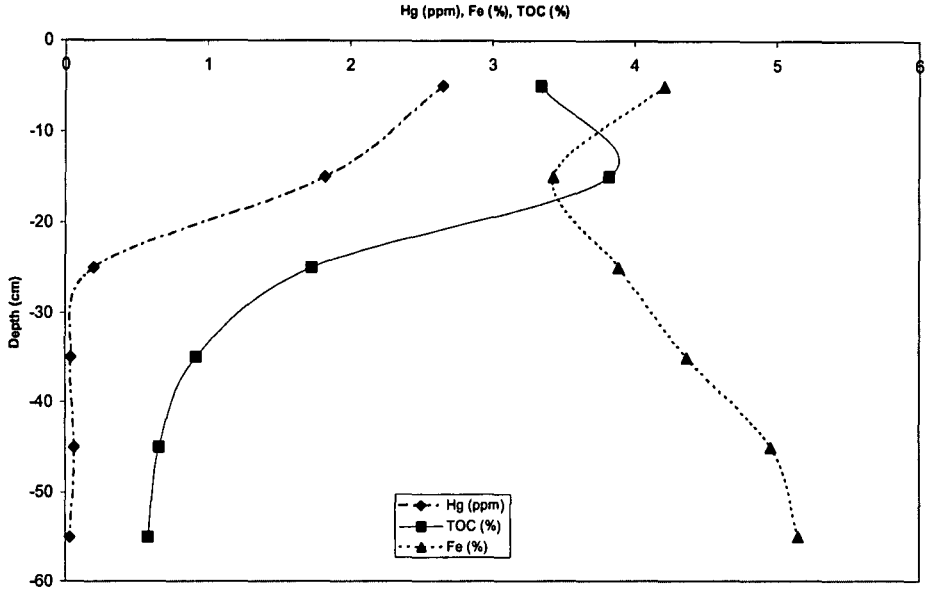

Figure 36. Vertical variation in Hg (ppm), TOC (%) and Fe (%) in soil profile A279-A284 (see Figure 10 for location)

Table 19. Chemistry of soil profile samples (see Figure 10 for locations; concentrations ppm (mg/kg) except Fe and TOC))

Sample	Cu	Pb	Zn	Fe (%)	As	Hg	TOC (%)	Cd	Depth*
Profile 1									
A 244	14	3	11	1.07	1	0.025	2.15	0.25	-5
A 245	14	3	11	1.05	2	0.02	2.3	0.25	-15
A 246	13	1.5	7	0.93	1	0.015	1.18	0.25	-25
A 247	10	3	5	0.78	1	0.005	0.65	0.25	-35
A 248	9	1.5	4	0.57	1	0.01	0.52	0.25	-45
Profile 2									
A 267	119	13	113	4.62	8	4.29	3.27	0.8	-5
A 268	36	4	32	2.73	2	0.05	1.51	0.25	-15
A 269	36	6	28	2.79	3	0.02	1.2	0.25	-25
A 270	39	6	31	3.6	2	0.025	1.11	0.25	-35
A 271	48	5	41	5.45	1	0.04	0.83	0.25	-45
Profile 3									
A 279	69	12	73	4.21	7	2.65	3.34	0.5	-5
A 280	66	8	72	3.43	7	1.825	3.82	0.5	-15
A 281	45	4	28	3.89	8	0.2	1.73	0.25	-25
A 282	45	4	27	4.37	8	0.04	0.92	0.25	-35
A 283	51	6	35	4.96	6	0.065	0.66	0.25	-45
A 284	53	5	37	5.15	9	0.03	0.58	0.25	-55

*mid-point of 10 cm sampling interval

4.5 AGRICULTURAL CROPS

In addition to the food crops listed in the socio-economic report (maize, cassava, sweet potatoes and bananas) vegetables, including onions, tomatoes, yams, cabbage, spinach, peppers, and beans are cultivated on the *mbuga* (seasonal swamp) bordering the Isingile River, to the N of Rwamagasa. This area is close to the main artisanal mineral processing area located at the northern edge of Rwamagasa village and is clearly contaminated, at least in part, with mercury. The vegetables are sold in the local market and constitute a significant part of the diet of the local people. Cotton and paddy were reported to be cash crops in the district, but only paddy was observed in the vicinity of Rwamagasa.

The vegetable and rice plots and some of the maize plots located on the *mbuga* area immediately north of Rwamagasa are irrigated using water from the Isingile R. (which was ponded at the end of the dry season, and not flowing). Although the filtered water samples collected during the present survey had low concentrations, some of the sediments and soils contain relatively high Hg concentrations.

Hg in vegetable and grains samples collected from the agricultural areas potentially impacted by Hg contamination are mainly below the detection limit of 0.004 ppm Hg with concentrations of 0.007 and 0.092 ppm Hg recorded in two yam samples and 0.035 ppm Hg in one rice sample (Table 20). A positive correlation between Hg in agricultural crops and soil was not detected during the present survey (Table 20).

Hg in beans, onions and maize samples purchased at Rwamagasa market are below the detection limit (<0.004 mg Hg/kg) whilst two dehusked rice samples contain 0.011 and 0.131 ppm Hg (Table 21)

Table 20. Hg in vegetable and grain samples with associated soil sample

Number	Description	Hg (ppm) in vegetable or grain	Soil sample number	Hg (ppm) in soil
105	Yam	0.007	105*	0.67
110	Yam	0.092	114, 115	0.66
111	Maize	< 0.004	114, 115	0.66
112	Cabbage	< 0.004	114, 115	0.66
113	Onions	< 0.004	114, 115	0.66
117	Rice	0.035	between 237 & 272	0.12
291	Onion	< 0.004	291	0.05
292	Yam	< 0.004	292	1.56
293	Cabbage	< 0.004	293	0.005
294A	Beans Fresh	< 0.004	294	0.275
294B	Beans Fresh	< 0.004	294	0.275
295	Beans Fresh	< 0.004	294	0.275
296	Tomatoes	< 0.004	296	0.085
297	Maize	< 0.004	297	0.055

* sediment sample

Table 21. Hg in vegetable and grain samples from Rwamagasa market

Number	Description	Hg (ppm)
303	Maize Dry	< 0.004
304	Rice	0.011
305	Rice	0.031
306	Onions	< 0.004
307	Dry Green Beans	< 0.004
308	Dry Green Beans	< 0.004
309	Dry White Beans	< 0.004
310	Dry Mixed Beans	< 0.004

The concentrations of Hg in rice are similar to those recorded for rice grown on the highly contaminated soils of the Naboc irrigation system (average 0.016, range 0.008 to 0.050 ppm Hg, wet weight; Appleton, 2000). Machiwa et al. (2003) reported similar concentrations of Hg in rice growing in Hg contaminated ground at Saragurwa (0.04 ppm) with much higher concentrations at Nyarugusu (0.09 ppm), Nungwe (0.13 ppm), Nyangalamila (0.25 ppm) and Lwamgasa (Rwamagasa, 0.29 ppm). All these values were converted from dry weight (dw) basis to wet weight (ww) basis by dividing by 1.3, which is the wet/dry weight ration for rice from the Naboc area (Appleton et al., in preparation). Comparison with data for the Quingzhen and Wanshan areas in China (Horvat et al., 2003) indicates that the rice Hg concentrations recorded by Machiwa et al., (2003) are unusually high in relationship to the Hg concentrations recorded in soils and sediments. Machiwa et al. (2003) observed that there was no significant difference in Hg concentrations between samples grown in areas impacted by the washing of gold ore and areas where no gold washing was carried out. Machiwa et al., (2003) recorded 1.42 ppm (ww) in a yam sample from Samina, which is more than an order of magnitude greater than the maximum recorded during the present survey (0.092 ppm).

4.6 FISH

4.6.1 Introduction

Fish muscle tissue samples should ideally be considered separately from whole fish (from which the head, tail and guts have been removed). A size-Hg relationship cannot be readily derived for small fish, which should be treated as biomonitors, the Hg concentrations of which can be used to indicate whether fish exposed to the impact of artisanal mining have consistently higher Hg than fish of the same species and size range from 'background' or 'reference' areas. Muscle tissue and whole fish samples for the same species and in adequate numbers, were obtained at only two sites (*Clarias alluadi*, Nymamsenga; *Clarias gariepinus*, Rwamagasa Pond 4). Average length and Hg data are presented in Tables 22-23 and individual fish data are plotted in Figure 38, together with data for *Clarias gariepinus* from Tembomine, which is the only site from which sufficient samples with a range of sizes were obtained to establish a Hg-length relationship. Although there are only three samples of muscle tissue from Nyamsenga, Hg in these is slightly higher than in the whole fish samples. The relationship between muscle and whole fish samples from Pond 4 is less systematic. In the following discussion of the results, whole fish and muscle tissue samples from the same site are plotted as one sample population.

With the exception of a laboratory study by Ikingura and Akagi (2002), in which a non-indigenous gold fish (presumably a carp species) were exposed to Hg spiked sediments, studies of Hg in fish tissues collected in this region have focussed on assessing human exposure through fish consumption. Consequently most published data is derived from the fish populations of Lake Victoria, and these have been shown to be largely unaffected by Hg from the Lake Victoria Gold Fields (LVGF) (Machiwa et al., 2003).

Hg concentrations are described with reference to the international marketing limit for the export of fish to the European Union, the United States and Canada, which is based on the FAO/WHO guideline level of 0.5 ppm wet weight total Hg (THg). To protect vulnerable groups (frequent fish consumers, pregnant women and those under 15 yrs old), the WHO has recommended a lower guideline level of 0.2 ppm wet weight. Mean total wet-weight Hg concentrations are summarised by area, site and species in Tables 22 to 25.

Table 22. Total Hg concentrations in fish in the Rwamagasa background areas.

Site	Species	Sample type	Mean L mm	Mean Hg & range ppm (μg/g)	n
Munekesi	*Clarias gariepinus*	Muscle tissue	201	0.119 (0.048-0.199)	4
	Clarias gariepinus	Whole fish	136	0.150 (0.138-0.161)	2
Nyamsenga	*Clarias alluadi*	Muscle tissue	161	0.134 (0.078-0.231)	3
	Clarias alluadi	Whole fish	93	0.083 (0.044-0.115)	11

Table 23. Total Hg concentrations in fish and gastropods in the Rwamagasa area.

Site	Species	Sample type	Mean L mm	Mean Hg & range ppm (μg/g)	n
Rwamagasa market	*Oreochromis niloticus*	Muscle tissue	171	0.009 (0.002-0.031)	5
Rwamagasa Pond 1	*Barbus spp*	Whole fish	54	1.05 (0.684-1.53)	5
	Clarias gariepinus	Muscle tissue	142	1.61 (1.24-1.97)	2
Rwamagasa Pond 2	*Clarias gariepinus*	Whole fish	67	1.67	1
	Haplochromis spp	Whole fish	30	2.06 (0.995-2.65)	5
Rwamagasa Pond 4	*Clarias gariepinus*	Muscle tissue	173	0.336 (0.163-0.637)	7
	Clarias gariepinus	Whole fish	111	0.222 (0.092-0.510)	12
	Haplochromis spp	Whole fish	47	0.323 (0.195-0.443)	4
Rwamagasa Pond 5	*Clarias gariepinus*	Whole fish	119	0.779 (0.189-1.64)	4
Rwamagasa Pond 6	*Barbus spp*	Whole fish	42	0.301 (0.285-0.318)	4
	Brycinus spp	Whole fish	67	0.338 (0.206-0.398)	6
	Clarias alluadi	Whole fish	85	0.267 (0.187-0.431)	4
	Clarias gariepinus	Whole fish	134	0.538 (0.339-0.792)	5
	Haplochromis spp	Whole fish	33	0.167 (0.145-0.189)	2
Nikonga River	*Clarias alluadi*	whole fish	86	0.071 (0.055-0.084)	5
	Cynodontis victoriae	whole fish	44	0.265	1
	Gastropoda	muscle tissue	41	0.040 (0.019-0.069)	5

Table 24. Total Hg concentrations in fish at Tembomine.

Site	Species	Sample type	Mean L mm	Mean Hg & range ppm (μg/g)	n
Tembomine	*Clarias gariepinus*	Muscle tissue	227	0.792 (0.173-1.84)	25

Table 25. Total Hg concentrations in fish in the Lake Tanganyika area.

Site	Species	Sample type	Mean L mm	Mean Hg & range ppm (µg/g)	n
Uvinza	*Barbus tropidolepsis*	Muscle tissue	122	0.030 (0.021-0.033)	4
	Oreochromis tanganicae	Muscle tissue	121	0.046 (0.014-0.074)	4
Ilagala Market	*Auchenoglanis occidentalis*	Muscle tissue	233	0.014 (0.005-0.034)	5
	Brycinus rhodopleura	Muscle tissue	201	0.028 (0.025-0.032)	3
	Clarias gariepinus	Muscle tissue	282	0.022 (0.002-0.042)	6
	Hydrocynus vittatus	Muscle tissue	197	0.034 (0.023-0.044)	8
	Lates malagarasi	Muscle tissue	202	0.025 (0.011-0.043)	5
	Oreochromis tanganicae	Muscle tissue	140	0.013 (0.007-0.021)	5

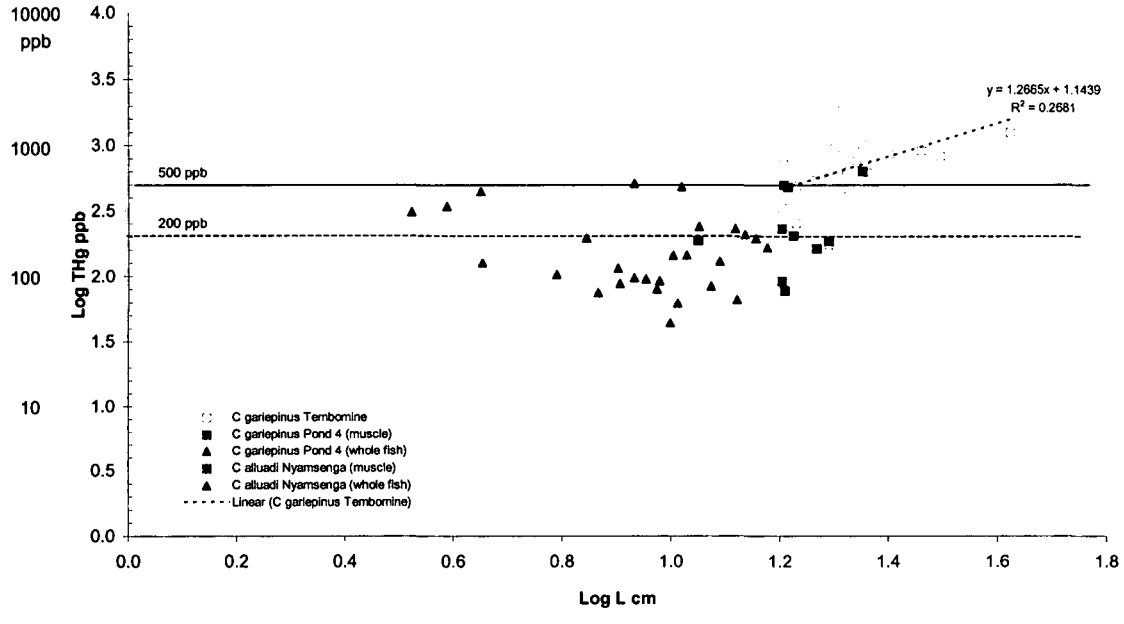

Figure 37 Hg (ppb) related to length (cm) for muscle tissue and whole fish samples collected at the same sites in the Rwamagasa area.

4.6.2 Results by site and species

At the two sites selected for background samples in the Rwamagasa area (Munekesi and Nyamsenga, Table 22) only one specimen, with at 0.231 ppm Hg, of the twenty *Clarias alluadi* sampled had tissue THg concentrations exceeding the WHO recommended guideline for vulnerable groups (0.2 ppm) and all were below the export guideline (0.5 ppm).

Samples of *Oreochromis nitolicus* were obtained from Rwamagasa market and were reported to originate from Lake Victoria. Fresh fish is very limited in Rwamagasa, making the collection of samples of locally consumed fish difficult, hence only nile tilapia, a detritivore/herbivore that occasionally consumes invertebrates and smaller tilapia, were available. The mean THg concentration of the market fish was well below both guideline levels at 0.009 ppm and also considerably lower than the levels found in the background *Clarias spp* samples from Munekesi and Nyamsenga. Higher levels of Hg have been found in *O. nitolicus* from Lake Victoria (Harada et al 1999, Campbell et al 2003a), but on the whole the level found here is consistent with the findings of other studies of Lake Victoria fishes (Machiwa et al 2003, Kahatano et al 1997, Ikingura 1996) and those of other lakes in this region (Campbell et al 2003b).

THg concentrations in fish collected from the reaches of the Isingile river closest to Rwamagasa (Ponds 1 and 2, Figure 13), consistently exceeded guideline values for export markets (Table 23). All of the specimens collected were very small, most likely because of their juvenile status although possibly augmented by poor growth. The predominantly insectivorous *Barbus spp.* from Pond 1 showed the lowest tissue concentrations at 1.05 ppm but were still twice the export guideline value. Both Ikingura (1996) and Kahatano (1997) found much lower levels (<0.020 ppm) in comparatively large insectivorous African tetra collected from Nungwe Bay and Mwakitolyo Mine/Mwanza, but this may reflect of differences in the specific ecological niches and feeding behaviour of the different species. Larger specimens of the *Barbus* genus collected from Lakes Baringo and Naivasha by Campbell (2003b) contained THg concentrations up to 0.100 ppm, an order of magnitude lower than those collected in Rwamagasa.

Clarias gariepinus from both Pond 1 and 2 showed similar average tissue Hg concentrations at over three times the guideline level, despite the different tissue sampling methods that were used. The tissue THg levels found in these two ponds are particularly high (Table 23 and Figure 38) and, in the case of this species, may be due to its sediment dwelling and feeding behaviour, and its ability to survive in poor quality water from which it may accumulate Hg. Few studies in this region have studied fish tissue THg as a means of identifying environmental hotspots, therefore little data is available for smaller fishes affected by Hg contamination. However, van Straaten (2000) reported a tissue concentration of 2.55 ppm THg for a single specimen of *Clarias spp* caught in a tailings pond in the Kahama District in northern Tanzania but no other data (size, length or weight) was reported. The sediment THg data indicates that these two Rwamagasa ponds are affected by tailings; the mean sediment THg was 0.798 ppm compared with 0.080 ppm across the two Rwamagasa background areas (Table 26). The elevated tissue concentrations of some specimens, compared with the sediment concentrations in these two ponds, might be interpreted as an indication of bioconcentration. However, due to the poor conditions for fish sampling, insufficient data is available to allow closer examination using length-THg relationships.

Haplochromis spp. are generally planktivores; those collected from Pond 2 showed the highest THg levels, at over four times the guideline, of the four species represented in Ponds 1 and 2. That there appears to be a marked difference between the tissue concentrations of *Barbus* and *Haplochromis* may be a reflection of differences in very specific ecological niches. Larger *Haplochromis spp.* caught in the Mara and Mwanza regions of Lake Victoria showed maximum tissue THg levels of 0.420 ppm, which

exceed the recommended level but are permissible for export (Machiwa et al, 2003). By comparison Campbell found a tissue level of a single small specimen of *Haplochromis spp.* caught in Lake Naivasha to be 0.005 ppm.

Where affected waters have been studied only top predator, piscivorous fishes have tended to contain Hg levels as high as those found in the planktivorous and omnivorous species in Ponds 1 and 2. For example, in a review of THg concentrations in fishes from Lake Victoria, levels up to 1.2 ppm were detected in large nile perch in the Mwanza Gulf (Campbell et al 2003a). Similarly high levels of Hg have also been observed in large piscivorous fish collected from a hydroelectric reservoir in Canada, although Tanzanian reservoir fishes examined in the same study showed very low levels of Hg (Ikingura and Akagi 2003).

Average Hg concentrations of *C. gariepinus* collected from Pond 5 also exceeded the export guideline and almost all specimens exceeded the recommended guideline. Individual specimens ranged from 0.189 to 1.64 ppm THg (mean 0.779 ppm). However, the fish were clearly stressed, either as a result of their capture or of the quality of their environment, and in poor condition. The Tembomine fish THg levels were comparable to the samples from Pond 5, although individual specimens spanned a much wider size range (Table 24). These levels are comparable to those found in the same species collected from the Isagana (Isanga) River, which is affected by the Bulyankulu and Katende Mines, and Winam Gulf in Kenya (Campbell et al., 2003a) although based on their reported weights (no length data was reported), those fish were considerably larger than those tested here. The sediment THg levels indicate that both Pond 5 (3.02 ppm) and Tembomine (0.670 ppm) were also affected by tailings. In Campbell's review (2003a) similar concentrations were found in stream sediments in which the catfish were caught at Bulyankulu Mine.

By comparison, *C. gariepinus* and *Haplochromis spp.* collected from Pond 4, which is isolated from the Isingile River channel, showed tissue THg concentrations exceeding the recommended guideline but below the export guideline. The tissue of C. gariepinus contained higher THg concentrations (0.336 ppm) than the composited whole fish samples (0.222 ppm). This is most likely a reflection of the length dependency of fish tissue Hg concentrations rather than of the sampling method used. Sediment levels at Pond 4 ranged between 0.315 and 0.850 ppm (Table 26).

The water quality of Pond 6 is influenced both by the Isingile River and by the outflow from Buckreef. Sediment concentrations were relatively low compared with those closer to Rwamagasa. Tissue THg concentrations varied with species with the piscivorous *Brycinus spp.* and insectivorous *Barbus spp.* tissue levels between the two guideline values. *C. gariepinus* showed the highest mean concentrations and were above the export guideline, despite the relatively low sediment concentrations. Again this is most likely a reflection of its sediment dwelling behaviour as Kahatano et al (1997) were able to compare sediment dwelling omnivores with predatory species in the LVGF and also found higher tissue THg levels in the catfish compared with predatory species. Specimens of *C. alluadi* showed tissue Hg concentrations greater than 0.200 ppm but lower than those of *C. gariepinus.* This may be attributable to the ability of *C. gariepinus* to survive out of water for longer periods than *C. alluadi* and this species is

able to migrate from pools in which the water level is very low. *C. gariepinus* collected from Pond 6 may have migrated downstream from areas affected by mining activities.

Fish collected from the Nikonga River typically contained tissue Hg levels comparable to those of the *O. nitolicus* from Lake Victoria, i.e. well below the recommended guideline. The gastropods tested also contained very low levels of Hg (Table 23), which is probably a consequence of this species herbivorous grazing feeding characteristics. Similarly all the samples collected from the Lake Tanganyika area (Uvinza and Ilagala, Table 25) had tissue THg levels well below the recommended guideline and were comparable to those of the Lake Victoria *O. nitolicus* samples. The exception was the single specimen of *Cynodontis* collected from the Nikonga River, again a benthic feeder, which may have taken on Hg from the sediment as it fed. In much larger specimens from Lake Victoria Machiwa et al (2003) found THg concentrations of <0.080 ppm. Of the samples collected at Uvinza, the insectivore *Barbus tropidolepsis* had lower tissue Hg levels compared with *O. tanganicae.*. The Ilagala market samples on the other hand showed the more common pattern of slightly higher tissue THg in the top predators i.e. *Lates malagarasi*, *Brycinus rhodopleura* and *Hydrocynus vittatus* compared with the other omnivorous species sampled.

Table 26. Total Hg concentrations in sediments at fish sampling points

Site	Mean Hg & range ppm (µg/g)
Rwamagasa Pond 1 & 2	0.798 (0.385-1.21)
Rwamagasa Pond 4	0.583 (0.315-0.850)
Rwamagasa Pond 5	3.02
Rwamagasa Pond 6	0.120 (0.085-0.175)
Nikonga River	0.128 (0.090-0.190)
Tembomine	0.670
Munekesi and Nyamsenga	0.080 (0.075-0.085)

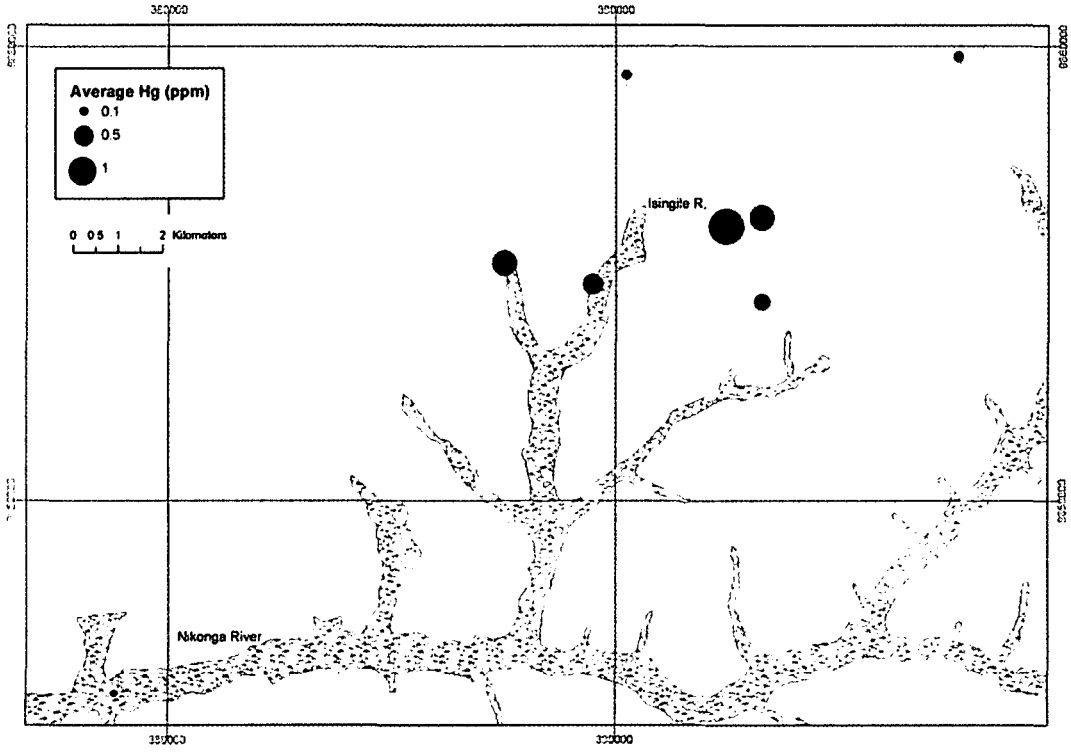

Figure 38. Average Hg (ppm) in *Clarias spp.* for fish sampling sites in the Rwamagasa area

Table 27. Average concentration of Hg (ppb) in fish from the Rwamagasa area, Malagarasi River – Lake Tanganyika (Uvinza & Ilagala) and Lake Victoria

Species (common or local name)	Area	Mean Hg (ng/g, ppb)	Source
Lates spp. (perch)	Ilagala	25	1
	Lake Victoria	123	2
	Nungwe Bay, Lake Victoria	10	3
	Lake Victoria (Mara and Mwanza)	61	4
	Lake Tanganyika (Burundi)	<50	5
Oreochromis spp (tilapia)	Ilagala	13	1
	Uvinza	46	1
	Rwamagasa Market (Lake Victoria)	9	1
	Lake Victoria	19	2
	Nungwe Bay, Lake Victoria	2	3
	Lake Victoria (Mara and Mwanza)	84	4
Clarias spp. (catfish)	Ilagala	22	1
	Rwamagasa background areas (Munekesi & Nyamsenga)	100	1
	Rwamagasa Pond 1	1610	1
	Rwamagasa Pond 4	336	1
	Tembomine	792	1
	Lake Victoria	19	2
	Nungwe Bay, Lake Victoria	2	3
	Lake Victoria (Mara and Mwanza)	132	4
Rastrineobola spp. (dagaa)	Lake Victoria	23	2
Barbus spp. (dagaa)	Rwamagasa Pond 1	1050	1
Barbus spp. (dagaa)	Rwamagasa Pond 6	301	1
Brycinus spp. (tigerfish)	Ilagala	28	1
	Lake Victoria (Mara and Mwanza)	92	4
*Haplochromis spp (*furu)	Rwamagasa Pond 2	2060	1
	Rwamagasa Pond 4	323	1
	Lake Victoria (Mara and Mwanza)	154	4

Source of data: 1= this study; 2 = Campbell et al., 2003; 3 = Ikingura and Akagi, 1996; 4 = Machiwa et al., 2003; 5 = Sindayigaya et al., 1994.

4.6.3 Length – mercury relationships

Data from the Lake Victoria Environmental Management Project (LVEMP) (Machiwa et al 2003) are compared with the fish tissue data for Rwamagasa and Lake Tanganyika in Figures 39 to 41 in which species and area are plotted separately but data is compared according to the species' broad trophic status. These comparisons are tentative as the LVEMP data was digitised from a dry weight basis and then

transformed to wet weight concentrations using Machiwa's mean conversion factors of 0.290 (*L. nitolicus*), 0.256 (*O. nitolicus*) and 0.242 (*C. gariepinus*).

Figure 39 shows data for *Clarias spp.* Where individual samples were composited for analysis, the mean length is plotted against concentration. The Ilagala samples plot within the LVEMP data indicating that this region of the Malagarasi River are not affected by Hg contamination. There is also some apparent overlap between the background samples from the Munekesi and Nyamsenga background areas but the difference in size ranges between the two data sets makes direct comparisons uncertain. *Clarias spp.* from the Rwamagasa area were consistently higher but the difference does not appear to be significant. It was not possible to derive length-Hg relationships from the data because of the narrow range of fish sizes and small numbers of individuals for each species available in the many of the sites. Also the selection of a standardised size from the data obtained here is unlikely to be relevant, particularly for the Rwamagasa area where the local population rarely consumes smaller fish. Furthermore, for the majority of species and sites, insufficient data are available to allow a valid statistical analysis. The exception may be Tembomine, which is outside the study area and was tested as a comparison.

Piscivores and other predators are compared in Figure 40. The Ilagala samples compare well with the LVEMP's unaffected *Lates nitolicus* data set. All the Rwamagasa samples (*Brycinus*, *Barbus* and *Haplochromis*) are grouped which may indicate it is possible to treat them as one population based on their broad feeding habits.

O. nitolicus samples from Rwamagasa market and *O. tanganicae* obtained in Ilagala in the Lake Tanganyika area (Figure 41) plot with the LVEMP data for *O. nitolicus* from Lake Victoria, the main difference between the datasets being the size range over which samples were collected.

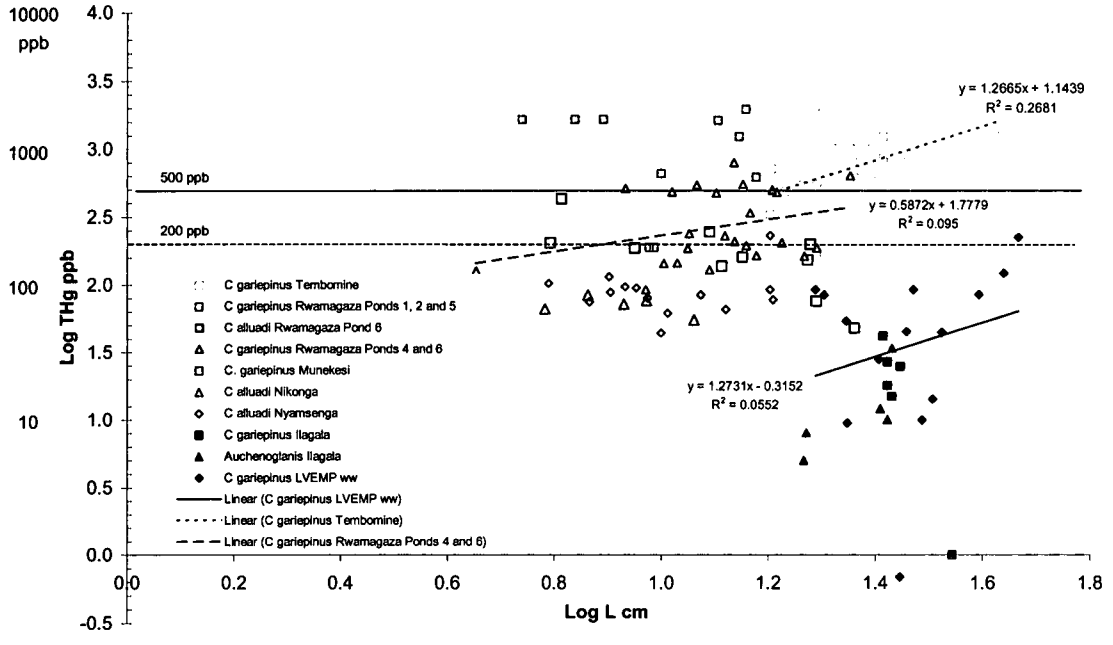

Figure 39 Hg (ppb) related to length (cm) in *Clarias sp.*

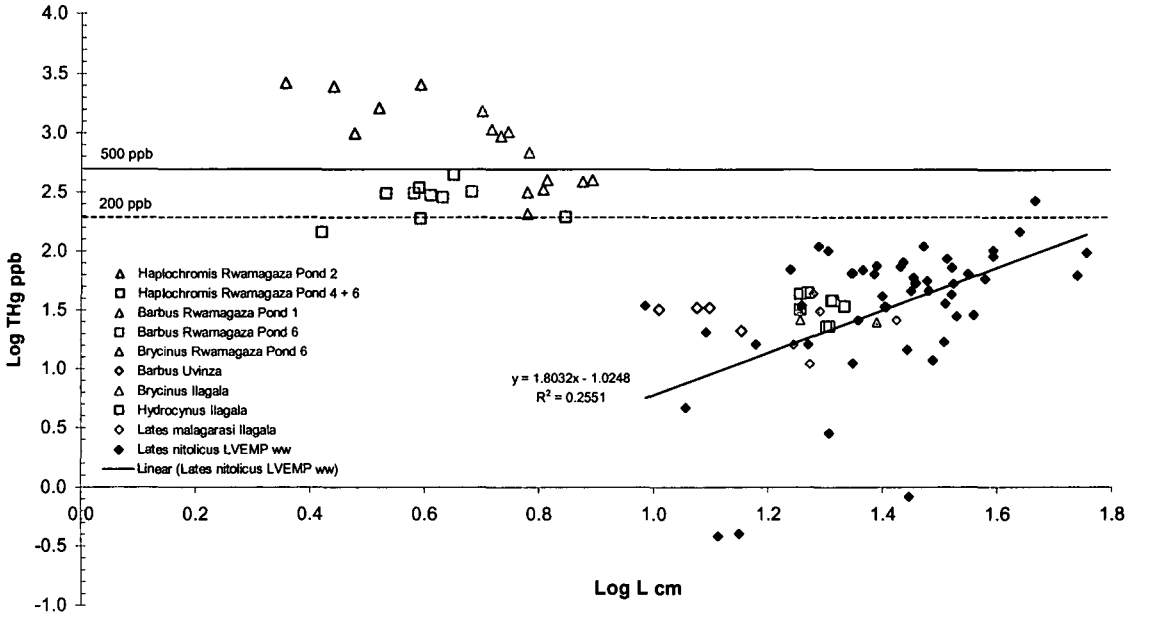

Figure 40 Hg (ppb) related to length (cm) in piscivores, insectivores and planktivores from the Rwamagasa area, River Malagarasi – Lake Tanganyika (Ilagala, Uvinza) and Lake Victoria (LVEMP, Machiwa, 2003)

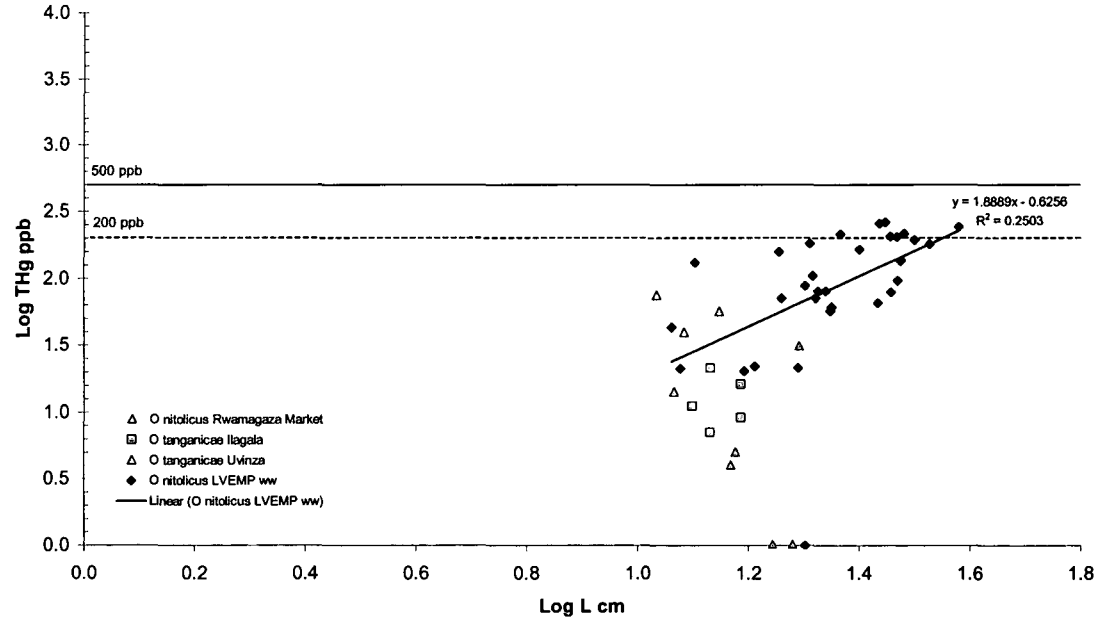

Figure 41 Hg (ppb) related to length (cm) in *Oreochromis spp* from the Rwamagasa area, River Malagarasi – Lake Tanganyika (Ilagala) and Lake Victoria (LVEMP, Machiwa, 2003)

4.6.4 Summary

The fish tissue THg data indicates that the sites sampled in the immediate area of mining activities at Rwamagasa, in particular Ponds 1, 2 and 5 are the worst affected and should be considered environmental or contamination 'hotspots' and sites of biomethylation. Tembomine is also a 'hotspot' as a result of local mining activity. Many fish tissues from these sites fail export market standards (0.5 ppm). Ponds 4 and 6 are moderately affected and depending on the species, fish from these sites fail the recommended standard for vulnerable groups (0.2 ppm). The Nikonga River fish samples were slightly elevated compared with the Lake Tanganyika (Ilagala) samples but are below the WHO threshold for vulnerable groups (0.2 ppm). The influence of the Rwamagasa mining activity on the THg of fish tissues collected at Lake Tanganyika is negligible as the levels were comparable to tissue levels found in Lake Victoria in this study and those of other authors.

5 Exposure to Environmental Mercury

5.1 DRINKING WATER

WHO guidelines for drinking water (1993) state that mercury is present in the inorganic form in surface and ground waters at concentrations usually of less than 0.5 μg/litre and that mean dietary intake of mercury in various countries ranges from 2 to 20 μg per day per person.

In 1972, JECFA established a provisional tolerable weekly intake (PTWI) of 5 μg/kg of body weight of total mercury (equivalent to 300 μg THg per week for a person weighing 60kg), of which no more than 3.3 μg/kg of body weight (equivalent to 200 μg MeHg per week for a person weighing 60kg) should be present as methylmercury. In 1988, JECFA reassessed methylmercury, as new data had become available, and confirmed the previously recommended PTWI of 3.3 μg/kg of body weight for the general population, but noted that pregnant women and nursing mothers were likely to be at greater risk from the adverse effects of methylmercury. To be on the conservative side, this PTWI for methylmercury was used to derive a guideline value for inorganic mercury in drinking-water. As the main exposure is from food, a 10% allocation of the PTWI to drinking-water was made. The WHO guideline value (1993) for total mercury was consequently set at 0.001 mg/litre (rounded figure). In June 2003, experts from the FAO and WHO met and have revised the PTWI for methyl mercury down to 1.6 μg/kg of body weight per week, the drinking water guideline value has not yet been revised to take this into account, FAO/WHO (2003).

According to the medical investigation all the 250 participants in the Rwamagasa area claimed they obtained drinking water from shallow, most likely hand-dug wells (personal communication from Stephan Böse-O'Reilly, 2004). Drawing of washing and cooking water from shallow wells by bucket was observed during the environmental survey, but not the abstraction of drinking water. In deriving its guideline values WHO assume the ingestion of 2 litres of water per day (WHO, 1993) there was no direct evidence to suggest this value was significantly higher in the Rwamagasa area.

Data summarized in Table 5 above indicate that none of the drainage samples collected from the river network, or associated drainage ponds exceeded the WHO or local Tanzanian guideline values of 1 μg/l Hg for drinking water. Whilst this suggests that mineral processing operations have not contaminated local surface waters and shallow groundwaters it does not indicate whether drinking water used by the local people has been contaminated. More extensive monitoring of drinking water sources (which was not

the focus of the current investigations) should be considered as a component of any subsequent follow up work.

The only samples of water collected during the survey that contained excess amounts of Hg were from amalgamation ponds. This highlights the need for careful management of waste waters from these ponds and monitoring of any nearby drinking water supplies.

5.2 FOODSTUFFS

According to the sociological report (Wagner, 2003) "Food consumption and nutrients patterns indicated the possible status of nutrient intake by the Rwamagasa community. The highest numbers of respondents (36%) take meat once a week and 7% eat meat every day, while 36% eat fish twice a week and 6% eat fish everyday. Moreover, 31% eat chicken at least once a week, 17% eat eggs once a week, 38% drink milk everyday, 36% eat bean everyday, 50% eat vegetables everyday and 27% each fruits everyday." Unfortunately, the socio-economic report did not provide information on the source of fish (local or imported from Lake Victoria) nor the relative proportions of the different species consumed. At the time of the field survey (September), all fish available in the market appeared to have been imported from Lake Victoria. Only catfish were found in any numbers in the local streams and most of these were sold as bait for perch fishing in Lake Victoria. It appears that the local people eat these fish only under extreme circumstances (unpublished information provided by Stephan Böse O'Reilly, 2004).

5.2.1 Locally produced rice, maize, cassava and vegetables

The maximum likely dietary intake of rice by the local residents in the Rwamagasa area is provisionally estimated to be 300g (air- dried) per person per day, although this may be an over estimate as the local people also usually consume cassava and maize. The average Hg concentration recorded for samples of rice grain grown in the study area was 0.026 µg/g (dry wt.), so the amount of mercury entering the body, assuming an average consumption of 300g rice per day, is 7.8 µg THg /day or 0.055 mg THg/week. This value is much lower than the Provisional Tolerable Weekly Intake (PTWI) of 0.3 mg for Total mercury in the diet set by the WHO and the FAO (1972). If 50% of the Hg in Rwamagasa rice is MeHg (see Horvat et al., 2003), then the total weekly MeHg intake from rice would be 27.5 µg MeHg which is equivalent to 0.46 µg MeHg/ kg bw/week. This is lower than the MeHg PTWI of 1.6 µg/ kg body weight/ week recommended by JECFA in June 2003. However, adults consuming Rwamagasa rice at the upper limit of the Hg concentration range recorded in the current survey (0.035 µg/g) would have a weekly intake of 73.5µg THg which is equivalent to 0.6 µg MeHg/kg bw/week (assuming a body weight of 60kg and that the rice contains 50% of the THg is MeHg). This is likely to be a maximum input because most people in the Rwamagasa area will also consume cassava and maize, which are grown on soils with low Hg.

No information is provided on the relative proportions of rice, maize, cassava and yams consumed in the area in either the sociological report (Wagner, 2003) or the report on the medical assessment (Drasch et al., 2004). Because of this it is impossible to calculate Hg inputs from each of these staple food sources.

Yams are generally relatively expensive and probably constitute less than 10% of dietary intake from staple crops (based on the extent of the area cultivated). An individual consuming 30 g/day of yam with the highest Hg concentration recorded in the current survey (0.09 mg THg /kg) would have a weekly intake from yam of 0.315 µg THg/kg bw/week, equivalent to 0.16 µg MeHg/kg bw/week, assuming that 50% of Hg in yam is MeHg.

5.2.2 Fish

Fish and fish products are the dominant source of methylmercury in the diet and levels greater than 1200 µg/kg have been found in edible marine species such as tuna and swordfish. Similar levels have also been recorded in fish from polluted freshwaters. Data from the medical assessment (Drasch et al., 2004) indicate that 4% of the 252 cases ate fish once a month, 69% ate fish at least once a week and 27% ate fish at least once a day. Of those that ate fish at least once a day, 78% ate only one fish meal a day, 15% twice a day and 7% three fish meals a day. The vast majority of cases principally ate Tilapia (*Oreochromis spp.*), Perch (*Lates spp.)* and dagaa (dagan; *Rastrineobola spp.* and equivalents). Catfish (*Clarias spp;* kamare, mumi) was eaten by only 9% (15 out of 173) of the cases who ate fish at least once a week and only 7% (5 out of 68) of cases who ate more than one fish meal a day.

98% of cases stated that the fish they consumed came from an area distant from the mining impacted area or from the market, so most of it is highly likely to have come from Lake Victoria. Of the 5 cases that stated that some of the fish came from mining impacted areas, the fish consumed was principally tilapia, perch and dagaa (likely to be from Lake Victoria) with hongue, kanago and furu (*Haplochromis spp.*) mentioned as the other fish species. None mentioned that catfish from mining impacted areas was eaten, although we came across at least one family living outside Rwamagasa village, who ate catfish from the mining contaminated Isingile River.

Average Hg concentrations in fish from the Rwamagasa area, the River Malagarasi-Lake Tanganyika (Ilagala-Uvinza) and Lake Victoria are given in Table 28. Consumption of 250g perch, 500g tilapia and 250g of catfish each week would result in an intake of 27 µg THg/week (0.35 µg MeHg/kg bw/week) for residents of Ilagala-Uvinza, 44 µg THg/week (0.58 µg MeHg/kg bw/week) for people depending totally on fish from Lake Victoria, 56 µg THg/week (0.75 µg MeHg/kg bw/week) for people in the Rwamagasa background area consuming tilapia and perch from Lake Victoria and catfish from the local streams, and 259 µg THg/week (3.45 µg MeHg/kg bw/week) for people in the Rwamagasa area consuming tilapia and perch from Lake Victoria and catfish from mining impacted streams (Table 29). Apart from the latter group consuming catfish from mining impacted stream (259 µg THg/week), these inputs related to fish consumption are below the Provisional Tolerable Weekly Intake (PTWI) of 300 µg for total mercury and 1.6 µg /kg bw/week for MeHg in the diet recommended by JECFA. In the relatively unlikely situation where people were consuming solely catfish from mining impacted streams, these cases would have an estimated weekly intake of 730 µg MeHg/week (Table 28), which is equivalent to 12.2 µg MeHg/kg bw/week - more than seven times the JECFA PTWI for MeHg. This situation is unlikely to occur with people living in Rwamagasa but may occur occasionally in people living close to the Isingile River and

near Tembomine, for example. Only those people consuming catfish from the Isingile River are likely to be at risk of exceeding the PTWI for MeHg.

People consuming 300g/day of rice grown on the Hg contaminated Isingile mbuga and 1kg/day of fish from Lake Victoria would have a combined estimated MeHg input of 1.04 μg MeHg /kg bw/week (0.46 μg MeHg/kg bw/week from rice and 0.58 μg MeHg/kg bw/week from fish) which is two thirds of the MeHg PTWI.

Table 28. Average concentration of Hg (μg/g) in fish from the Rwamagasa area, Malagarasi River – Lake Tanganyika (Uvinza & Ilagala) and Lake Victoria eaten people in the Rwamagasa and Ilagala areas (see Table 27 for further details).

				Potential Hg input related to consumption of 1kg fish/week	
Species consumed	Source of fish	Hg (ng/g)	Hg (μg/g)	Hg (μg THg/week)[1]	Hg (μg MeHg/week)[2]
Perch (*Lates spp.*)	Ilagala	25	0.025	25	22
	Lake Victoria	65	0.065	65	52
Tilapia (*Oreochromis spp.*)	Ilagala	30	0.030	30	24
	Lake Victoria	29	0.029	29	23
Catfish (*Clarias spp.*)	Ilagala	22	0.022	22	18
	Rwamagasa background	100	0.100	100	80
	Rwamagasa mining impacted	912	0.912	912	730
	Lake Victoria	51	0.051	51	41
Dagaa (*Rastrineobola spp.* and *Haplochromis spp.*)	Lake Victoria	23	0.023	23	18
	Rwamagasa mining impacted	675	0.675	675	540

[1] based on consumption of 250g fish, four times a week (i.e. 1 kg/week); [2] MeHg = 0.8*THg

Table 29. Average THg (μg/week) and MeHg (μg/week) potentially consumed by people in the Rwamagasa and Ilagala areas based on weekly consumption of 250g Perch, 500g Tilapia and 250g Catfish (see Table 28 for further details).

			Potential Hg input related to consumption of 1kg fish/week	
Area and species consumed	Source of fish	wet weight (g) fish consumed/week	Hg (μg THg/week)	Hg (μg MeHg/week) [1]
Ilagala-Uvinza				
Perch (Lates spp.)	Ilagala	250	6	5
Tilapia (Oreochromis spp.)	Ilagala	500	15	12
Catfish (Clarias spp.)	Ilagala	250	6	4
		Total Hg per week	*27*	*21*
Lake Victoria				
Perch (Lates spp.)	Lake Victoria	250	16	13
Tilapia (Oreochromis spp.)	Lake Victoria	500	15	12
Catfish (Clarias spp.)	Lake Victoria	250	13	10
		Total Hg per week	*44*	*35*
Rwamagasa (background area)				
Perch (Lates spp.)	Lake Victoria	250	16	13
Tilapia (Oreochromis spp.)	Lake Victoria	500	15	12
Catfish (Clarias spp.)	Rwamagasa background	250	25	20
		Total Hg per week	*56*	*45*
Rwamagasa (mining impacted area)				
Perch (Lates spp.)	Lake Victoria	250	16	13
Tilapia (Oreochromis spp.)	Lake Victoria	500	15	12
Catfish (Clarias spp.)	Rwamagasa mining impacted	250	228	182
		Total Hg per week	*259*	*207*

[1] MeHg = 0.8*THg

5.3 INADVERTENT AND DELIBERATE INGESTIONS OF SOIL AND DUST

Whilst exposure via foods and drinking water have traditionally been considered to be major sources of exposure to potentially toxic elements such as mercury the development of risk assessment methodologies for contaminated sites and mine workings has highlighted the importance of the inadvertent and deliberate ingestion of soils and dusts (e.g. Ferguson et al., 1998; Williams et al., 1998). For example in deriving the UK's guideline values for Hg in soil approximately 80% of the total exposure is apportioned to the inadvertent ingestion of contaminated soils and dusts (Environment Agency, 2002)

However, the amount of soil and/or dust that is ingested has been discussed extensively in the literature (e.g. Simon 1998). Some studies considered to be influential (e.g. Kimborough et al 1984) have been criticised for using ultraconservative soil ingestion rates with little empirical support (Paustenbach et al., 1986; Gough 1991). More recent research has been dominated by mass-balance studies of 'conservative tracer elements', i.e. chemical elements that are present in soil but which are not significantly absorbed by passage through the gut (Calabrese 1989; Davies 1990; van Wijnen et al 1990).

The ingestion of soil and/or dust occurs both within and outside the household environment and to improve on the accuracy of predicting exposure it is desirable to establish, where possible, the concentration of Hg in both environments. Alternatively, a general relationship between indoor dust and outdoor soil contaminant concentrations may have to be assumed. For example, Keenan et al (1989) and Murphy et al (1989) have reported the proportion of locally derived soil particles in indoor dust to be in the order of 75% to 100%. This estimate was based mainly on a study of land contamination around a series of smelters. However, some studies such as those by Franzen et al (1988) and Steele et al (1990) indicated that in mining communities the proportion was much less than this (typically indoor concentrations were 14% to 15% of soil concentrations). However, data used in these studies was obtained in European and North American mining communities and would not be expected to reflect the situation in northern Tanzania. It is therefore (conservatively) assumed for the purposes of this study that locally derived soil particles account for all of the household dust.

Three distinct categories of soil ingestion may be considered, and these are discussed below along with suggested quantities of ingested material. From these examples it can be clearly seen that the amount of soil and/or dust ingested varies greatly, and that it is essential that the likely magnitude of geophagic activity is assessed in potentially exposed populations. During surveys of geophagic behaviour, it is essential that great care is exercised to prevent false-negative results being obtained due to cultural taboos associated with this practice (e.g. being considered to be improper or of lower social status).

5.3.1 Inadvertent ingestion of small quantities of soil and dust

It is likely that all members of an exposed population will have intakes by this route, although exposure is likely to be greatest for children under seven years old. Sources of soil and dust are likely to be derived from both outdoors and indoors, and the relative magnitude of exposure will depend greatly on the habits and behaviour of an individual. Despite the wide number of studies, considerable uncertainties still exist in data relating to this activity (e.g. Simon 1998). This is in part due the difficulty in the methodological use of tracers to estimate such quantities, and also the highly individualistic nature of exposure. Median inadvertent soil ingestion rates derived from tracer studies performed in the USA range from 25 to 81 mg soil/day for children (Davies, 1990; Calabrese (1989) and from 0.5 to 517 mg soil/day for adults (Calabrese et al., 1990), although it should be noted that a high level of uncertainty applies to these estimates. It should be noted that these values are generally higher than those suggested by WHO (20 mg per day; WHO 2001) and those used in a recent assessment of mercury exposure in the Lake Victoria area (35 mg/day adults, 50 mg/day children; Campbell et al., 2003a). It is equally important to consider that these inadvertent ingestion estimates may be lower than those encountered in the Rwamagasa area where people working in and close to the mineral processing centres will be exposed to a dusty environment (Drasch et al., 2004).

5.3.2 Occasional deliberate consumption of soil and dust (pica)

Most young children indulge in this type of exploratory behaviour for a relatively short time, although there is hardly any quantitative information on the amount of soil deliberately ingested during these activities. This is due in part to the difficulty in separating the occasional consumption of soil from the habitual practice of soil ingestion (geophagy), and from exposures that typically occur during the mouthing of other objects. For a group of 64 US children studied by Calabrese et al (1991) the median soil ingestion rate ranged from 9 to 96 mg per day according to tracer measurements, but one child (a three-and-a-half-year-old girl) ingested much greater quantities (up to 13.6 g per day). Earlier estimates of the amount of soil deliberately ingested as five grams per day (USEPA, 1984) and ten grams per day (USEPA, 1989) have generally been based purely on 'judgement'. As this behaviour is by definition occasional, it is unrealistic to use yearly or indeed daily consumption as a quantitative way of expressing occasional exposure. It is more realistic to use an exposure per event. For the purpose of this exercise it is assumed that the event is of one day duration.

5.3.3 Geophagia

The term geophagia refers to the persistent and purposeful consumption of soil and/or dust, often in relatively large quantities. It is typically associated with children and pregnant females who may be subject to nutrient deficiencies. Geophagia should be considered as being distinct from pica (see above), which relates to the inadvertent ingestion of soil/dusts when mouthing or eating unusual objects, and should not be considered as only occurring in rural environments. Geophagia has been studied in both the UK and North America within the wider context of pica (e.g. Cooper 1957; Barltrop 1966; Bicknell 1975; Morgan et al 1988). However, as Lacey (1990) comments 'The body of literature on pica is so fragmented that it is difficult to find a precise summary of the knowns and unknowns about the condition. There is little consistency in defining pica, classifying substances ingested, identifying key characteristics of practitioners, recommending treatment or projecting outcomes'. The fragmentary nature of this information therefore makes it extremely difficult to calculate exposure of populations or individuals via this route. The situation elsewhere is even more complicated, particularly in tribal cultures where geophagy is commonly practised. For example, studies by Geissler et al (1998) indicated that a large proportion of male and female children in Kenya practise geophagy up to the age of 16 years, with an average soil consumption rate of 25 g per day. Geophagy has also been recorded as being prevalent in Tanzania amongst pregnant females on the coastal plains (Antleman et al, 2000) and slopes of Mount Kilimanjaro (Knusden, 2002) and its presence is therefore likely to be widely established throughout Tanzania. No information on soil eating was collected during the medical assessment in the Rwamagasa area (Drasch et al., 2004).

5.3.4 Predicted Exposures from soil/dust ingestion

The calculation of chemical exposure from soil and dust ingestion uses the following formula:

D = Conc. x ingrate

where

D = exposure (mg per day)

Conc. = concentration of mercury in soil or dust (mg per kg)

ingrate = soil ingestion rate for infants (kg per day)

It should be noted that this calculation does not include dust inhaled transferred to the gut and assumes that all of the ingested Hg is of a similar bioavailability to the forms of Hg administered during animal experiments from which the tolerable daily intakes have been derived. Unfortunately, tests to define the actual bioaccessibility of Hg in contaminated soils, such as those described in Smith et al. (2000) have yet to be validated for Hg.

5.3.4.1 INADVERTENT INGESTION OF SMALL QUANTITIES OF SOIL AND DUST

Concentration of Hg in soil and dust = 9 mg per kg

(Representative of upper Hg concentration in soils and average Hg in tailing tips)

Central estimate soil ingestion rate = 0.080 g soil per day

Worst-case soil ingestion rate = 0.200 g soil per day

Chemical exposure = central estimate 0.72 μg Hg per day and worst case 1.8 μg Hg per day.

5.3.4.2 OCCASIONAL DELIBERATE CONSUMPTION OF SOIL AND DUST

Concentration of Hg in soil and dust = 9 mg per kg

(Representative of upper Hg concentration in soils and average Hg in tailing tips)

Central estimate soil ingestion = 0.096 g soil per event

Worst case soil ingestion = 13.6 g soil per event

Chemical exposure = central estimate 0.86 μg per event and worst case 120 μg Hg per event.

5.3.4.3 GEOPHAGIA

Concentration of Hg in soil and dust = 9 mg per kg

(Representative of upper Hg concentration in soils and average Hg in tailing tips)

Central estimate soil ingestion via geophagy = 26 g soil per day

Worst-case soil ingestion via geophagy = 85 g soil per day

Chemical exposure = central estimate 230 μg Hg per day and worst case 770 μg Hg per day

5.3.5 Discussion and conclusions

From the results presented above it is clear that elevated exposures to Hg can result from the occasional deliberate and habitual consumption of contaminated soils and dusts. For example, the Provisional Tolerable Weekly Intake (PTWI) of 0.3 mg for total mercury (THg) in the diet set by the WHO and the FAO, which is equivalent to 26 μg THg/day for a 30kg child is exceeded by an individual practising geophagia (central estimate and worst-case) or on a case by case basis by an individual occasionally consuming soil/dust (worst-case). The recorded practice of geophagy by pregnant females is of particular concern in this regard given the sensitivity of the foetus to mercury.

The inadvertent ingestion of dusts and soils even those having Hg concentrations significantly above the regional background, and hence considered to be moderately contaminated, does not appear to lead to a significant excess exposure to mercury. For example comparison of exposures due to inadvertent ingestion of soils and/or dusts (0.72 to 1.8 μg THg/day or 5 to 13 μg THg/week) is typically less than individual exposure via other dietary sources water, rice and fish (see preceding sections). This is consistent with the observations made by Campbell et al (2003a) and is subject to similar observations of Hg bioavailability. However, given the uncertainties involved in estimating inadvertent dust and soil intake in the rural Rwamagasa environment, exposure via this route, in addition to more classical geophagic behaviour, should be considered when planning remedial/intervention measures. Such measures could include the marking and fencing off of waste tips and areas of enhanced contamination and improvements in hygiene (washing of hands and food preparation such as the drying of cassava and other crops directly on the ground and the use of soil as a desiccant to aid the storage of groundnuts and beans). Whilst, as pointed out by Campbell et al (2003a) and others, geophagy does have an important cultural and possibly nutritional benefit the resulting levels of potential exposure to young adults and pregnant woman are high enough to suggest that this practice should be positively discouraged within the mining districts. To this end the importation of geophagic materials into local markets from outside the contaminated region should be encouraged and the negatives effects of using local soils conveyed though local woman's groups and childhood development officers.

6 Monitoring systems for water quality and biota

6.1 WATER QUALITY

6.1.1 Introduction

Any protocol for monitoring water quality in drainage systems impacted by mining and mineral processing needs to be designed with the objective of identifying short-term temporal variations related to fluctuations in the flux of processing wastes entering river systems, as well as long-term variation in water quality related to major changes in processing technologies and regimes. Ideally the system needs to be capable also of identifying sporadic water contamination incidents, although this may be extremely difficult where continuous monitoring is not a practical option.

The main sequential stages in the planning and execution of a monitoring programme are indicated in Figure 42. The major objectives of a water-quality monitoring programme are likely to be to:

- establish an understanding of the baseline;
- determine contaminant concentrations in the drainage water and their relation to water quality criteria (WQC) and compliance with water quality standards (WQS);
- determine contaminant concentrations in the suspended and bottom sediment and their relation to sediment quality criteria (SQC);
- determine the potential impacts of contaminants on aquatic biota and humans.

Such monitoring programmes are normally carried out by government agencies in fulfilment of their environmental protection responsibilities.

The following steps will help to ensure the successful execution of a water-quality monitoring programme:

1. Evaluate the prior history and the existing database for the area. Identify relevant data and the need for additional data.
2. Identify areas of potential environmental concern. If appropriate, subdivide the area into project segments on the basis of an assessment of the level of environmental concern within the area. This may be an iterative process that starts before sampling, using available information, and that is refined after sampling, based on new data.
3. Determine the number of samples to be collected, the sampling frequency and select sampling locations.
4. Determine what sampling methods will be used.
5. Define procedures for sample handling, preservation, and storage

6. Define procedures for analysis.
7. Identify logistical considerations and safety precautions.
8. Establish a QA/QC protocol. This is essential to ensure that there will be sufficient and appropriate data of known and documented quality to make reliable conclusions.

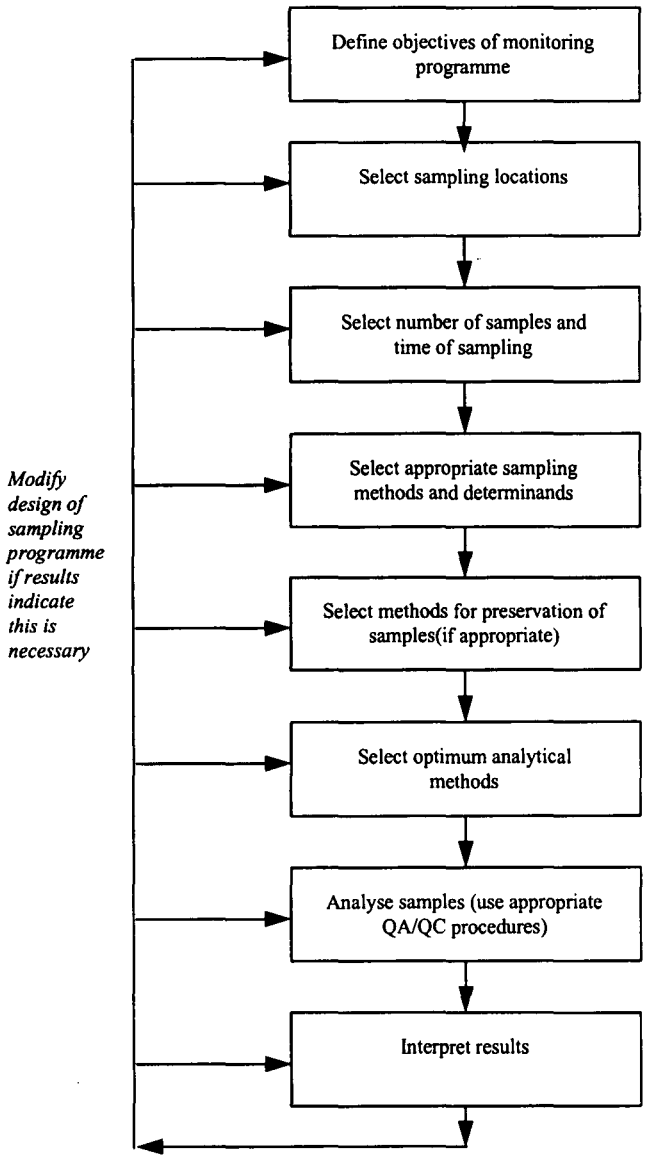

Figure 42: Major sequential stages in the planning and execution of a monitoring programme (adapted from Figure 5, SCA, 1996)

Important points to be considered at the design stage include:

- any environmental evaluation is only as complete and reliable as the sampling (and sample handling and storage) upon which it is based. Inadequacies or biases in sampling will limit the accuracy and usefulness of the results.
- careful planning can reduce the need to repeat costly sampling and analytical procedures.

Full discussion with all relevant personnel involved in the management, field sampling, laboratory analysis, and data management/analysis will help to ensure the efficient design and execution of the monitoring program and effective communication between participating groups.

The following procedure may be used to determine the sampling frequency and time of sampling for a monitoring programme designed to characterise water quality (adapted from SCA, 1996, Figure 8):

1. Define the objectives of the monitoring programme with respect to acceptable error and information required (e.g. mean, median concentration). User of monitoring results defines the permitted magnitude and duration of deviations from the control or guideline concentration
2. Determine probability of occurrence of deviations from the control limit or guideline value by either:
    - (A) if historical monitoring data are available, determine the average concentration, type of frequency distribution and standard deviation. Evaluate data for trends and cycles.
    - Or (B) if historical data are not considered to provide a useful indication of future trends and concentrations, set the sampling interval greater than the shortest period for which unacceptable water quality can be tolerated.
3. Compare average and standard deviation with control limit or guideline value.
4. Consider implications of cyclic variations, trends, and periods of abnormal variability.
5. Calculate the number of samples required to estimate the mean or median concentration (depends on standard deviation, mean or median concentration and confidence limits required).
6. Select times for sampling
7. Select initial sampling frequency according to frequency distribution, cycles and trends.
8. Execute programme based on selected sampling frequency and times.
9. Review sampling programme and, if necessary, consider means of reducing sampling frequency

From this information it is possible to determine the number of samples and frequency of sampling required. The volume of sample is determined by the need to obtain samples that are both representative and sufficiently large for the analytical method to be used to determine contaminant concentrations.

A range of manual and instrumental sampling procedures may be employed. It is important to emphasise the importance of maintaining high quality during the sampling programme by the use of field blanks and duplicates as well as the evaluation of potential sources of sample contamination (for example through the use of low purity preservative acids or sample containers that contain metals (e.g. Zn in water bottle cap inserts).

Factors to consider for the selection of sampling locations (Fig. 43) include:

- Location of (postulated) source(s) of contamination
- Extent and duration of operation of contaminating processes
- Characteristics of the drainage system
- Predicted spatial distribution of contaminants in relation to sources
- Impacts of water systems
- Influence of the rate of flow
- Accessibility of sampling locations
- Methods of determining exact location of sampling sites

Periodic releases of contaminants in solution or as suspended matter may be detectable only for a relatively short period until the contaminant flux passes through the drainage system. Bottom or interfacial sediments are often the best sample media for non-biological sampling. However, biomarkers are generally more effective because stress induced by short-term exposure is detectable long after the ambient contaminant level has declined. This is particularly true where species death is involved. From dose-response data it is possible to tentatively infer exposure magnitude and/or time.

A more extensive discussion of sampling frequency, sampling procedures (including handling, preservation and storage), analysis, and quality control are given in a number of reports from which the reader may obtain detailed guidance (U.K. Environment Agency, 1998; APHA, 1995, ASTM 1994a, U.S. EPA, 1986, 1995; SCA, 1996).

6.1.2 Monitoring of water quality in the Nikonga River system

In general, it is clear from the new data collected during the current survey, that:

(1) it does not appear likely that mercury will exceed water quality criteria in the Nikonga river system, unless, of course, there is a significant movement of Hg contaminated mineral processing waste into the Isingile River caused by unusually heavy rain fall.

(2) No water quality criteria are currently exceeded or likely to be exceeded in the lower Malagarasi River, unless further studies indicate that there are significant concentrations of Hg in brines at Uvinza.

(3) It was not possible to test whether there is significant short and /or medium term temporal variation in contaminant load in the Isingile-Nikonga River system because there was no flow at the time of the field survey.

(4) Surrogate discharge and contaminant load indicators such as the suspended sediment load (TSS) were not determined or investigated for the same reason.

Generic guidelines for water quality monitoring are given in this section and in Section 6.1 above. Monitoring in the current survey followed, as closely as was practicable, the internationally accepted protocols recommended in Veiga and Baker (2003). It is recommended that water monitoring is carried out during the wet season to test for Hg in solution and in the suspended sediment, including studies of the short term and medium term temporal variation in these pollution indicators.

Continuous monitoring equipment capable of determining Hg at low concentrations is, as far as the authors of this report are aware, not available commercially. So any monitoring system would be periodic rather than continuous.

The USEPA recommends that monitoring of surface drinking water sources (including wells) should be annual unless Hg is detected at levels of >2 μg/L, in which case sampling should be every quarter. The level of Hg detected in filtered water samples from the Isingile stream reached a maximum level of 0.07 μg/L (Table 5). On this basis it may be concluded that the quarterly monitoring will probably be adequate for the Isingile and Nikonga Rivers for a period of two years. If no significant Hg concentrations are detected during that period, and there are no significant changes in the amount of mineral processing and associated factors, then annual monitoring, following the USEPA recommendations, will probably be adequate. Peaks of relatively high Hg in filtered water are less likely to be released from the mineral processing plants in this area than is the case in some other areas (e.g. Diwalwal in the Philippines; Appleton, 2000). No practical periodic monitoring system can be guaranteed to identify abnormal pulses of contaminant discharge, which could occur at any time during the day or night if they were related to a sudden influx of Hg contaminated mineral processing waste caused by abnormal rainfall events.

The only effective option to prevent the continuing Hg pollution of the Isingile stream and surrounding agricultural areas is to require (a) the removal of all the existing mineral processing waste currently located close to the Isingile River and (b) the termination of all mineral processing activities in the vicinity.

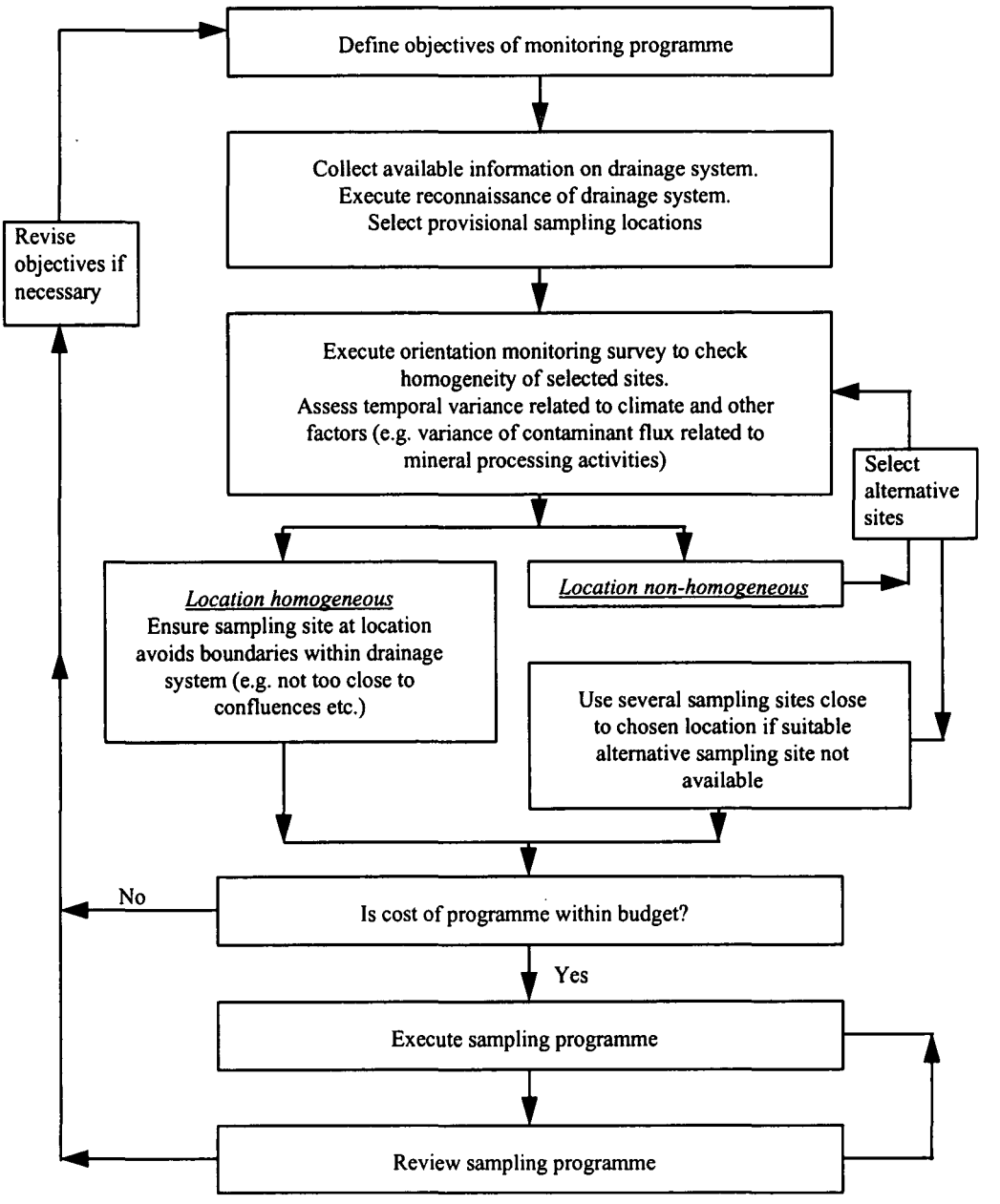

Figure 43: Major stages in the selection of sampling sites/locations for a monitoring programme (adapted from Figure 6, SCA, 1996)

6.2 BIOTA

Monitoring of biota (fish and agricultural crops) has been carried out as part of the current study and could be carried out periodically using the methods outlined in Section 3 above, which follow, as closely as practicable, the UNIDO sampling protocols (Veiga and Baker, 2003). Fish monitoring is used to assess Hg bioavailability and the transfer of Hg from mineral processing waste, drainage sediment and soil into aquatic biota and plants. The second purpose of monitoring aquatic biota, and especially fish, is to evaluate the potential impact on the health of people consuming fish from Hg contaminated rivers, streams and ponds. Monitoring agricultural crops, especially those grown on land impacted by Hg-contaminated mineral processing waste, can be used to assess the uptake of Hg by these crops and the potential impact on the health of people consuming the crops. The protocols for the periodic monitoring of aquatic biota are comprehensively documented in Veiga and Baker (2003). Periodic monitoring of agricultural crops could also be carried out, although the results of this study indicate that little Hg is present in most of the crops. Due to time and funding constraints, the current study was able to sample only a relatively limited number of sites. For this reason it is recommended that a more comprehensive survey should be carried out, in order to verify the results presented in this study.

7 Measures for the remediation and possible rehabilitation of the "hot spot"

7.1 RIVER SYSTEM

The contract implies that it should be possible - using the results of the current investigations to identify pollution "hot-spots" in the Isingile and Nikonga river systems as well as in surface soils adjacent to the rivers. Some general comments on pollution "hot-spots" are given in Sections 3 and 4 above.

7.1.1 Water

The present survey did not detect any concentrations of Hg in solution that would require remediation as they did not exceed water quality standards (see section 4.1 above). Should future water quality monitoring detect concentrations that require remediation, then the following remediation technologies may be appropriate.

Whereas the US EPA states that coagulation/filtration, granulated activated carbon, lime softening, reverse osmosis and chlorination are the best available technologies (BATs) for the treatment of Hg contaminated water required for drinking, these treatments are only recommended if the influent Hg concentration is less than 10 µg/L. Chemical precipitation as the sulphide at an alkaline pH followed by filtration, carbon adsorption and ion exchange is the demonstrated BAT for waters contaminated with high concentrations of inorganic mercury. Where the Hg is present in waters as organo-mercury or the Hg is in an organic matrix, then chemical oxidation has to be carried out prior to the processing stages recommended for waters contaminated with inorganic mercury (Smith et al., 1995).

7.1.2 Sediment

From a practical point of view, there would be little sense in trying to remediate and rehabilitate the Hg contaminated bottom sediments of the Isingile River until (a) the releases of Hg contaminated mineral processing tailings from the Rwamagasa area have been terminated, (2) the risk of future contamination of the drainage system by progressive or catastrophic releases of Hg contaminated processing waste has been eradicated. It is, however, relatively unlikely that the tailings piles located adjacent and to the south of the Isingile are a potential source of catastrophic contamination as the waste piles are small and the slopes are relatively gentle.

The most urgent requirement is to prevent further additions of Hg to the river bottom sediment by stopping or at least strictly controlling mineral processing activities and the use of Hg in the Rwamagasa area. The cessation or strict control of mining processing activities at Rwamagasa would lead to a significant reduction in the Hg-contaminated mineral processing waste. Unpolluted sediment derived

from soil run-off would progressively cover contaminated bottom sediment in the Isingile and Nikonga Rivers, thereby helping to prevent further downstream transfer.

One costly and possibly impractical option would be to dredge contaminated sediments from the Isingile River and place them in disposal areas protected by secure dykes and covered with clean sediment or soils. There may be potential for ground water contamination if this action was followed. Best Demonstrated Available Technologies (BDATs) for remediation of Hg contaminated sediments are discussed in the following section on soils. Specific practical remediation measures cannot be recommended until a more detailed assessment has been made of the drainage sediments.

7.2 SOIL

The EPA Draft Mercury Action Plan (November 1998) highlighted the need to address the potential for mercury contamination of watersheds that drain abandoned mine sites, and the need to fully research the extent and nature of Hg contamination associated with gold mining sites including the characterisation and mapping of sites, and the study of downstream impacts. The document observes that common disposal options currently include:

- coverage of the contaminated soils with clean soil, or some other material, or excavation and transportation of the contaminated soil to a secure off-site depository or landfill.
- permanent stabilisation of mercury.

The scientific feasibility and costs of the process are not specified. This latter approach would be more suited to industrial sites rather than in the situation in the Rwamagasa area where agricultural soils are contaminated by mercury.

No records of remediation of mercury contaminated soils or river sediment from mining areas has been encountered apart from the Carson River Mercury Superfund Site in the US. Elevated mercury levels were discovered on the Carson River drainage basin in the 1970's downstream of pre-1900 ore milling sites where amalgamation had been used for gold extraction. The U.S. EPA carried out various evaluations during the period 1990 to 1996, but remediation appears to have been restricted to excavation and treatment (by cyanidation) of mercury-laden tailings from limited areas followed by back filling with clean soil. The objective of this work was to prevent exposure of people to soil with Hg concentrations greater than 25 ppm (mg/kg). There were also plans to excavate mercury-contaminated soils from residential yards with disposal of the soil to a municipal or hazardous waste landfill, dependent on the Hg concentration. The objective was to address the incidental soil ingestion pathway that was of potential concern to populations near the impacted areas. Another pathway of potential concern was through the consumption of fish or waterfowl from the Carson River system. In 1995, no remedial action was attempting to address this pathway. The principal remedial action at this site was, therefore, the excavation of approximately 5000 cubic yards of contaminated soils followed by the implementation of institutional controls on-site. It has been estimated that approximately 700,000 m^3 of contaminated materials at the site contain 31,500 kg of Hg and 18,200 oz of Au, 1,205,800 oz of Ag, worth

approximately $12 million, which would defray the cost of clean-up operations. Hg in tailings is reported to be in the range 3 - 1610 ppm.

The Best Demonstrated Available Technologies (BDATs) for mercury wastes identified by the U.S. EPA are:

1. thermal recovery through retorting, sometimes following pyrometallurgical recovery, is the BDAT for waste that has a total Hg concentration greater than 260 ppm. The US EPA plans to evaluate other options for high level waste because (i) the supply of recycled mercury is increasing while the demand is decreasing and (ii) there are concerns over potential emissions from retorting (Smith et al, 1995; USEPA, 1997). Hempel and Thöming (1999), in their review paper, seem to imply that thermal treatment of soil can be effective at lower concentrations but they do not give any specific indication on the likely effectiveness of the process when soil Hg ranges from <0.01 to 9 ppm, as in the Rwamagasa agricultural soils.
2. acid leaching for soils with a total Hg content less than the thermal mercury recovery limit (260 mg/kg). Hg in the acid leachate has to be treated to precipitate mercury (Smith et al, 1995; USEPA, 1997).

In the US, soil clean-up goals for both total and leachable Hg vary from 1 to 21 mg/kg above a background range of 0.01 to 0.30 mg/kg (USEPA, 1997, Table 2). The California Total Threshold Limit Concentration, for example is 20 mg/kg, which is above the mean and median concentration of Hg in the agricultural soils in the Rwamagasa area. The California Soluble Threshold Leachate Concentration is 200 µg/L. As far as the author is aware, no clean-up goals have been set in Tanzania, the UK or the EC.

The principal remediation-rehabilitation options for Hg-contaminated soils and sediments in the Isingile River – Rwamagasa area include:

1. Excavation of Hg-contaminated soil and disposal to an off-site secure landfill or depository
2. Electroleaching, comprising wet extraction followed by electrolytic preparation of the leachate is an emerging and potential alternative cleanup method that is reported to offer a cheaper and more environmentally friendly alternative to thermal treatment or the acid leaching process. Electroleaching is reported to have the advantage of larger thermodynamic separation factors, lower capital costs and no air pollution problems (Hempel and Thöming, 1999). The process is reported to be capable of reducing total Hg by 90% at the 5 mg/kg level to 99.7% at 100 mg/kg. In both cases, Hg is reduced to less than 1 mg/kg after leaching (Thöming J and Franke S, 1998; Hempel and Thöming, 1999; Thöming et al., 1999; Thöming et al., 2000). It is understood that this remediation process has been tested principally in laboratory/bench-scale trials on a range of contaminated soils including those from chlor-alkali plants and artisanal gold mining sites.

Thöming (pers. comm. 22 February 2000) advised the senior author that a few years ago he was asked to make recommendations for remediation of Brazilian artisanal gold mining tailings. Such tailings offer the possibility of simultaneously recovering remaining traces of gold if they are treated by electroleaching. It is understood that a huge amount of Brazilian funds were invested in pilot-plant tests but that no reliable data was obtained on the efficacy of this remediation method.

The cost of these potential remediation options has not been estimated.

Other potential remediation options include:

(i) physical treatment by wet classification, although this would be of limited use as this method is only effective if the soils contains high quantities of sand and gravel;

(ii) immobilization by:

- physical barriers
- geohydrological isolation
- solidification and stabilization
- chemical immobilization.

(iii) extraction of Hg from soil using chelating agents;

(iv) biological treatment technologies including:

- Methylation (tested at the bench scale for arsenic but apparently not for mercury)
- Phytoremediation of mercury- and methylmercury-polluted soils using genetically engineered plants
- use of genetically engineered bacteria.

Unfortunately, these technologies do not appear to be applicable to the Hg contaminated soils of the Rwamagasa area. Many have been tested only in the laboratory and not in field scale trials so their efficacy cannot be evaluated. Hempel and Thöming (1999) observe in their review of remediation techniques that whereas there are a large number of techniques available to immobilize mercury in soils, these are not of proven long-term stability. In addition, subsequent clean-up of chemically stabilized soils may be very expensive and in some cases impossible.

Specific practical remediation measures can not be recommended until a much more detailed assessment has been made of Hg concentrations in the agricultural soils. On the basis of evidence collected during this survey, it appears that significant amounts of Hg are not adsorbed into the grain of the agricultural plants. If this can be confirmed by more detailed surveys (involving further collection and analysis of soil and rice grain samples from exactly the same areas, for example) it may be possible to confirm that there is little or no potential for a direct negative impact on human health caused by the consumption of rice

grown on these high Hg soils. Should this be the case, there would be no compelling reason to prevent the continued cultivation of rice and other agricultural crops on the Hg-contaminated soils.

Should there be a change of land use from rice paddy to corn cultivation, for example, then the adsorption of Hg by other crops and its potential impact on human health would need to be investigated more thoroughly.

8 Role of government departments, the mining industry and research institutions

8.1 MINISTRY OF ENERGY AND MINERALS

The responsibilities of the Ministry of Energy and Minerals are defined by the Mining Act (1998) and the Mining Regulations (1999). The Government recognizes the need to put into place an internationally competitive investment environment for the mineral sector that will contribute towards industrial development, employment creation, social and economic infrastructure development (particularly for the rural areas); income generation, foreign exchange earning and government revenue. The Mineral Sector Policy Objectives are (i) to encourage, promote and facilitate exploration and utilization of mineral resources; (ii) to increase the countries foreign exchange earnings; (iii) to increase government revenue; (iv) to ensure environmental protection and management; (v) to ensure that government services and the institutional framework are adequate; (vi) to increase gainful and secure employment in the mineral sector; (vii) to promote forward and backward linkages in the mineral based industries; (viii) to facilitate development of mineral based local services and supply industries and (ix) to promote appropriate technological advancements related to the mineral sector. However, the Government of Tanzania also recognises that mineral sector activities shall be carried out on the basis of safe and environmentally sound practices (for sustainability). In order to accomplish these objectives, the Government will (i) develop an enabling legal, regulatory, fiscal and institutional environment for private sector mining investment; (ii) strengthen the ability of the state to effectively carry out its regulatory, promotional (investment and marketing) functions; (iii) establish and ensure compliance with environmental, health and safety guidelines; (iv) carry out geological mapping, maintain an up-to-date mineral resource database, and promote the development of Tanzania's mineral potential; (v) reinforce the provision of extension services and assistance to artisanal and small-scale miners so that safe and environmentally-sound mining and processing practices can be adopted; (vi) facilitate the development of adequate industrial infrastructure for mining development.

The Government of Tanzania wishes to promote the use of best practices in environmental management systems in mining development and is adopting a number of strategies to achieve this including: (i) establishment of comprehensive environmental management programmes for the mining industry; (ii) establishment of effective environmental regulations and procedures for monitoring compliance; (iii) setting up and strengthening the institutional capacity especially the field offices (zonal and district mines offices) for monitoring and enforcing environmental regulations; (iv) requiring new projects to carry out baseline environmental studies and prepare environmental impact assessment and environmental action plans; (v) instigating environmental audits to evaluate the performance of existing mines and identify areas for improvement; (vi) specifying procedures for determining environmental liability; (vii) providing

rules of setting up reclamation funds to reinstate land to alternative uses after mining; (viii) setting appropriate guidelines for allowing the conduct of mining in restricted areas such as forests, national parks, sources of water and other designated areas; and (ix) abating the use of toxic chemicals and pollutants by promoting environment friendly technologies.

Legal mining is controlled by Reconnaissance, Prospecting, and Mining Licences, Environmental Assessments and Environmental Management Plans. Regulations covering the artisanal mining sector include the Mining Act, Section 14 and Regulation 16 in the Mining (Minerals Rights) Regulations, p.82). Small-scale miners operate legally only if they hold a Primary Mining Licence (PML). Only the Blue Reef Mine has a PML in the Rwamagasa area whilst the majority of the artisanal miners appear to operate illegally.

The Mining Act, 1998 Act No.5 of 1998 is the Principal Legislation governing the application and grant of mineral rights (mining and exploration licenses), and trading of minerals. The Mining (Environmental Management and Protection) Regulations, 1999 is one of seven sets of subsidiary legislation and rules made under the Mining Act, 1998. Sections 38 (5) and 64 of the Mining Act, 1998 describe the framework of environmental considerations during the licensing process. The Act requires an applicant to commission independent consultants of International standing short-listed by the applicant and approved by the Government to undertake an environmental impact assessment (EIA) on the proposed mining operations. The EIA includes environmental risk assessment to assist the project proponent to produce an Environmental Management Plan acceptable to the Government. The Mining (Environment Management and Protection) Regulations, 1999 describe in details the principles outlined in sections 38(5) and 64 of the Mining Act 1998. Holders of Mining Licences have a duty to take all appropriate measures for environmental protection (Mining Act 1998, 49(2)(c) and 53(2)(c)). The approval process for a new mining project comprises project screening and scoping, together with the evaluation of the EIA and EMP by experts from the National Environment Management Council (NEMC), the Vice Presidents Office – Division of Environment, the Ministry of Water, the Ministry of Natural Resources and Tourism, the Ministry of Lands and Human Settlement and the Ministry of Energy and Minerals (Minerals Division). In addition, representations from the Regional Administration, Local Government Authorities and the public are sought and considered during the approval process. The approved Environmental Management Plan is reviewed by government experts at the end of a 2-year period and thereafter every five years.

Responsibility for administration, implementation and enforcement of regulations under the Mining Act (1998) and Minerals Regulations (1999) in the Geita – Rwamagasa area is delegated to the Ministry's Local Mines Office. The Local Mines Office is responsible for the extremely difficult task of ensuring that the small scale miners follow relevant mining and environmental regulations and approved practices, such as ensuring that all amalgamation is carried out in cemented ponds and that all tailings from these amalgamation ponds are stored in appropriate cemented storage areas that prevent dispersal of mercury contamination onto adjacent land and into water courses. Observations during the field project indicated that many small- scale miners in the Rwamagasa area do not follow these regulations.

8.2 NATIONAL ENVIRONMENT MANAGEMENT COUNCIL

The National Environment Management Act, 1983 established the National Environment Management Council (NEMC), which advises the Government on all matters relating to the environment and formulates policy on environmental management. It is also responsible for coordinating the activities of all institutions concerned with environmental matters; evaluating existing and proposed policies and activities on pollution control and enhancement of environmental quality; recommending measures to ensure Government policies take adequate account of environmental effects; and formulating proposals for legislation in the area of environmental issues and recommending their implementation by the Government.

The National Environment Management Act, (No. 19 of 1983) establishes the office of the Director General of the NEMC who is required to consider the "means and initiate steps for the protection of the environment and for preventing, controlling, abating or mitigating pollution; and investigate problems of environmental management, among others." The NEMC reviews development projects in the country in order to ensure that they conform to requisite environmental standards.

In 1997, the NEMC prepared Environmental Impact Assessment Guidelines and Procedures that are particularly important because they incorporate public participation and access to information in respect of projects with likely environmental impacts, such as mining.

8.3 DEPARTMENT OF THE ENVIRONMENT

The National Environmental Policy[9], formulated and administered by the Department of the Environment, has as its principle objective "the prevention, reduction, control and elimination of damage, and minimisation of the risk from the generation, management, transportation, handling and disposal of hazardous wasters, other wastes and emissions." The environmental problems associated with small scale and artisanal gold mining is highlighted because of the use of mercury. The National Environmental Policy states that a number of policies "shall be undertaken to minimise pollution arising from the mining sector:

(a) overall project cycle of mining (including reclamation and restoration of land after use shall be adequately managed to minimise adverse environmental impacts;

(b) mining discharges to grounds and water shall be controlled;

(c) preventive and clean up measures from accidents shall be formulated and implemented;

(d) air pollution from mining areas shall be controlled;

(e) strict regulations shall be put in place to control the use of mercury in mining activities, use of retorts will be promoted; and

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[9] National Environmental Policy. Vice President's Office, Dar es Salaam, December 1997.

(f) regular and periodic environmental audits shall be maintained to ensure the adoption of environmentally sound practices in mining operations"

It is assumed that these policies apply to both large scale and artisanal mining. The Instruments for Environmental Policy comprise Environmental Impact Assessment, Environmental Legislation, Economic Instruments such as adoption of the polluter-pays principle, Environmental Standards and Indicators, adoption of the Precautionary Approach and International Cooperation. Standards exist for drinking water (1 μg Hg/L, water for use in feeding domestic animals, fisheries, shell cultures, recreation (1 μg Hg/L); irrigation water (5 μg Hg/L) and water for industrial activities (5 μg Hg/L) (UNEP, 2002).

8.4 UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANISATION

UNIDO has provided technical assistance to the small-scale gold mining sector in developing countries since 1985. UNIDO is responsible for the execution of the GEF funded project *Removal of Barriers to the Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies* (also referred to as the Global Mercury Project (GMP)) that is being carried out in six developing countries located in several key trans-boundary river/lake basins. Project coordination and support is executed globally through the UNIDO head office in Vienna. Local management and coordination is carried out by the UNIDO Assistant Country Focal Point, Mr A Tesha.

8.5 UNIVERSITY OF DAR ES SALAAM

Research related to artisanal gold mining at the University of Dar es Salaam is carried out principally by the Department of Geology (Professor Mruma, Prof. Ikingura, and Dr Kinabo) and the Faculty of Aquatic Sciences and Technology (Professor Yunus D Mgaya and Dr John F Machiwa). Dr Machiwa is responsible for a major on-going research project that he is carrying out on behalf of the Lake Victoria Environmental Management Project (LVEMP)[10]. This is carried out in collaboration with the Tanzania Fisheries Research Institute.

8.6 TANZANIA FISHERIES RESEARCH INSTITUTE

The Fisheries Department, Ministry of Agriculture and Rural Development, Dar-es-Salaam, Tanzania includes the Tanzania Fisheries Research Institute (TAFIRI), which is a parastatal organization established in 1980 to cater for fisheries research in the country. TAFIRI comprises five centres: Mwanza and Soti on Lake Victoria; Kigoma on Lake Tanganyika; Kyela on Lake Nyasa (Malawi) and Dar es Salaam on the Indian Ocean, which is also the Institute's headquarters.

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[10] "Impact of gold mining in the Lake Victoria basin on mercury levels in the environment" by JF Machiwa, MA Kishe, HG Mbilinga, A Mdamo, and O Mnyanza, Report for the Lake Victoria Environmental Management Project; March 2003.

Collaboration with TAFIRI for the present study was approved in principle by Dr Ben Ngatunga (Deputy Director, Tanzania Fisheries Research Institute, TAFIRI, Kyela), although it was left to BGS to organise the practicalities with TAFIRI staff based in Kigoma and Mwanza.

8.7 SOUTHERN AND EASTERN AFRICAN MINERAL CENTRE

The Southern and Eastern Africa Mineral Centre (SEAMIC) is an independent regional service and research centre established in 1977 under the umbrella of the United Nations Economic Commission for Africa (UNECA). SEAMIC offers laboratory testing and analysis services and has well equipped sample preparation and analytical laboratories. The possibility of having the environmental samples from the present survey prepared and analysed at SEAMIC was given serious consideration but was rejected, mainly because SEAMIC has not yet been able to obtain appropriate accreditation.

8.8 LAKE VICTORIA ENVIRONMENTAL MANAGEMENT PROJECT (LVEMP[11])

Lake Victoria Environmental Management Project (LVEMP) is a comprehensive environmental program for the conservation of Lake Victoria and its basin. It is a regional Project formed under a Tripartite Agreement signed on 5th August 1994 by the three riparian countries – the Republic of Kenya, United Republic of Tanzania, and the Republic of Uganda; which provided for its preparation and implementation

The major objective of the LVEMP is to restore a healthy, varied lake ecosystem that is inherently stable and able to support, in a sustainable way, the increasing activities in the lake and its catchment for the benefit of the people of the riparian countries as well as the international community.

The LVEMP was initially a five-year project running from July 1997 to June 2002. The project is funded by a credit from the International Development Association (IDA) and a grant from the Global Environmental Facility (GEF) through the World Bank to a total of US$70.0 million for the three East African countries. Out of this, the United Republic of Tanzania is receiving US$ 20.4 million over a period of five years. Kenya and Uganda are receiving US$ 24.3 million and US$ 25.3 million respectively.

One of the principle objectives of the project is to harmonize national and regional management programs in order to achieve the reversal of environmental degradation of Lake Victoria and establishing a lake wide water quality and rainfall monitoring system with agreed parameters to generate information on eutrophication management and pollution control. The LVEMP appears to have been extended for an additional time period as work on the project was in progress during 2003.

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[11] http://www.lvemp.org/ and http://www.lvemp.org/L_Whats_new/gold_mining.htm

9 Summary and recommendations

9.1 SAMPLE PREPARATION AND ANALYSIS

(a) Results for Hg determination in duplicate water samples indicate an acceptable level of reproducibility

(b) Replicate analytical determinations indicate a generally acceptable precision although this varies with concentration, as would be expected. The precision data for field duplicate soil and tailings samples are also acceptable for this type of study

(c) Some of the field duplicate sediment samples indicate significant variability in Zn and also Hg, which might reflect inhomogeneous particulate distribution in the sediments of anthropogenic Zn (from galvanised roof material, for example, and possibly also from ball mills) and Hg (from amalgamation). This inhomogeneity is to be expected and is also apparent in one pair of tailings duplicate samples.

(d) Accuracy of the ICP-ES and Organic Carbon (TOC) data is good, with recoveries of 96-102%. A recovery of 95% for CV-AAS determination of Hg based on CANMET-STSD-4.

(e) Repeat determination of Hg in twelve sediment and soil samples from the Naboc area in Mindanao in which Hg had previously been determined by CV-AFS (BGS) confirm that the accuracy of the Hg analyses for the present study is adequate

(f) Analytical accuracy for Hg in fish and vegetable was monitored using Certified Reference Materials BCR 422 (Cod muscle) and BCR-060 (Aquatic plant). Recovery figures were in the range 94-103% for BCR-422 and 90-93% for BCR-060. The analytical precision (Relative Percent Difference) at concentrations greater than 0.5 mg/kg was +/- 2.6% and the average %RPD was 0.1%.

(g) Duplicate samples of 20 fish analysed for Hg indicate a broad agreement and the average combined sampling and analytical precision (%RPD) is ±15% for samples containing >0.1 mg/kg Hg. However, the precision at low concentrations (<0.1 mg/kg) is less satisfactory, ranging from –67% to +176%. The reason for these relatively high RPD at low Hg concentrations is not known and would require further and more detailed investigation in future studies.

9.2 MERCURY IN WATER SEDIMENT, TAILINGS, SOIL, CROPS AND FISH

(a) Mercury in filtered water samples ranges from 0.01 to 0.07 µg/L. No filtered water samples exceeded any of the Tanzanian Water Quality Standards or other national and international water quality standards or criteria for drinking water, protection of aquatic biota or protection of human health.

(b) Arsenic in filtered water ranged from 0.1 to 2.4 µg/L. No samples exceeded any water quality standards or criteria.

(c) Hg concentrations in the fine fraction of streams sediments from the River Malagarasi at Ilagala range up to 0.65 ppm, which is rather high for an area that does not appear to be unduly affected by anthropogenic contamination. Concentration of Hg in the fine fraction, together with adsorption of Hg onto Fe and organic material, may in part explain these relatively enhanced Hg concentrations. Other possible sources include the geothermal springs at Uvinza or contamination of sediment by mercuric soap used for skin lightening.

(d) In the Rwamagasa area, Hg in the fine fraction of drainage sediments ranges from 0.08 to 2.84 ppm, although Hg does not exceed the Toxic Effects Threshold (1 ppm) for more than 2 km downstream from the major mineral processing centre to the south of the Isingile River. The Toxic Effects Thresholds for As, Cd, Cu, Pb and Zn are not exceeded in drainage sediments from the Rwamagasa area.

(e) There is little difference between Hg concentrations in samples taken from historic (dry) tailings piles (geometric mean, GM 5 ppm) and samples taken from recent sluice box tailings (GM 3 ppm). Hg in tailings samples from the amalgamation ponds and amalgamation pond tailings (GM 86 ppm) are on average about 20 times higher. An association between Cd-Cu-Hg-Zn probably reflects contamination from mercury used in amalgamation with metals that are possibly derived from the ball mills. Ball mills are typically made of soldered metal plates so there may be Cd and Zn in the solder would be expected to contaminate tailings. Cadmium is used extensively as a protective coating on iron and steel, and as an alloying agent with other metals. Cadmium is also used in batteries and occurs as a contaminant in zinc for galvanized roof sheets and steel piping. Correlations between As and Fe probably reflect the influence of trace quantities of arsenopyrite and pyrite in the gold ore. Further studies are required to confirm these hypotheses

(f) Generally low concentrations of Hg occur in most of the cassava, maize, rice, mbuga, and unclassified soils whilst higher concentrations are found in the urban, mbuga and vegetable plot soils. In the urban soils, Hg might be derived mainly from air borne transport and deposition of Hg released during the burning of amalgam whereas in the mbuga and vegetable plot soils high Hg appears to occur where these are impacted by Hg-contaminated water and sediment derived from mineral processing activities located on the southern side of the Isingile River. There is a clear association between Cd-Cu-Zn, which reflects contamination from metals that are possibly derived from the ball mills and/or galvanized roof sheets. Associations between As, Cu and Fe may reflect the influence of trace quantities of arsenopyrite and pyrite in the gold ore.

(g) Hg exceeds (1) the maximum permissible concentration of Hg in agricultural soil in the UK (1 mg/kg) in 12 soil samples;(2) the Canadian Soil Quality Guideline for agricultural soils (6.6 mg/kg) in three samples; (3) the UK soil guideline value for inorganic Hg for allotments (8 mg/kg; Environment Agency, 2002) in two samples. The level of contamination of agricultural and urban soils is significantly less both in magnitude and extent than in other areas, such as the Naboc irrigation systems on the island of Mindanao, Philippines.

(h) Cd and Zn exceed the maximum permissible concentrations for agricultural soil in the UK (3 mg Cd/kg and 200 mg Zn/kg) in only a few soil samples. Arsenic exceeds the Canadian Soil Quality Guideline for agricultural soils (12 mg/kg) in nine agricultural and urban soils.

(i) Soil profile data demonstrate that surface contamination by mineral processing waste in some agricultural soils affects the root zone. Hoeing of the soils will lead to mixing of the Hg contamination throughout the root zone.

(j) Hg in vegetable and grains samples collected from the agricultural areas potentially impacted by Hg contamination are mainly below the detection limit of 0.004 ppm Hg with concentrations of 0.007 and 0.092 ppm Hg recorded in two yam samples and 0.035 ppm Hg in one rice sample. A positive correlation between Hg in agricultural crops and soil was not detected during the present survey. Hg in beans, onions and maize samples purchased at Rwamagasa market are below the detection limit (<0.004 mg Hg/kg) whilst two dehusked rice samples contain 0.011 and 0.131 ppm Hg. The concentrations of Hg in rice are similar to those recorded in rice grown on the highly contaminated soils of the Naboc irrigation system, Mindanao.

(k) The fish tissue THg data indicates that the sites sampled in the immediate area of mining activities at Rwamagasa, are the worst affected and should be considered environmental or contamination 'hotspots' and sites of biomethylation. Tembomine is also a 'hotspot' as a result of local mining activity. Many fish tissues from these sites fail export market standards (0.5 ppm). Fish from these sites fail the WHO recommended standard for vulnerable groups (0.2 ppm). The Nikonga River fish samples were slightly elevated compared with the Lake Tanganyika (Ilagala) samples but are below the WHO threshold for vulnerable groups (0.2 ppm). The influence of the Rwamagasa mining activity on the THg of fish tissues collected at Lake Tanganyika appears to be negligible as Hg concentrations are comparable to tissue levels found in Lake Victoria fish.

9.3 EXPOSURE TO ENVIRONMENTAL MERCURY

(a) None of the water samples collected from the river network, or associated drainage ponds exceeded the WHO or local Tanzanian guideline values of 1 µg/l Hg for drinking water. Whilst this suggests that mineral processing operations have not contaminated local surface waters and shallow groundwaters it does not indicate whether drinking water used by the local people has been contaminated. More extensive monitoring of drinking water sources (which was not the focus of the current investigations) should be considered as a component of any subsequent follow up work.

(b) The only samples of water collected during the survey that contained relatively high Hg concentrations (max. 0.45 μg Hg/l) were from amalgamation ponds. This highlights the need for careful management of waste waters from these ponds and monitoring of any nearby drinking water supplies.

(c) The average Hg concentration recorded for samples of rice grain grown in the study area was 0.026 μg/g (dry wt.), so the amount of mercury entering the body, assuming an average consumption of 300g rice per day, is 7.8 μg Hg /day. The total intake from rice is equivalent to 0.055 mg/week which is much lower than the Provisional Tolerable Weekly Intake (PTWI) of 0.3 mg for total mercury in the diet set by the WHO and the FAO (1972). If 50% of the Hg in Rwamagasa rice is MeHg, then the total weekly MeHg intake from rice would be 27.5 μg MeHg which is equivalent to 0.46 μg MeHg/ kg bw/week. Individuals consuming Rwamagasa rice at the upper limit of the Hg concentration range (0.035 μg/g) would have a weekly intake of 0.6 μg MeHg/ kg bw/week, compared with the MeHg PTWI of 1.6 μg MeHg/kg bw/week recommended by JECFA in June 2003. This is likely to be a maximum input because most people in the Rwamagasa area will also consume cassava and maize, which are grown on soils with low Hg.

(d) The vast majority of people in the Rwamagasa area principally eat Tilapia (*Oreochromis spp.*), Perch (*Lates spp.)* and dagaa (dagan; *Rastrineobola spp.* and equivalents) from Lake Victoria. Catfish (*Clarias spp;* kamare, mumi) is eaten by less than 10% of those people.

(e) Consumption of 250g perch, 500g tilapia and 250g of catfish each week would result in an intake of 27 μg THg/week (equivalent to 0.35 μg MeHg/kg bw/week) for residents of Ilagala-Uvinza, 44 μg THg/week (equivalent to 0.58 μg MeHg/kg bw/week) for people depending totally on fish from Lake Victoria, 56 μg THg/week (equivalent to 0.75 μg MeHg/kg bw/week) for people in the Rwamagasa background area consuming tilapia and perch from Lake Victoria and catfish from the local streams, and 259 μg THg/week (equivalent to 3.45 μg MeHg/kg bw/week) for people in the Rwamagasa area consuming tilapia and perch from Lake Victoria and catfish from mining impacted streams. Apart from the latter group consuming catfish from mining impacted stream (259 μg Hg/week), these inputs related to fish consumption are well below the JECFA (WHO/FAO) Provisional Tolerable Weekly Intake (PTWI) of 300 μg for total mercury and 1.6 μg /kg bw/week for methyl mercury (JECFA 2003). Only those people consuming catfish from the Isingile River are likely to be at risk of exceeding the PTWI.

(f) People consuming 300g/day of rice grown on the Hg contaminated Isingile mbuga and 1kg of fish from Lake Victoria would have a combined estimated MeHg input of 1.04 μg MeHg/kg bw/week which is two thirds of the MeHg PTWI.

(g) Elevated exposures to Hg can result from the occasional deliberate and habitual consumption of contaminated soils and dusts. For example, the Provisional Tolerable Weekly Intake (PTWI) of 0.3 mg for total mercury in the diet set by the WHO and the FAO, which is equivalent to 26 μg THg/day for a 30kg child is exceeded by an individual practising geophagia (central estimate and worst-case) or on a case by case basis by an individual occasionally consuming soil/dust (worst-case). The

practice of geophagy by pregnant females is of particular concern in this regard given the sensitivity of the foetus to mercury.

(h) The inadvertent ingestion of dusts and soils even those having Hg concentrations significantly above the regional background, and hence considered to be moderately contaminated, does not appear to lead to a significant excess exposure to mercury. For example comparison of exposures due to inadvertent ingestion of soils and/or dusts (0.72 to 1.8 μg THg/day or 5 to 13 μg THg/week) is typically less than individual exposure via other dietary sources water, rice and fish.

(i) However, given the uncertainties involved in estimating inadvertent dust and soil intake in the rural Rwamagasa environment, exposure via this route, in addition to more classical geophagic behaviour, should be considered when planning remedial/intervention measures. Such measures could include the marking and fencing off of waste tips and areas of enhanced contamination and improvements in hygiene (washing of hands and food preparation such as the drying of cassava and other crops directly on the ground and the use of soil as a desiccant to aid the storage of groundnuts and beans). Whilst geophagy does have an important cultural and possibly nutritional benefit the resulting levels of potential exposure to young adults and pregnant woman are high enough to suggest that this practice should be positively discouraged within the mining districts. To this end the importation of geophagic materials into local markets from outside the contaminated region should be encouraged and the negatives effects of using local soils conveyed though local woman's groups and childhood development officers.

9.4 MONITORING SYSTEMS FOR WATER QUALITY AND BIOTA

(a) Monitoring in the current survey followed, as closely as was practicable, the internationally accepted protocols recommended in Veiga and Baker (2003). It is recommended that water monitoring is carried out during the wet season to test for Hg in solution and in the suspended sediment, including studies of the short term and medium term temporal variation in these pollution indicators.

(b) Continuous monitoring equipment capable of determining Hg at low concentrations is, as far as the authors of this report are aware, not available commercially. So any monitoring system would be periodic rather than continuous. Quarterly monitoring will probably be adequate for the Isingile and Nikonga Rivers for a period of two years. If no significant Hg concentrations are detected during that period, and there are no significant changes in the amount of mineral processing and associated factors, then annual monitoring, following the USEPA recommendations, will probably be adequate.

(c) The only effective option to prevent the continuing Hg pollution of the Isingile stream and surrounding agricultural areas is to require (a) the removal of all the existing mineral processing waste currently located close to the Isingile River and (b) the termination of all mineral processing activities in the vicinity.

(d) Monitoring of biota (fish and agricultural crops) has been carried out as part of the current study and could be carried out periodically using the UNIDO sampling protocols (Veiga and Baker, 2003), which document procedures for the periodic monitoring of aquatic biota. Periodic monitoring of agricultural crops could also be carried out, although the results of this study indicate that little Hg is present in most of the crops. Due to time and finding constraints, the current study was able to sample only a relatively limited number of sites. For this reason it is recommended that a more comprehensive survey should be carried out, in order to verify the results presented in this study.

9.5 MEASURES FOR THE REMEDIATION AND POSSIBLE REHABILITATION OF MERCURY 'HOT SPOTS'

(a) The present survey did not detect any concentrations of Hg in solution that would require remediation as they did not exceed water quality standards. Should future water quality monitoring detect concentrations that require remediation, then a number of remediation technologies may be appropriate.

(b) From a practical point of view, there would be little sense in trying to remediate and rehabilitate the Hg contaminated bottom sediments of the Isingile River until (a) the releases of Hg contaminated mineral processing tailings from the Rwamagasa area have been terminated, (2) the risk of future contamination of the drainage system by progressive or catastrophic releases of Hg contaminated processing waste has been eradicated. It is, however, relatively unlikely that the tailings piles located adjacent and to the south of the Isingile are a potential source of catastrophic contamination as the waste piles are small and the slopes are relatively gentle.

(c) In the US, soil clean-up goals for both total and leachable Hg vary from 1 to 21 mg/kg above a background range of 0.01 to 0.30 mg/kg The California Total Threshold Limit Concentration, for example is 20 mg/kg, which is above the mean and median concentration of Hg in the agricultural soils in the Rwamagasa area. As far as the author is aware, no clean-up goals have been set in Tanzania, the UK or the EC.

(d) The principal remediation-rehabilitation options for Hg-contaminated soils and sediments in the Isingile River – Rwamagasa area include (i) excavation of Hg-contaminated soil and disposal to an off-site secure landfill or depository, (ii) electroleaching, comprising wet extraction followed by electrolytic preparation of the leachate is an emerging and potential alternative cleanup method that is reported to offer a cheaper and more environmentally friendly alternative to thermal treatment or the acid leaching process. The cost of these potential remediation options has not been estimated.

(e) Other technologies, such as physical treatment by wet classification, extraction of Hg using chelation agents, or biological treatment, do not appear to be particularly applicable to the Hg contaminated soils of the Rwamagasa area. Many have been tested only in the laboratory and not in field scale trials so their efficacy cannot be evaluated.

(f) Specific practical remediation measures can not be recommended until a much more detailed assessment has been made of Hg concentrations in the agricultural soils. On the basis of evidence collected during this survey, it appears that significant amounts of Hg are not adsorbed into the grain of the agricultural plants. If this can be confirmed by more detailed surveys (involving further collection and analysis of soil and rice grain samples from exactly the same areas, for example) it may be possible to confirm that there is little or no potential for a direct negative impact on human health caused by the consumption of rice grown on these high Hg soils. Should this be the case, there would be no compelling reason to prevent the continued cultivation of rice and other agricultural crops on the Hg-contaminated soils.

(g) Should there be a change of land use from rice paddy to corn cultivation, for example, then the adsorption of Hg by other crops and its potential impact on human health would need to be investigated more thoroughly.

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Appendix 1

TERMS OF REFERENCE

EG/GLO/01/G34

TERMS OF REFERENCE OF SUBCONTRACT ON ASSESSMENT OF HEALTH AND ENVIRONMENT

Background Information

Mercury is one of the most toxic substances in the world causing significant damage to the environment and to the health of people who handle it. Mercury, which is used mostly by artisanal gold miners, is absorbed by the human organism through drinking water, food or breathed air. Artisanal mining activities provide income to the world's poorest populations and ethnic minorities; a great majority of the miners being women and children. For every gram of gold recovered, about two grams of mercury are released into the environment - often resulting in the death of men, women and children and in a permanently ruined habitat. The relevant simplicity and effectiveness of the technology, known as amalgamation, mask its dangers. This process can be improved with procedures using inexpensive and highly efficient devices that can be manufactured locally and at low cost.

The objective of the GEF/UNDP/UNIDO Project is to replace mercury amalgamation in the project demonstration sites to the extent possible with new technology while improving the income of the miners through more efficient recovery, increasing knowledge and awareness and providing policy advice on the regulation of artisanal gold mining with due consideration for gender issues.

The ultimate goals of the GEF/UNDP/UNIDO Project are:

1) to reduce mercury pollution of international waters by emissions emanating from small-scale gold mining;
2) to introduce cleaner technologies for gold extraction and to train people in their application;
3) to develop capacity and regulatory mechanisms that will enable the sector to minimize mercury pollution;
4) to introduce environmental and health monitoring programmes;
5) to build capacity of local laboratories to assess the extent and impact of mercury pollution.

The primary target beneficiaries will be artisanal miners - men and women alike. The secondary beneficiaries will be governments, local institutions and the society at large due to the very nature and extent of the damage caused by artisanal mining.

The activities will mainly be directed towards the introduction of safe and high-yield extraction methods that could pre-empt the use of mercury - i.e. introduction of new technology and its dissemination; training of miners in the application of new technology, training of local manufacturers; awareness creation on the protection of the environment as well as policy advice to governments and local institutions.

Scope of services

It is expected that the preparatory work, field work, analyses and the evaluation of results will be completed over a period of 3 months within 30 working days. The field work is expected to be 8 to 10 days in Lao PDR, Sudan, Tanzania and Zimbabwe where one site has been selected and 20 days in Brazil and Indonesia where two project demonstration sites are identified.

The field work will be prepared by National Experts covering the areas of public health and mining. Their salaries will be paid by the Project; i.e. their services are not part of the sub-contract. The National Experts will accompany and assist the team of the sub-contractor during the field work.

Cost of transportation in the field incurring to sub-contractor through use of air-taxi and/or speed-boat have to be included in the sub-contract. The distances to overcome in the field are listed for each country in the following table.

EG/GLO/01/G34 – Selected Project Demonstration Sites

	Brazil	Indonesia	Lao PDR	Sudan	Tanzania	Zimbabwe
Site 1	Creporizinho located in the garimpo area in Para. Can be reached with a one-engine plane, access to mining site requires 4 wheel- drive and one-hour drive from landing strip. Creporizinho has the infrastructure of a small village. Gold in small gold veins, mercury used in open circuit.	Bawan area at Kahayan River/Kalimantan Accessible from Palangkaraya (having airport) by 3-hours drive on a speedboat. - 600 dredging operations on 100 km - Using mercury - Heat treatment of amalgam at the shore (for example in floating restaurants)	Mekong River - 1h30 by boat from speed boat station Ban Don/Luang Prabang - 1,000 miners working during Feb-March, less during other months - Using mercury - Child labor witnessed	Gugob - 80km from Al Damazin (2h) - Village of miners - Hard rock and alluvial mining - Processing in the village - Burning in individual household	Rwamagasa - 3h from Geita on dirt road - Village of miners - Usage of mercury in cemented ponds - Usage of retorts mandatory, but often not applied.	Chakari - Approx. 120km from Harare (1h30) - Sites located 200m from the main road - Processing on site - Burning of amalgam
Site 2	San Francisco (São Domingos) located in the garimpo area of Para. Can be reached with a one- engine plane from either Itaituba or Creporizinho. Garimpo in 2km distance from the landing strip. Garimpo consists only of residence of owner and a shanty town of garimpeiros. Air taxi for the flight Itaituba, Creporizinho, San Fancisco, Santarem costed US$1,500 in 2001.	North Sulawesi, 20 km away from Manado and from there easily accessible by car, Hard rock mining. Run of mine crushed in drums and mixed with mercury-Final mercury containing tailings discharded into a river draining to the ocean 20 km away from the coast. In the mining area some thousand small-scale gold miners	N/A	N/A	N/A	N/A

Part A: ASSESSMENT OF HEALTH

The services of the subcontractor must encompass the following activities:

- Refine and develop a UNIDO questionnaire on general health condition of members of the mining community and on indications for symptoms of mercury poisoning;
- Cooperate with Ministry of Health in assessing the health condition of people affected by mercury poisoning;
- Advise on most suitable sampling techniques for the survey;
- Develop protocols and interact with local health institutions and the National Expert on Health, i.e. the nurse seconding the Sub-contractor;
- Based on the sociological survey of the selected mining community undertaken by a National Expert, take and analyze human specimens from a pre-determined cohort of approx. 200 people in the hot spot area and 50 persons from a non-exposed group;
- Based on analytical results, advise on the health risk of people living near mining operations and gold shops where gold is melted;
- Conduct anamnestic/clinical/neurological/toxicological test programme according to the state of the art;
- Check for neurological disturbances, behavioral disorders, motor neurological functions, cognitive capabilities, balance, gait, reflexes etc;
- Deliberate with health authorities on appropriate medical treatment;
- Maintain accurate medical records to assure compliance with examinations;
- Compile data for statistical purposes and maintain confidentiality regarding all health-related issues;
- Encourage communicable disease prevention practices, and;
- Prepare a report summarizing facts and conclusions.

Reports

(a) A Draft Final Report in English, to be submitted to UNIDO/Contract Section in three (3)copies, not later than 1 month after receipt of last samples.

(b) A Final Report of 100 pages, in English, in seven (7) copies and a diskette (MS Word), submission 3 weeks after discussion of draft report and its results with UNIDO Chief Technical Advisor.

Part B: ASSESSMENT OF ENVIRONMENT IN HOT SPOT AREA

The services of the subcontractor must encompass the following activities:

- Based on the sociological survey of the selected mining community undertaken by a National Expert, take and analyze inorganic and biological (food) samples;
- Meet officials of Government and mining related institutions and discuss present situation of the environment in the selected gold mining area. Coordinate field work with the national team.

- Investigate the situation of the habitat/agricultural sites in the vicinity of the selected small-scale mining activities and take samples;
- Analyse biological samples;
- Evaluate the nature and extent of the mercury pollution in produce, especially in those being part of the main diet;
- Propose a monitoring system for continuous biological sampling and analyses;
- Prepare a concise report on all findings and data on biological sampling including recommendations;
- Investigate the situation of the environment in the spot area and take samples from waters, sediments and soils, where pollution can be assumed;
- Analyze inorganic samples. Expected number of samples is at least 500, but not exceeding most probably 750 per country. The exact number of samples within these limits will be determined during project implementation;
- Evaluate the nature and extent of the mercury pollution in the river system adjacent to the hot spot area;
- Propose a monitoring system for continuous water quality assessment;
- Formulate measures for the remediation and possible rehabilitation of hot spot;
- Advise on necessary interactions between government departments, mining industry and research institutions;
- Prepare a concise report on all findings and data on environmental sampling including recommendations.

Reports

(a) A Draft Final Report in English, to be submitted to UNIDO/Contract Section in three (3) copies, not later than 3 month after receipt of last samples.

(b) A Final Report in English of 100 pages including annexes, in seven (7) copies and a diskette (MS Word), submission 3 weeks after discussion of draft report and its results with UNIDO Chief Technical Advisor.

Appendix 2

TABLE A-2-1 FISH DATA: SPECIES, DIMENSIONS, LOCATION AND SAMPLE TYPE

Sample No.	Species	L cm	W cm	Lab No.	Location	Sample type
101	*Lates malagarasi*	26.5	3.5	F101	Illagala (Malagarasi R.)	muscle tissue
102	*Clarias gariepinus*	26.5	4.5	F102	Illagala (Malagarasi R.)	muscle tissue
103	*Oreochromis tanganicae*	13.5	2.5	F103	Illagala (Malagarasi R.)	muscle tissue
104	*Auchenoglanis occidentalis*	27.0	5.0	F104	Illagala (Malagarasi R.)	muscle tissue
105	*Brycinus rhodopleura*	24.5	3.0	F105	Illagala (Malagarasi R.)	muscle tissue
106	*Auchenoglanis occidentalis*	18.7	2.2	F106	Illagala (Malagarasi R.)	muscle tissue
107	*Clarias gariepinus*	27.0	4.0	F107	Illagala (Malagarasi R.)	muscle tissue
108	*Clarias gariepinus*	26.0	4.0	F108	Illagala (Malagarasi R.)	muscle tissue
109	*Clarias gariepinus*	26.5	4.0	F109	Illagala (Malagarasi R.)	muscle tissue
110	*Clarias gariepinus*	35.0	5.5	F110	Illagala (Malagarasi R.)	muscle tissue
111	*Auchenoglanis occidentalis*	18.5	2.5	F111	Illagala (Malagarasi R.)	muscle tissue
112	*Clarias gariepinus*	28.0	4.5	F112	Illagala (Malagarasi R.)	muscle tissue
113	*Auchenoglanis occidentalis*	26.5	4.7	F113	Illagala (Malagarasi R.)	muscle tissue
114	*Oreochromis tanganicae*	13.5	2.2	F114	Illagala (Malagarasi R.)	muscle tissue
115	*Oreochromis tanganicae*	12.5	2.2	F115	Illagala (Malagarasi R.)	muscle tissue
116	*Oreochromis tanganicae*	15.3	2.5	F116	Illagala (Malagarasi R.)	muscle tissue
117	*Auchenoglanis occidentalis*	25.7	4.5	F117	Illagala (Malagarasi R.)	muscle tissue
118	*Oreochromis tanganicae*	15.3	2.5	F118	Illagala (Malagarasi R.)	muscle tissue
119	*Lates malagarasi*	19.0	2.2	F119	Illagala (Malagarasi R.)	muscle tissue
120	*Lates malagarasi*	19.5	2.5	F120	Illagala (Malagarasi R.)	muscle tissue
121	*Lates malagarasi*	17.5	2.0	F121	Illagala (Malagarasi R.)	muscle tissue
122	*Hydrocynus vittatus*	21.5	2.5	F122	Illagala (Malagarasi R.)	muscle tissue
123	*Hydrocynus vittatus*	18.0	1.0	F123	Illagala (Malagarasi R.)	muscle tissue
124	*Hydrocynus vittatus*	20.2	2.2	F124	Illagala (Malagarasi R.)	muscle tissue
125	*Hydrocynus vittatus*	18.6	2.2	F125	Illagala (Malagarasi R.)	muscle tissue
126	*Brycinus rhodopleura*	17.9	2.0	F126	Illagala (Malagarasi R.)	muscle tissue
127	*Hydrocynus vittatus*	20.5	2.0	F127	Illagala (Malagarasi R.)	muscle tissue
128	*Brycinus rhodopleura*	18.0	2.1	F128	Illagala (Malagarasi R.)	muscle tissue
129	*Hydrocynus vittatus*	20.0	2.0	F129	Illagala (Malagarasi R.)	muscle tissue
130	*Hydrocynus vittatus*	18.0	1.9	F130	Illagala (Malagarasi R.)	muscle tissue
131	*Hydrocynus vittatus*	20.4	1.9	F131	Illagala (Malagarasi R.)	muscle tissue
132	*Lates malagarasi*	18.7	2.2	F132	Illagala (Malagarasi R.)	muscle tissue
1001	*Clarias gariepinus*	19.0	3.8	F1001	Munekesi bk. area	muscle tissue
1002	*Clarias gariepinus*	18.8	1.8	F1002	Munekesi bk. area	muscle tissue
1003	*Clarias gariepinus*	19.5	2.0	F1003	Munekesi bk. area	muscle tissue
1004	*Clarias gariepinus*	23.0	2.4	F1004	Munekesi bk. area	muscle tissue
1005	*Clarias gariepinus*	13.0	1.5	F1005	Munekesi bk. area	muscle bone skin
1006	*Clarias gariepinus*	14.2	1.5	F1006	Munekesi bk. area	muscle bone skin
601	*Clarias alluadi*	12.3	2.1	F6013104	Nyamsenga bk. area	muscle bone skin
604	*Clarias alluadi*	11.4	1.9	F6013104	Nyamsenga bk. area	muscle bone skin
631	*Clarias alluadi*	11.9	1.8	F6013104	Nyamsenga bk. area	muscle bone skin
602	*Clarias alluadi*	8.0	0.8	F6020610	Nyamsenga bk. area	muscle bone skin
606	*Clarias alluadi*	8.0	0.8	F6020610	Nyamsenga bk. area	muscle bone skin
610	*Clarias alluadi*	8.0	1.0	F6020610	Nyamsenga bk. area	muscle bone skin
603	*Clarias alluadi*	10.0	1.0	F6031429	Nyamsenga bk. area	muscle bone skin
614	*Clarias alluadi*	10.0	0.9	F6031429	Nyamsenga bk. area	muscle bone skin

Sample No.	Species	L cm	W cm	Lab No.	Location	Sample type
629	*Clarias alluadi*	10.0	0.8	F6031429	Nyamsenga bk. area	muscle bone skin
605	*Clarias alluadi*	16.0	1.5	F605	Nyamsenga bk. area	muscle tissue
608	*Clarias alluadi*	5.1	0.6	F6083625	Nyamsenga bk. area	muscle bone skin
625	*Clarias alluadi*	7.0	0.7	F6083625	Nyamsenga bk. area	muscle bone skin
636	*Clarias alluadi*	6.4	0.7	F6083625	Nyamsenga bk. area	muscle bone skin
616	*Clarias alluadi*	12.9	2.0	F6162120	Nyamsenga bk. area	muscle bone skin
620	*Clarias alluadi*	13.5	2.2	F6162120	Nyamsenga bk. area	muscle bone skin
621	*Clarias alluadi*	13.3	2.0	F6162120	Nyamsenga bk. area	muscle bone skin
617	*Clarias alluadi*	9.0	0.9	F6171937	Nyamsenga bk. area	muscle bone skin
619	*Clarias alluadi*	9.0	1.0	F6171937	Nyamsenga bk. area	muscle bone skin
637	*Clarias alluadi*	9.0	1.1	F6171937	Nyamsenga bk. area	muscle bone skin
618	*Clarias alluadi*	8.7	1.0	F6222418	Nyamsenga bk. area	muscle bone skin
622	*Clarias alluadi*	8.5	0.8	F6222418	Nyamsenga bk. area	muscle bone skin
624	*Clarias alluadi*	8.5	1.0	F6222418	Nyamsenga bk. area	muscle bone skin
623	*Clarias alluadi*	16.2	1.9	F623	Nyamsenga bk. area	muscle tissue
626	*Clarias alluadi*	16.0	2.0	F626	Nyamsenga bk. area	muscle tissue
612	*Clarias alluadi*	8.1	0.8	F6281227	Nyamsenga bk. area	muscle bone skin
627	*Clarias alluadi*	8.1	0.9	F6281227	Nyamsenga bk. area	muscle bone skin
628	*Clarias alluadi*	8.0	0.8	F6281227	Nyamsenga bk. area	muscle bone skin
611	*Clarias alluadi*	9.4	1.0	F6301115	Nyamsenga bk. area	muscle bone skin
615	*Clarias alluadi*	9.6	1.2	F6301115	Nyamsenga bk. area	muscle bone skin
630	*Clarias alluadi*	9.3	1.1	F6301115	Nyamsenga bk. area	muscle bone skin
613	*Clarias alluadi*	10.4	1.2	F6333413	Nyamsenga bk. area	muscle bone skin
633	*Clarias alluadi*	10.2	1.0	F6333413	Nyamsenga bk. area	muscle bone skin
634	*Clarias alluadi*	10.3	0.8	F6333413	Nyamsenga bk. area	muscle bone skin
607	*Clarias alluadi*	7.4	0.8	F635320709	Nyamsenga bk. area	muscle bone skin
609	*Clarias alluadi*	7.5	0.8	F635320709	Nyamsenga bk. area	muscle bone skin
632	*Clarias alluadi*	7.3	0.9	F635320709	Nyamsenga bk. area	muscle bone skin
635	*Clarias alluadi*	7.2	1.0	F635320709	Nyamsenga bk. area	muscle bone skin
1201	*Oreochromis niloticus*	19.5	3.5	F1201	Rwamagasa market	muscle tissue
1202	*Oreochromis niloticus*	17.5	3.5	F1202	Rwamagasa market	muscle tissue
1203	*Oreochromis niloticus*	19.0	4.0	F1203	Rwamagasa market	muscle tissue
1204	*Oreochromis niloticus*	15.0	3.0	F1204	Rwamagasa market	muscle tissue
1205	*Oreochromis niloticus*	14.7	3.0	F1205	Rwamagasa market	muscle tissue
301	*Clarias gariepinus*	14.0	2.1	F301	Rwamagasa Pond 1	muscle tissue
302	*Clarias gariepinus*	14.4	2.3	F302	Rwamagasa Pond 1	muscle tissue
306	*Barbus spp*	5.0	0.5	F3061114	Rwamagasa Pond 1	muscle bone skin
311	*Barbus spp*	5.0	0.5	F3061114	Rwamagasa Pond 1	muscle bone skin
314	*Barbus spp*	5.0	0.5	F3061114	Rwamagasa Pond 1	muscle bone skin
307	*Barbus spp*	5.2	0.6	F3071013	Rwamagasa Pond 1	muscle bone skin
310	*Barbus spp*	5.2	0.5	F3071013	Rwamagasa Pond 1	muscle bone skin
313	*Barbus spp*	5.2	0.5	F3071013	Rwamagasa Pond 1	muscle bone skin
305	*Barbus spp*	6.1	0.7	F30905	Rwamagasa Pond 1	muscle bone skin
309	*Barbus spp*	6.0	0.7	F30905	Rwamagasa Pond 1	muscle bone skin
304	*Barbus spp*	5.5	0.5	F3150804	Rwamagasa Pond 1	muscle bone skin
308	*Barbus spp*	5.4	0.6	F3150804	Rwamagasa Pond 1	muscle bone skin
315	*Barbus spp*	5.3	0.7	F3150804	Rwamagasa Pond 1	muscle bone skin
303	*Barbus spp*	5.6	0.5	F3160312	Rwamagasa Pond 1	muscle bone skin
312	*Barbus spp*	5.6	0.8	F3160312	Rwamagasa Pond 1	muscle bone skin
316	*Barbus spp*	5.5	0.6	F3160312	Rwamagasa Pond 1	muscle bone skin
402	*Haplochromis spp*	3.3	0.4	F4021213	Rwamagasa Pond 2	muscle bone skin
412	*Haplochromis spp*	3.3	0.4	F4021213	Rwamagasa Pond 2	muscle bone skin
413	*Haplochromis spp*	3.3	0.4	F4021213	Rwamagasa Pond 2	muscle bone skin
403	*Haplochromis spp*	4.1	0.6	F4050803	Rwamagasa Pond 2	muscle bone skin
405	*Haplochromis spp*	3.8	0.7	F4050803	Rwamagasa Pond 2	muscle bone skin
408	*Haplochromis spp*	3.8	0.6	F4050803	Rwamagasa Pond 2	muscle bone skin
407	*Haplochromis spp*	2.7	0.3	F410071615	Rwamagasa Pond 2	muscle bone skin
410	*Haplochromis spp*	2.6	0.3	F410071615	Rwamagasa Pond 2	muscle bone skin
415	*Haplochromis spp*	2.9	0.4	F410071615	Rwamagasa Pond 2	muscle bone skin

Sample No.	Species	L cm	W cm	Lab No.	Location	Sample type
416	*Haplochromis spp*	2.8	0.4	F410071615	Rwamagasa Pond 2	muscle bone skin
404	*Haplochromis spp*	2.3	0.3	F4110409	Rwamagasa Pond 2	muscle bone skin
409	*Haplochromis spp*	2.3	0.4	F4110409	Rwamagasa Pond 2	muscle bone skin
411	*Haplochromis spp*	2.2	0.3	F4110409	Rwamagasa Pond 2	muscle bone skin
401	*Haplochromis spp*	3.1	0.4	F417061401	Rwamagasa Pond 2	muscle bone skin
406	*Haplochromis spp*	3.0	0.3	F417061401	Rwamagasa Pond 2	muscle bone skin
414	*Haplochromis spp*	3.0	0.4	F417061401	Rwamagasa Pond 2	muscle bone skin
417	*Haplochromis spp*	2.9	0.4	F417061401	Rwamagasa Pond 2	muscle bone skin
418	*Clarias gariepinus*	6.9	0.9	F4191820	Rwamagasa Pond 2	muscle bone skin
419	*Clarias gariepinus*	5.5	0.9	F4191820	Rwamagasa Pond 2	muscle bone skin
420	*Clarias gariepinus*	7.8	0.9	F4191820	Rwamagasa Pond 2	muscle bone skin
502	*Haplochromis spp*	3.0	0.5	F5020409	Rwamagasa Pond 4	muscle bone skin
504	*Haplochromis spp*	3.5	0.5	F5020409	Rwamagasa Pond 4	muscle bone skin
509	*Haplochromis spp*	3.5	0.4	F5020409	Rwamagasa Pond 4	muscle bone skin
503	*Haplochromis spp*	4.6	0.7	F5060803	Rwamagasa Pond 4	muscle bone skin
506	*Haplochromis spp*	4.3	0.5	F5060803	Rwamagasa Pond 4	muscle bone skin
508	*Haplochromis spp*	4.5	0.5	F5060803	Rwamagasa Pond 4	muscle bone skin
511	*Haplochromis spp*	7.0	1.1	F511	Rwamagasa Pond 4	muscle bone skin
505	*Haplochromis spp*	4.0	0.4	F512070510	Rwamagasa Pond 4	muscle bone skin
507	*Haplochromis spp*	3.8	0.4	F512070510	Rwamagasa Pond 4	muscle bone skin
510	*Haplochromis spp*	4.0	0.4	F512070510	Rwamagasa Pond 4	muscle bone skin
512	*Haplochromis spp*	3.7	0.6	F512070510	Rwamagasa Pond 4	muscle bone skin
513	*Clarias gariepinus*	16.4	2.6	F513	Rwamagasa Pond 4	muscle tissue
514	*Clarias gariepinus*	11.2	1.8	F514	Rwamagasa Pond 4	muscle tissue
518	*Clarias gariepinus*	16.8	1.9	F518	Rwamagasa Pond 4	muscle tissue
515	*Clarias gariepinus*	10.3	1.7	F5202315	Rwamagasa Pond 4	muscle bone skin
520	*Clarias gariepinus*	10.0	0.8	F5202315	Rwamagasa Pond 4	muscle bone skin
523	*Clarias gariepinus*	10.0	1.5	F5202315	Rwamagasa Pond 4	muscle bone skin
521	*Clarias gariepinus*	19.5	2.5	F521	Rwamagasa Pond 4	muscle tissue
525	*Clarias gariepinus*	22.5	3.3	F525	Rwamagasa Pond 4	muscle tissue
526	*Clarias gariepinus*	18.5	2.9	F526	Rwamagasa Pond 4	muscle tissue
517	*Clarias gariepinus*	10.6	1.9	F5283617	Rwamagasa Pond 4	muscle bone skin
528	*Clarias gariepinus*	10.3	1.3	F5283617	Rwamagasa Pond 4	muscle bone skin
536	*Clarias gariepinus*	10.5	1.2	F5283617	Rwamagasa Pond 4	muscle bone skin
529	*Clarias gariepinus*	12.1	2.0	F529414340	Rwamagasa Pond 4	muscle bone skin
540	*Clarias gariepinus*	12.5	1.7	F529414340	Rwamagasa Pond 4	muscle bone skin
541	*Clarias gariepinus*	12.3	1.4	F529414340	Rwamagasa Pond 4	muscle bone skin
543	*Clarias gariepinus*	12.3	1.7	F529414340	Rwamagasa Pond 4	muscle bone skin
530	*Clarias gariepinus*	9.5	1.0	F5323035	Rwamagasa Pond 4	muscle bone skin
532	*Clarias gariepinus*	9.2	1.8	F5323035	Rwamagasa Pond 4	muscle bone skin
535	*Clarias gariepinus*	9.9	0.5	F5323035	Rwamagasa Pond 4	muscle bone skin
519	*Clarias gariepinus*	8.4	0.6	F5331931	Rwamagasa Pond 4	muscle bone skin
531	*Clarias gariepinus*	9.1	1.1	F5331931	Rwamagasa Pond 4	muscle bone skin
533	*Clarias gariepinus*	8.2	0.9	F5331931	Rwamagasa Pond 4	muscle bone skin
524	*Clarias gariepinus*	11.2	1.5	F534142442	Rwamagasa Pond 4	muscle bone skin
534	*Clarias gariepinus*	11.1	1.4	F534142442	Rwamagasa Pond 4	muscle bone skin
542	*Clarias gariepinus*	11.5	1.5	F534142442	Rwamagasa Pond 4	muscle bone skin
538	*Clarias gariepinus*	4.5	1.2	F538	Rwamagasa Pond 4	muscle bone skin
516	*Clarias gariepinus*	10.8	1.9	F5393716	Rwamagasa Pond 4	muscle bone skin
537	*Clarias gariepinus*	10.7	1.3	F5393716	Rwamagasa Pond 4	muscle bone skin
539	*Clarias gariepinus*	10.6	1.2	F5393716	Rwamagasa Pond 4	muscle bone skin
545	*Clarias gariepinus*	15.0	1.8	F54551	Rwamagasa Pond 4	muscle bone skin
551	*Clarias gariepinus*	15.1	2.3	F54551	Rwamagasa Pond 4	muscle bone skin
501	*Clarias gariepinus*	14.5	1.9	F5464901	Rwamagasa Pond 4	muscle bone skin
546	*Clarias gariepinus*	14.2	1.8	F5464901	Rwamagasa Pond 4	muscle bone skin
549	*Clarias gariepinus*	14.3	2.1	F5464901	Rwamagasa Pond 4	muscle bone skin
544	*Clarias gariepinus*	13.1	1.9	F5474448	Rwamagasa Pond 4	muscle bone skin
547	*Clarias gariepinus*	13.0	2.0	F5474448	Rwamagasa Pond 4	muscle bone skin
548	*Clarias gariepinus*	13.3	1.7	F5474448	Rwamagasa Pond 4	muscle bone skin

Sample No.	Species	L cm	W cm	Lab No.	Location	Sample type
522	*Clarias gariepinus*	13.7	1.8	F5502227	Rwamagasa Pond 4	muscle bone skin
527	*Clarias gariepinus*	13.9	1.7	F5502227	Rwamagasa Pond 4	muscle bone skin
550	*Clarias gariepinus*	13.5	1.9	F5502227	Rwamagasa Pond 4	muscle bone skin
552	*Clarias gariepinus*	16.1	2.0	F552	Rwamagasa Pond 4	muscle tissue
701	*Clarias gariepinus*	9.7	1.0	F70201	Rwamagasa Pond 5	muscle bone skin
702	*Clarias gariepinus*	9.5	1.2	F70201	Rwamagasa Pond 5	muscle bone skin
703	*Clarias gariepinus*	15.0	1.5	F70310	Rwamagasa Pond 5	muscle bone skin
710	*Clarias gariepinus*	15.1	2.0	F70310	Rwamagasa Pond 5	muscle bone skin
705	*Clarias gariepinus*	10.0	1.7	F70509	Rwamagasa Pond 5	muscle bone skin
709	*Clarias gariepinus*	10.0	1.8	F70509	Rwamagasa Pond 5	muscle bone skin
704	*Clarias gariepinus*	12.5	2.0	F707040608	Rwamagasa Pond 5	muscle bone skin
706	*Clarias gariepinus*	13.2	1.8	F707040608	Rwamagasa Pond 5	muscle bone skin
707	*Clarias gariepinus*	12.2	1.8	F707040608	Rwamagasa Pond 5	muscle bone skin
708	*Clarias gariepinus*	13.2	2.0	F707040608	Rwamagasa Pond 5	muscle bone skin
802	*Haplochromis spp*	4.5	0.6	F803050602	Rwamagasa Pond 6	muscle bone skin
803	*Haplochromis spp*	3.5	0.5	F803050602	Rwamagasa Pond 6	muscle bone skin
805	*Haplochromis spp*	3.6	0.6	F803050602	Rwamagasa Pond 6	muscle bone skin
806	*Haplochromis spp*	4.0	0.7	F803050602	Rwamagasa Pond 6	muscle bone skin
801	*Haplochromis spp*	2.7	0.5	F808070104	Rwamagasa Pond 6	muscle bone skin
804	*Haplochromis spp*	3.2	0.6	F808070104	Rwamagasa Pond 6	muscle bone skin
807	*Haplochromis spp*	2.5	0.3	F808070104	Rwamagasa Pond 6	muscle bone skin
808	*Haplochromis spp*	2.1	0.3	F808070104	Rwamagasa Pond 6	muscle bone skin
809	*Barbus spp*	4.7	0.9	F8091018	Rwamagasa Pond 6	muscle bone skin
810	*Barbus spp*	4.7	0.7	F8091018	Rwamagasa Pond 6	muscle bone skin
818	*Barbus spp*	5.0	1.0	F8091018	Rwamagasa Pond 6	muscle bone skin
814	*Barbus spp*	3.7	0.5	F8142019	Rwamagasa Pond 6	muscle bone skin
819	*Barbus spp*	3.9	0.7	F8142019	Rwamagasa Pond 6	muscle bone skin
820	*Barbus spp*	3.8	0.5	F8142019	Rwamagasa Pond 6	muscle bone skin
811	*Barbus spp*	4.4	0.7	F8151611	Rwamagasa Pond 6	muscle bone skin
815	*Barbus spp*	4.2	0.8	F8151611	Rwamagasa Pond 6	muscle bone skin
816	*Barbus spp*	4.2	0.8	F8151611	Rwamagasa Pond 6	muscle bone skin
812	*Barbus spp*	4.1	0.7	F8171213	Rwamagasa Pond 6	muscle bone skin
813	*Barbus spp*	4.1	0.7	F8171213	Rwamagasa Pond 6	muscle bone skin
817	*Barbus spp*	4.0	0.6	F8171213	Rwamagasa Pond 6	muscle bone skin
821	*Brycinus*	6.4	0.8	F821	Rwamagasa Pond 6	muscle bone skin
822	*Brycinus*	6.5	1.0	F822	Rwamagasa Pond 6	muscle bone skin
823	*Brycinus*	7.5	1.2	F823	Rwamagasa Pond 6	muscle bone skin
824	*Brycinus*	6.0	0.8	F824	Rwamagasa Pond 6	muscle bone skin
825	*Brycinus*	6.0	0.9	F825	Rwamagasa Pond 6	muscle bone skin
826	*Brycinus*	7.8	1.2	F826	Rwamagasa Pond 6	muscle bone skin
841	*Clarias gariepinus*	12.0	1.8	F8445041	Rwamagasa Pond 6	muscle bone skin
844	*Clarias gariepinus*	11.0	1.9	F8445041	Rwamagasa Pond 6	muscle bone skin
850	*Clarias gariepinus*	11.9	1.4	F8445041	Rwamagasa Pond 6	muscle bone skin
845	*Clarias gariepinus*	13.8	1.4	F8474845	Rwamagasa Pond 6	muscle bone skin
847	*Clarias gariepinus*	13.5	1.5	F8474845	Rwamagasa Pond 6	muscle bone skin
848	*Clarias gariepinus*	13.7	1.7	F8474845	Rwamagasa Pond 6	muscle bone skin
846	*Clarias gariepinus*	13.0	1.4	F851524649	Rwamagasa Pond 6	muscle bone skin
849	*Clarias gariepinus*	13.0	1.5	F851524649	Rwamagasa Pond 6	muscle bone skin
851	*Clarias gariepinus*	12.5	1.4	F851524649	Rwamagasa Pond 6	muscle bone skin
852	*Clarias gariepinus*	12.5	1.8	F851524649	Rwamagasa Pond 6	muscle bone skin
853	*Clarias gariepinus*	14.5	2.0	F8535455	Rwamagasa Pond 6	muscle bone skin
854	*Clarias gariepinus*	14.5	2.0	F8535455	Rwamagasa Pond 6	muscle bone skin
855	*Clarias gariepinus*	14.9	1.9	F8535455	Rwamagasa Pond 6	muscle bone skin
842	*Clarias gariepinus*	14.1	2.0	F8564243	Rwamagasa Pond 6	muscle bone skin
843	*Clarias gariepinus*	14.5	1.8	F8564243	Rwamagasa Pond 6	muscle bone skin
856	*Clarias gariepinus*	14.0	1.8	F8564243	Rwamagasa Pond 6	muscle bone skin
857	*Clarias alluadi*	12.3	1.4	F857	Rwamagasa Pond 6	muscle bone skin
858	*Clarias alluadi*	6.5	0.5	F858	Rwamagasa Pond 6	muscle bone skin
859	*Clarias alluadi*	8.9	1.0	F859	Rwamagasa Pond 6	muscle bone skin

Sample No.	Species	L cm	W cm	Lab No.	Location	Sample type
860	*Clarias alluadi*	6.2	0.7	F860	Rwamagasa Pond 6	muscle bone skin
827	*Clarias alluadi*	11.3	1.8	F8272931	Nikonga R.	muscle bone skin
829	*Clarias alluadi*	11.3	1.8	F8272931	Nikonga R.	muscle bone skin
831	*Clarias alluadi*	12.0	1.5	F8272931	Nikonga R.	muscle bone skin
828	*Clarias alluadi*	8.5	1.8	F8283233	Nikonga R.	muscle bone skin
832	*Clarias alluadi*	8.5	0.8	F8283233	Nikonga R.	muscle bone skin
833	*Clarias alluadi*	8.6	1.0	F8283233	Nikonga R.	muscle bone skin
830	*Clarias alluadi*	9.5	1.0	F83530	Nikonga R.	muscle bone skin
835	*Clarias alluadi*	9.3	1.2	F83530	Nikonga R.	muscle bone skin
834	*Clarias alluadi*	7.2	0.6	F8383437	Nikonga R.	muscle bone skin
837	*Clarias alluadi*	8.0	0.9	F8383437	Nikonga R.	muscle bone skin
838	*Clarias alluadi*	6.7	0.7	F8383437	Nikonga R.	muscle bone skin
836	*Clarias alluadi*	6.2	0.7	F8394036	Nikonga R.	muscle bone skin
839	*Clarias alluadi*	6.0	0.7	F8394036	Nikonga R.	muscle bone skin
840	*Clarias alluadi*	6.0	0.5	F8394036	Nikonga R.	muscle bone skin
915	*Cynodontis victoriae*	4.4	0.9	F915	Nikonga R.	muscle bone skin
916	*Gastropoda*	3.9	3.5	F916	Nikonga R.	muscle inc. foot.
917	*Gastropoda*	4.5	4.2	F917	Nikonga R.	muscle inc. foot.
918	*Gastropoda*	4.6	4.2	F918	Nikonga R.	muscle inc. foot.
919	*Gastropoda*	4.8	4.0	F919	Nikonga R.	muscle inc. foot.
920	*Gastropoda*	2.9	2.2	F920	Nikonga R.	muscle inc. foot.
1101	*Clarias gariepinus*	18.5	2.1	F1101	Tembomine	muscle tissue
1102	*Clarias gariepinus*	19.5	2.5	F1102	Tembomine	muscle tissue
1103	*Clarias gariepinus*	22.5	3.8	F1103	Tembomine	muscle tissue
1104	*Clarias gariepinus*	26.0	4.0	F1104	Tembomine	muscle tissue
1105	*Clarias gariepinus*	26.0	4.0	F1105	Tembomine	muscle tissue
1106	*Clarias gariepinus*	20.0	2.5	F1106	Tembomine	muscle tissue
1107	*Clarias gariepinus*	42.0	5.5	F1107	Tembomine	muscle tissue
1108	*Clarias gariepinus*	23.0	3.8	F1108	Tembomine	muscle tissue
1109	*Clarias gariepinus*	21.0	2.5	F1109	Tembomine	muscle tissue
1110	*Clarias gariepinus*	24.0	3.7	F1110	Tembomine	muscle tissue
1111	*Clarias gariepinus*	21.0	2.8	F1111	Tembomine	muscle tissue
1112	*Clarias gariepinus*	23.5	2.8	F1112	Tembomine	muscle tissue
1113	*Clarias gariepinus*	17.0	2.4	F1113	Tembomine	muscle tissue
1114	*Clarias gariepinus*	28.9	3.6	F1114	Tembomine	muscle tissue
1115	*Clarias gariepinus*	20.8	2.7	F1115	Tembomine	muscle tissue
1116	*Clarias gariepinus*	19.5	2.4	F1116	Tembomine	muscle tissue
1117	*Clarias gariepinus*	24.0	3.0	F1117	Tembomine	muscle tissue
1118	*Clarias gariepinus*	22.0	3.3	F1118	Tembomine	muscle tissue
1119	*Clarias gariepinus*	21.2	2.8	F1119	Tembomine	muscle tissue
1120	*Clarias gariepinus*	16.1	2.2	F1120	Tembomine	muscle tissue
1121	*Clarias gariepinus*	16.0	2.8	F1121	Tembomine	muscle tissue
1122	*Clarias gariepinus*	25.5	4.0	F1122	Tembomine	muscle tissue
1123	*Clarias gariepinus*	17.0	2.5	F1123	Tembomine	muscle tissue
1124	*Clarias gariepinus*	20.0	3.1	F1124	Tembomine	muscle tissue
1125	*Clarias gariepinus*	31.3	5.0	F1125	Tembomine	muscle tissue
201	*Oreochromis tanganicae*	11.6	2.2	F201	Uvinza (Malagarasi R.)	muscle tissue
202	*Barbus tropidolepsis*	14.2	2.8	F202	Uvinza (Malagarasi R.)	muscle tissue
203	*Barbus tropidolepsis*	10.2	1.6	F203	Uvinza (Malagarasi R.)	muscle tissue
204	*Barbus tropidolepsis*	12.5	2.0	F204	Uvinza (Malagarasi R.)	muscle tissue
205	*Barbus tropidolepsis*	11.9	1.7	F205	Uvinza (Malagarasi R.)	muscle tissue
206	*Oreochromis tanganicae*	10.8	2.2	F206	Uvinza (Malagarasi R.)	muscle tissue
207	*Oreochromis tanganicae*	14.0	2.9	F207	Uvinza (Malagarasi R.)	muscle tissue
208	*Oreochromis tanganicae*	12.1	2.0	F208	Uvinza (Malagarasi R.)	muscle tissue
209	*Ctenopharyngodon idella*	22.5	2.6	F209	Uvinza (Malagarasi R.)	muscle tissue

Appendix 3

TABLE A-3-1 REPLICATE ANALYSES OF SEDIMENT, TAILINGS AND SOIL SAMPLES

		Original	Replicate	
		A 003	RE A 003	%RPD
Cu	ppm	2	1	67
Pb	ppm	3	3	0
Zn	ppm	8	7	13
Fe	%	0.16	0.16	0
As	ppm	< 2	< 2	
Hg	ppb	105	110	**-5**
ORG/C	%	0.16	0.16	0
		A 040	RE A 040	%RPD
Cu	ppm	108	115	-6
Pb	ppm	23	33	-36
Zn	ppm	82	83	-1
Fe	%	4.97	5.44	-9
As	ppm	63	67	-6
Hg	ppb	127000	123000	**3**
ORG/C	%	nd	nd	
		A 080	RE A 080	%RPD
Cu	ppm	28	29	-4
Pb	ppm	13	9	36
Zn	ppm	27	27	0
Fe	%	2.93	2.92	0
As	ppm	4	6	-40
Hg	ppb	10	15	**-40**
ORG/C	%	3.76	3.6	4
		A 120	RE A 120	%RPD
Cu	ppm	48	49	-2
Pb	ppm	9	9	0
Zn	ppm	13	14	-7
Fe	%	8.58	8.37	2
As	ppm	12	9	29
Hg	ppb	30	25	**18**
ORG/C	%	1.8	1.89	-5
		A 210	RE A 210	%RPD
Cu	ppm	42	41	2
Pb	ppm	6	4	40
Zn	ppm	14	13	7
Fe	%	4.3	4.29	0
As	ppm	6	6	0
Hg	ppb	25	20	**22**
ORG/C	%	3.3	3.21	3

TABLE A-3-1 REPLICATE ANALYSES OF SEDIMENT, TAILINGS AND SOIL SAMPLES (CONTD)

		Original	Replicate	
		A 240	RE A 240	%RPD
Cu	ppm	49	51	-4
Pb	ppm	5	5	0
Zn	ppm	38	40	-5
Fe	%	4.86	4.99	-3
As	ppm	5	7	-33
Hg	ppb	30	30	**0**
ORG/C	%	1.92	1.97	-3
		A 270	RE A 270	%RPD
Cu	ppm	39	39	0
Pb	ppm	6	9	-40
Zn	ppm	31	31	0
Fe	%	3.6	3.58	1
As	ppm	2	3	-40
Hg	ppb	25	20	**22**
ORG/C	%	1.11	1.21	-9
		A 300	RE A 300	%RPD
Cu	ppm	36	35	3
Pb	ppm	9	10	-11
Zn	ppm	21	20	5
Fe	%	6.24	6.31	-1
As	ppm	3	< 2	
Hg	ppb	45	40	**12**
ORG/C	%	2.46	2.4	2

TABLE A-3-2 ANALYTICAL AND PRECISION (RPD) DATA FOR SOIL AND TAILINGS DUPLICATE SAMPLES

Sample	Dup	Cu ppm	Pb ppm	Zn ppm	Fe %	As ppm	Hg ppb	ORGC %	Cd ppm		%RPD Cu	Pb	Zn	Fe	As	Hg	ORGC	Cd
A 243	DS	31	4	23	1.98	3	25	2.35	0.25		76	29	71	60	100	0	9	0
A 244	DS	14	3	11	1.07	1	25	2.15	0.25									
A 005	DT	368	1.5	1476	2.72	8	54000	nd	13.9		-6	0	-1	-1	0	-9		-1
A 006	DT	392	1.5	1487	2.75	8	59000	nd	14									
A 011	DT	176	51	243	5.5	40	83000	nd	2.1		47	46	59	57	76	-35		47
A 012	DT	109	32	133	3.06	18	118000	nd	1.3									
A 020	DT	115	22	143	8.54	21	13910	nd	0.5		10	-4	4	29	5	-26		-18
A 021	DT	104	23	137	6.38	20	18000	nd	0.6									
A 040	DT	108	23	82	4.97	63	127000	nd	0.25		-15	-20	-11	-3	2	7		0
A 041	DT	126	28	92	5.1	62	118000	nd	0.25									
A 057	DT	67	10	43	3.58	18	2780	nd	0.25		2	0	-5	-1	-5	0		0
A 058	DT	66	10	45	3.63	19	2785	nd	0.25									
										Average	7	4	9	16	15	-12		6
A 089	SS	19	14	15	1.81	1	15	2.87	0.25		0	0	0	5	0	0	1	0
A 090	SS	19	14	15	1.72	1	15	2.83	0.25									
A 096	SS	43	12	16	5.98	7	65	2.64	0.25		-2	40	0	-2	55	89	-13	0
A 097	SS	44	8	16	6.09	4	25	3.01	0.25									
A 133	SS	88	6	101	7.37	7	145	1.96	0.25		1	0	1	-3	-13	-3	-8	0
A 134	SS	87	6	100	7.58	8	150	2.12	0.25									
A 141	SS	30	5	23	2.91	3	80	2	0.25		3	-33	19	6	100	21	1	0
A 142	SS	29	7	19	2.73	1	65	1.99	0.25									
A 208	SS	27	8	17	2.13	2	20	2.18	0.25		-20	-40	-30	-24	-40	-127	-23	0
A 209	SS	33	12	23	2.71	3	90	2.74	0.25									
A 221	SS	90	9	36	9.17	14	25	1.55	0.25		5	-20	-3	7	7	0	-8	-67
A 222	SS	86	11	37	8.58	13	25	1.68	0.5									
A 231	SS	51	3	27	3.83	7	30	2.8	0.25		0	-80	-4	2	0	0	-3	0
A 232	SS	51	7	28	3.76	7	30	2.88	0.25									
A 254	SS	70	7	44	5.34	10	1185	3.28	0.25		4	-13	-2	1	11	5	17	-67
A 255	SS	67	8	45	5.27	9	1125	2.76	0.5									
A 258	SS	66	12	37	4.2	5	1260	4.72	0.25		-13	0	-13	-8	22	-15	0	0
A 259	SS	75	12	42	4.57	4	1460	4.74	0.25									
A 265	SS	117	9	133	4.52	11	4875	2.69	0.9		-4	-11	-7	-5	20	-8	7	-29
A 266	SS	122	10	143	4.73	9	5280	2.51	1.2									
A 273	SS	123	10	115	5.72	31	7160	1.65	1		-5	22	-3	-2	3	12	7	-10
A 274	SS	129	8	118	5.81	30	6380	1.54	1.1									
										Average	-3	-12	-4	-2	15	-2	-2	-16
A 024	ST	153	20	112	6.56	25	4630	nd	0.25		-1	22	0	0	-4	7		0
A 025	ST	154	16	112	6.57	26	4325	nd	0.25									
A 029	ST	88	12	78	4.75	40	6015	nd	0.5		-2	-22	-11	4	3	-10		-18
A 030	ST	90	15	87	4.58	39	6675	nd	0.6									
A 042	ST	142	12	117	4.38	26	5335	nd	1		-6	-8	-3	0	-4	37		0
A 043	ST	151	13	121	4.4	27	3685	nd	1									
A 046	ST	91	14	113	4.54	20	2620	nd	0.8		0	7	2	-9	-5	-11		29
A 047	ST	91	13	111	4.98	21	2915	nd	0.6									
A 059	ST	125	8	181	4.22	18	12540	nd	1.6		4	13	11	-6	0	-3		6
A 060	ST	120	7	162	4.5	18	12870	nd	1.5									
A 102	ST	332	1.5	1956	2.47	7	26000	nd	22.1		-1	-67	-2	-9	-35	-18		0
A 103	ST	335	3	1986	2.71	10	31000	nd	22.1									
										Average	-1	-9	0	-4	-8	0		3

DS = Field Duplicate Soil; DT = Field Duplicate Tailings; SS= Field Subsample Duplicate Soil; ST = Field Subsample Duplicate Tailings

TABLE A-3-3 ANALYTICAL DATA FOR DUPLICATE SEDIMENT SAMPLES

Sample Number	Cd	Cu	Pb	Zn	Fe	As	Hg ppb	Hg ppm	ORGC
69	<0.5	75	9	68	4.0	2	180	0.18	6.27
70	<0.5	65	9	62	3.5	1	140	0.14	6.30
AVERAGE	<0.5	70	9	65	3.8	2	160	0.16	6.29
82	<0.5	16	11	13	1.1	3	40	0.04	1.83
203	<0.5	24	13	336	1.4	1	335	0.34	2.36
AVERAGE	<0.5	20	12	175	1.3	2	188	0.19	2.10
85	<0.5	54	11	36	5.1	3	65	0.07	1.73
106	<0.5	49	6	25	5.1	8	175	0.18	3.49
AVERAGE	<0.5	52	9	31	5.1	6	120	0.12	2.61
86	<0.5	58	18	57	3.4	1	315	0.32	3.18
218	<0.5	59	33	592	3.5	1	850	0.85	4.23
AVERAGE	<0.5	59	26	325	3.4	1	583	0.58	3.71

TABLE A-3-4 REPLICATE ANALYTICAL DATA FOR ACME INTERNAL STANDARD DS5[1]

ELEMENT	Cu	Pb	Zn	Fe	As	ORG/C
	ppm	Ppm	ppm	%	ppm	%
	143	24	130	2.98	18	2.00
	147	24	131	3.04	19	Nd
	146	26	138	3.02	19	2.01
	147	25	133	3.00	18	2.01
	147	23	134	3.00	19	2.01
	146	23	135	3.01	17	2.02
	146	24	135	3.00	18	2.02
	139	24	131	3.00	17	2.01
Average	145	24	133	3.01	18	2.01
Minimum	139	23	130	2.98	17	2.00
Maximum	147	26	138	3.04	19	2.02
Range	8	3	8	0.06	2	0.02
Geometric Mean	145	24	133	3.01	18	2.01
Standard Deviation	2.8	1.0	2.7	0.02	0.8	0.01
Recommended value	142	25	137	2.94	18	2.0
% Recovery	102%	96%	97%	102%	100%	100%

[1] DS5 was certified against CANMET Reference Materials TILL-4, LKSD-4 and STD-1.

TABLE A-3-5 COMPARISON OF HG DETERMINATIONS BY BGS AND ACME

Sample Number	BGS CV-AFS	BGS CV-AFS	BGS CV-AFS	BGS CV-AFS average	ACME CV-AAS[1]	ACME CV-AAS	ACME CV-AAS[1]	ACME CV-AAS[1] average	ACME ICP-MS
UNBS 012	12.6			12.60	10.01		11.17	10.59	
UNBS 026	28.3	27.1		27.70	27		27	27	
UNS 106	69.2	66.3	71.4	68.97	67		74	71	
UNS 108	4.84	4.7	4.55	4.70	2.88		3.51	3.20	4.31
UNS 109	35.6	30.5	30.4	32.17	33		33	33	
UNS 117	21	19.2	20.2	20.13	21		22	22	
UNS 124	0.07	0.06		0.065	0.065		0.05	0.06	0.08
UNS 127	1.24			1.24	0.795		1.00	0.90	1.05
UNS 134	5.8			5.80	4		4.60	4.30	4.88
UNS 159	0.15			0.15	0.095		0.09	0.09	0.13
UNS 163	8.47			8.47	6.14	5.65	7.31	6.37	7.19
UNS 168	42.5			42.50	36		38	37	
UNS 174	88.8	88.8		88.80	80		84	82	
CANMET STSD-4	Recommended value for *aqua regia* Hg = 0.93							0.88	0.85

[1] concentrations above 10 ppm determined by ICP-ES

TABLE A-3-6 HG CV-AAS DATA FOR ACME INTERNAL STANDARD DS5

ELEMENT	Hg[1]
	ppb
	125
	110
	110
	100
	105
	120
	115
	95
Average	110
Minimum	95
Maximum	125
Range	30
Geometric Mean	110
Standard Deviation	10
Coefficient of variation (%)	9

[1] DS5 not certified for CV-AAS

TABLE A-3-7 HG RESULTS FOR STANDARD REFERENCE MATERIALS BCR 422 (COD MUSCLE) AND BCR-060 (*LAGAROSIPHON MAJOR* (AQUATIC PLANT)).

SRM	Hg	%Recovery	SRM	Hg	%Recovery
BCR-422	0.538	96.2	BCR-060	0.305	89.7
BCR-422	0.542	97.0	BCR-060	0.307	90.3
BCR-422	0.537	96.1	BCR-060	0.317	93.2
BCR-422	0.525	93.9			
BCR-422	0.55	98.4			
BCR-422	0.525	93.9			
BCR-422	0.543	97.1			
BCR-422	0.539	96.4			
BCR-422	0.54	96.6			
BCR-422	0.537	96.1			
BCR-422	0.536	95.9			
BCR-422	0.534	95.5			
BCR-422	0.578	103.4			
BCR-422	0.533	95.3			
BCR-422	0.544	97.3			
BCR-422	0.528	94.5			
BCR-422	0.528	94.5			
BCR-422	0.54	96.6			
BCR-422	0.553	98.9			
BCR-422	0.528	94.5			
BCR-422	0.556	99.5			
BCR-422	0.554	99.1			
BCR-422	0.571	102.1			
Average	0.542	96.9		0.310	91.1
Minimum	0.525	93.9		0.305	89.7
Maximum	0.578	103.4		0.317	93.2
Standard Deviation	0.014	2.4		0.006	1.9
Coeff. Of Variation	2.519	2.5		2.076	2.1
Official min.	0.543			0.30	
Official max.	0.559			0.34	
Official average	0.575			0.38	
Average recovery	97%			91%	

TABLE A-3-8 ANALYTICAL PRECISION (%RELATIVE PERCENT DIFFERENCE, %RPD) FOR FISH AND VEGETABLE SAMPLES

Sample ID	Mercury mg/kg	Replicate 1	Replicate 2	%RPM Rep. 1	%RPD rep. 2
F301	1.240	1.208	1.266	2.6	-2.1
F302	1.970	1.960	1.986	0.5	-0.8
F525	0.637	0.650	0.624	-2.0	2.1
F552	0.497	0.502	0.491	-1.0	1.2
F858	0.431	0.429	0.432	0.5	-0.2
F1101	0.544	0.546	0.542	-0.4	0.4
F1102	0.559	0.555	0.562	0.7	-0.5
F1103	1.016	1.010	1.022	0.6	-0.6
F1104	1.236	1.252	1.219	-1.3	1.4
F1105	0.852	0.851	0.852	0.1	0.0
F1106	0.952	0.959	0.944	-0.7	0.8
F1107	1.250	1.253	1.240	-0.2	0.8
F1108	0.616	0.617	0.614	-0.2	0.3
F1109	0.628	0.631	0.624	-0.5	0.6
F1110	1.136	1.148	1.123	-1.1	1.2
F1111	0.638	0.624	0.652	2.2	-2.2
F1112	0.798	0.814	0.782	-2.0	2.0
F1114	0.906	0.896	0.916	1.1	-1.1
F1115	1.021	1.011	1.030	1.0	-0.9
F1117	1.194	1.194	1.193	0.0	0.1
F1118	0.763	0.751	0.775	1.6	-1.6
F1120	0.715	0.727	0.703	-1.7	1.7
F1122	0.656	0.649	0.663	1.1	-1.1
F1124	1.837	1.796	1.878	2.3	-2.2
F1125	0.825	0.808	0.842	2.1	-2.0
F1506	0.870	0.882	0.858	-1.4	1.4
F1507	0.737	0.725	0.749	1.6	-1.6
F1508	1.307	1.329	1.285	-1.7	1.7
F30905	0.684	0.678	0.690	0.9	-0.9
F70310	0.622	0.616	0.627	1.0	-0.8
F70509	0.665	0.662	0.668	0.5	-0.5
F3061114	1.532	1.521	1.543	0.7	-0.7
F3071013	1.081	1.077	1.081	0.4	0.0
F3150804	0.943	0.931	0.954	1.3	-1.2
F3160312	1.027	1.017	1.037	1.0	-1.0
F4021213	1.621	1.597	1.645	1.5	-1.5
F4050803	2.559	2.612	2.506	-2.0	2.1
F4110409	2.649	2.707	2.590	-2.2	2.3
F4191820	1.669	1.709	1.628	-2.4	2.5
F5331931	0.510	0.508	0.512	0.4	-0.4
F8445041	0.541	0.553	0.528	-2.2	2.4
F8474845	0.792	0.807	0.776	-1.9	2.0
F8564243	0.547	0.548	0.546	-0.2	0.2
F410071615	2.471	2.445	2.496	1.1	-1.0
F417061401	0.995	0.989	1.001	0.6	-0.6
F707040608	1.640	1.656	1.625	-1.0	0.9
A110 Yam	0.092	0.091	0.092	1.1	0.0
			average %RPD	0.1	0.1

%RPD = 100*(Original-Replicate)/((Original-Replicate)/2)

TABLE A-3-9 COMBINED SAMPLING AND ANALYTICAL PRECISION (RELATIVE PERCENT DIFFERENCE) FOR DUPLICATE FISH SAMPLES

Original	Duplicate	Original Hg (mg/kg)	Duplicate Hg (mg/kg)	%RPD
110	1511	0.002	0.004	-67
1202	1502	0.002	0.002	0
113	1515	0.01	0.012	-18
117	1519	0.012	0.013	-8
107	1510	0.015	0.018	-18
105	1520	0.025	0.021	17
112	1513	0.025	0.032	-25
101	1514	0.026	0.019	31
209	1509	0.028	0.055	-65
120	1518	0.031	0.031	0
1201	1503	0.031	0.002	176
104	1517	0.034	0.024	34
122	1512	0.034	0.043	-23
119	1521	0.043	0.073	-52
1004	1501	0.048	0.073	-41
526	1504	0.163	0.152	7
521	1505	0.187	0.208	-11
1122	1507	0.656	0.737	-12
1103	1506	1.016	0.87	15
1107	1508	1.25	1.307	-4

	%RPD
Average	-13
Minimum	-67
Maximum	34
Average(>0.1)	-1
min (>0.1 mg/kg)	-12
max (>0.1 mg/kg)	15
average (<0.1 mg/kg)	-4
min. (<0.1 mg/kg)	-67
max. (<0.1 mg/kg)	176

%RPD = 100*(Original-Replicate)/((Original-Replicate)/2)

Appendix 4

TABLE A-4-1 RWAMAGASA, SEDIMENT, SOIL AND TAILINGS SAMPLES: LOCATION AND ANALYTICAL DATA

Number	Type	Easting	Northing	As	Cd	Cu	Fe	Hg	Pb	Zn	TOC
1	SEDIMENT	31.90671	-3.20417	1	0.25	12	0.87	0.090	11	13	2.77
2	SEDIMENT	31.90851	-3.20446	1	0.25	5	0.28	0.190	5	5	1.07
3	SEDIMENT	31.90932	-3.20479	1	0.25	2	0.16	0.105	3	8	0.16
4	TAILINGS	32.04276	-3.11665	6	15.70	377	3.21	15.000	5	1588	
5	TAILINGS	32.04276	-3.11665	8	13.90	368	2.72	54.000	2	1476	
6	TAILINGS	32.04276	-3.11665	8	14.00	392	2.75	59.000	2	1487	
7	TAILINGS	32.04136	-3.11522	28	0.25	99	6.88	1.525	101	85	
8	TAILINGS	32.04121	-3.11513	21	0.25	92	4.75	3.605	23	76	
9	TAILINGS	32.04177	-3.11523	25	0.25	118	3.32	39.000	22	92	
10	TAILINGS	32.04187	-3.11453	38	1.20	103	4.02	23.000	24	136	
11	TAILINGS	32.04187	-3.11453	40	2.10	176	5.50	83.000	51	243	
12	TAILINGS	32.04187	-3.11453	18	1.30	109	3.06	118.000	32	133	
13	TAILINGS	32.04170	-3.11438	39	1.70	120	4.45	50.000	95	192	
14	TAILINGS	32.04170	-3.11438	25	1.80	127	3.76	35.000	32	200	
15	TAILINGS	32.04120	-3.11380	12	0.80	108	4.66	2.825	11	144	
17	TAILINGS	32.04120	-3.11380	18	2.00	231	4.49	81.000	5	260	
18	TAILINGS	32.04075	-3.11450	23	1.40	96	4.54	2.640	16	169	
19	TAILINGS	32.04075	-3.11450	27	8.10	179	4.30	104.000	36	803	
20	TAILINGS	32.04039	-3.11503	21	0.50	115	8.54	13.910	22	143	
21	TAILINGS	32.04039	-3.11503	20	0.60	104	6.38	18.000	23	137	
22	TAILINGS	32.04039	-3.11503	55	1.00	146	4.43	165.000	48	153	
23	TAILINGS	32.04017	-3.11378	22	0.25	95	4.02	1.055	21	49	
24	TAILINGS	32.03992	-3.11387	25	0.25	153	6.56	4.630	20	112	
25	TAILINGS	32.03992	-3.11387	26	0.25	154	6.57	4.325	16	112	
26	TAILINGS	32.03960	-3.11410	22	0.25	83	5.02	3.130	17	53	
27	TAILINGS	32.03944	-3.11364	29	0.25	91	5.01	1.945	27	61	
28	TAILINGS	32.03831	-3.11401	49	0.70	109	5.56	193.000	23	100	
29	TAILINGS	32.03831	-3.11401	40	0.50	88	4.75	6.015	12	78	
30	TAILINGS	32.03831	-3.11401	39	0.60	90	4.58	6.675	15	87	
31	TAILINGS	32.03833	-3.11305	21	0.50	77	3.55	1.735	12	63	
32	TAILINGS	32.03833	-3.11305	18	0.25	88	4.38	1.395	16	54	
33	TAILINGS	32.03815	-3.11320	23	0.25	90	4.21	0.690	34	39	
34	TAILINGS	32.03815	-3.11320	30	0.60	103	4.69	18.170	30	108	
35	TAILINGS	32.03815	-3.11320	14	0.60	57	2.69	1.455	8	89	
36	TAILINGS	32.03815	-3.11320	34	1.30	117	4.72	128.000	28	159	
37	TAILINGS	32.03898	-3.11241	44	0.90	135	7.00	7.195	25	150	
38	TAILINGS	32.03898	-3.11241	25	0.60	80	3.84	4.630	10	96	
39	TAILINGS	32.03902	-3.11244	23	0.90	92	3.85	7.940	11	119	

Number											TOC
40	TAILINGS	32.03902	-3.11244	63	0.25	108	4.97	127.000	23	82	
41	TAILINGS	32.03902	-3.11244	62	0.25	126	5.10	118.000	28	92	
42	TAILINGS	32.03910	-3.11247	26	1.00	142	4.38	5.335	12	117	
43	TAILINGS	32.03910	-3.11247	27	1.00	151	4.40	3.685	13	121	
44	TAILINGS	32.03920	-3.11266	20	1.00	92	4.07	8.230	20	110	
45	TAILINGS	32.03920	-3.11266	39	1.40	353	6.38	21.000	42	168	
46	TAILINGS	32.03928	-3.11306	20	0.80	91	4.54	2.620	14	113	
47	TAILINGS	32.03928	-3.11306	21	0.60	91	4.98	2.915	13	111	
48	TAILINGS	32.03928	-3.11306	26	0.25	95	5.12	0.420	36	64	
49	TAILINGS	32.03961	-3.11275	19	0.25	97	4.35	4.410	39	95	
50	TAILINGS	32.03985	-3.11280	23	0.25	149	5.04	1.780	18	84	
51	TAILINGS	32.03985	-3.11280	15	0.25	74	3.62	0.165	11	77	
52	TAILINGS	32.04027	-3.11288	46	0.25	78	4.14	0.645	24	58	
53	TAILINGS	32.03936	-3.11185	19	0.25	76	4.22	38.000	15	42	
54	TAILINGS	32.03936	-3.11185	21	0.25	80	4.27	1.730	15	61	
55	TAILINGS	32.03891	-3.11186	15	0.25	61	3.99	2.320	10	38	
56	TAILINGS	32.03795	-3.11121	23	0.25	95	4.87	5.795	13	66	
57	TAILINGS	32.03795	-3.11121	18	0.25	67	3.58	2.780	10	43	
58	TAILINGS	32.03795	-3.11121	19	0.25	66	3.63	2.785	10	45	
59	TAILINGS	32.03805	-3.11092	18	1.60	125	4.22	12.540	8	181	
60	TAILINGS	32.03805	-3.11092	18	1.50	120	4.50	12.870	7	162	
61	TAILINGS	32.03927	-3.11058	19	0.50	83	3.65	2.715	8	90	
62	TAILINGS	32.03927	-3.11058	20	0.80	78	4.51	2.445	8	111	
63	TAILINGS	32.03898	-3.11052	22	1.70	148	5.56	8.030	10	214	
64	TAILINGS	32.03897	-3.11072	20	0.25	68	4.96	1.175	7	67	
65	TAILINGS	32.03897	-3.11072	28	0.50	78	3.46	1.560	6	80	
66	TAILINGS	32.03868	-3.11069	21	0.25	82	4.53	2.510	9	55	
67	TAILINGS	32.03868	-3.11069	19	0.25	77	3.64	2.295	10	52	
68	SEDIMENT	32.04030	-3.11041	4	0.25	82	4.82	3.020	13	59	4.50
69	SEDIMENT	32.04188	-3.10963	2	0.25	75	3.97	0.180	9	68	6.27
70	SEDIMENT	32.04188	-3.10963	1	0.25	65	3.54	0.140	9	62	6.30
72	SOIL	31.99214	-3.12494	1	0.25	43	5.11	0.025	5	13	2.56
73	SOIL	31.99272	-3.13209	2	0.25	29	2.95	0.010	10	10	3.20
74	SOIL	31.99072	-3.13532	5	0.25	38	2.84	0.055	15	26	4.60
75	SOIL	31.99094	-3.13506	7	0.25	33	2.84	0.040	13	26	2.99
76	SOIL	31.99094	-3.13506	12	0.25	37	3.65	0.090	12	30	3.17
77	SOIL	31.99094	-3.13506	3	0.25	37	2.81	0.030	14	29	3.91
78	SOIL	31.99094	-3.13506	8	0.25	34	2.90	0.045	12	27	3.40
79	SOIL	31.99127	-3.13486	5	0.25	33	3.15	0.015	11	23	4.00
80	SOIL	31.99226	-3.13493	4	0.25	28	2.93	0.010	13	27	3.76
81	SOIL	31.99649	-3.13621	1	0.25	20	1.47	0.035	12	12	2.11
82	SEDIMENT	31.99686	-3.13608	3	0.25	16	1.14	0.040	11	13	1.83
83	SOIL	31.99695	-3.13636	1	0.25	14	1.06	0.030	11	12	2.41
84	SOIL	31.99747	-3.13675	2	0.25	13	1.43	0.005	8	10	3.05
85	SEDIMENT	32.00508	-3.12349	3	0.25	54	5.08	0.065	11	36	1.73
86	SEDIMENT	32.04130	-3.12501	1	0.25	58	3.38	0.315	18	57	3.18
87	SEDIMENT	32.01278	-3.08087	1	0.25	5	0.62	0.085	8	12	1.33
88	SEDIMENT	32.01396	-3.10443	1	0.25	40	3.38	0.035	10	29	1.34
89	SOIL	32.01449	-3.10452	1	0.25	19	1.81	0.015	14	15	2.87
90	SOIL	32.01449	-3.10452	1	0.25	19	1.72	0.015	14	15	2.83

Number	Type	Easting	Northing	As	Cd	Cu	Fe	Hg	Pb	Zn	TOC
91	SOIL	32.01600	-3.10769	5	0.25	58	4.77	0.090	11	42	2.61
92	SOIL	32.01600	-3.10769	3	0.25	62	4.63	0.095	13	56	3.76
93	SOIL	32.01691	-3.10949	4	0.25	46	5.06	0.020	10	19	3.24
94	SOIL	32.01691	-3.10949	1	0.25	42	4.39	0.015	12	14	4.33
95	SOIL	32.01670	-3.11295	7	0.25	55	6.86	0.040	10	17	3.36
96	SOIL	32.02206	-3.11757	7	0.25	43	5.98	0.065	12	16	2.64
97	SOIL	32.02206	-3.11757	4	0.25	44	6.09	0.025	8	16	3.01
98	SEDIMENT	32.02824	-3.11159	9	0.25	77	6.42	0.385	14	44	3.80
99	SEDIMENT	32.03094	-3.11199	16	0.25	106	6.96	1.210	38	80	2.26
100	SEDIMENT	32.03486	-3.11198	13	0.70	108	5.39	2.835	11	90	4.07
101	TAILINGS	32.05098	-3.11946	2	6.10	179	2.28	0.265	2	513	
102	TAILINGS	32.05053	-3.11929	7	22.10	332	2.47	26.000	2	1956	
103	TAILINGS	32.05053	-3.11929	10	22.10	335	2.71	31.000	3	1986	
104	SEDIMENT	32.07893	-3.07891	1	0.25	13	0.78	0.075	18	20	2.61
105	SEDIMENT	31.98780	-3.11910	6	0.25	40	3.08	0.670	15	35	3.16
106	SEDIMENT	32.00511	-3.12350	8	0.25	49	5.12	0.175	6	25	3.49
107	SEDIMENT	32.03365	-3.11236	7	0.25	51	4.23	0.075	9	37	3.26
114	SOIL	32.03874	-3.11237	12	0.25	77	5.05	0.950	7	62	3.49
115	SOIL	32.03874	-3.11237	13	0.25	45	4.83	0.365	7	37	2.90
116	SOIL	32.03876	-3.11210	11	0.25	65	4.94	1.380	7	64	2.85
118	SOIL	32.04497	-3.10917	18	0.25	53	10.39	0.035	9	26	2.76
119	SOIL	32.04530	-3.11091	6	0.25	35	4.40	0.020	7	17	1.48
120	SOIL	32.04554	-3.11267	12	0.25	48	8.58	0.030	9	13	1.80
121	SOIL	32.04554	-3.11445	4	0.25	36	3.92	0.025	4	16	2.63
122	SOIL	32.04557	-3.11628	7	0.25	69	9.79	0.030	9	27	2.60
123	SOIL	32.04555	-3.11808	5	0.25	42	5.95	0.030	13	19	1.46
124	SOIL	32.04378	-3.11816	6	0.25	36	5.44	0.040	13	60	1.50
125	SOIL	32.04392	-3.11630	3	0.25	40	4.51	0.070	11	84	3.16
126	SOIL	32.04373	-3.11450	1	0.25	51	5.01	0.060	7	22	2.05
127	SOIL	32.04388	-3.11268	4	0.25	35	2.97	0.070	5	13	2.03
128	SOIL	32.04383	-3.11092	6	0.25	22	3.21	0.010	8	11	2.13
129	SOIL	32.04392	-3.10915	7	0.25	44	3.71	0.020	12	33	3.28
130	SOIL	32.04228	-3.10988	8	0.25	47	7.47	0.020	11	32	4.87
131	SOIL	32.04235	-3.11169	5	0.25	33	2.92	0.085	7	65	3.24
132	SOIL	32.04243	-3.11358	3	0.25	29	2.56	0.180	5	60	2.01
133	SOIL	32.04256	-3.11533	7	0.25	88	7.37	0.145	6	101	1.96
134	SOIL	32.04256	-3.11533	8	0.25	87	7.58	0.150	6	100	2.12
135	SOIL	32.04252	-3.11717	7	0.25	36	6.88	0.070	9	31	1.50
136	SOIL	32.04185	-3.11891	6	0.25	49	7.22	0.095	10	39	2.48
137	SOIL	32.03994	-3.11899	2	0.25	44	5.06	0.005	6	17	1.33
138	SOIL	32.04013	-3.11718	4	0.25	39	5.75	0.165	7	139	2.50
139	SOIL	32.04044	-3.11549	2	0.25	60	4.86	0.570	8	104	2.74
140	SOIL	32.04090	-3.11359	67	0.25	180	8.35	1.440	2	120	0.31
141	SOIL	32.04055	-3.11181	3	0.25	30	2.91	0.080	5	23	2.00
142	SOIL	32.04055	-3.11181	1	0.25	29	2.73	0.065	7	19	1.99
143	SOIL	32.04093	-3.11001	1	0.25	56	3.42	0.075	7	57	5.90
144	SOIL	32.04806	-3.11911	5	0.25	39	6.26	0.020	6	19	1.21
200	SOIL	31.99180	-3.13485	4	0.25	34	3.32	0.005	8	25	2.28
201	SOIL	31.99308	-3.13482	2	0.25	22	2.17	0.005	6	22	2.80
202	SOIL	31.99683	-3.13567	1	0.25	14	1.05	0.005	4	10	1.66

Number	Type	Easting	Northing	As	Cd	Cu	Fe	Hg	Pb	Zn	TOC
203	SEDIMENT	31.99683	-3.13607	1	0.25	24	1.43	0.335	13	336	2.36
204	SOIL	31.99695	-3.13636	1	0.25	14	1.03	0.020	11	14	1.88
205	SOIL	31.99800	-3.13711	1	0.25	16	1.44	0.015	11	13	2.53
206	SOIL	31.99863	-3.13737	1	0.25	16	1.54	0.010	8	15	2.16
207	SOIL	31.99949	-3.13743	3	0.25	10	1.08	0.005	8	10	1.87
208	SOIL	32.00471	-3.12539	2	0.25	27	2.13	0.020	8	17	2.18
209	SOIL	32.00471	-3.12539	3	0.25	33	2.71	0.090	12	23	2.74
210	SOIL	32.00888	-3.12505	6	0.25	42	4.30	0.025	6	14	3.30
211	SOIL	32.01253	-3.12732	10	0.25	27	2.87	0.010	6	13	1.78
212	SOIL	32.01679	-3.12663	12	0.25	27	4.06	0.010	11	17	1.60
213	SOIL	32.02149	-3.12651	3	0.25	25	3.83	0.015	10	21	3.55
214	SOIL	32.02537	-3.12529	4	0.25	47	7.10	0.020	12	21	3.56
215	SOIL	32.02912	-3.12325	3	0.25	54	5.61	0.020	11	23	2.94
216	SOIL	32.03254	-3.12052	4	0.25	54	5.51	0.010	11	24	2.65
217	SOIL	32.03581	-3.11784	2	0.25	44	5.10	0.050	12	22	2.15
218	SEDIMENT	32.04130	-3.12501	1	0.25	59	3.49	0.850	33	592	4.23
219	SOIL	32.02589	-3.11140	3	0.25	56	6.55	0.030	13	19	3.52
220	SOIL	32.02603	-3.11084	10	0.25	73	7.13	0.020	10	28	2.11
221	SOIL	32.02590	-3.11042	14	0.25	90	9.17	0.025	9	36	1.55
222	SOIL	32.02590	-3.11042	13	0.50	86	8.58	0.025	11	37	1.68
223	SOIL	32.02587	-3.11025	5	0.25	70	6.57	0.060	7	27	4.42
224	SOIL	32.02622	-3.11022	3	0.25	65	6.87	0.025	7	17	3.28
225	SOIL	32.03003	-3.11172	8	0.25	72	5.52	0.425	11	49	3.68
226	SOIL	32.02992	-3.11193	6	0.25	60	5.65	0.055	5	34	1.25
227	SOIL	32.02986	-3.11244	5	0.25	56	6.89	0.090	11	20	3.57
228	SOIL	32.03272	-3.11438	1	0.25	38	2.53	0.005	6	18	3.20
229	SOIL	32.03441	-3.11490	4	0.25	33	2.86	0.005	2	17	4.32
230	SOIL	32.03481	-3.11425	3	0.25	28	2.06	0.045	7	26	3.21
231	SOIL	32.03498	-3.11363	7	0.25	51	3.83	0.030	3	27	2.80
232	SOIL	32.03498	-3.11363	7	0.25	51	3.76	0.030	7	28	2.88
233	SOIL	32.03490	-3.11298	6	0.25	50	3.71	0.160	7	40	3.22
234	SOIL	32.03483	-3.11236	7	0.25	66	4.32	1.335	7	47	3.23
235	SOIL	32.03468	-3.11184	3	0.25	51	3.99	0.050	12	39	3.10
236	SOIL	32.03470	-3.11141	6	0.25	49	4.24	0.035	6	30	3.33
237	SOIL	32.03829	-3.11133	3	0.25	48	4.97	0.080	4	37	3.22
238	SOIL	32.03733	-3.11140	23	1.30	176	6.99	9.205	12	161	3.14
239	SOIL	32.03645	-3.11158	4	0.25	59	4.57	0.085	8	48	2.53
240	SOIL	32.03558	-3.11169	5	0.25	49	4.86	0.030	5	38	1.92
241	SOIL	32.03555	-3.11268	6	0.25	31	4.41	0.030	8	19	2.41
242	SOIL	32.03547	-3.11361	7	0.25	23	1.94	0.005	4	11	1.07
243	SOIL	32.03547	-3.11450	3	0.25	31	1.98	0.025	4	23	2.35
244	SOIL	32.03547	-3.11450	1	0.25	14	1.07	0.025	3	11	2.15
245	SOIL	32.03547	-3.11450	2	0.25	14	1.05	0.020	3	11	2.30
246	SOIL	32.03547	-3.11450	1	0.25	13	0.93	0.015	2	7	1.18
247	SOIL	32.03547	-3.11450	1	0.25	10	0.78	0.005	3	5	0.65
248	SOIL	32.03547	-3.11450	1	0.25	9	0.57	0.010	2	4	0.52
249	SOIL	32.03540	-3.11539	2	0.25	29	2.24	0.030	2	23	2.64
250	SOIL	32.03628	-3.11562	1	0.25	30	3.58	0.040	5	21	2.15
251	SOIL	32.03629	-3.11461	2	0.25	18	1.64	0.055	5	13	1.67
252	SOIL	32.03624	-3.11366	4	0.25	20	2.09	0.020	5	10	1.55

Number											
253	SOIL	32.03609	-3.11284	8	0.25	46	3.99	0.175	6	33	3.81
254	SOIL	32.03597	-3.11185	10	0.25	70	5.34	1.185	7	44	3.28
255	SOIL	32.03597	-3.11185	9	0.50	67	5.27	1.125	8	45	2.76
256	SOIL	32.03606	-3.11096	16	0.25	52	5.11	0.055	6	114	4.24
257	SOIL	32.03702	-3.11093	5	0.25	50	5.16	0.070	5	41	2.88
258	SOIL	32.03681	-3.11186	5	0.25	66	4.20	1.260	12	37	4.72
259	SOIL	32.03681	-3.11186	4	0.25	75	4.57	1.460	12	42	4.74
260	SOIL	32.03689	-3.11274	2	0.25	54	4.95	0.270	8	40	2.32
261	SOIL	32.03693	-3.11369	1	0.25	11	1.05	0.015	2	8	1.13
262	SOIL	32.03700	-3.11457	2	0.25	24	2.65	0.050	7	14	1.83
263	SOIL	32.03791	-3.11458	4	0.25	38	8.70	0.055	11	19	2.18
264	SOIL	32.03790	-3.11369	1	0.25	21	2.16	0.050	3	12	1.60
265	SOIL	32.03799	-3.11270	11	0.90	117	4.52	4.875	9	133	2.69
266	SOIL	32.03799	-3.11270	9	1.20	122	4.73	5.280	10	143	2.51
267	SOIL	32.03799	-3.11270	8	0.80	119	4.62	4.290	13	113	3.27
268	SOIL	32.03799	-3.11270	2	0.25	36	2.73	0.050	4	32	1.51
269	SOIL	32.03799	-3.11270	3	0.25	36	2.79	0.020	6	28	1.20
270	SOIL	32.03799	-3.11270	2	0.25	39	3.60	0.025	6	31	1.11
271	SOIL	32.03799	-3.11270	1	0.25	48	5.45	0.040	5	41	0.83
272	SOIL	32.03793	-3.11191	3	0.25	50	4.09	0.155	7	36	3.52
273	SOIL	32.03773	-3.11091	31	1.00	123	5.72	7.160	10	115	1.65
274	SOIL	32.03773	-3.11091	30	1.10	129	5.81	6.380	8	118	1.54
275	SOIL	32.03764	-3.10996	22	0.25	51	4.78	0.030	10	65	3.19
276	SOIL	32.03843	-3.11227	6	0.25	56	3.71	1.145	7	54	3.63
277	SOIL	32.03843	-3.11227	4	0.25	51	4.75	0.095	7	32	0.78
279	SOIL	32.03843	-3.11227	7	0.50	69	4.21	2.650	12	73	3.34
280	SOIL	32.03843	-3.11227	7	0.50	66	3.43	1.825	8	72	3.82
281	SOIL	32.03843	-3.11227	8	0.25	45	3.89	0.200	4	28	1.73
282	SOIL	32.03843	-3.11227	8	0.25	45	4.37	0.040	4	27	0.92
283	SOIL	32.03843	-3.11227	6	0.25	51	4.96	0.065	6	35	0.66
284	SOIL	32.03843	-3.11227	9	0.25	53	5.15	0.030	5	37	0.58
285	SOIL	32.03852	-3.11316	29	1.20	136	5.11	8.855	15	176	0.65
286	SOIL	32.03858	-3.11417	5	0.25	40	5.67	0.075	11	25	2.46
287	SOIL	32.03959	-3.11413	7	0.25	57	5.57	1.135	16	84	2.65
288	SOIL	32.03950	-3.11272	8	0.25	47	5.38	0.290	9	34	3.08
289	SOIL	32.05076	-3.12008	3	6.20	226	4.96	0.390	2	651	1.44
290	SOIL	32.04942	-3.12130	2	0.25	36	3.90	0.065	12	24	3.22
291	SOIL	32.03427	-3.11222	1	0.25	50	3.88	0.050	8	39	3.72
292	SOIL	32.03448	-3.11253	11	0.25	69	4.55	1.560	15	55	3.81
293	SOIL	32.03404	-3.11234	2	0.25	51	3.70	0.005	8	49	6.25
294	SOIL	32.03512	-3.11179	6	0.25	52	4.71	0.275	11	42	4.59
296	SOIL	32.03467	-3.11202	5	0.25	44	4.07	0.085	8	36	3.38
297	SOIL	32.03568	-3.11161	1	0.25	51	4.87	0.055	10	41	2.42
298	SOIL	32.04678	-3.11767	2	0.25	48	6.10	0.045	13	25	1.83
299	SOIL	32.04844	-3.11763	3	0.25	36	4.42	0.035	9	21	2.58
300	SOIL	32.04915	-3.11614	3	0.25	36	6.24	0.045	9	21	2.46
301	SOIL	32.05131	-3.11685	2	0.25	37	4.68	0.050	8	24	3.14
302	SOIL	32.05487	-3.11489	1	0.25	55	6.51	0.040	10	23	2.86

TABLE A-4-2 ILAGALA-UVINSA SEDIMENT SAMPLES: LOCATION AND ANALYTICAL DATA

AREA	NUMBER	EASTING	NORTHING	As	Cd	Cu	Fe	Hg	Pb	Zn	ORGC
K	1	29.84243	-5.21052	1	0.3	49	4.14	455	10	42	2.90
K	2	29.84243	-5.21052	1	0.3	49	4.17	655	11	186	3.62
K	3	29.84243	-5.21052	1	0.3	44	3.95	160	10	50	2.70
K	4	29.86371	-5.19843	1	0.3	55	4.40	615	10	49	3.00
K	5	29.85630	-5.20530	3	0.3	42	3.96	95	12	37	3.31
K	7	30.40343	-5.10650	1	0.3	9	1.11	165	6	11	0.86
K	8	30.39016	-5.11111	1	0.3	7	1.04	240	7	11	0.80

TABLE A-4-3 HG (µG/L) IN FILTERED WATER SAMPLES, RWAMAGASA AREA

Sample Number	Hg µg/l	Source
16	0.01	Well
68	0.05	Drainage
69	0.04	Drainage
85	0.05	Drainage
86	0.04	Drainage
87	0.04	Drainage
88	0.05	Drainage
98	0.03	Drainage
99	0.04	Drainage
100	0.07	Drainage
104	0.05	Drainage
105	0.05	Drainage
108	0.43	Hg amalgamation pond
109	0.45	Hg amalgamation pond

Summary statistics (drainage and well)	
Average	0.04
Minimum	0.01
Maximum	0.07
Geometric Mean	0.04
Standard Deviation	0.01

TABLE A-4-4 HG (µG/L) IN FILTERED WATER SAMPLES, KIGOMA AREA

Sample Number	Hg µg/l
1	0.01
2	0.02
3	0.01
4	0.02
5	0.02
7	0.03
8	0.02

Summary statistics	
Average	0.02
Minimum	0.01
Maximum	0.03
Geometric Mean	0.02
Standard Deviation	0.00

TABLE A-4-5 AS (µG/L) IN FILTERED WATER SAMPLES, RWAMAGASA AREA

Sample Number	As µg/l
16	0.13
68	0.71
69	0.86
70	0.77
71	0.13
85	2.22
86	0.65
87	0.51
88	0.36
98	0.89
99	1.18
100	1.26
104	0.13
105	2.42
108	0.54
109	1.50
218	0.62

Average	0.87
Minimum	0.13
Maximum	2.42
Geometric Mean	0.63
Standard Deviation	0.67

Appendix 5 : PLATES

Plate 1. View of pit head and waste rock tip, Blue Reef Mine, Rwamagasa

Plate 2. Blue Reef Mine, Rwamagasa

Plate 3. Gold and sulphide-bearing quartz from Blue reef Mine, Rwamagasa

Plate 4. Gold bearing quartz ore awaiting mineral processing, Rwamagasa mine.

Plate 5. Ball mills in fenced mineral processing compound, Blue Reef mine, Rwamagasa

Plate 6. Petrol motor–driven ball mills in fenced mineral processing compound, Blue Reef mine, Rwamagasa

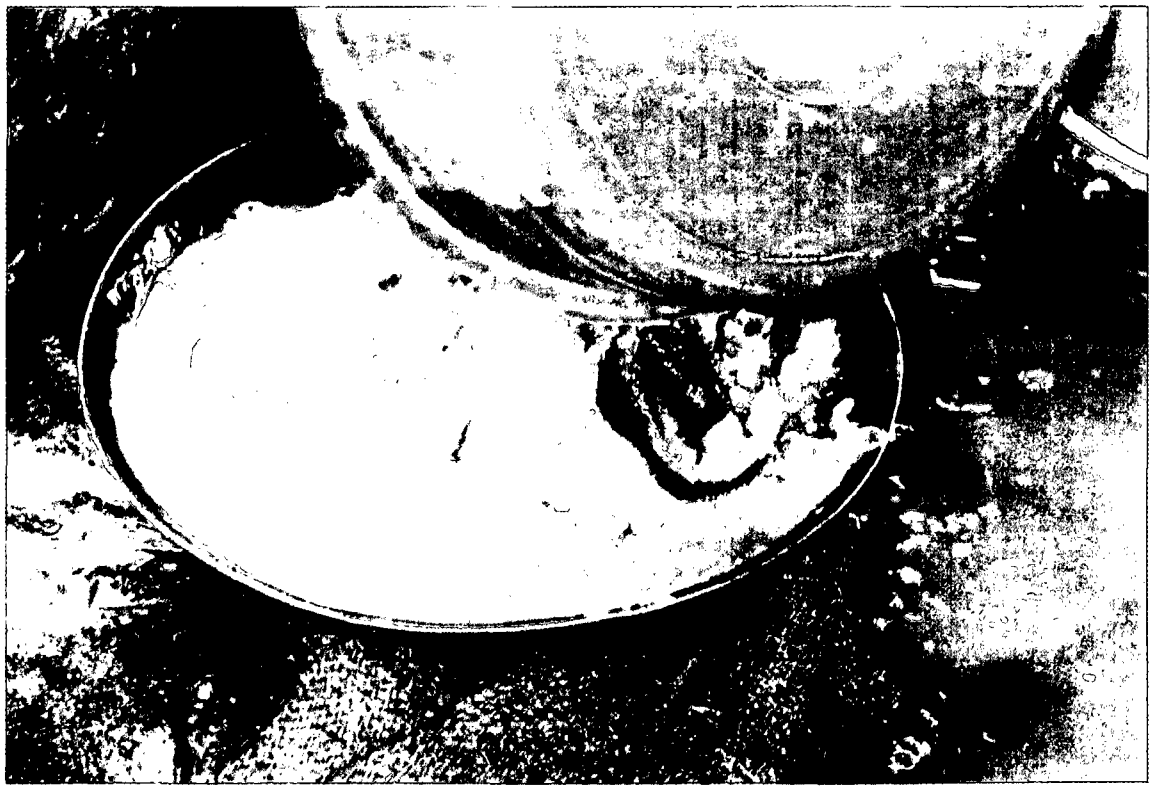


Plate 7. Artisanal miner using bare hands to mix mercury with sluice heavy mineral concentrate (Blue Reef Mine)

Plate 8. Agitating pan to promote settling of amalgam and mercury, Blue Reef Mine

Plate 9. Residual mercury and amalgam at end of amalgamation process (Blue Reef Mine)

Plate 10. Decanting mercury and amalgam into cloth for removal of excess mercury by squeezing (Blue Reef Mine)

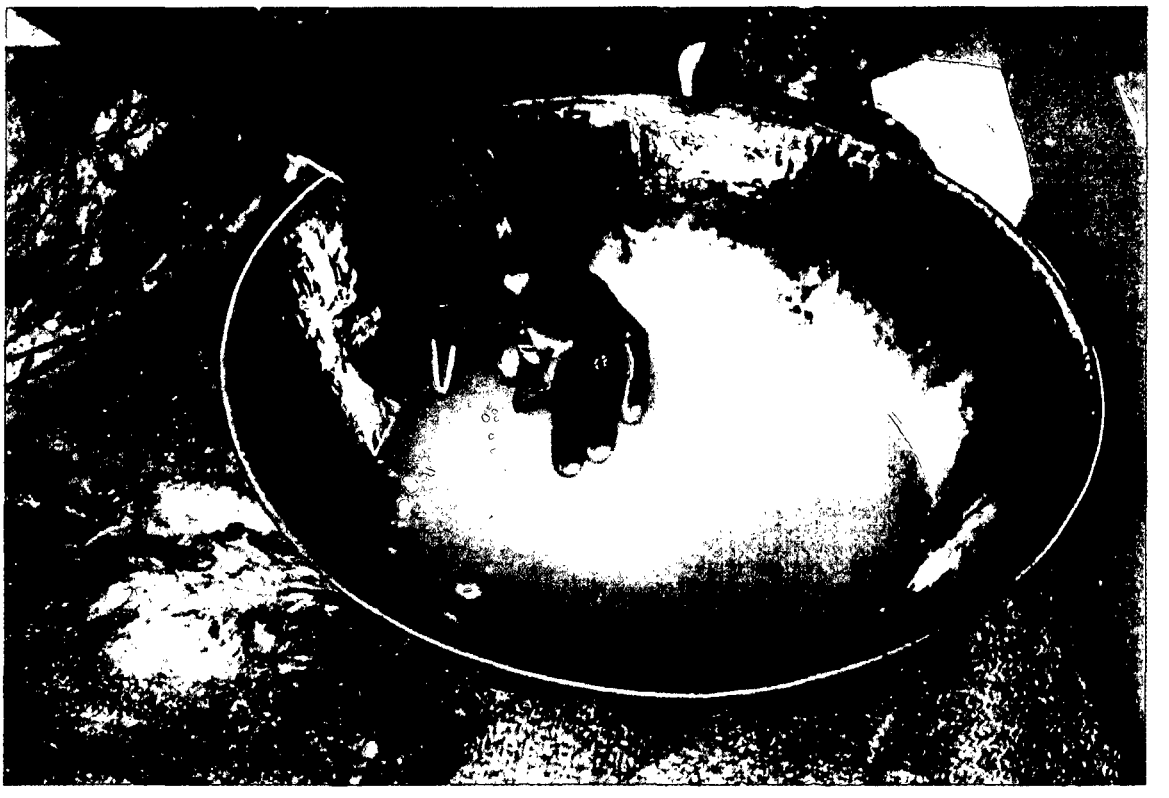


Plate 11. Squeezing cloth to remove excess mercury (Blue Reef Mine)

Plate 12. Amalgam placed in paper for burning in charcoal fire (Blue reef mine).

Plate 13. Burning amalgam in charcoal fire to drive off mercury (Blue Reef mine)

Plate 14. Wood used to retain amalgamation tailings pond at site A41-A42. Note the mercury contaminated heavy mineral tailings are being removed for re-processing. Note also, proximity of amalgamation pond to cultivated are where yams, maize and beans are being grown. There was evidence at the site that water-borne tailings contaminate the cultivated area.

Plate 15. Covered amalgamation pond and sluices at tailings reprocessing site (A031) overlooking the *mbuga* of the River Isingile.

Plate 16. Sluices at historic tailings reprocessing site (A031) overlooking the *mbuga* of the River Isingile.

Plate 17. Covered amalgamation pond and sluices at tailings reprocessing site (A031) overlooking the *mbuga* of the River Isingile.

Plate 18. Sluices at tailings reprocessing site (A42-43) on the slope to the north of Rwamagasa village.

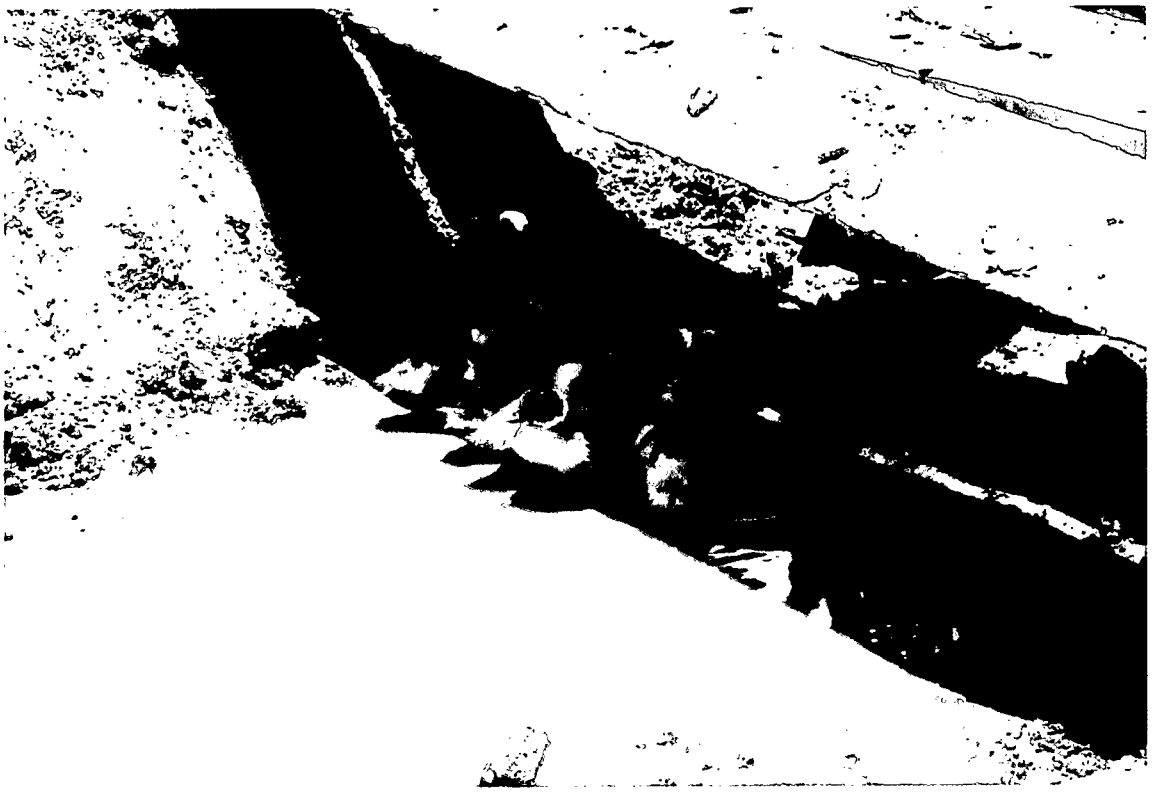


Plate 34. Ducklings paddling in water that had overflown from an amalgamation pond (tailings sample site A20-22)

Plate 20. Deploying the Van Veen grab sampler, Malagarasi River, near Ilagala.

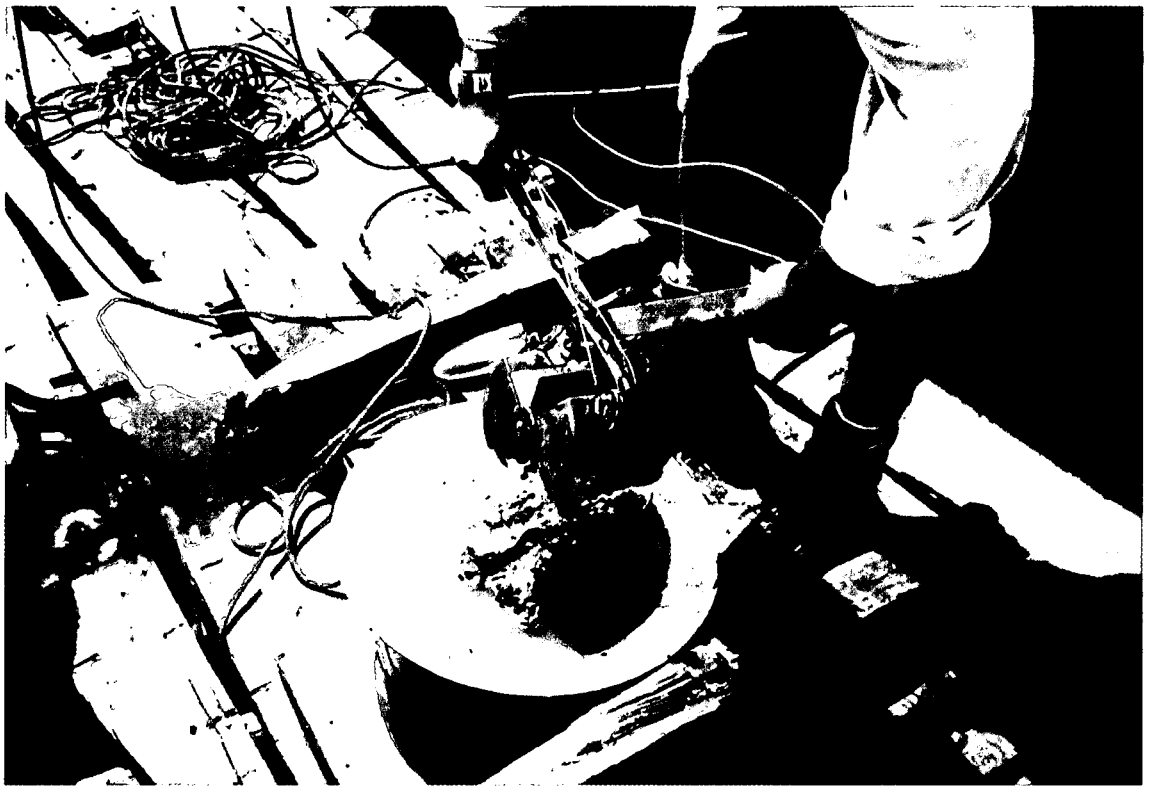


Plate 21 Emptying sub-sample of bottom sediment from Van Veen grab sampler, Malagarasi River, near Ilagala

Plate 22 River sediment sampling about 1 km upstream from Uvinsa, Malagarasi River. Sediment in pan has been wet-sieved through 2mm and 150µm sieves.

Plate 23. Nikonga River (stream sediment site A1 to A3 (Figure 10)

Plate 24. Attempting to catch fish at Pond 1, Isingile River (see location map, Figure 11)

Plate 25. Attempting to catch fish by netting Pond 4 (see location map, Figure 11)

Plate 26. Attempting to catch fish by draining Pond 2, Isingile River (see location map, Figure 11)

Plate 27. Measuring water pH, Eh and conductivity at site A69 (see Figure 9).

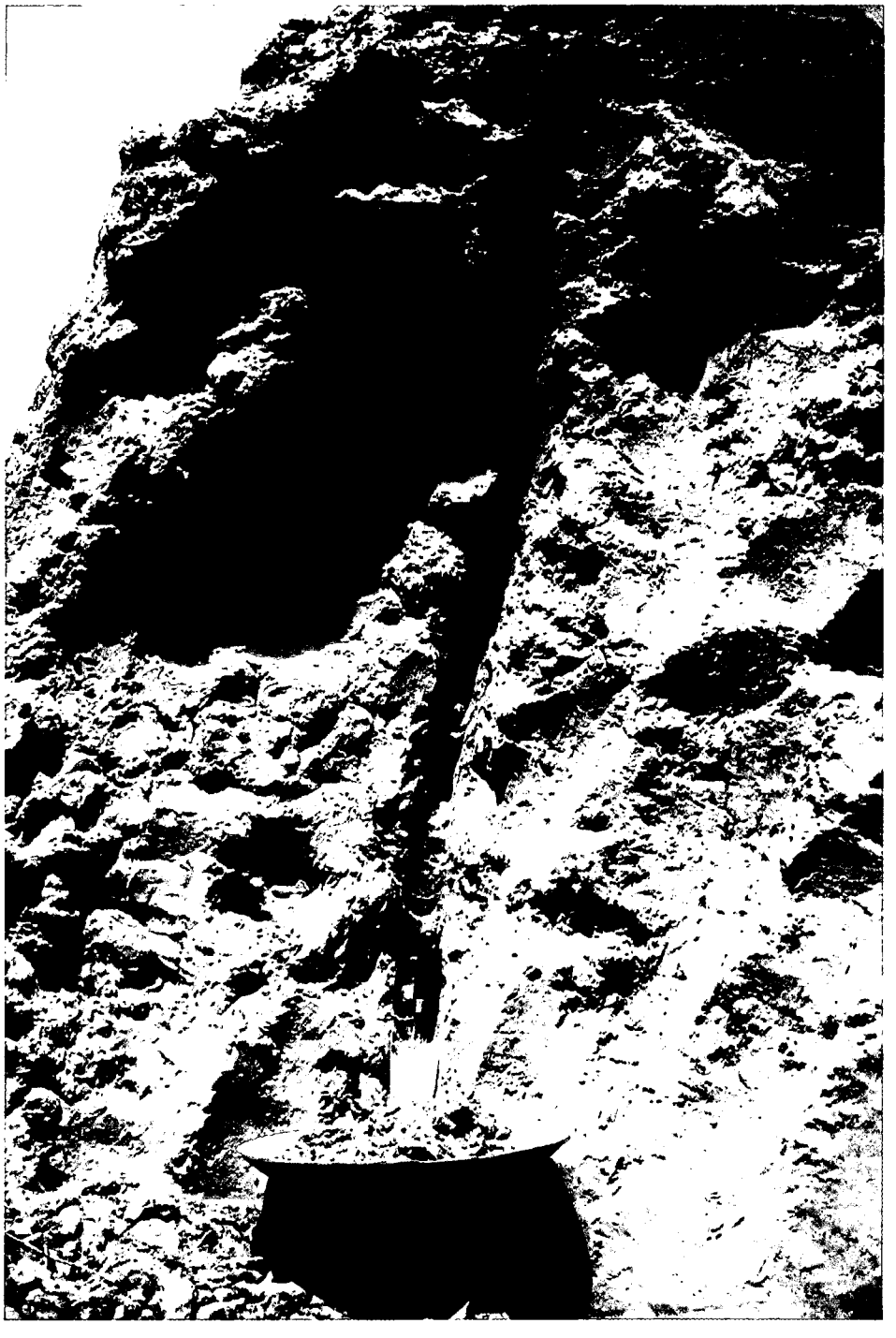


Plate 28. Channel sampling of tailings pile being reworked (site A23)

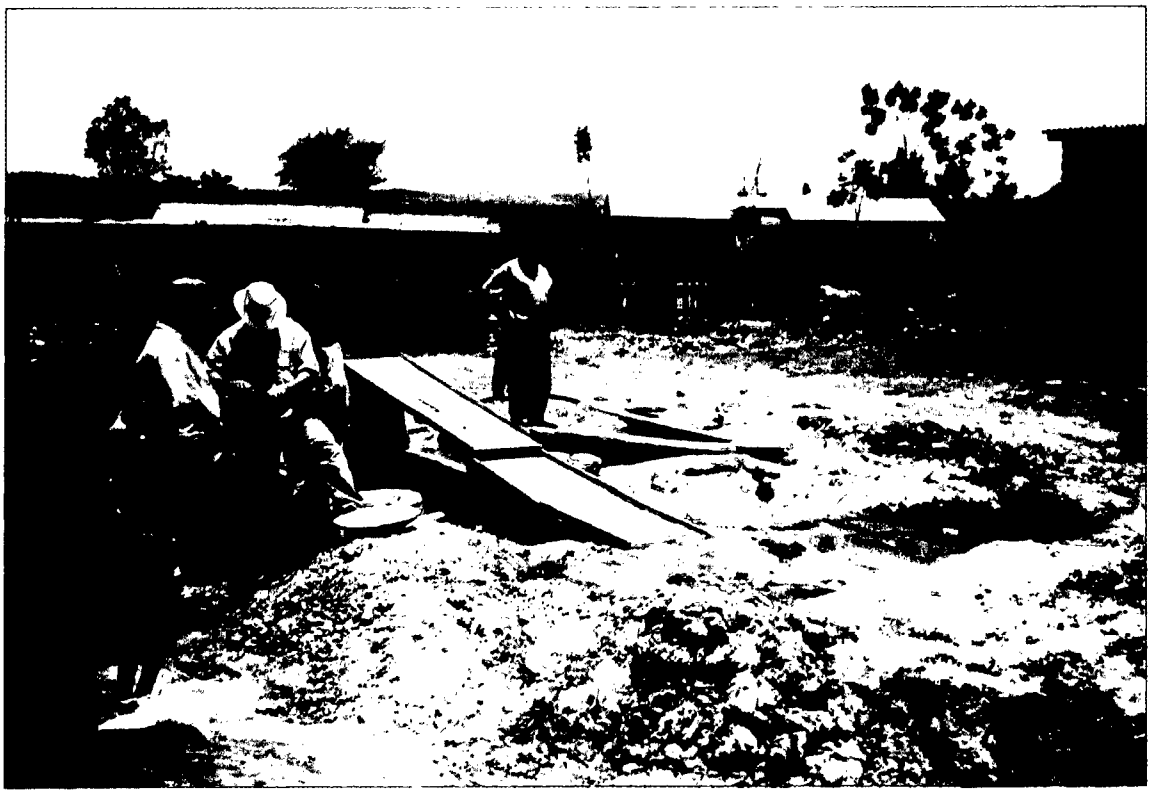


Plate 29. Historic sluicing and amalgamation site in the built-up area of Rwamagasa (site A13-14)

Plate 30. Sluicing crushed primary ore in the back-yard of a house in the centre of Rwamagasa village (site A7)

Plate 31. Sluicing and covered amalgamation pond located within the built-up part of Rwamagasa (site A9)

Plate 32. Historic sluicing site within Rwamagasa village (site A14)

Plate 33. Historic sluicing site and covered amalgamation pond within Rwamagasa village (site A20)

Plate 34. Tailings piles on slope down to the Isingile River (site A29)

Plate 35. Tailings heaps at site A31 on slope overlooking the River Isingile *mbuga*.

Plate 36. Historic sluicing site and tailings heaps located at edge of River Isingile *mbuga*, about 100m west of motorable track from Rwamagasa to Buck Reef.

Plate 37. Historic sluicing site and tailings heaps located either side of motorable track from Rwamagasa to Buck Reef, about 100m south of River Isingile.

Plate 38. Tailings piles and covered amalgamation pond within the Blue reef mine mineral processing compound.

Plate 39. Inhomogeneous soil sample prior to disaggregation and mixing (site A69)

Plate 40. Homogenised and quartered soil sample after disaggregation and mixing (see Plate 46 above)

Plate 41. Soil profile (samples A279 (0-10cm) to A284 (50-60 cm))

Plate 42. Collecting crop samples (A110-A113) from an area impacted by overflow water from an amalgamation pond (site A37-A39)

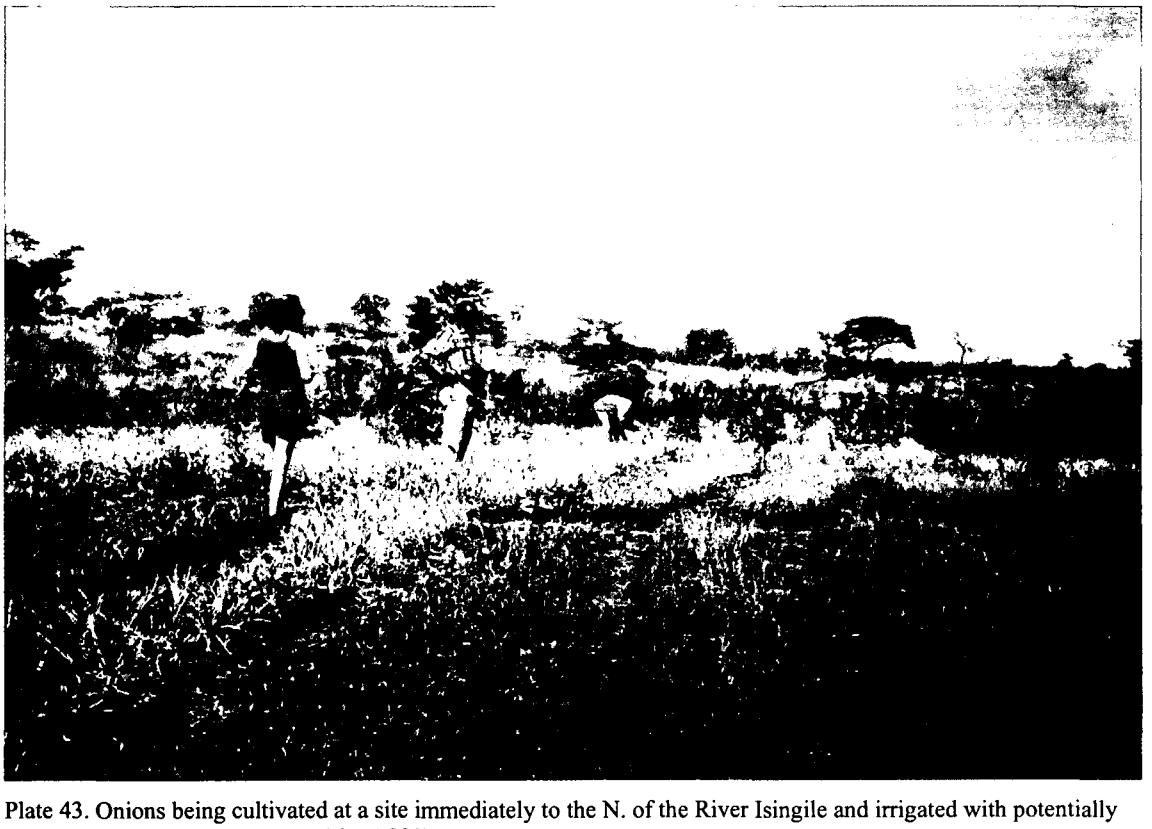


Plate 43. Onions being cultivated at a site immediately to the N. of the River Isingile and irrigated with potentially contaminated stream water (site A291)

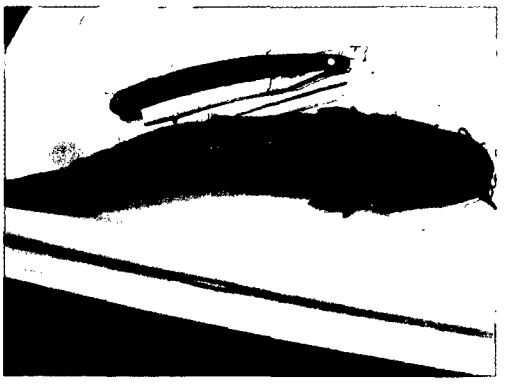
Plate 44. Onions being cultivated at a site immediately to the N. of the River Isingile and irrigated with potentially contaminated stream water (site A291)

Plate 45. Cabbages being cultivated at a site immediately to the N. of the River Isingile and irrigated with potentially contaminated stream water (site A293).

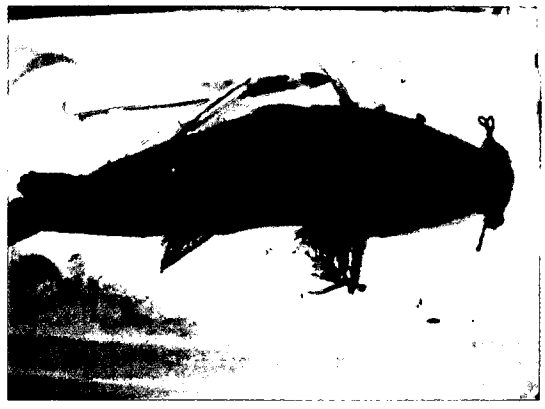
Plate 46. Maize being cultivated at a site immediately to the N. of the River Isingile and irrigated with potentially contaminated stream water (site A297).

Plate 47 Purchasing fish samples from the market, Ilagala

Plate 48 *Oreochromis tanganicae* (Tilapia), Ilagala market.



Plates 49 and 50. *Clarias gariepinus*



Plates 51 & 52. *Auchenoglanis occidentalis*

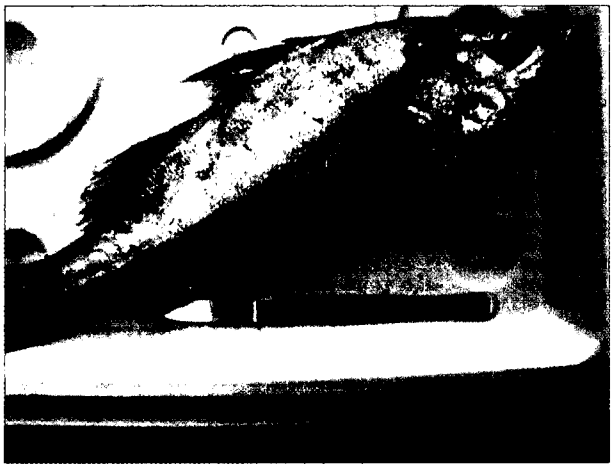


Plate 53. *Lates Malagarasi*

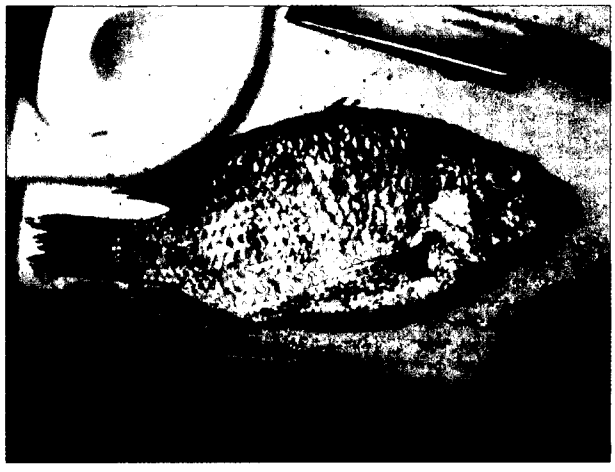


Plate 54. *Oreochromis tanganicae*

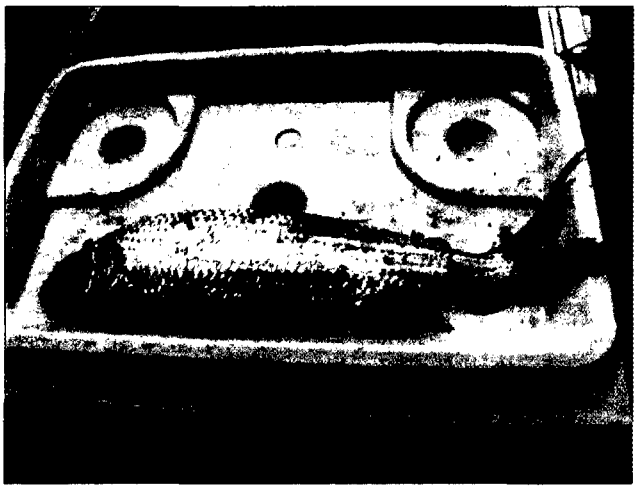


Plate 55. *Brycinus rhodopleura*

Plate 56. Catching fish using a net, Malagarasi River about 1 km upstream from Uvinza.

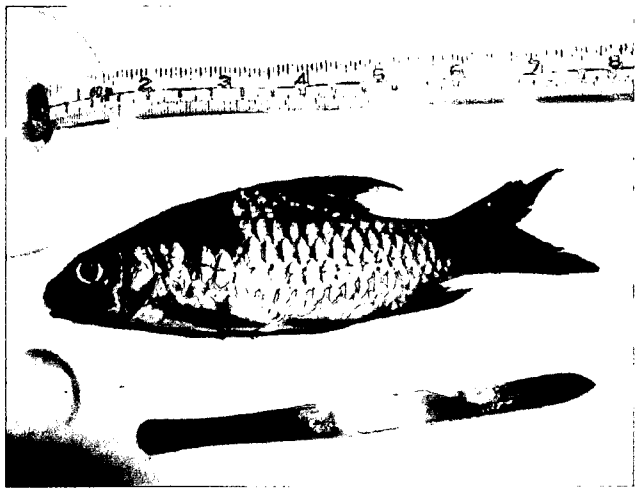


Plate 57. *Barbus tropidolepsis*

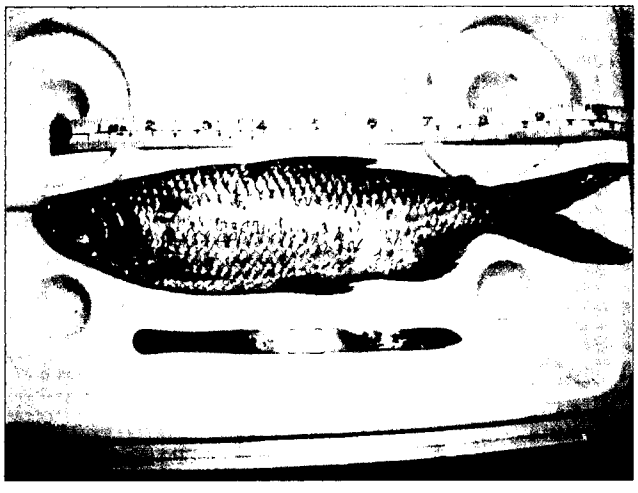


Plate 58. *Ctenopharyngodon idella*

Plate 59. *Clarias alluadi*

Plate 60. *Haplochromis spp*

Plate 61. *Barbus spp*

Part 2

Assessment of Health in the Rwamagasa area, Tanzania

by

Institute of Forensic Medicine, Ludwig-Maximilians-University, Munich

BGS Report CR/04/129 (Issue 1.0) for UNIDO Contract 03/088

Medical Investigation of 250 People living in the Rwamagasa Area, Geita District in the UNITED REPUBLIC OF TANZANIA

Institute of Forensic Medicine, Ludwig-Maximilians-University,
Munich, 21st of May 2004

Final Report

by Gustav Drasch and Stephan Boese-O´Reilly

Removal of Barriers to the Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies

UNIDO (United Nations Industrial Development Organization)

GEF (Global Environment Facility)

UNDP (United Nations Development Programme)

UNIDO
Project EG/GLO/01/G34

British Geological Survey
Subcontract GA/03F/36

BGS Report CR/04/129 (Issue 1.0) for UNIDO Contract 03/088

Contents

Study Setting and Clinical Examinations

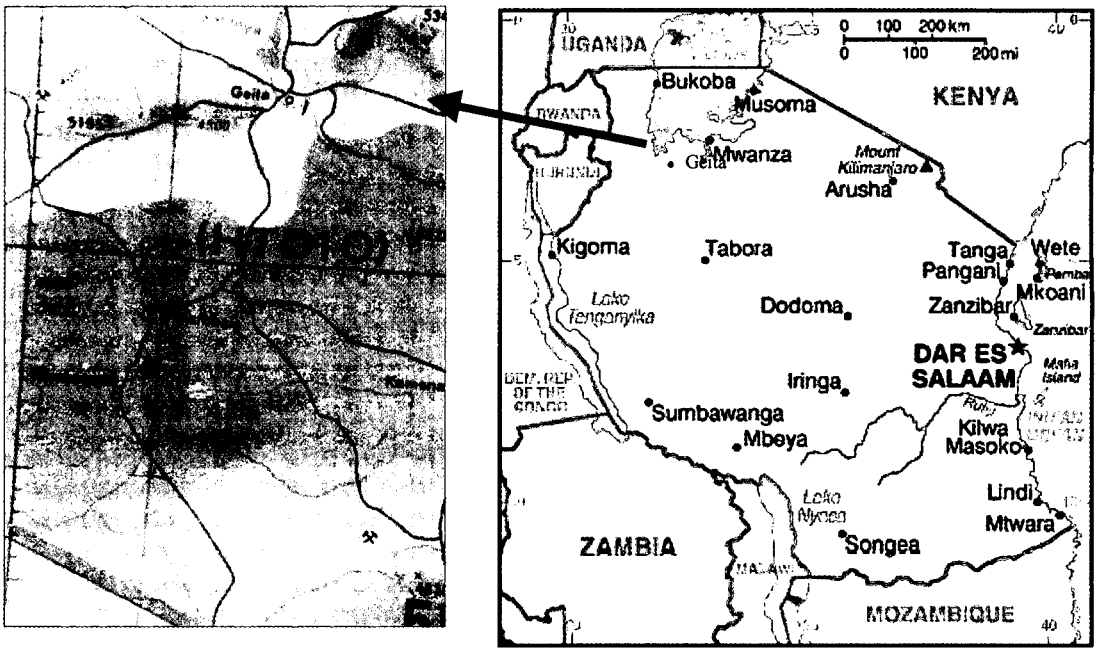
(Stephan Boese-O´Reilly)

INTRODUCTION

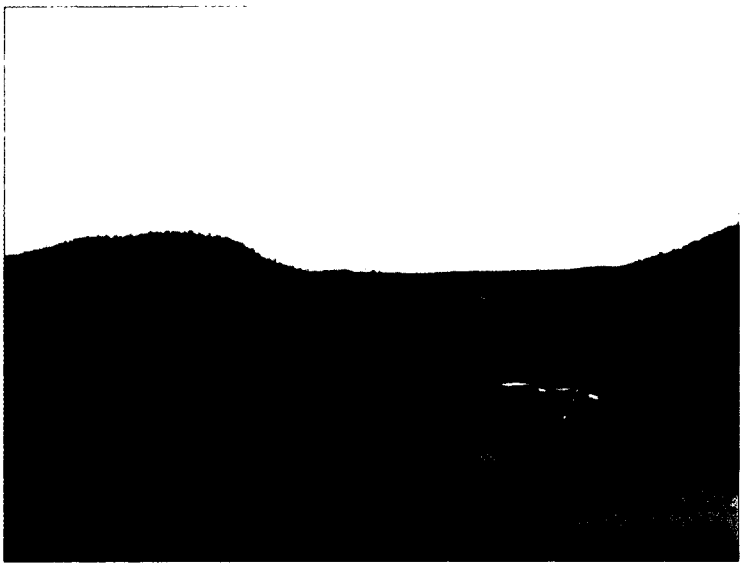
The aim of the subcontract was to undertake a medical investigation of approximately 250 people living in the Rwamagasa area, Geita District in the United Republic of Tanzania. The ultimate aim of the whole UNIDO project is to replace mercury amalgamation in the project demonstration sites with new technology, while improving the income of the miners through more efficient recovery, increasing knowledge and awareness, and providing policy advice on the regulation of artisanal gold mining with due consideration for gender issues.

Rwamagasa small scale mining area – Geita district

Tanzania is in East Africa. Geita District is near Lake Victoria (Mwanza Region). Farming is the main activity of the rural population.



There is one big employer in the area, a big gold mining company (Geita Gold Mine).

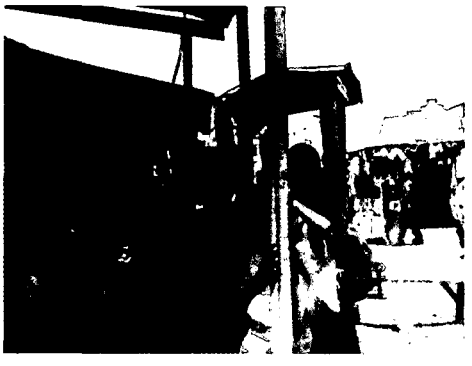


Geita Gold Mine

Geita Gold Mine (GGM) is a joint venture of Ashanti Goldfields and Anglo American and Tanzania's biggest gold mine. GGM employs approx. 1.900 workers. By large scale mining GGM extracts 500.000 ounces of gold per year (Raging Bull 13.4.2003, www.ragingbull.lycos.com).

Geita Gold Mine

Rwamagasa village is approx. 45 km southwest from Geita on off-roads. The area is slightly hilly, semi-dry, and covered by grassland and woodland. The Rwamagasa mining area itself is logged, and the surface is open at many spots, either for tunnels or for amalgamation areas. Mining operations have been carried out in this area since 1972, and activities increased in 1998 (Wagner 2003). The infrastructure is poor. All roads are in a very bad condition, traveling for the people is difficult and time-consuming. The two schools in Rwamagasa have 1650 pupils, but only half of the pupils attend school daily. Some children begin school at very late age – 10 years or above. Many drop out early. Illiteracy is approx 10% in female adults, and 5% in male adults in Rwamagasa village (Wagner 2003).



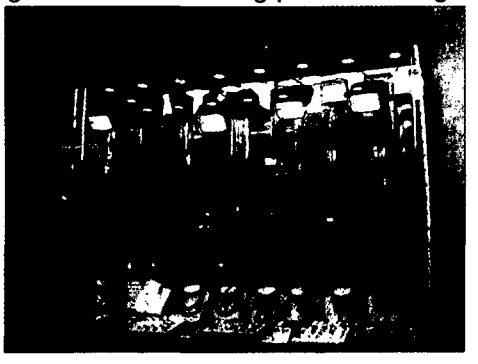
Some miners work in small-scale mining companies, which are licensed. Equipped with generators and other technical equipment miners work in tunnels to extract the ore. The tunnels have a small diameter. The miners try to follow veins, so tunnels are curved, and tend to be very steep. Miners work in shifts. The ore is crushed by workers with hammers, and then powdered in ball mills.

Rwamagasa village –hammering rocks, ball mills and panning

The ore is then diluted with water. The miners try to concentrate the gold containing materials using a sluice box with a rough cloth.

The concentrated material is then panned, and at this stage liquid mercury is added to the ore. After panning the still liquid amalgam is squeezed through some fine cloth. Sometimes the miners use their mouth to hold the cloth whilst squeezing stronger. The proper amalgam is formed now. The amalgam is either sold to gold dealers, or burnt. The burning takes place in the kitchen or nearby, over a wooden fire. Artisanal miners work in smaller units, they mainly concentrate on the crushing of the ore, running of ball mills, the amalgamation process and burning of the amalgam. The artisanal miners have very limited equipment and tools.

The young and strong men, so called healthy workers, are mainly found in the bigger and technically higher equipped properties. Older people, women of all ages and children mainly work in the smaller artisanal mining properties. Retorts are not used, or any other protection against any kind of mercury contamination. There is no proper ventilation for the mercury fumes. Housing areas, food stalls and the schools are nearby to the amalgamation and burning places. Tailings containing mercury are everywhere within the village, beside the farming land or beside the local water wells The mercury is usually stored in the miner's houses in small soft drink bottles, near to where they and their families sleep. The mercury is traded from Nairobi, Kenya. The gold is either used for jewelry in Tanzania or sold to Dubai.



Dubai gold market

STUDY DESIGN

The "Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners" were developed by UNIDO in collaboration with the Institute of Forensic Medicine, LMU of Munich, and other international experts (Veiga 2003). The declaration to volunteer was translated in Swahili (see appendix 2). The "Health Assessment Questionnaire" was partly translated in Swahili (Appendix 2) to be used to examine the general health condition of members of the mining community and to indicate symptoms of mercury poisoning. Anamnestic / clinical / neurological / toxicological tests were used according to the state of the art. Participants were examined to identify neurological disturbances, behavioral disorders, motor neurological functions, cognitive capabilities, balance, gait, reflexes etc.. The data was compiled for statistical purposes and maintain confidentiality regarding all health related issues. All participants were physically examined including neurological testing.

FIELD PROJECT

The field project took place from the 19th of October 2003 until the 9th of November 2003. The equipment was set up in the office building of Blue Reef Mining Company. The mining company offered its facilities to perform the examination, which was much appreciated by the health assessment team. The facilities were sufficient to perform the examinations, including a mobile analysis of Hg in urine samples (four rooms for the team, electricity, toilet, water).

Team members for the field project were Dr. med. Stephan Boese-O´Reilly (pediatrician, master of public health, environmental medicine), Stefan Maydl (physician), Katalin Drasch (pharmacist). Mrs. Katrin Hupe (journalist) accompanied the team in agreement with BGS and UNIDO. Mr. Tesha was the Assistant Country Focal Point to UNIDO and comes from the Tanzanian Ministry of Energy and Mineral Resources. Assigned to the project were nurses to assist the medical examinations, Mrs. Mwajuma Libuburu, Mr. Sosthenes T. Mchunguzi, Mrs. Asila Rashid and Mrs. Felister Malima. These four nurses interviewed all 252 participants.

A mobile Hg analyzer was used to determine total mercury in urine.

Video and photo documentation was carried out.

The control group was examined in Katoro. The same method and team as in Rwamagasa was used. The local health unit supported us. Katoro is approx 30 km away from the mining area, and mercury is not used there.

Blood, urine and hair were analyzed for mercury later at the Ludwig-Maximilians-University of Munich, Germany.

Questionnaire

The participants filled in a questionnaire with assistance from the nurses. Questions included:

- Working with mercury or with mercury polluted tailings?
- Burning amalgam in the open?
- Melting gold in the open or with inadequate fume hoods?
- Drinking alcohol?
- Having a kind of a metallic taste?
- Suffering from excessive salivation?
- Problems with tremor / shaking at work?
- Sleeping problems?

Neurological examination

All participants were clinically, mainly neurologically examined. Results were mainly primarily scored according to „Skalen und Scores in der Neurologie" (Masur 1995):

- Signs of bluish discoloration of gums
- Rigidity, ataxia and tremor
- Test of alternating movements or test for dysdiadochokinesis
- Test of the field of vision
- Reflexes: knee jerk reflex and biceps reflex

- Pathological reflexes: Babinski reflex and mento-labial reflex
- Sensory examination

Neuro-psychological testing

The following tests were carried out (Zimmer 1984, Lockowandt 1995, Masur 1996):

- Memory disturbances: Digit span test (Part of Wechsler Memory Scale) to test the short term memory
- Match Box Test (from MOT) to test co-ordination, intentional tremor and concentration
- Frostig Score (subtest Ia 1-9) to test tremor and visual-motoric capacities
- Pencil Tapping Test (from MOT) to test intentional tremor and co-ordination

Specimens

The following specimens were taken, and two tests (Hg in urine and proteinuria) were performed immediately:

- Blood (EDTA-blood 10 ml)
- Urine (spontaneous urine sample 10 ml)
- Hair

The specimen urine and blood were cooled permanently after collection until arrival in the laboratory in Munich, Germany.

Laboratory

A mobile Hg analyzer was used (Hg-254 NE, Seefelder Messtechnik, Seefeld, Germany). It is possible to quantify inorganic mercury in urine. 1 ml urine was diluted with 100 ml water (bottled drinking water). A 2 ml solution of 10% tin(II)chloride in 6N hydrochloric acid was added to the water-urine solution. The sample was analyzed by atomic emission spectrometry. Bottled drinking water was used as zero standard, and a mercuric nitrate solution as standard. In 231 of 252 cases it was possible to analyze the sample. One urine sample can be analyzed in approximately 3 minutes. At the last day it was not possible to work with the analyzer, due to problems with an adequate electric power supply in Katoro. All urine samples were re-analyzed in the "Institute of Forensic Medicine", Munich, Germany.

Test for protein in urine

Proteinuria was tested with a commercial kit (Bayer). The test is based on the error-of-indicator principle.

Test reagents are 0,3 % w/w tetrabromophenol blue; 99,7 % w/w buffer and non-reactive ingredients. At a constant pH, the development of any green color is due to the presence of protein. Colors range from yellow for "Negative" reaction to yellow-green and blue-green for a "positive" reaction. The test area is more sensitive to albumin than to globulin, hemoglobin, Bence-Jones proteins and muco-proteine. The test area is sensitive to 15 mg/dl albumin. The test strip was dipped into the native urine and the result was taken after 1 minute.

The test is semi-quantitative. Possible results are 0, 10, 20, 30, 100 and 300 mg Protein / dl urine.

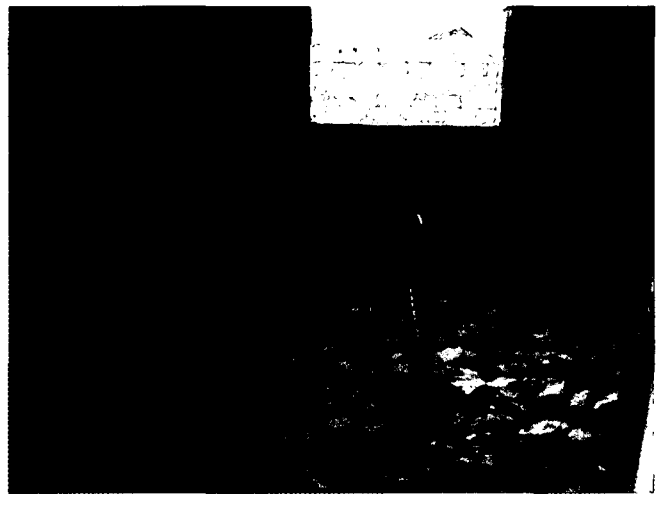
Problems during the field project

The sociological report (Wagner 2003) was an excellent source of information. Mr. Tesha and Mr. Kabadi selected the volunteers well, so that these volunteers are a good representation of the population in Rwamagasa.

The infrastructure in Rwamagasa area is very poor, just sufficient to perform the examination. It is only due to excellent preparation of the field project by UNIDO Dar es Salaam, Mr. Tesha and Don Appleton, that the project was successful at all.

The regional health authorities supported the project. But on the national level there was no support for the project. When asked for support before the start of the project, the Ministry of Health did not support the health assessment.

Many participants especially men had no or nearly no hair on their head, near under their axils or in the genital region. So sometimes only very little hair was gained or even none.



GENERAL HEALTH SITUATION IN RWAMAGASA

Nurses, engineers, teachers and participants were interviewed on possible health effects in relation to the mining activities.

Health care system in the Geita district

The population is estimated to be "26,990, comprised of 13,879 males and 13,111 females, with 5,017 households having an average size of 5.4 people in Rwamagasa" ward (Wagner 2003). Large families with 6-12 children are common. A mayor part of the population is directly involved in the mining activities in the village.

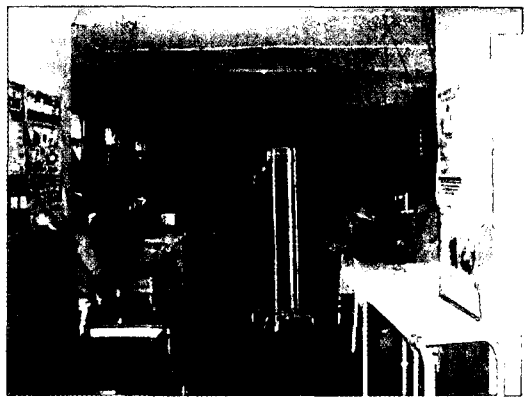
Rwamagasa – future health center

Many of these inhabitants are work migrants. Only few of the miners have a licensed small-scale mine, most miner work as artisanal small scale miners. Most mining families also farm land – mainly for private consumption.

Poverty is the main problem of Rwamagasa area. 64% have a monthly income below 50 US$ per month (Wagner 2003).

There is no health service for the approximately 27.000 people in Rwamagasa. The next dispensary is 10-20 km away. A local dispensary is under construction, but the building has been stopped due to lack of money. The village lacks social welfare services and a police post for security.

The next district hospital is in Geita. All non-minor illnesses have to be transferred to Geita hospital, which is adequately equipped for a district hospital.



Geita District Hospital

Traditional healers (herbalists) and so-called "witch doctors" are an essential part of the health system.

General health problems

The main health problems in the area seem to be:

- Dangerous tunnels, lethal accidents occur each year in Rwamagasa. Miners reported of being caught in collapsing tunnels for hours before their colleagues rescued them. Lacking rescue and medical facilities cause insufficient medical treatment. This leads to secondary healing wounds and skin defects.

- Bicycle, bus, and truck accidents are common. The road conditions are very bad, most cars and trucks are in a very bad technical condition. On the off-road cars, and trucks share the narrow roads (at night very dark) with bicycles, pedestrians and all kind of cattle. There is no infrastructure to rescue and treat any kind of accident.
- Infectious diseases are widespread. Nearly everybody in the surveyed population had malaria, many of them within the last year. Malaria is diagnosed clinically and treated orally mainly with Fansidar SP (Sulfadoxine/Pyrimethamine). Tuberculosis is endemic, but

not epidemic. Tuberculosis is treated under a governmental program. According to the WHO scheme daily-observed treatment (DOT) with quadruple treatment for 2 months (Isoniazid, Rifampicin, Pirazinamid, Etambutol) and follow-up double treatment for 4 month (Isoniazid, Rifampicin) is performed. Typhoid fever, leprosy, polio, cholera and tetanus occur occasionally.

- Sexually transmitted diseases (STD) are common. Promiscuity and prostitution are very common. 35% of the mine workers in Geita town had multiple sex partners during the last 3 months; 54% mine workers had sex with a prostitute at least once a year and 30% of them did not regularly use condoms (WEF 2002). According to an AMREF survey 19% of the male population in Geita between the ages of 16 and 45 are HIV positive. Almost 39% of the female sex workers are HIV positive. The rate of Hepatitis B and Hepatitis C cases is unknown. Syphilis and Gonorrhea are common.
- The dental status of people differs. Some people have many stumps; other people have fairly good teeth. Most children have fairly good teeth.
- Due to insufficient sanitary conditions diarrhea is common. But it is not a major cause of mortality.
- Pneumonia, parasitism, skin diseases, eye diseases and upper respiratory infections are other important diseases in Rwamagasa.
- The volunteers, we examined, presented diseases such as skin infections, scares, hernias, dysuria etc.. These conditions should have been diagnosed and treated much earlier.
- Smoking is more common among men then women.

No.	RANK	<5 YEARS		5 YEARS AND ABOVE		
	Diseases	No. of cases	% of all diseases	Diseases	No. of cases	% of all diseases
1.	Malaria	79,065	63%	Malaria	102,316	53.3%
2.	A.R.I.	18,935	15.2%	A.R.I.	34,002	18.04%
3.	Diarrhea	12,737	10.3%	Diarrhea	35,026	18.6%
4.	Pneumonia	9,560	7.8%	Pneumonia	7,649	4.06%
5.	U.T.I	3,509	2.8%	U.T.I	8,554	4.6%
6.				HIV/AIDS	575	0.3%
7.				TB	265	0.14%
Total		123,806	100%		188,387	100%

Top Outpatient Diagnoses 2002 in Geita District (Wagner 2003)

	RANK	Disease	<5 YEARS		5 YEARS AND ABOVE	
			No of Cases	% of all Diagnosis	No of Cases	% of all diagnosis
GEITA	1	Malaria	2210	56.5%	1037	51%
	2.	Diarrhea	247	6.3%	153	7.5%
	3.	Pneumonia	632	16.1%	454	22.4%
	4.	Anemia	771	19.7%	175	9%
	5.	Meningitis	11	0.3%	25	0.05%
	6.	Others	39	0.9%	184	9.07%
TOTAL			3910	100%	2028	100%

Top Inpatient Admission Diagnoses (Wagner 2003).

Source: District Medical Officer, Geita District

Children's health

A high proportion of the population in the area is children under the age of 12. The main health problems of children in Rwamagasa seem to be: High exposure to mercury in the area. Children to have access to fluid mercury, they play with this mercury with their hands. They live within the houses where panning or amalgam burning is carried out; therefore they are also exposed to mercury fumes.

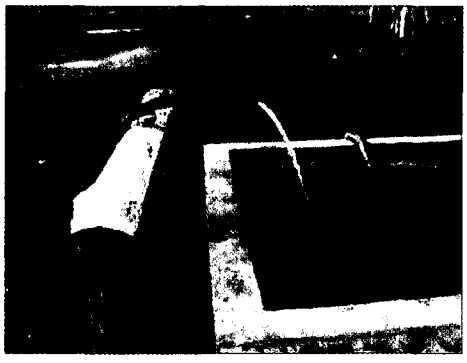
Many children do not go to school. Many children and teenagers work after school or at weekends. Children begin to work in this area as young as 10 years. They work in the amalgamation and burning process with direct contact to mercury.

28 children and teenagers were examined (age 10 to 17, average 15,4 years; 6 females, 22 males). 19 reported to work with mercury, 9 did not work with mercury. 7 reported to perform burning of amalgam. The age they started to work was between 10 and 15 (average 13,4). They were working between 1 and 6 six, on average 2,3 years.

This is child labor at its worst limits, partially physically very hard, partially related to high exposure of mercury. Accidents related to work are a health hazard for these children.

Due to poor sanitary conditions infectious diseases like gastro-intestinal infections and malaria are very common and are a risk for children's health.

Hygienic and social problems



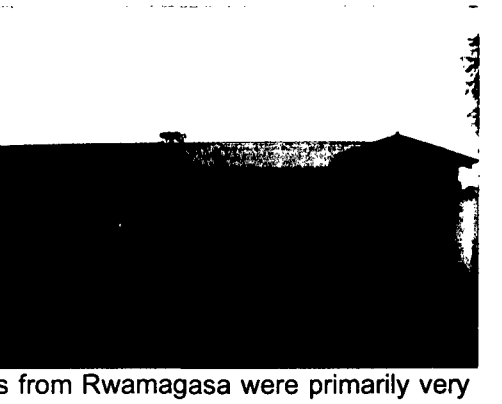
The interviews showed some other problems: The hygienic condition is disastrous, only 625 out of 848 households have pit latrines (Wagner 2003). Water is gained from boreholes, or wells. Water is not safe due to inappropriate hygienic conditions, and due to mercury leaking into the often-shallow wells. The drinking water is sometimes turbid, which is a sign of insufficient hygienic quality. Due to mining activities there are many small pools in the area. These pools are certainly an excellent habitat for transmitters of vector borne diseases, like Malaria.

The main problem was the striking poverty of the population in the area. During the field project the medical experts (pediatrician, gynecologist) and the pharmacist diagnosed, referred or treated many people in Rwamagasa. Medication was provided free of charge to the people. This medication was donated by two pharmacies in Munich free of charge (Allacher Apotheke, St. Heinrich Apotheke). Our limits became very clear quickly. A 1 ½ year old child, suffering from a pneumonia and malaria came to our attention. The child was already very sick, when the parents came to the dispensary in Katoro as the family did not have the funds to obtain medical assistance nor medication. We organized the immediate transport to Geita district hospital. But it was too late, the child died during the night. His death is due to poverty, and not to the disease itself.

Many miners, as well as children are aware of the possibility of environmental and health hazards due the use of mercury. But due to poverty and lacking job opportunities they continue to use mercury. A more detailed report is Susan Wagner's "Socio-economic survey of Rwamagasa mining site in Geita district".

Small-scale miners are mobile men with money, and they form a high-risk group for spreading the virus in the community and into other areas. The AIDS / HIV topic needs to be discussed further.

Clinical and neurological impression



The clinical impression was, that a fair amount of workers from Rwamagasa showed severe symptoms, well related to the classical picture of mercury intoxication. They reported sleep disturbances, excessive salivation, tremor and metallic taste. Intentional tremor, mainly fine tremor of eye lids, lips and fingers, ataxia, dysdiadochokinesia and altered tendon reflexes were observed. It should be noted that many workers from Rwamagasa were primarily very healthy and strong young men (healthy worker effect).

Participants who worked for more than 5 to 10 years in the area seemed to have more severe clinical symptoms. It is possible that we missed the most severe cases. Due to a lack of a highly developed social system in Tanzania, some very sick workers might also have moved back to their original homes and families elsewhere in Tanzania.

The health status of the children in the area is poor. Malnourished and undernourished small children are common (Kwashiokor). Many children suffer from skin problems, diarrhea and upper respiratory tract infections. Malaria is by far the most serious health hazard for children in the area. Most children were physically fit, and well socialized.

The control group in Katoro was healthy and did not show any special health problems (41 people).

Katoro Health Center

Specimen Analysis and Statistical Results

(Gustav Drasch)

LABORATORY METHODS

Material and sample storage

From 252 participants in Tanzania 252 blood samples, 249 urine samples and 212 hair samples were taken. The blood samples were taken in EDTA-coated vials. The urine samples were acidified with hydrochloric acid. To avoid de-gradation, all blood and urine samples were stored permanently and transported by flight to Germany in an electric cooling box. Until analysis these samples were stored continuously at 4 °C.

Sample preparation

Hair: As mentioned above, most people from the investigated area had thin, short and curly hair. Therefore only extreme small hair quantities could be received for mercury analysis. In most cases, just one working-up procedure could be performed from the total available hair sample for the total mercury analysis. Another working up procedure with a second hair sample for the determination of methyl-mercury (as planned) was not possible. Therefore a method was developed to determine both total mercury and inorganic mercury in parallel from one working-up procedure. For this, 20 mg – 200 mg (if available) hair was cut in small pieces and weight exactly. All mercury was extracted from the hair samples by shaking with 10 ml hydrochloric acid 6 N for 15h at room temperature in the dark. Parts of the elute were analysed by CV-AAS with two different reduction agents (see below).

Intentionally washing steps with water, detergents or organic solvents like acetone were not performed before the elution. Washing procedures with different solvents are frequently applied before hair analyses with the aim to remove air-borne heavy metal pollution from the surface of the hair. But as shown in literature, a distinct differentiation between air-borne and interior mercury cannot be achieved which such washing procedures (Kijewski 1993). Orientating pre-experiments with washing hair samples from burdened groups supported this

assumption. After washing some samples from the same strain, the results were not reproducible. Therefore the hair samples were eluted without any further pre-treatment.

Blood, urine: Aliquots of up to 1.0 ml were analysed directly without further pre-treatment (method see below).

Mercury determination and quality control

The total amount of mercury in the samples (blood, urine, elute from hair) was determined by means of so-called cold-vapour atomic absorption spectrometry (CV-AAS), using a Perkin-Elmer 1100 B spectrometer with a MHS 20 and an amalgamation unit, Perkin-Elmer, Germany. Sodium-borohydride ($NaBH_4$) was applied for the reduction of all mercury (inorganic and organic bound). $NaBH_4$ reduces inorganic mercury quicker than organic bound mercury like methyl-mercury. Nevertheless it is possible with this method, to determine the correct amount of total mercury, because all nascent mercury vapour is inter-collected on a gold-platinum-net. In a second step the net is heated and all trapped metallic mercury is released at once and could be quantified by CV-AAS. The accuracy of the method for inorganic as well as organic mercury compounds was proved by inorganic and methyl-mercury standard solutions. The determination limit for total Hg in blood or urine was 0.20 µg/l, for total Hg in hair 0.02 µg/g (calculated for a 100 mg hair sample).

In addition, in the elutes of the hair samples, the amount of inorganic mercury was determined by CV-AAS, using a Lumex Zeeman mercury analyser RA-915+, Lumex Ltd., St. Petersburg, Russia. This equipment operates with $SnCl_2$ (tin-II-chloride) for reduction. With this method, only inorganic mercury can be detected, because under acid conditions $SnCl_2$ reduces only inorganic mercury and not organic bound mercury like methyl-mercury. This was proven by inorganic mercury standards (which show a signal) and methyl-mercury standards (which show no signal at all). The determination limit for inorganic Hg in hair is 0.05 µg/g (calculated for 100 mg hair).

All analyses were performed under strict internal and external quality control. The following standard reference materials served as matrix-matched control samples: human hair powder GBW No. 7601 (certified Hg 0.36 ± 0.05 µg/g) and Seronorm whole blood No. 201605 (certified Hg 6.8 – 8.5 µg/l). Since many years the lab participates successfully in external quality control tests for mercury in human specimen.

STATISTICAL ANALYSIS

Statistical methods

Statistics were calculated by means of the SPSS 9.0 programme (SPSS-software, Munich, Germany). As expected, the mercury concentrations in the bio-monitors (blood, urine, hair) were not distributed normally but left-shifted. Therefore in addition to the arithmetic mean (only for comparison to other studies) the median (50% percentile) is given. For all statistical calculations distribution-free methods like the Mann-Whitney-U-test for comparing two independent groups, the Kruskal-Wallis-test for comparing n independent groups, the Chi-square test for cross-tables or the Spearman rank test for correlation were used. "Statistically significant" means an error probability below 5% ($p < 0.05$).

Some graphs were shows as so-called "box-plots". For a brief explanation: The "box" represents the inter-quartile (this means from the 25% to the 75% percentile). The strong line in the box is the median (50% percentile). The "whiskers" show the span. Outliners are indicated by dots.

Description of mercury levels in urine, blood and hair

In table 1 the mercury concentrations of all analysed blood, urine and hair samples are summarised. In all blood samples the mercury concentration was above the detection limit of 0.20 µg/L. In 30 urine samples the mercury concentration was below the detection limit of 0.20 µg/L. For statistical purposes, in these cases the value was set to ½ of the detection limit (0.10 µg/L). In all hair samples the content of total mercury was above the detection limit (0.02 µg/g). In 123 cases the concentration of inorganic mercury was above the detection limit of 0.05 µg/g. In these cases the concentration of organic bound mercury could be calculated by the difference total Hg minus inorganic Hg (table 2).

For comparison the results of a recent study in a small scale gold mining area of the Philippines (Drasch 2001) are reported in the same table; further, for blood and urine, the result of a representative epidemiological study, performed 1990/92 in Germany, an industrial country in Western Europe (Krause 1996). For a better comparison of the hair values, recently published own data from Germany are cited (Drasch 1998). In recent literature from Europe and Northern America similar Hg concentrations in blood, urine and hair have been reported (Drasch 2004). From populations with a high consumption of methyl-mercury-contaminated sea food like in Japan, the Faeroes Islands, the Seychelles or

Canadian Inuit higher Hg values in the bio-monitors have been reported recently e.g. on the International Conferences on "Mercury as a Global Pollutant" 1996 in Hamburg, Germany, 1999 in Rio de Janeiro, Brazil and 2002 in Minamata, Japan (for literature in detail see proceedings). From other areas with small scale gold mining like in the Amazon, Brazil, mercury concentrations, comparable to the found levels, have been reported e.g. at these congresses or summarised in the book "Mercury from Gold and Silver Mining: A Chemical Time Bomb?" by de Lacerda and Salomons (1998).

		This study	for comparison	
		Tanzania	Philippines (gold mining area)	Germany
Hg-blood (µg/l)	case number	252	323	3958
	span	0.22 – 33.3	< 0.25 – 107.6	< 0.2 – 12.2
	median	1.7	8.2	0.6
	arithm. mean	2.92	11.48	0.51
	literature		(Drasch 2001)	(Krause 1996)
Hg-urine (µg/l)	case number	249	313	4002
	span	< 0.20 - 224	< 0.25 – 294	< 0.2 – 53.9
	median	1.18	2.5	0.5
	arithm. mean	6.82	11.08	1.11
	literature		(Drasch 2001)	(Krause 1996)
Hg-urine (µg/g crea)	case number	248	313	4002
	span	< 0.20 – 106.6	< 0.1 – 196.3	< 0.1 – 73.5
	median	0.79	2.4	0.4
	arithm. mean	3.85	8.40	0.71
	literature		(Drasch 2001)	(Krause 1996)
total Hg-hair (µg/g)	case number	212	316	150
	span	0.08 – 48.74	0.03 – 37.76	0.04 – 2.53
	median	0.55	2.72	0.25
	arithm. mean	1.62	4.14	
	literature		(Drasch 2001)	(Drasch 1998)

Table 1: Concentration of total mercury in blood, urine and hair

		Tanzania (this study)
organic Hg-hair (µg/g)	case number	123
	span	0.10 – 5.25
	median	0.44
	arithm. mean	0.62

Table 2: Concentration of organic mercury in hair

All mercury concentrations in the different bio-monitors blood, urine and hair are highly significant rank correlated (table 3 in appendix 1). Despite this, the individual values scatter widely (see figures 8-10a).

Exclusion of data

From the total group 10 cases were excluded from further statistical analysis:

- 3 children below 10 years of age
- 4 seniors older than 59 years
- 3 participants with severe neurological diseases.

Their age or disease might have biased the result of their neurological investigations and/or their neuro-psychological tests.

Nevertheless, for these 10 cases the decision about an individual diagnosis of mercury intoxication (see below) was made as well .

Forming subgroups due to residence and occupation

To distinguish between the possible sources of mercury burden, we formed subgroups. The remaining 242 participants were subdivided due to residence and occupation criteria. The following subgroups were formed:

1. **Katoro control group**: 31 volunteers from Katoro, without special Hg burden.
2. **Katoro, former occupational Hg burdened**: 9 participants living in the control area of Katoro, but have been former worked in the burdened area of Rwamagasa. As a persistent Hg burden could not be excluded in these cases, there were separated from the control group.
3. **Rwamagasa, no Hg occupation**: 24 participants, living in Rwamagasa without any special occupational Hg-burden.
4. **Rwamagasa, amalgam-burners**: 99 amalgam-burners from the mining area (3-5 of them may also melt gold).
5. **Rwamagasa, other occupation**: 67 workers (25 ball-millers, 28 miners, 14 children working with mercury)
6. **Rwamagasa, former occupational burdened**: 12 retired workers, still living in the mining area

In group 5 (other Hg occupation) ball-millers, miners and children, working with mercury were compiled. A further differentiation to the sub-groups results in no further information, because (i) most miners work on the ball-mills, too, and (ii) the number of the subgroups (25, 28, 14) are too small for a sound statistical evaluation. Furthermore, in non volunteer of group 5 a mercury intoxication was diagnosed (see table 13).

Unless other indicated, all further statistical analysis was performed with these subgroups.

The mean age and the age distribution (figure 1) of all sub-groups are similar. As expected, there is a surplus of males in the occupational burdened groups (amalgam-burners and

former occupational burdened volunteers) (table 4 in appendix 1). This gender difference could not be controlled in field under the given conditions.

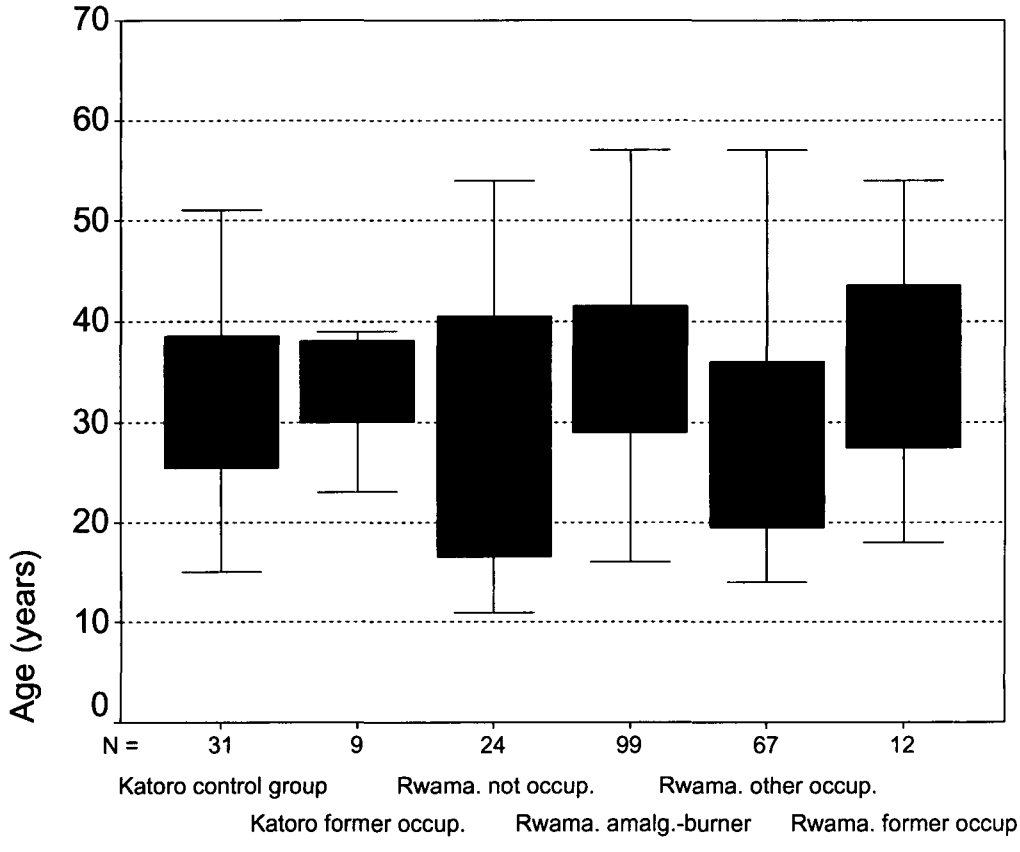


Figure 1: Age distribution of all volunteers, selected for the statistical evaluation

In principle, alcohol abuse may bias the results, because alcohol abuse causes neurological deficiencies similar to a mercury intoxication like tremor, ataxia, etc. There are no indications for a higher rate of alcohol abuse, neither in the control area of Katoro nor in the burdened area of Rwamagasa. The percentage of heavy drinker is similar (table 4 in appendix 1). This self-information of the volunteers fits to the impression of the medical team in field. Moreover, the alcohol consumption pattern of the intoxicated and non-intoxicated group (as classified

by us, see table 4 in appendix 1) does not differ on a statistical significant level (Chi-square test).

Reducing of redundant data for statistical analysis

From the extremely large data volume (see appendix 2), collected in field by the medical team, the relevant facts and test results were selected by pre-investigations (see table 4 in appendix 1). Many test results were primarily scored (for instance: no, moderate, strong, extreme). For the anamnestic and clinical data these results could be reduced to a yes/no decision, which enables a statistical analysis and facilitates the readability of table 4 in appendix 1 markedly without a relevant loss of information. The neuro-psychological data (memory, match-box, Frostig, pencil tapping) was reduced according to a box-plot procedure. With this procedure the results of the participants could be divided into three categories: The best performing 25% of participants of each group were given a score of 0 points, the worst performing 25% of participants were given a score of 2 points and the middle group of participants received a score of 1 point. In table 4 in appendix 1 the results of the statistical analysis of the transformed anamnestic, clinical and neurological data versus the different Hg-burdened subgroups, is shown. The significance of the differences was calculated with Chi-square test. Grey marked fields contain results, differing from the control group on a statistical significant level ($p < 0.05$, one-tailed).

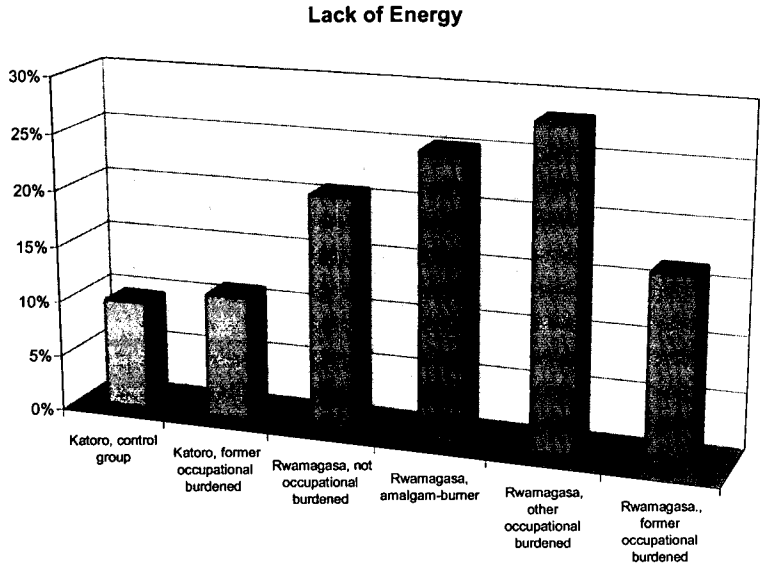


Figure 2: Frequency of the anamnestic statement "lack of energy"

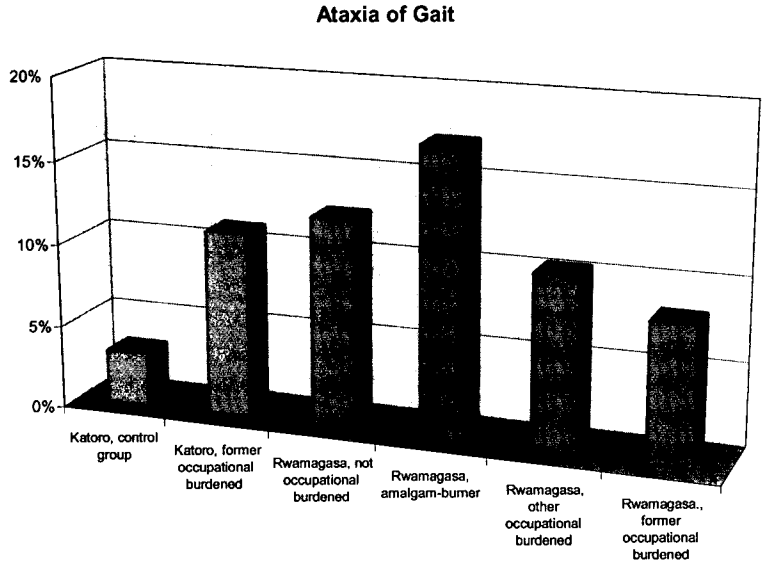


Figure 3: Frequency of the clinical parameter "ataxia of gait"

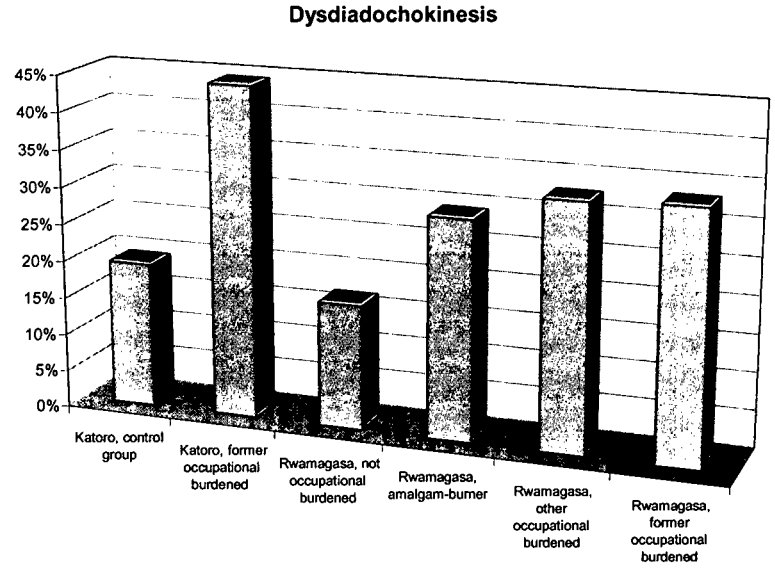


Figure 4: Frequency of the clinical parameter "dysdiadochokinesia"

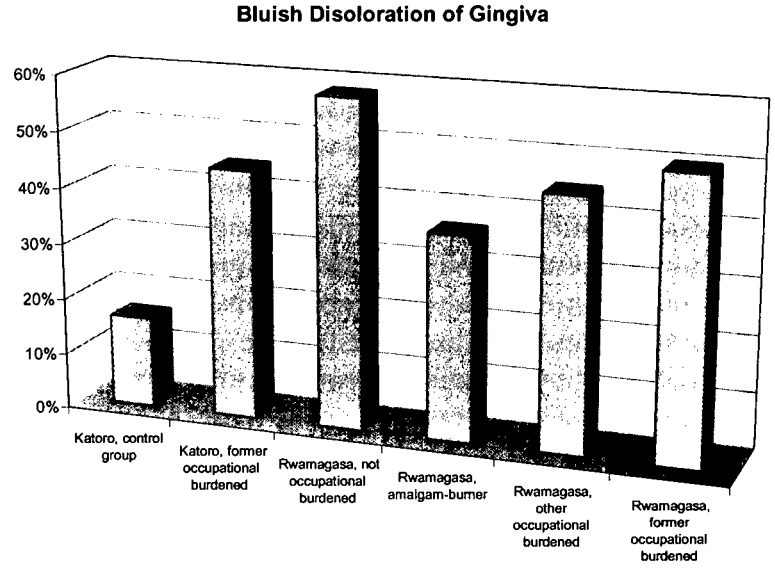


Figure 5: Frequency of the clinical parameter "bluish discoloration of gingiva"

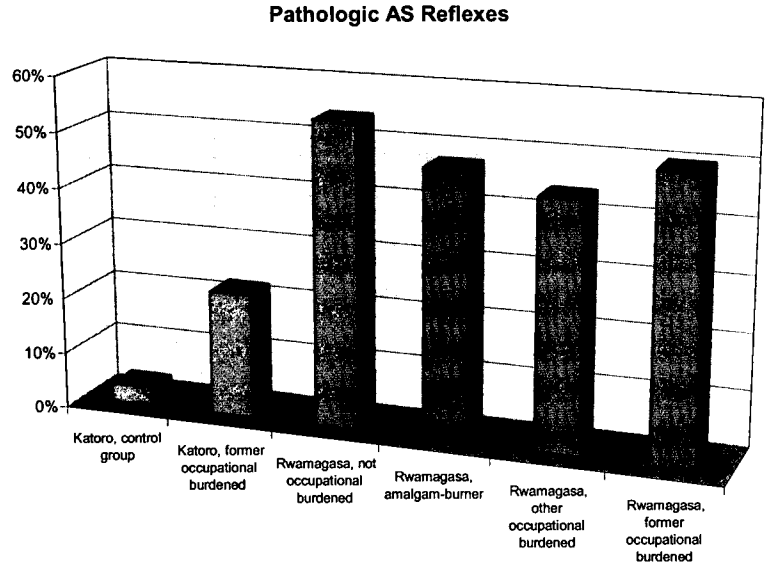


Figure 6: Frequency of the clinical parameter "pathologic achilles reflexes"

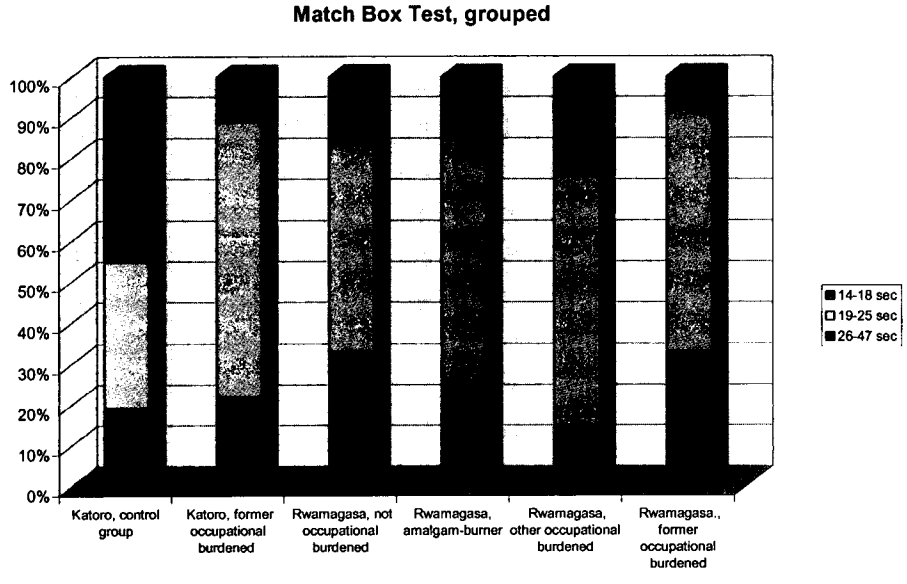


Figure 7: Matchbox test, grouped (blue is good, green is middle, red is bad).

In the figures 2-6 one subjective (lack of energy) and some objective (ataxia, dysdiadochokinesia, bluish coloration of the gingiva, pathologic achilles reflexes) criteria, typical for a chronic mercury burden are figured graphically. In table 7 the grouped results of the matchbox test, a neuro-psychological test is shown. (For a quick explanation: In this test matches have to be sorted in a box as quick as possible).

It is striking that in comparison to the control group from Katoro, many test results even from the non occupationally Hg-burdened population, living in the burdened area of Rwamagasa are considerably worse. The negative results increase even more in the occupational Hg-burdened group of amalgam-burners. The results of the former occupational burdened groups from Katoro and Rwamagasa should not be over-interpreted, due to the low case numbers (9 and 12, respectively) and the missing homogeneity of these groups.

Scoring of medical results

The evaluation so far showed statistically significant medical test results versus the different Hg-burdened subgroups. These significant medical test results are typical clinical signs of chronic mercury intoxication, such as tremor, metallic taste, excessive salivation, sleeping problems, memory disturbances and proteinuria (Drasch 1994, Kommission Human-Biomonitoring 1999, Wilhelm 2000, Drasch 2004). Furthermore ataxia, dysdiadochokinesia, pathological reflexes, co-ordination problems and concentration problems are clinical signs of a damaged central and peripheral nervous system. For a further evaluation of these medical results a medical score was established. The factors, included into this medical score and the score-points per factor are shown in table 5. This score was developed from the results of a mercury burdened group in a gold mining area in the Philippines (Drasch 2001) and adopted by UNIDO, to get comparable results (Veiga 2003). The higher the score is in total, the worse the health problems of a participant were.

Statistic testing of the different Hg-burdened subgroups versus the total medical score sum showed once again significant results. The results are shown in table 4, appendix 1 and in figure 8 graphically as a box-plot. The mean scores of all other groups are higher than the control group from Katoro.

Test	Score Points
Anamnestic data	
Metallic taste	0/1
Excessive salivation	0/1
Tremor at work	0/1
Sleeping problems at night	0/1
Health problems worsened since Hg exposed	0/1
Clinical data	
Bluish coloration of gingiva	0/1
Ataxia of gait	0/1
Finger to nose tremor	0/1
Dysdiadochokinesia	0/1
Heel to knee ataxia	0/1
Heel to knee tremor	0/1
Mento-labial-reflex	0/1
Proteinuria	0/1
Neuro-psychological tests	
Memory test	0/1/2
Matchbox test	0/1/2
Frostig test	0/1/2
Pencil tapping test	0/1/2
Maximum	21

Table 5: Anamnestic, clinical, neurological and neuro-psychological scoring scale

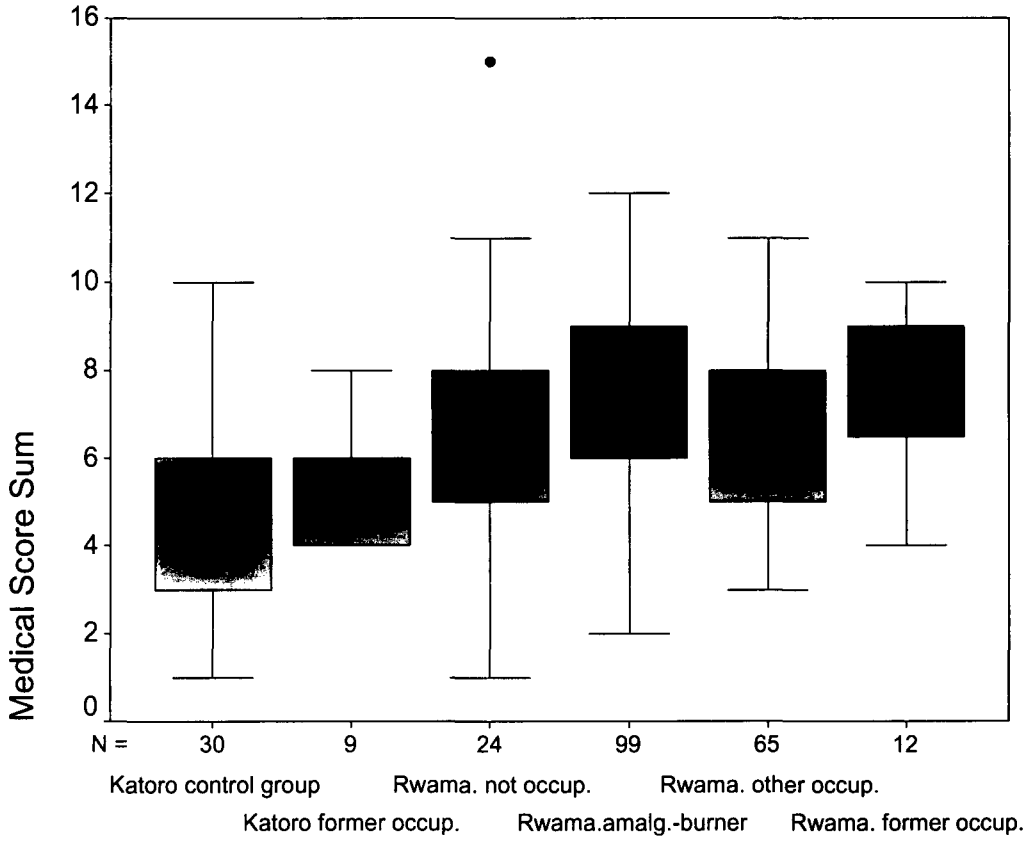


Figure 8: Medical score sum of different sub-groups

Statistical analysis of mercury levels in urine, blood and hair

Statistical testing of the different Hg-burdened subgroups versus mercury concentration in blood, urine and hair show significant results (table 3, figures 9 - 11a). While the majority of the values even of the burdened groups are in a moderate region, some amalgam-burners show extreme high mercury concentration in the bio-monitors. These extreme values were comparable to results from other studies from gold mining areas like the Philippines (Drasch 2001, Boese-O´Reilly 2002) or Brazil (Cleary 1994), but the frequency of such high burdened persons was lower in Rwamagasa.

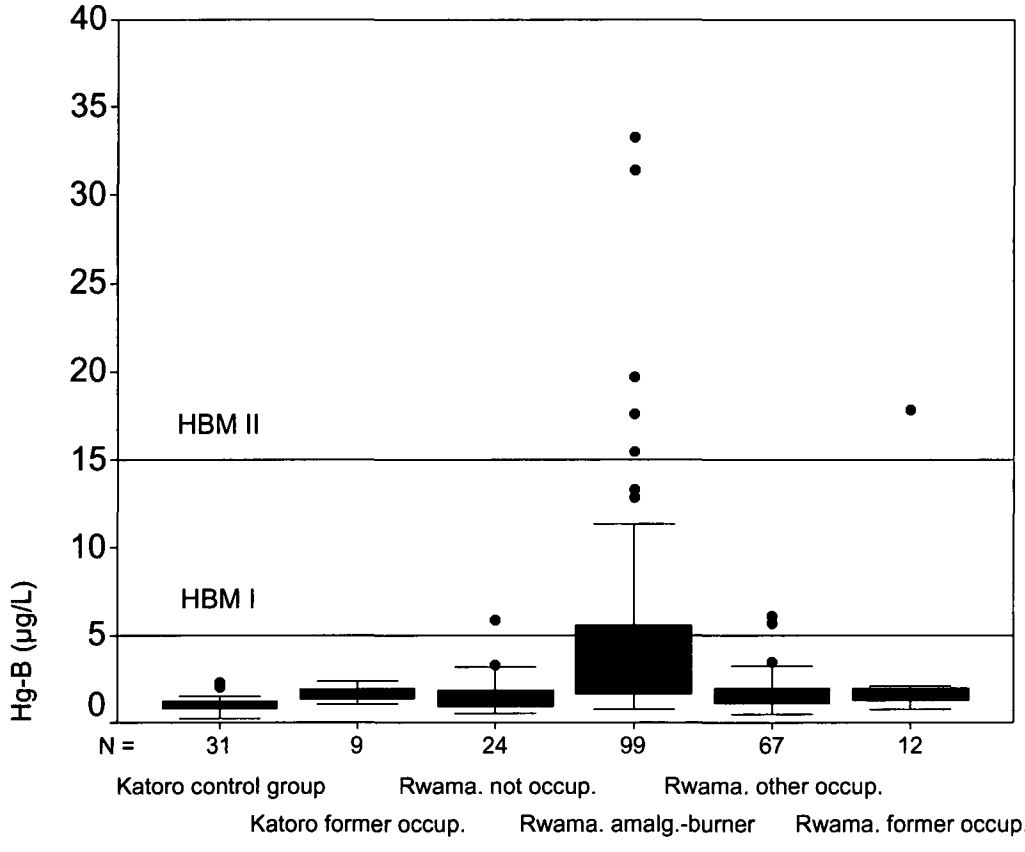


Figure 9: (Total) mercury concentration in blood

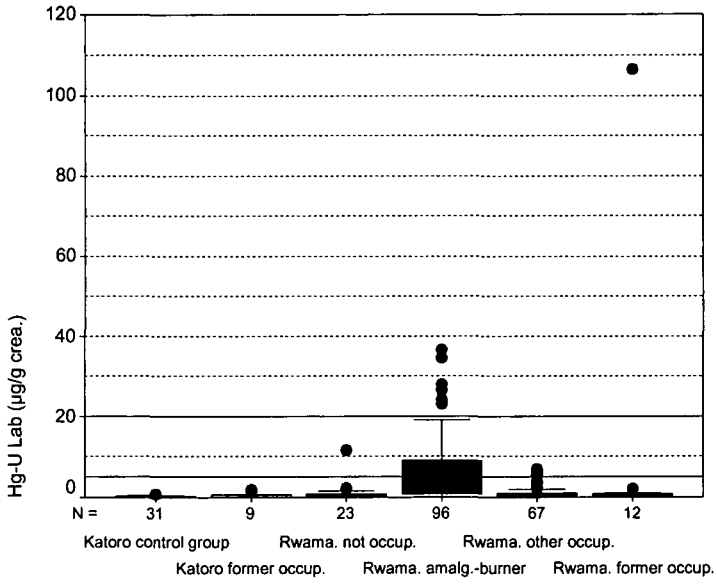


Figure 10: (Total) mercury concentration in urine, determined in laboratory

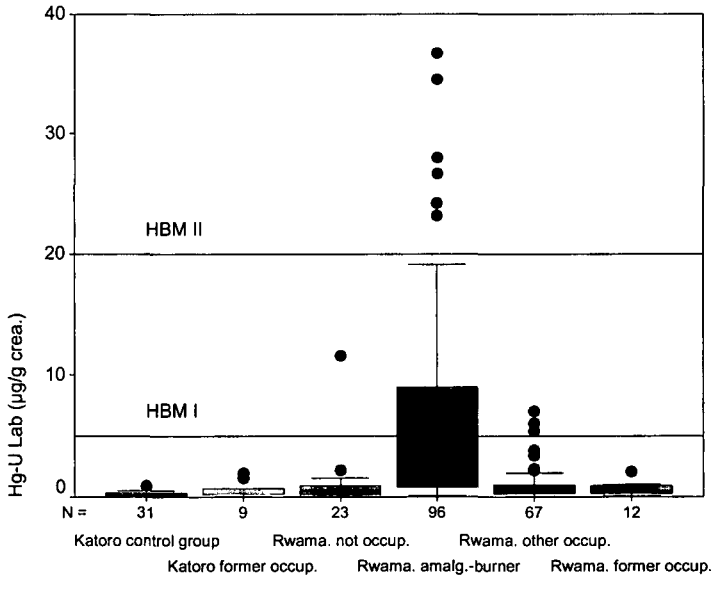


Figure 10a (expanded y-axis): (Total) mercury concentration in urine, determined in laboratory

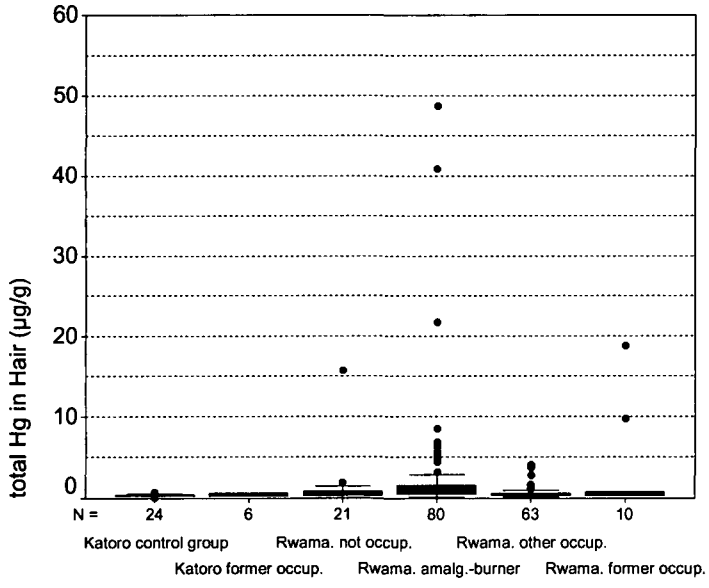


Figure 11: Total mercury concentration in hair

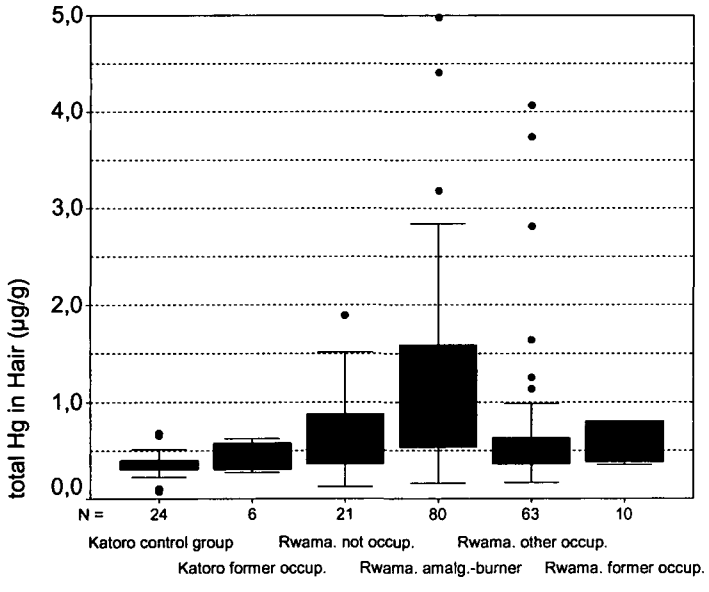


Figure 11a (expanded y-axis): Total mercury concentration in hair

As expected, the highest mercury concentration is found in the bio-monitors of the Hg-occupational burdened group of amalgam-burners, followed by other inhabitants of the Rwamagasa area. The mercury concentration in blood, urine or hair of the control group from Katoro is in the same order of magnitude as in non-burdened populations in Western Europe (see table 1). This is in contrast to the gold mining area of Mt. Diwata in the Philippines (Drasch 2001, Boese-O'Reilly 2003), where an additional high nutritional burden with methyl-mercury from fish and seafood was found. The reversal conclusion is that almost all mercury in the burdened groups of Rwamagasa derived from gold mining activities. Some of the retired workers, still living in Rwamagasa or now in Katoro, show still high mercury concentrations in the bio-monitors.

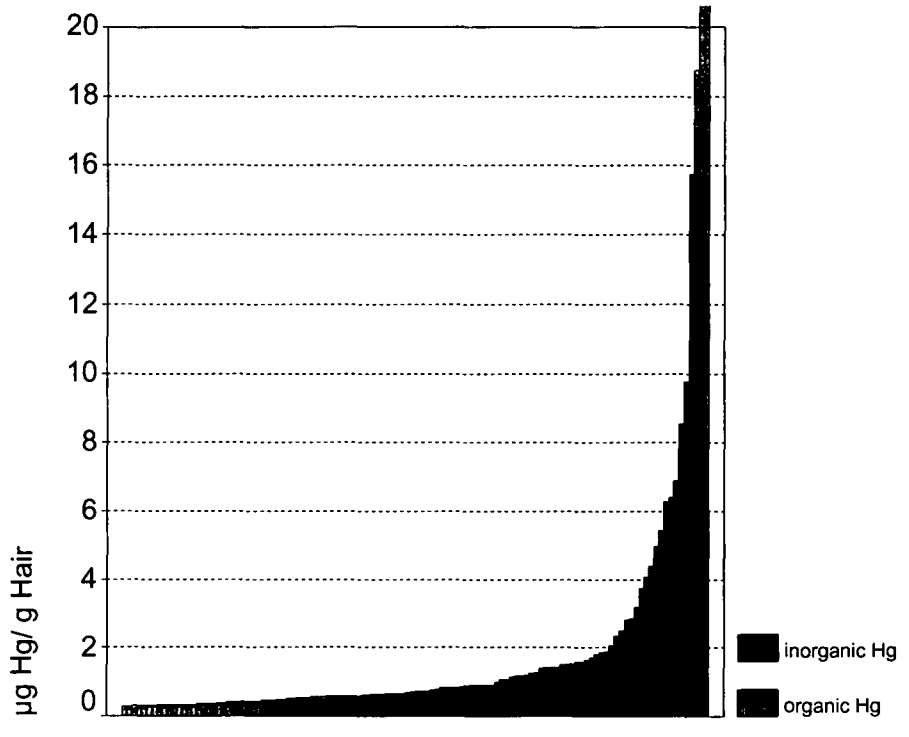


Figure 12: Available speciation of mercury in hair of volunteers from all sub-groups (n = 118)

Figure 12 shows the result of the mercury speciation in hair. It is striking that especially in cases with higher total mercury concentration in hair most of this mercury is inorganic bound. Only in some few cases a higher burden with organic bound mercury like methyl-mercury was found at all. Just in one single case with a higher total mercury concentration (total Hg 6.28 µg/g, see figure 12) this consists predominantly (83.4%) of organic mercury.

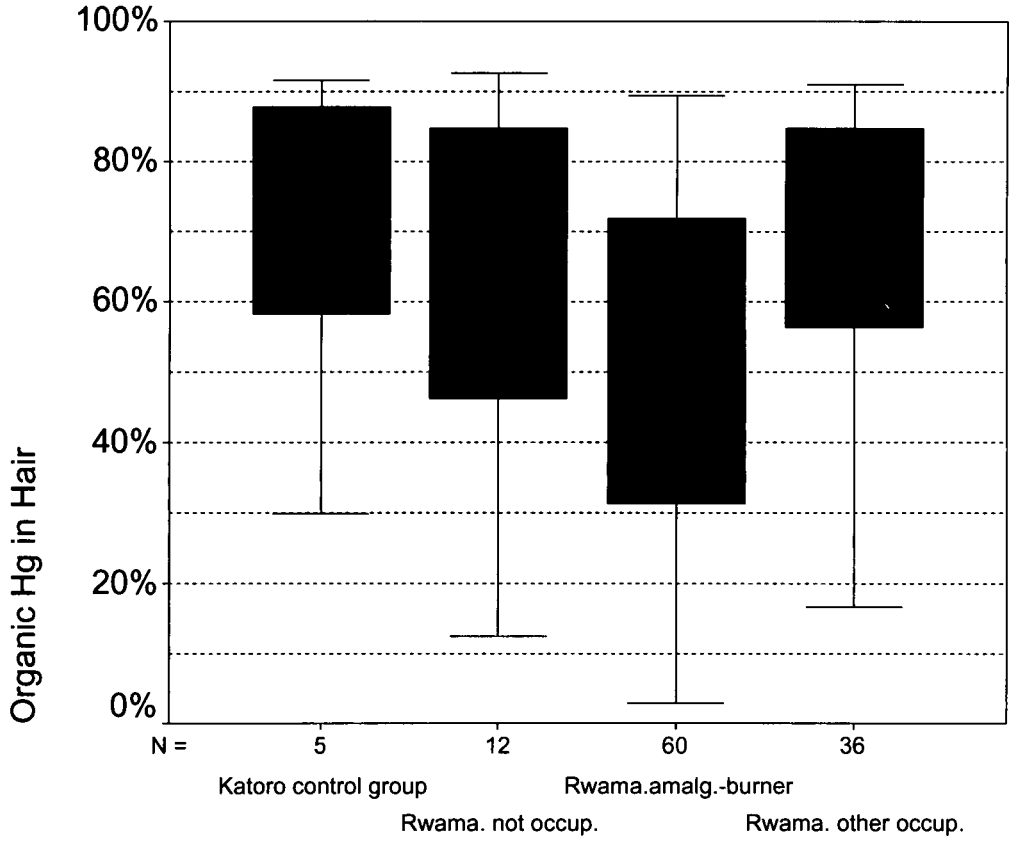


Figure 13: Percentage of organic bound mercury in hair

Accordingly, the percentage of organic bound mercury in the hair samples of the control group from Katoro is high (median 76.5 %) (figure 13). This means that most of the - low - mercury burden in the control area derived from nutritional methyl-mercury. As expected, the additional occupational burden of the amalgam-burners with (inorganic) mercury vapour reduces the percentage of organic bound mercury in hair to a median value of 50.8 %. (The

two groups of the retired workers are not shown in figure 13, as the number of cases, in which a speciation could be performed, was too low.)

Statistical analysis of mercury levels versus clinical data

Correlation tests between mercury concentrations in the bio-monitors and clinical data were performed on the sub-group of the amalgam-burners only (n = 99). This group was selected, because it was the highest burden group with highest mercury concentration in the bio-monitors and highest frequency of health disturbances, characteristic for a mercury burden. Performing the same analysis including all investigated persons, or all volunteers from Rwamagasa, will just "water down" the results.

As can seen from the tables 6 -10, just some few of the medical data correlate significantly to the Hg concentration in the bio-monitors (Chi-square-test, Spearman rank correlation).

AnamnesticData	**Hg-Urin (µg/g crea.)**	**Hg-Blood**	**total Hg-Hair**	**MeHg-Hair**
Male/female	-	-	-	-
Age	-	-	-	-
Alcohol consumption	-	-	-	-
Metallic taste	-	-	-	-
Salivation	-	-	-	-
Tremor daily	-	*	-	-
Tremor at work	*	*	*	-
Sleeping problems	*	-	-	-
Health problems worsened since Hg exposed	-	-	-	-
Lack of appetite	-	*	-	-
Sleep disturbances	-	-	-	-
Easily tired	-	-	-	-
Loss weight	-	-	-	-

Table 6: Significant correlations between anamnestic data and mercury concentration in bio-monitors (group of amalgam-burners only, n = 99). * = $p < 0.05$.

AnamnesticData	Hg-Urine (µg/g crea.)	Hg-Blood	Total Hg-Hair	MeHg-Hair
Rest more	-	*	-	-
Feel sleepy	-	*	*	-
Problems to start things	-	*	-	-
Lack of energy	*	*	-	-
Less strength	-	-	-	-
Weak	-	*	*	*
Problems with concentration	-	*	-	-
Problems to think clear	*	*	-	-
Word finding problems	-	-	-	-
Eyestrain	*	-	-	-
Memory problems	-	-	-	-
Feel nervous	*	-	-	-
Feel sad	-	-	-	-
Headache	-	-	-	-
Nausea	*	*	-	-
Numbness	-	-	-	-

Table 7: Significant correlations between anamnestic data and mercury concentration in bio-monitors (group of amalgam-burners only, n = 99). * = $p < 0.05$.

Clinical Data	**Hg-Urine (µg/g crea.)**	**Hg-Blood**	**Total Hg-Hair**	**MeHg-Hair**
Bluish coloration of gingiva	-	-	-	-
Gingivitis	-	-	-	-
Ataxia of gait	-	-	-	-
Finger to nose tremor	-	-	-	-
Finger to nose dysmetria	-	-	-	-
Dysdiadocho-kinesia	-	-	-	-
Tremor of eyelid	-	-	-	-
Field of vision	-	-	-	-
Heel to knee ataxia	-	-	-	-
Heel to knee tremor	-	-	*	-
PSR pathologic	-	-	-	-
BSR pathologic	-	-	-	-
ASR pathologic	-	-	-	-
Babinski reflex prositive	-	-	-	-
Mento-labial reflex positive	-	-	-	-
Bradykinesia	-	-	-	-
Hypomimia	-	-	-	-
Proteinuria	-	-	-	-

Table 8: Significant correlations between clinical data and mercury concentration in bio-monitors (group of amalgam-burners only, n = 99) . * = $p < 0.05$.

Neuro-psychological test	Hg-Urine (µg/g crea.)	Hg-Blood	Total Hg-Hair	MeHg-Hair
Memory test	-	-	-	-
Matchbox test	*	*	-	-
Frostig test	-	-	-	-
Pencil tapping test	-	-	-	-

Table 9: Significant correlations between neuro-psychological test classes and mercury concentration in bio-monitors (group of amalgam-burners only, n = 99).
* = $p < 0.05$.

Medical Scores	Hg-Urine (µg/g crea.)	Hg-Blood	Total Hg-Hair	MeHg-Hair
Anamnestic score	*	*	-	-
Clinical score	-	-	-	-
Neuro-psychological test score	-	-	-	-
Medical score sum	*	-	-	-

Table 10: Significant correlations between medical scores and mercury concentration in bio-monitors (group of amalgam-burners only, n = 99). * = $p < 0.05$.

DISCUSSION OF THE STATISTICAL ANALYSIS

The relatively poor correlation of classic clinical signs of mercury intoxication to the mercury concentrations in the bio-monitors (blood, urine, hair, MeHg hair) of the amalgam-burners may be explained by factors like:

- The mercury concentration in the target tissues, especially the brain, correlates to the mercury concentration in bio-monitors like urine, blood or hair. This correlation is statistically significant and good enough to mirror different burden of different groups (here e.g. workers, non-workers and controls). But the inter-individual differences are so large that it is rather pointless to conclude the heavy metal burden in the target tissue of an individual from the concentration in the bio-monitors (Drasch 1997).
- Most of the amalgam-burners are chronically burdened by mercury and not only acute. This means that a reversible or even irreversible damage of the central nervous system may be set months or years before the actual determination of the mercury concentration in the bio-monitors under a quite different burden. The medical score sum distinguishes well between the control group and Rwamagasa amalgam-burners. But former occupationally exposed participants still show a high medical score median (see figure 8). So even the bio-monitor values are lower (see figure 9 to 11) the symptoms, expressed as medical score sum remain.

MERCURY LEVELS COMPARED TO TOXICOLOGICAL THRESHOLD LIMITS

In the international literature only a few threshold limits for mercury in bio-monitors are recommended, especially for an at least predominant burden with mercury vapour, as could be expected in the investigated population (Drasch 2004). Most studies in this field are performed in populations with a exclusively methyl-mercury burden from fish or sea-food, like the former data from Minamata, or the more recent data from the Seychelles (Davidson 1998), the Faeroes Islands (Grandjean 1997) or even from the Amazon (Grandjean 1999). To estimate the toxicological relevance of the burden with predominantly mercury vapour of the investigated population from Rwamagasa, the following threshold limits were used:

German human-bio-monitoring (HBM) values for mercury

In 1999 the German Environmental Agency ("Umweltbundesamt") published recommendations for human-bio-monitoring-values (HBM) for mercury ("Kommission Human-Biomonitoring" 1999).

The HBM I was set to be a "**check value**", this means an elevated mercury concentration in blood or urine, above which the source of the Hg-burden should be searched and, as far as possible, eliminated. But even by an exceeding of this HBM I the authors claimed that a health risk is not to be expected.

In contrast to this, the (higher) HBM II value is an "**intervention value**". This means, at blood or urine levels above HBM II, especially for a longer time, adverse health effects cannot be excluded. Therefore interventions are necessary. On the one hand the source should be found and reduced urgently. On the other hand a medical check for possible symptoms should be performed. For hair, comparable values are not established, but the HBM II in blood is directly derived from the assumption of a stable ratio of mercury in blood and hair (1:300) and the result of the Seychelles study, where adverse effects could be seen at mercury concentration in hair above 5 µg/g (Davidson 1998). Therefore this value was taken in our study as an analogous value for HBM II for the toxicological evaluation of mercury concentration determined in hair. It must be kept in mind, that this threshold limit in hair was established in a population burdened with methyl-mercury from marine food and not with

mercury vapour, as is predominant in the Rwamagasa area of Tanzania, investigated in this study.

	Hg-blood (µg/l)	Hg-urine (µg/l)	Hg-urine (µg/g crea)	Hg-hair (µg/g)
HBM I	5	7	5	
HBM II	15	25	20	5 (in analogy)
US EPA bench mark				1
WHO		50		7
BAT for metallic and inorganic Hg	25	100		
BAT for organic Hg	100			
BEI (Biological exposure index)	15 (after working)		35 (before working)	

Table 11: Toxicologically established threshold limits for mercury in blood, urine and hair (HBM = **H**uman **B**io-**M**onitoring; BAT = "**B**iologischer **A**rbeitsstoff-**T**oleranzwert" (biological work-exposure tolerance limit); BEI = **B**iological **E**xposure **I**ndices)

In 1991 the WHO expert group stated that mercury in urine is the best indicator for a burden with inorganic mercury. The maximum acceptable concentration of mercury in urine was set to 50 µg/l (WHO 1991). A distinct threshold for mercury in blood was not given. Mercury in hair is widely accepted as best indicator for the assessment of contamination in populations exposed to methyl-mercury (de Lacerda 1998). For this, a maximum allowable concentration of 7.0 µg/g hair was set by the FAO/WHO. In 1997 the US EPA calculated the "benchmark limit" for total Hg in hair to 1 µg/g. This benchmark was derived from a burden with methyl-mercury from seafood and not with mercury vapour. US EPA has set a threshold limit for mercury vapour in the ambient air, but not in bio-monitors (US EPA 1997).

All these limits and others, former published, are respected at the most recent recommendation from the German Environmental Agency 1999, as cited above. The high numbers of recently published investigations on mercury burdened populations from gold mining areas like in South-America or by sea food like on the Faeroes Islands or the

Seychelles require a continuous re-evaluation of toxicologically defined threshold limits. Therefore the international latest recommendation from the German Environmental Agency was taken for further comparison. This was committed with UNIDO for the total global programme, to get comparable results (Veiga 2003).

Occupational threshold limits (BAT, BEI)

Other toxicologically founded limits are occupationally threshold limits. Such limits are established for mercury e.g. in the USA (biological exposure indices BEIs of the American Conference of Governmental Industrial Hygienists) or Germany (BAT value, Deutsche Forschungsgemeinschaft (German Scientific Community) 1999). For a better comparison with the HBM-values (which are, to our knowledge, only established in Germany) the German BAT-values for metallic and inorganic mercury are taken for this study. From the definition, these BAT-values are exclusively valid for healthy adult workers under occupational medical control. The occupational burden must be stopped, if this threshold is exceeded. These occupational threshold limits are not valid for the total population, especially not for risk groups like children, pregnant women, and older or ill persons. Nevertheless, the BAT-values were taken for a further classifying of our highest results, too. BAT-values for mercury are established only for blood and urine, but not for hair.

Table 11 gives an overview of the HBM-, BAT- and BEI-values. In Table 4 in appendix 1 the percentage of the exceeding of the HBM II- and BAT-limits in the various population groups of our study is summarised.

As shown in the next chapter the biological threshold limits should not be overestimated for the diagnosis. Therefore the question, which of the limits is best for evaluating the results of this study is only of secondary interest.

DECISION FOR THE DIAGNOSIS OF A CHRONIC MERCURY INTOXICATION

For the different Hg burdened groups (< HBM I; HBM I - HBM II; HBM II - BAT; > BAT) no striking differences in the results of the medical and neuro-psychological tests could be seen (for possible reasons, see above). Therefore at least a chronic mercury intoxication could not be diagnosed on the basis of the blood, urine and/or hair concentration alone, to what values ever the threshold limits are set (see above). An intoxication is defined by the presence of the toxin in the body and typical adverse health effects. Deriving from this interpretation we have tried to find a balanced result by the combination of mercury concentration in blood, urine and hair and the negative health effects, as summarised in the medical score sum, as described above in detail (Drasch 2001). The medical test scores were divided in three groups, according to the quartiles (0-25%, 25-75%, 75-100%). Table 12 shows this combination. This definition of mercury intoxication was committed with UNIDO, to get comparable results in the different sites in the global project (Veiga 2003).

		Medical Score Sum		
		0 – 4	5 – 9	10 - 21
Hg in all bio-monitors	< HBM I	–	–	–
Hg at least in one bio-monitor	> HBM I	–	–	+
	> HBM II	–	+	+
	> BAT	+	+	+

Table 12: Decision for the diagnosis "chronic mercury intoxication"

In principle this means, that the higher the mercury concentration in at least one of the bio-monitors was, the lower the number of adverse effects for a positive diagnosis of a mercury intoxication must be and vice versa.

Cases with only moderately elevated mercury levels (i.e. between HBM I and HBM II) are taken for positive, too, if the medical test scores are in the upper quartile region (score sum 10-21).

The case, that a mercury concentration above the occupational threshold limit BAT alone (this means without clinical signs, i.e. medical score 0-4) is responsible for the classification of intoxication, can be neglected. All four cases found in this study in Tanzania with mercury concentrations above the BAT value (3 amalgam-burners, 1 retired worker in Rwamagasa) exceeded the medical score sum of 4 by far (individual medical sore sums: 7, 7, 10, 11)

PREVALENCE OF THE DIAGNOSIS "MERCURY INTOXICATION"

Group	Total number	Number of mercury intoxicated cases	% cases, mercury intoxicated
Katoro, control group	31	0	0 %
Katoro, former occupational burdened	9	0	0 %
Rwamagasa, not occupational burdened	23	(1) 0	(4.2 %) 0 %
Rwamagasa, amalgam-burners	99	25	25.3 %
Rwamagasa, other occupational burden	67	0	0 %
Rwamagasa, former occupational burdened	12	(2) 3	(16.7 %) 20.0 %

Table 13: Frequency of mercury intoxication

By this classification the results shown in table 13 and figure 14 were obtained. As expected, no volunteer from the control area of Katoro has been found to be mercury intoxicated. 25.3 % of the amalgam-burners in Rwamagasa have to be classified as mercury intoxicated. This percentage is markedly lower, as we have found with the same protocol in the Mt. Diwata region of the Philippines (Drasch 2001, Boese-O'Reilly 2003), where 85,4% (!) of the

amalgam-burners were classified to be mercury intoxicated. The difference cannot be explained by a different, i.e. a safer burning technique in Rwamagasa. In Rwamagasa as on Mt. Diwata the gold amalgam is burned in open crucibles, heated just on an open fire or by a blowtorch, hold on it.

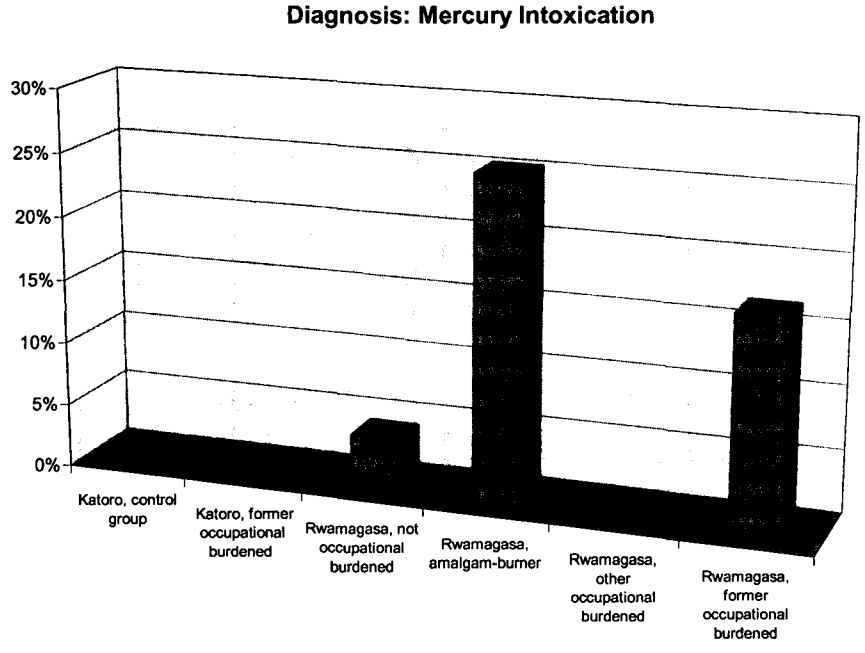


Figure 14: Frequency of the diagnosis of mercury intoxication in the different sub-groups

	Hg-Blood (µg/l)	Hg-Urine (µg/g crea.)	t-Hg-Hair (µg/g)	MeHg-Hair (µg/g)
N	25	25	20	18
median	8.6	13.2	4.1	0.8
maximum	33.3	36.8	48.7	5.3

Table 14: Mercury concentrations in biomonitors of the intoxicated amalgam burners (in some cases hair samples were not available).

Table 14 shows the mercury concentrations in the bio-monitors of the intoxicated amalgam burners.

Just 1 volunteer from Rwamagasa out of 23, which had declared to be not occupational burdened was found to be intoxicated, too. This man had a total mercury concentration in hair of 15.8 µg/g, while t-Hg-Hair of all other non-occupational burdened volunteers from Rwamagasa (n = 22) did not exceed 2 µg/g. His Hg-U (4.7 µg/L) and Hg-B (1.9 µg/L) was below HBM I. From this it can be assumed, that he was formerly occupational mercury burdened but now a farmer, as indicated by him. Therefore this case should be shifted to the group of former occupational burdened volunteers. In Rwamagasa none of the other 22 not occupational burdened volunteers and none of the 67 volunteers occupationally burdened in another way than amalgam burning (miners and ball millers) are found to be mercury intoxicated. 2 (plus 1, see above) out of 12 retired workers in Rwamagasa have to be classified as mercury intoxicated.

INFLUENCE ON NURSED BABIES

One major problem of mercury is a known adverse effect on the growing foetus and baby due to a high maternal burden and a cross of mercury through the placenta or to the breast-milk. High numbers of miscarriages, stillbirths and birth defects have been reported as consequence of the mass intoxication with mercury in Minamata, Japan, 1956 or the Iraq, 1972/73 (Drasch 2004). This study in Tanzania was not designed to detect possible adverse effects on the foetus, but as a side result some data on mercury in breast-milk samples were obtained.

16 samples of mature breast-milk were collected and analysed for total mercury. In table 15 these cases are shown individually in decreasing order of the Hg concentration in the breast-milk samples. For comparison: In some recent studies from Germany in samples from mature breast-milk maximal mercury concentrations below 2 µg/L have been found (Drasch 1998). As expected, the one sample from the control group and the two from non-occupational burdened mothers from Rwamagasa were well below this limit; most of the milk samples from occupational burdened or former burdened mothers, too. But two out of five of the breast-milk samples from active female amalgam-burners show extreme high mercury

concentrations (48.5 and 149.6 µg/L). Both mothers had been identified as "intoxicated" and had high total mercury concentration in hair, too. As expected, most of the mercury in their hair is inorganic (90.8% and 88.4%), deriving from a burden with mercury vapour. Therefore these cases cannot be compared directly to mothers from the Seychelles or the Faeroes Islands, which are predominantly burdened by methyl-mercury from fish. But even if most of the mercury in these breast-milk samples is inorganic, it gives rise to great concern: A full nursing of a baby with approximately 850 ml breast-milk per day with a Hg milk concentration of 50 –150 µg/L (as found in these amalgam-burners), results in a daily uptake of 40 to 120 µg inorganic mercury.

Hg-Breast milk (µg/L)	t-Hg-Hair (µg/g)	Me-Hg-Hair (µg/g)	Hg-U (µg/L)	Hg-B (µg/L)	Mother's Profession	Mother intoxicated
149,6	21,75	2,01	3,1	11,36	Amalgam-burner	yes
48,5	40,83	4,72	20,35	11	Amalgam-burner	yes
7,25	0,63	0,22	2,05	2,35	Katoro former occup.	no
3,4	0,36		1,12	2,18	Rwamagasa other occup.	no
1,75			14	4,4	Amalgam-burner	no
1,15	3,74	0,82	1,8	1,99	Rwamagasa other occup.	no
0,5	0,36	0,3	0,54	0,83	Rwamagasa other occup.	no
0,5	0,43		0,1	1,6	Rwamagasa other occup.	no
0,5	0,66	0,6	0,31	1,89	Rwamagasa other occup.	no
0,5			0,23	1,85	Amalgam-burner	no
0,5	0,42	0,37	0,1	0,94	Amalgam-burner	no
0,5	0,36		0,1	1	Katoro control group	no
0,4	0,55		0,5	2,03	Rwamagasa other occup.	no
0,4	0,32	0,26	0,1	0,89	Rwamagasa not occup.	no
0,3	0,4	0,31	0,29	1,2	Rwamagasa other occup.	no
0,3	0,39		1,2	1,53	Rwamagasa not occup.	no

Table 15: (Total) mercury concentration in breast-milk samples, compared to other data from the mothers.

US EPA has calculated the so-called "Reference Dose" for inorganic mercury to 0.3 µg/ kg body weight and day (US EPA 1997). For a 6 kg baby this means a maximum daily uptake of 1.8 µg inorganic mercury. The real uptake of these two babies of the amalgam-burners was 20 to 60 times higher. Moreover it must be considered that the absorption rate for inorganic mercury especially from milk in the gastro-intestinal tract of babies is markedly higher than of adults (Drasch 2004).

SCREENING OF MERCURY URINE CONCENTRATION IN FIELD

In field a mobile Hg analyzer (Hg-254 NE, Seefelder Messtechnik, Seefeld, Germany) was used to screen for inorganic mercury in urine. In a baker, 1ml urine was diluted with 100 ml water (bottled drinking water). A 2 ml solution of 10% tin(II)chloride in 6N hydrochloric acid was added , the system closed, and the formed mercury vapour in the gas phase above the liquid transferred in a closed loop to a quartz cell, where it was detected by atomic emission spectrometry. Bottled drinking water (as to be got locally) was used for zero standard, and a mercuric nitrate solution for standard. The limit for a quantitative detection was approximately 2 µg/L urine. As the HBM limits for Hg in urine are 7 and 25 µg/L, respectively (see table 11), this method seems to be sufficient sensitive for urine Hg screening in the field. One analysis lasts approximately 3 minutes. 231 urine samples could be analysed with this method in field. At the last day in the control area of Katoro it was not possible to work with this system, due to problems with an inadequate electric power supply.

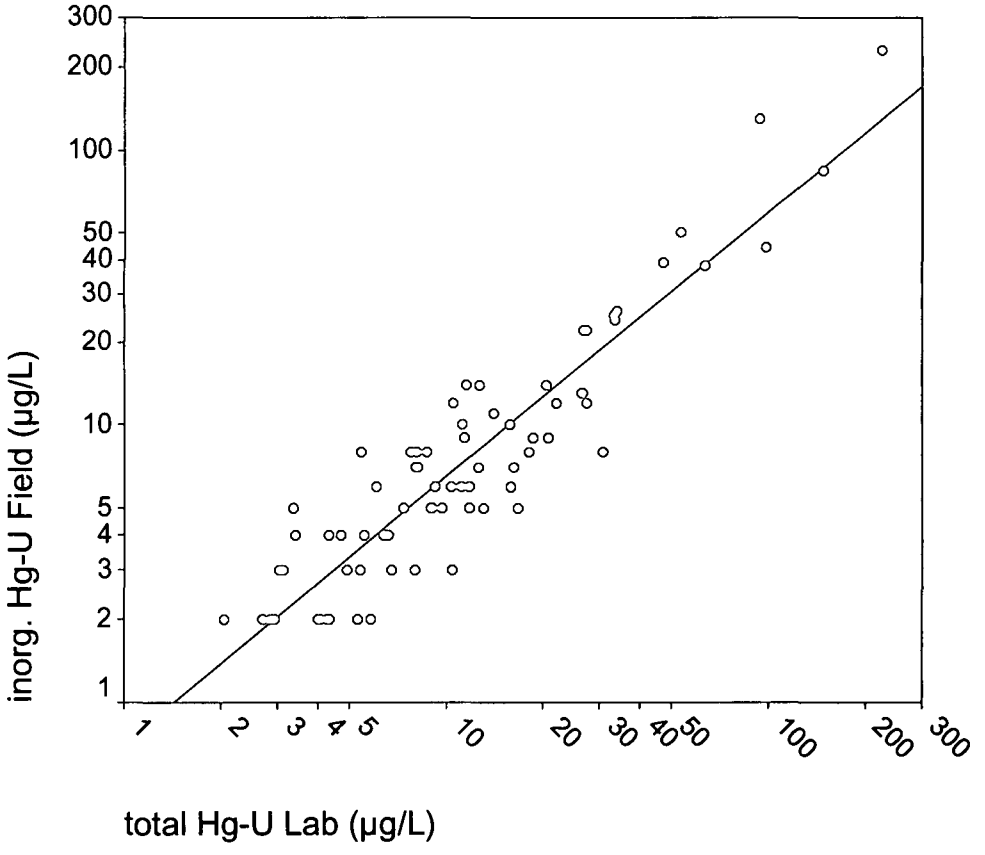


Figure 16: Comparison of the concentration of inorganic Hg-U, as determined in field and the total Hg-U concentration, as determined in the lab.

The correlation between the concentration of inorganic Hg, determined with this method in field, and the concentration of total Hg, as determined in lab, was excellent (Spearman-r_o = + 0.72, statistical highly significant). A scatter plot (figure 16) proves the sufficient correspondence of both methods in the region above the detection limit of the field method (2 µg/L). It must kept in mind that with this field method just inorganic mercury can be detected. But at least in the Rwamagasa area of Tanzania most of the mercury burden of men is inorganic. Furthermore it is known, that inorganic mercury is much better urinary excreted than organic bound mercury like methyl-mercury. From this it could be concluded that most

mercury in the urine samples has been in the inorganic form. Nevertheless, as expected, in the mean the total mercury concentration in urine (as detected in the lab), was higher than the inorganic mercury concentration determined in field (see regression line in figure 16).

All data from the medical investigations and from the urine screening were put during the field project into an excel data sheet . The medical sum score could be calculated and 17 cases preliminary classified as "mercury intoxicated" by the combination of the medical sum score and the Hg concentration in urine, as determined in field (according to table 12). From the medical sum score and the final lab results, 16 out of these 17 intoxications could be confirmed. Only in one case the primarily field diagnosis could not be confirmed. The total number of finally (i.e. after the Hg determination in all three bio-monitors in the lab) diagnosed intoxications from all cases was 29. In the remaining 12 cases, the intoxication was diagnosed by elevated Hg concentrations in blood and/or hair. Overall, the urine mercury screening during the field project has proved to be a sound method to get quick information during the field project on the order of magnitude of the mercury burden of sub-groups of the population. Together with a computer based evaluation of the medical results during the field project it was possible in more than one half of the cases to find out mercury intoxicated individuals just during the field mission and to give a primarily estimation of the local burden situation.

Summary and Recommendations
(G. Drasch and S. Boese-O´Reilly)

SUMMARY

Rwamagasa is a typical small-scale mining village with approximately 27.000 inhabitants in Geita District, near Lake Victoria/Tanzania. Artisanal small-scale miners use mercury to extract the gold from the ore. It is estimated that approx. 150.000 to 300.000 people work and live in similar small scale mining communities all over Tanzania.

There is no clean and safe drinking water, no waste disposal for the toxic mercury or any other waste or human discharge. Hygienic standards are extremely low and are a reason for many infectious diseases such as diarrhoea, typhoid and parasitism.

Road accidents, accidents in insecure tunnels and amalgamation plants, malaria, tuberculosis, and sexually transmitted diseases including AIDS are the dominant causes of morbidity and mortality. No health service exists for the mining community.

The extraction of the gold with liquid mercury releases serious amounts of mercury, especially high toxic mercury fumes into the local environment. The health status of 211 volunteers in Rwamagasa and 41 from a near by control area in Katoro was assessed with a standardised health assessment protocol from UNIDO (Veiga 2003) by an expert team from the University of Munich/Germany in October/November 2003.

The mercury levels in the bio-monitors urine, blood and hair were statistically significant higher in the exposed population in Rwamagasa then in the control group, but only amalgam-burners showed mercury levels above the toxicological threshold limit HBM II in urine, blood and hair. Mainly inorganic mercury contributes to the high body burden of the workers.

Typical symptoms of mercury intoxication were prevalent in the exposed group. The medical score sum plus the bio-monitoring results made it possible to diagnose in 25 out of 99 amalgam-burners the diagnosis of a chronic mercury intoxication, and in 3 out of 15 former amalgam-burners. Within the other population in Rwamagasa and in the control group there was no case of a mercury intoxication. The percentage of intoxications among amalgam-

burners was lower in Rwamagasa than e.g. in the comparable small scale gold mining area of Mt. Diwata in the Philippines, where 85.4 % of the amalgam-burners were intoxicated (Drasch 2001). The difference cannot be explained by a different, i.e. a safer burning technique in Rwamagasa. Moreover, it must kept in mind, that the maximal burden (as expressed in the top mercury concentrations found in the bio-monitors) was comparable to Mt. Diwata. The impression in the field was that this difference may be explained just by a lower consumption of liquid mercury in Rwamagasa, due to a lower output of gold from the ore. This results in a lower number of higher burdened, intoxicated persons.

Child labour in the mining sites is very common from the age of 10 on, the children work and play with their bare hands with toxic mercury. Mercury can cause severe damage to the developing brain.

Nursed babies of amalgam-burning mothers are at special risk. In two out of five breast-milk samples of nursing amalgam-burners extremely high mercury concentrations were detected. In addition to a placental transfer of mercury during pregnancy from the mother to the foetus (as has been proved in other studies) this high mercury burden of nursed babies give rise to great concern.

Poverty is the main reason of the disastrous health status of the small-scale mining communities. Struggling for pure survival makes mining for gold a necessity to find any financial resource. The daily fight of survival makes the miners put their own health and the health of their children at risk.

A reduction of the release of mercury vapours from small-scale gold mining like in Tanzania into the atmosphere will not only reduce the number of mercury intoxicated people in the mining area proper. It will reduce the global pollution of the atmosphere with mercury, because most of the mercury vapour formed by open burning of gold amalgam is not deposited locally, but is transported by air on long-range distances all over the globe (Lamborg 2002). The total release of mercury vapour from gold mining is estimated today up to 1,000 metric tons per year (MMSD 2002), while from all other anthropogenic sources approximately 1.900 tons were released into the atmosphere (Pirrone 2001).

The primary result is, that mercury is a serious health hazard in the small-scale gold mining area of Rwamagasa. Working for many years in the amalgamation or burning process, especially amalgam-burning resulted in severe symptoms of mercury intoxication. The exposure of the whole community to mercury is reflected in raised mercury levels in the

urine, and first symptoms of brain damage like ataxia, tremor and movement disorders. In 25% of the amalgam-burners from Rwamagasa a mercury intoxication (according to the definition of UNIDO (Veiga 2003)) was diagnosed. Some of the former occupational burdened persons were intoxicated, too. People from Rwamagasa, not directly involved in amalgam burning, are higher mercury burdened than the control group, but at least in the majority, still not intoxicated. The background burden in the control group is in the same order of magnitude as in western industrial countries.

RECOMMENDATIONS

How to improve General Health?

Poverty is the main reason for all health and environmental problems.

- At the moment it does not seem to be acceptable that **children** live in Rwamagasa. Missing sanitary standards and high exposure to mercury are the main reasons. Sanitary standards need urgent improvement.
- The **occupational** related **health risk** of mining should be assessed in more detail (accidents, malaria, drinking water quality, sexually transmitted diseases, tuberculosis, HIV / AIDS). One first step to reduce the health hazards in Rwamagasa might be a proper zoning into industrial areas, commercial areas and housing areas. And imposing basic hygienic standards, such as proper drinking water and reduction of Anopheles mosquitoes.
- To reduce the obvious risk of **accidents** in mining sites, raising awareness is necessary. Introducing proper mining techniques is necessary (e.g. tunnel safety).
- The risk of **sexually transmitted diseases** could be reduced, if campaigns for safer sex were more effective.
- To improve the health status of the communities a proper health service is urgently required.

How to reduce Mercury as a Health Hazard?

Referring to the clinical testing and laboratory results, mercury is a major health hazard in the area. Some first suggestions are:

- Child labour with highly toxic substances must be stopped immediately. Legal restrictions on child labour need to be immediately implemented.
- Women in childbearing age need special information campaigns on this risk of mercury to the foetus and the nursed baby.
- The participants with intoxication need medical treatment. It is necessary to build up a system to diagnose and treat mercury related health problems in the area. Capacity building including establishing laboratory facilities to analyse mercury in human specimens is required. The financial aspect of treatment and legal problem of importing drugs (chelating agents like DMPS or DMSA, to sweep mercury out of the body) need to be solved. Funding of preventive campaigns and for treatment facilities is now needed.
- Training programs for the health care providers in the district in Geita and other health centres in mining areas to raise awareness of mercury as a health hazard.
- Clinical training of local health workers, including a standardised questionnaire and examination flow scheme (MES = mercury examination score)
- Mercury ambulance: A mobile „mercury ambulance" might easier reach small-scale miners, than any local health office. A bus could be used as a mobile mercury ambulance. Equipped with the necessary medical and laboratory utensils, the bus could be driven into the mining areas. Two or three specially trained doctors or nurses could perform the examinations, and begin to carry out treatment. The bus could also be used for health awareness programs (e.g. video equipment). Miners in remote areas might welcome any evening entertainment. Soccer videos might attract more miners to the bus, than much other information material. Why not ask e.g. sponsors for such a bus (or truck).

How to improve the Knowledge on Mercury as a Health Hazard

- Assessing in a different study design the possibility of mercury related birth and growth defects, increased abortion/miscarriage rates, infertility problems, learning difficulties in childhood or other neuro-psychological problems related to mercury exposure

- Assessing in a different study in more detail the possible transfer of mercury from mother to child via breast-milk and related possible adverse health effects. Females at childbearing age and before need urgently more awareness to refrain from amalgam burning, at least during pregnancy and nursing. If this is not possible, a discussion whether to provide them with milk powder and mercury free water (!), and training them to prepare hygienically unobjectionable formula food for their babies needs to be based on a larger data base and a different epidemiological approach.

How to reduce the Release of Mercury into the Environment

- The exposure to mercury for the miners and the community has to be drastically decreased. Proper mining techniques to reduce the burden of accidents and mercury exposure are essentially needed. Small-scale miners need all possible support to introduce cleaner and safer gold mining and extraction technologies.
- The exposure with mercury is avoidable with such simple technology as retorts. Technical solutions need to go hand in hand with awareness raising campaigns.
- To improve the social, health and environmental situation of artisanal small-scale gold miners an alliance of local, regional, governmental and intergovernmental bodies is needed. Cooperation between health and environmental sectors is needed on local, regional, national and intergovernmental level. E.g. UNIDO and WHO in Dar es Salaam could form a nucleus of a national mercury task force.

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Appendix 1:

Hg-B	r_o = + 0.75 ** (N = 248)			
t-Hg-Hair	r_o = + 0.70 ** (N = 208)	r_o = + 0.78 ** (N = 212)		
inorganic-Hg-Hair	r_o = + 0.70 ** (N = 121)	r_o = + 0.70 ** (N = 123)	r_o = + 0.88 ** (N = 123)	
organic-Hg-Hair	r_o = + 0.40 ** (N = 121)	r_o = + 0.53 ** (N = 123)	r_o = + 0.72 ** (N = 123)	r_o = + 0.42 ** (N = 123)
	Hg-U Lab (µg/ g crea)	Hg-B	t-Hg-Hair	inorganic-Hg-Hair

Table 3: Spearman' rank correlations (r_o) between the mercury concentration in the different bio-monitors.
**** = p < 0.01 (one-tailed), N = case number**

Data or Test	**Value or score**	**Katoro (Control Area)**		**Rwamagasa (Burdened Area)**			
		control group	**former occupational burdened**	**not occupational burdened**	**amalgam-burners**	**other occupational burdened**	**former occupational burdened**
Case number		31	9	24	99	67	12
Anamnestic data:							
Male/female		12/19	6/3	11/13	82/17	35/32	9/3
Mean age (years)		32.4	32.4	29.7	34.6	29.4	34.8
Heavy alcohol drinker	0/1	6.5%	11.1%	4.2%	8.1%	6.0%	8.3%
Metallic taste	0/1	3.2%	0%	8.3%	4.0%	3.0%	0%
Salivation	0/1	16.1%	22.2%	8.3%	29.3%	13.4%	16.7%
Tremor at work	0/1	9.7%	0%	4,2%	21.2%	6.0%	8,3%
Sleeping problems	0/1	19.4%	22.2%	20.8%	28.3%	22.4%	25.0%
Health problems worsened since Hg exposed	0/1	0%	0%	0%	21.2%	6.0%	16.7%

Data or Test	**Value or score**	**Katoro (Control Area)**	**Rwamagasa (Burdened Area)**

		control group	former occupational burdened	not occupational burdened	amalgam-burners	other occupational burdened	former occupational burdened
Case number		31	9	24	99	67	12
Anamnestic data:							
Lack of appetite		25.8%	33.3%	20.8%	34.3%	14.9%	25.0%
Loss of weight		0	0	0	1.0%	1.5%	0
Easily tired		22.6%	33.3%	33.3%	52.5%	31.3%	25.0%
Rest more		19.4%	11.1%	8.3%	24.5%	30.3%	8.3%
Feel sleepy		12.9%	22.2%	8.3%	20.2%	20.9%	25.0%
Problems to start things		0	0	8.3%	9.2%	4.5%	16.7%
Lack of energy		9,7%	11,1%	20,8%	25.3%	28.4%	16,7%
Less strength		9,7%	11,1%	12,5%	25.3%	22.4%	16,7%
Weak		12.9%	33.3%	25.0%	24.5%	31.3%	16.7%

Data or Test	**Value or score**	**Katoro (Control Area)**		**Rwamagasa (Burdened Area)**			
		control group	**former occupational burdened**	**not occupational burdened**	**amalgam-burners**	**other occupational burdened**	**former occupational burdened**
Case number		31	9	24	99	67	12
Anamnestic data:							
Problems with concentration		9.7%	0	8.3%	20.2%	14.9%	16.7%
Problems to think clear		9.7%	0	12.5%	22.2%	19.4%	16.7%
Word finding problems		0	0	0	8.1%	0	0
Eyestrain		16.1%	33.3%	16.7%	38.4%	28.4%	33.3%
Memory problems		32.3%	11.1%	20.8%	43.4%	23.9%	0
Feel nervous		16.1%	11.1%	12.5%	19.2%	9.0%	0
Feel sad		22.6%	22.2%	25.0%	43.4%	31.3%	25.0%
Headache		61.3%	77.8%	58.3%	47.5%	52.2%	50.0%
Nausea		29.0%	33.3%	33.3%	26.3%	19.4%	25.0%
Numbness		35.5%	44.4%	25.0%	40.4%	38.8%	50.0%

Data or Test	Value or score	Katoro (Control Area)		Rwamagasa (Burdened Area)			
		control group	former occupational burdened	not occupational burdened	amalgam-burners	other occupational burdened	former occupational burdened
Case number		31	9	24	99	67	12
Clinical data:							
Bluish coloration of gingiva	0/1	16,1%	44,4%	58,3%	36.4%	44.8%	50,0%
Gingivitis		0	0	0	3.0%	0	0
Ataxia of gait	0/1	3,2%	11,1%	12,5%	17.2%	10.4%	8,3%
Finger to nose tremor	0/1	9,7%	11,1%	4,2%	14.1%	4.5%	8,3%
Finger to nose dysmetria	0/1	6,4%	0%	4,2%	7.1%	3.0%	16,7%
Dysdiadochokinesia	0/1	19,4%	44,4%	16,7%	29.3%	32.8%	33,3%
Tremor of eyelid	0/1	19,4%	0%	29,2%	32.3%	20.9%	0%

Data or Test	**Value or score**	**Katoro (Control Area)**		**Rwamagasa (Burdened Area)**			
		control group	**former occupational burdened**	**not occupational burdened**	**amalgam-burners**	**other occupational burdened**	**former occupational burdened**
Case number		31	9	24	99	67	12
Clinical data:							
Horizontal field of vision (median)		170°	163°	163°	164°	164°	162°
Heel to knee ataxia	0/1	6.5%	0%	20.8%	18.2%	9.0%	16.7%
Heel to knee tremor	0/1	0%	0%	0%	2.0%	0%	0%
PSR normal	0/1	80,6%	66,7%	66,7%	63.9%	69.7%	68,2
BSR normal	0/1	100%	77,8%	70,8%	78.8%	76.1%	83,3%
ASR normal	0/1	96,8%	77,8%	45,8%	52.6%	56.1%	50,0%
Babinski reflex path.	0/1	6,5%	0%	0%	4.0%	0%	16,7%
Mento-labial reflex pathologic	0/1	32.4%	33.3%	37.5%	36.4%	17.9%	33.3%
Sensory disturbance	0/1	0%	11,1%	4,2%	16.0%	1.5%	0%
Bradykinesia	0/1	3,2%	0%	12,5%	12.2%	11.9%	8,3%
Hypomimia	0/1	6,5%	0%	12,5%	18.4%	13.4%	16,7%
Proteinuria		9.7%	0%	4.2%	19.2%	11.9%	41.7%

Data or Test	**Value or score**	**Katoro (Control Area)**		**Rwamagasa (Burdened Area)**			
		control group	**former occupational burdened**	**not occupational burdened**	**amalgam-burners**	**other occupational burdened**	**former occupational burdened**
Case number		31	9	24	99	67	12
Neuro-psychological test							
Memory test	0-2	19.4%	22.2%	12.5%	10.1%	9.0%	8.3%
	3	35.5%	55.6%	33.3%	48.5%	49.3%	25.0%
	4	45.2%	22.2%%	54.2%	41.4%	41.8%	66.7%
Match box test	14-18 sec	45.2%	11.1%	16.7%	15.2%	24.2%	8.3%
	19-25 sec	35.5%	66.7%	50.0%	58.6%	60.6%	58.3%
	26-47 sec	19.4%	22.2%	33.3%	26.3%%	15.2%%	33.3%

Data or Test	**Value or score**	**Katoro (Control Area)**		**Rwamagasa (Burdened Area)**			
		control group	**former occupational burdened**	**not occupational burdened**	**amalgam-burners**	**other occupational burdened**	**former occupational burdened**
Case number		31	9	24	99	67	12
Neuro-psychological test							
Frostig test	16-12	25.8%	44.4%	29.2%	29.3%	28.4%	41.7%
	11-9	67.7%	22.2%	37.5%	40.4%	38.8%	25.0%
	8-0	6.5%	33.3%	33.3%	30.3%	32.8%	33.3%
Pencil tapping test	85-64	30.0%	33.3%	12.5%	21.4%	25.8%	25.0%
	63-51	53.3%	55.6%	37.5%	52.0%	51.5%	50.0%
	50-27	16.7%	11.1%	50.0%	26.5%	22.7%	25.0%

Data or Test	Value or score	Katoro (Control Area)		Rwamagasa (Burdened Area)			
		control group	former occupational burdened	not occupational burdened	amalgam-burners	other occupational burdened	former occupational burdened
Bio-monitoring							
Hg-urine (µg/l)	No.	31	9	23	97	67	12
	median	0.31	0.91	0.58	6.36	0.85	1.13
	> HBM II	0	0	0	15 (15.4%)	0	1 (8.3%)
	> BAT	0	0	0	1 (1.0%)	0	1 (8.3%)
	max.	1.8	6.8	11.4	147.2	9.7	224.0
Hg-urine (µg/g crea)	No.	31	9	23	96	67	12
	median	0.22	0.26	0.49	3.59	0.58	0.48
	> HBM II	0	0	0	6 (6.3%)	0	1 (8.3%)
	max.	0.9	2.0	11.6	36.8	7.0	106.6

Data or Test	Value or score	Katoro (Control Area)		Rwamagasa (Burdened Area)			
		control group	former occupational burdened	not occupational burdened	amalgam-burners	other occupational burdened	former occupational burdened
Bio-monitoring							
Hg-blood	No.	31	9	24	99	67	12
	median	0.98	1.37	1.50	2.58	1.58	1.70
	> HBM II	0	0	0	6 (6.1%)	0	1 (8.3%)
	> BAT	0	0	0	2 (2.0%)	0	0
	max.	2.3	2.4	5.8	33.3	6.1	17.9
Total Hg-hair	No.	24	6	21	80	63	10
	median	0.36	0.36	0.46	0.79	0.46	0.49
	> 5 µg/g	0	0	1 (4.8%)	9 (11.3%)		2 (20.0%)
	max.	0.68	0.63	15.75	48.74	4.07	18.75

Data or Test	**Value or score**	**Katoro (Control Area)**		**Rwamagasa (Burdened Area)**			
		control group	**former occupational burdened**	**not occupational burdened**	**amalgam-burners**	**other occupational burdened**	**former occupational burdened**
		31	9	24	99	67	12
Medical test score	median	5	7	7	7	6	7
	0-4	40.0%	33.3%	8.3%	9.1%	23.1%	8.3%
	5-9	56.7%	66.7%	79.2%	72.7%	70.8%	83.3%
	10-21	3.3%	0%	12.5%	18.2%	6.2%	8.3%
HBM II and BAT							
Blood or urine or hair	> HBM II	0	0	1 (4.2%)	22 (22.2%)	0	2 (16.7%)
Blood or urine	> BAT	0	0	0	3 (3.0%)	0	1 (8.3%)
Diagnosis		31	9	24	99	67	12
Hg intoxication	No. (%)	0%	0%	1 (4.2%)	25 (25.3%)	0%	2 (16.7%)

Table 4: Relevant data of the sub-groups. Grey shaded fields in the table contain results that differ from the control group on a statistically significant level ($p < 0.05$, one-tailed Chi-square test

Appendix 2: Health Assessment Questionnaire

ID Nr:_____

Health Assessment Questionnaire

by Dr. Stephan Boese O'Reilly, Prof. Dr. Gustav Drasch, Stefan Maydl, Dr. Milan Vosko
Ludwig-Maximilians University, Munich, Germany.
and Dr. Claude Casellas, Prof. Dr. André Rambaud
University of Montpellier, France
Marcello Veiga, UNIDO Vienna, Austria

Removal of Barriers to the Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies
United Nations Industrial Development Organization (UNIDO)
Global Environment Facility (GEF)
United Nations Development Programme (UNDP)
Health Assessment

Jina:
Name: _____

I hereby declare that I want to take part in the UNIDO project. I will be questioned about my living circumstances and health problems related to mercury. I will be medically examined including neurological examination. Blood, urine and a small amount of hair will be taken. The UNIDO will inform me after the laboratory analysis about my personal results. The assessment is done respecting the "Recommendation for Conduct of Clinical Research" (World Health Organization Declaration of Helsinki).

>>Nakubali kushiriki katika Mradi wa UNIDO kwa kuulizwa maswali yanayohusiana na maisha yangu kwa ujumla na matatizo ya kiafya yanayohusiana na zebaki. Nitachunguzwa kiafya kwa kuchukuliwa damu, mkojo, na kiasi kidogo cha nywele. Matokeo ya uchunguzi huo nitafahamishwa binafsi na kwa siri kwa kuzingatia taratibu zote za Kimataifa>>

(Jina la eneo na tarehe)
Local and Date: _____ _____
Signature ***(Sahihi)***
(in case of children signature of parents/guardian)
(kwa watoto sahihi ya mzazi au mlezi)
Witnesses (if needed) (Shahidi kama itahitajika):

_____ and _____
(Name) ***(Jina):*** (Name) ***(Jina):***

1 Personal Data

1.1 Participant ID Number: _____

1.1.1 Family Name: .....

1.1.2 Surname .....

1.1.3 Date of Birth: .....

1.1.3.1 Age: ..... (years)

1.1.4 Gender:

0 Female
1 Male

1.1.5 Address: .....
.....

1.1.6 (if possible local codes, like settlement A,B, C ....)

2 General Questionnaire

2.1.1 Date of interview:.....

2.1.2 Name of the interviewer for this section:.....

2.1.3 **Code of the interviewer _____**
(please give every interviewer a code, like A,B,C)

2.2 Work Exposure

2.2.1 How long have you been living in this area? _____ year(s)

2.2.2 Occupation (Detailed description of the job)

A Miner, but no exposure to mercury
B Miner, with exposure to mercury, such as amalgamation, but no smelter
C Gold smelter, or gold buyer
D Worker at a cyanidation plant, but no contact to mercury
E Farmer
F Office Job
G Driver
H School child (not working)
J Other job.....
K School child (working in mining area, with exposure to mercury)

2.2.3 Have you ever worked in the _____ area?

0 ____ No
1 ____ Yes
2.2.3.1 If yes, for how many _____ year(s)?

2.2.4 Have you ever worked as a miner with direct contact with mercury?

0 ____ No
1 ____ Yes
2.2.4.1 If from when to when: _____
= _____ years of mercury contact

2.2.5 Have you ever worked burning amalgam or melting gold?

0 ____ No
1 ____ Yes
2.2.5.1 If yes, from when to when: _____
= _____ years of mercury contact

2.2.6 Have you been using retort?

1 ____ No
0 ____ Yes

2.2.7 Have you stored mercury containers or flasks?

0 ____ Never
1 ____ At work
2 ____ At home

2.2.8 Have you kept your dirty working clothes at your home?

0 ____ No
1 ____ Yes

2.2.9 For how many years have you been working with mercury?

0 ____ not applicable (have not working directly with mercury)
1 ____ year(s)

2.3 Diet Issues

2.4 Fish eating habits

2.4.1 How frequently do you eat fish?

0 ____ Never
1 ____ At least once a **month**
2. ____ At least once a **week**
3. ____ At least once a **day**

2.4.2 If at least once a day, how much fish to you eat?

2.4.2.1 _____ *meals per day*

2.4.3 Name the types of fish you consume regularly. If possible, indicate the type of fish that you eat the most:

Fish Name

2.4.3.1 _____
2.4.3.2 _____
2.4.3.3 _____
2.4.3.4 _____
2.4.3.5 _____
2.4.3.6 _____
2.4.3.7 _____
2.4.3.8 _____
2.4.3.9 _____

Please code the fishes like A, B, D, E, F, ...(Please use useful list of fish according to local habits)

2.4.4 Do you know where the fish come from?

0 _____ from areas distant from mining
1 _____ from areas impacted by mining
9 _____ don't know the origin of the fish (buy in the market)

2.4.5 Can you name the river and local where you catch most fish you have consumed?

A ____ No
B____ Yes, the river (or lake or pool) is _____
(Please give the areas codes, like C, D, E, F ...)

2.5 Other dietary issues

2.5.1 Name the place where you obtain drinking water: _____ (Please give the areas codes, like C, D, E, F ...)

2.5.2 Do you consume from local production chicken, ducks or eggs?

0 ____ Never
1 ____ At least once a **month**
2 ____ At least once a **week**
3 ____ At least once a **day**

2.5.3 Do you consume from local production meat?

0 ____ Never
1 ____ At least once a **month**
2 ____ At least once a **week**
3 ____ At least once a **day**

2.5.4 Do you consume from local production vegetables, fruits?

0 ____ Never
1 ____ At least once a **month**
2 ____ At least once a **week**
3 ____ At least once a **day**

2.6 Confounders

2.6.1 Do you smoke?

0 ____ Never
1 ____ Rarely (0-10 cigarettes per day)
2 ____ Medium (10-20 cigarettes per day)
3 ____ Lots (more then 20 cigarettes per day)

2.6.2 Do you drink alcohol?

0 ____ Never
1 ____ at least once a **month**
2 ____ at least once a **week**
3 ____ at least once a **day**

2.6.3 Have you been constantly handling gasoline and kerosene?

0 ____ No
1 ____ Yes
2.6.3.1 If yes, how many years you have been doing this? _____ (years)

2.6.4 Have you been constantly handling insecticides or pesticides?

0 ____ No
1 ____ Yes
2.6.4.1 If yes, how many years you have been doing this? _____ (years)

2.6.5 Do you use whitening soap (for lightening the skin)?

0 ____ No
1 ____ Yes

2.6.6 How is your current financial situation?

0 ____ ☺ (OK)
1 ____ 😐 (medium)
2 ____ ☹ (bad)

2.6.7 How is your current social life? (friends, family, hobby activities, etc.)

0 ____ ☺ (OK)
1 ____ 😐 (medium)
2 ____ ☹ (bad)

3 Health Problems not related to mercury

3.1.1 Date of interview:.....

3.1.2 Name of the interviewer for this section:.....

3.1.3 **Code of the interviewer** _____

3.2 Are you healthy now?

0 ____ Yes
1 ____ No
Why not? _____

3.3 Do you have fever at the moment?

0 ____ No
1 ____ Yes

3.4 Did you loose weight within the last year?

0 ____ No
1 ____ Yes

3.5 Did you cough within the last year for more then for 3 month?

0 ____ No
1 ____ Yes

3.6 Have you ever had malaria?

0 ____ No
1 ____ Yes

3.6.1 If yes, how many time ago you had your last malaria? _____ (days or weeks or months or years)

3.7 Africa

3.7.1 Have you ever had sleeping sickness?

0 ____ No
1 ____ Yes

3.7.2 Do you have HIV /AIDS?

0 ____ No
1 ____ Yes
since when _____ years

3.7.3 Do you or did you suffer from Leprosy?

0 ____ No
1 ____ Yes

3.8 Have you ever had any other major infectious disease?

0 ____ No
1 ____ Yes

3.8.1 Which disease (problem)? _____

3.9 Have you ever had kidney disease except urinary tract infection?

0 ____ No
1 ____ Yes

3.9.1 Which disease (problem)? _____

3.10 Have you ever had hepatitis or any other hepatic disorder?

0 ____ No
1 ____ Yes

3.10.1 Which disease (problem)? _____

3.11 Have you ever had severe respiratory problems (asthma, pneumonia)?

0 ____ No
1 ____ Yes

3.11.1 Which disease (problem)? _____

3.12 Did you ever have tuberculosis?

0 ____ No
1 ____ Yes

3.12.1 When did this happen ? _____ (days or weeks or months or years) ago

3.13 Have you ever had any neurological disorders (epilepsy, stroke, Parkinson etc.) or mental disorders?

0 ____ No
1 ____ Yes

3.13.1 Which disease (problem)? _____

3.14 Did you have any serious accidents (did you have to go to hospital)?

0 ____ No
1 ____ Yes, but not severe (less then 1 hour unconsciousness)
2 ___ Yes, and it was severe (more then 1 hour unconsciousness)

3.14.1 When did this happen ? _____ (days or weeks or months or years) ago

3.15 Exclusion criteria from statistical evaluation

Severe neurological disease such as Parkinson, stroke or severe accident (brain injury), birth trauma, tetanus, polio, diabetes, hyperthyroidism or any acute severe disease, etc...
To be filled in by project doctor.

0 ____ No
1 ____ Yes

Why this individual should be excluded from the assessment:

_____

3.16 Do you breastfeed (for women only)

0 ____ No
1 ____ Yes

3.17 Are you pregnant (for women only)

0 ____ No
1 ____ Yes

4 Health Questions related to mercury exposure

4.1.1 Date of interview:.....

4.1.2 Name of the interviewer for this section:.....

4.1.3 **Code of the interviewer** _____
(please give every interviewer a code, like A,B,C)

4.2 Has the actual or former health problem worsened since exposure to mercury occurred?

0 _____ No mercury exposure
1 _____ Mercury exposure, but no worsening effects
2 ____ Yes, mercury exposure **and** worsening

4.3 How is your appetite?

0 ____ ☺ (OK)
1 ____ 😐 (medium)
2 ____ ☹ (bad)

4.4 Did you loose hair within the last year?

0 ____ No or only rarely
1 ____ Yes, slight to moderate
2 ____ Yes, marked to sever

4.5 Sleep disturbances

How do you feel after a usual night of sleep?
0 ____ ☺ (OK)
1 ____ 😐 (medium)
2 ____ ☹ (bad)

4.6 Do you feel a kind of a metallic taste?

0 ____ Never
1 ____ at least once a **month**
2 ____ at least once a **week**
3 ____ at least once a **day**

4.7 Do you suffer from excessive salivation?

0 ____ Never
1 ____ at least once a **month**
2 ____ at least once a **week**
3 ____ at least once a **day**

4.8 Have you had any problems with tremor (shaking)?

(Clinical Tremor Rating Scale)

0 ____ I have no tremor or tremor does not interfere with my job
1 ____ I am able to work, but I need to be more careful than the average person
2 ____ I am able to do everything, but with errors; poorer than usual performance because of tremor
3 ____ I am unable to do a regular job, I may have changed to a different job due to tremor; it limits some housework, such as ironing
4 ____ I am unable to do any outside job; housework very limited

4.9 Fatigue

Score to estimate the state of fatigue (Wessely S, Powell R: Fatigue syndrome)

4.9.1 Have you got tired easily?

0 ____ Same as usual
1 ____ Worse then usual
2 ____ Much worse than usual

4.9.2 Do you need to rest more?

0 ____ Same as usual
1 ____ Worse then usual
2 ____ Much worse than usual

4.9.3 Do you feel sleepy or drowsy?

0 ____ Same as usual
1 ____ Worse then usual
2 ____ Much worse than usual

4.9.4 Can you no longer start anything?

0 ____ Same as usual
1 ____ Worse then usual
2 ____ Much worse than usual

4.9.5 Do you always lack energy?

0 ____ Same as usual
1 ____ Worse then usual
2 ____ Much worse than usual

4.9.6 Do you have less strength in your muscles?

0 ____ Same as usual
1 ____ Worse then usual
2 ____ Much worse than usual

4.9.7 Do you feel weak?

0 ____ Same as usual
1 ____ Worse then usual
2 ____ Much worse than usual

4.9.8 Can you start things without difficulties, but get weak as you go on?

0 ____ Same as usual
1 ____ Worse then usual
2 ____ Much worse than usual

4.9.9 Physical fatigue sum: _____ score sum (4.9.1 to 4.9.8)

4.9.10 Do you have problems concentrating?

0 ____ Same as usual
1 ____ Worse then usual
2 ____ Much worse than usual

4.9.11 Do you have problems thinking clearly?

0 ____ Same as usual
1 ____ Worse then usual
2 ____ Much worse than usual

4.9.12 Do you have problems to find correct words when you speak?

0 ____ Same as usual
1 ____ Worse then usual
2 ____ Much worse than usual

4.9.13 Do you have problems with eyestrain?

0 ____ Same as usual
1 ____ Worse then usual
2 ____ Much worse than usual

4.9.14 Do you have problems with memory?

0 ____ Same as usual
1 ____ Worse then usual
2 ____ Much worse than usual

4.9.15 Mental fatigue sum: _____ score sum (4.9.10 to 4.9.14)

4.10 Well being

4.10.1 Do you feel nervous?

0 ____ Never
1 ____ at least once a **month**
2 ____ at least once a **week**
3 ____ at least once a **day**

4.10.2 Do you feel sad?

0 ____ Never
1 ____ at least once a **month**
2 ____ at least once a **week**
3 ____ at least once a **day**

4.10.3 Do you have palpitations?

Feeling the heart beating
0 ____ Never
1 ____ at least once a **month**
2 ____ at least once a **week**
3 ____ at least once a **day**

4.10.4 Do you have a headache?

0 ____ Never
1 ____ at least once a **month**
2 ____ at least once a **week**
3 ____ at least once a **day**

4.10.5 Do you have nausea?

0 ____ Never
1 ____ at least once a **month**
2 ____ at least once a **week**
3 ____ at least once a **day**

4.10.6 Do you feel numbness, prickling, aching at any location of your body?

Mainly perioral dysesthesia and sensory impairment of the glove and-stocking type
0 ____ Never
1 ____ at least once a **month**
2 ____ at least once a **week**
3 ____ at least once a **day**

5 Clinical – neurological examination

5.1.1 Date of neurological examination:.....

5.1.2 Name of the neurological examiner:.....

5.1.3 Code of the examiner _____

5.2 Mouth and Teeth Conditions

5.2.1 Clinical signs of stomatitis

0 ____ No
1 ____ Yes

5.2.2 Clinical signs of gingivitis

0 ____ No
1 ____ Yes

5.2.3 Bluish discoloration of the gums

0 ____ No
1 ____ Slight
2 ____ Yes, obvious

5.2.4 How many teeth with dental fillings (Amalgam)?

0 ____ None
(n) ___ One or more → how many _____

5.2.5 Examination of the eyes:

0 _____ No changes
1 _____ Bluish colored iris ring
2 _____ Kayser-Fleischer ring

5.3 Walking

Person is asked to walk up and down, first with eyes open, then with eyes closed.

5.3.1 Ataxia of gait (walking)

Examiner is watching for signs of ataxia (Klockgether Score p 435)
0 ___ Absent
1 ___ Slight (ataxia only visible when walking on tandem or without visual feedback)
2 ___ Moderate (ataxia visible in normal walking; difficulties, when walking on tandem)
3 ___ Marked (broad-based, staggering gait; unable to walk on tandem)
4 ___ Severe (unable to walk without support; wheelchair bound)
5 ___ Most severe (bedridden)

5.3.2 Rigidity of gait (walking)

Examiner is watching the gait, the swing of the arms, general posture and rates
0 ____ Normal
1 ____ Mild diminution in swing while the patient is walking
2 ____ Obvious diminution in swing suggesting shoulder rigidity
3 ____ Stiff gait with little or no arm swinging noticeable
4 ____ Rigid gait with arms slightly pronated; this would also include stopped-shuffling gait with propulsion and retropulsion

5.4 Standing

5.4.1 Tremor - finger to nose test

Person is asked to stand still, legs together– arms outstretched. Eyes closed. Finger tip should touch the nose. Examiner is watching and rates the **tremor** (modified Clinical Tremor Rating Scale)
0 ____ None
1 ____ Slight to moderate (amplitude < 0,5 cm – 1cm); may be intermittent, may be intermittent
2 ____ Marked amplitude (1-2 cm)
3 ____ Severe amplitude (> 2 cm)

5.4.2 Dysmetria - finger to nose test

Person is asked to stand still, legs together – arms outstretched. Eyes closed. Finger tip should touch the nose. Examiner is watching and rates the dysmetria
0 ____ Normal
1 ____ Moderate pathologic
2 ____ Severe pathologic

5.4.3 Dysdiadochokinesis

Person is asked to twist hands very quickly (alternating movements of the wrists (Klockgether Score)
0 ____ Absent
1 ____ Slight (minimal slowness of alternating movements)
2 ____ Moderate (marked slowness of alternating movements)
3 ____ Severe (severe irregularity of alternating movements)
4 ____ Most severe (inability to perform alternating movements)

5.4.4 Tremor – eye lid

Eyes closed. Examiner is watching and rates the **tremor** (Davao Pool score)
0 ____ None
1 ____ Slight
2 ____ Marked

5.5 Lying - Reflexes

Person is asked to lie on the examination bench.

5.5.1 Mentolabial reflex (Positive pyramidal sign)

0 ____ Negative
1 ____ Positive

5.5.2 Babinski reflex (Positive pyramidal signs)

0 ____ Negative
1 ____ Positive

5.5.3 Sucking reflex (Positive pyramidal signs)

0 ____ Negative
1 ____ Positive

5.5.4 Grasp reflex

0 ____ Negative
1 ____ Positive

5.5.5 PSR (quadrizeps reflex)

A No reflex
B Hyporeflexia
C Normal
D Hyperreflexia
E Clonus

5.5.6 BSR (bizeps brachii reflex)

A No reflex
B Hyporeflexia
C Normal
D Hyperreflexia
E Clonus

5.5.7 AR (Achilles reflex, ankle jerk)

A No reflex
B Hyporeflexia
C Normal
D Hyperreflexia
E Clonus

5.6 Lying – other tests

5.6.1 Intentional Tremor - heel-to-shin test

Person is asked to touch with his heel the knee of the other leg. Then to move with the heel along the shin to the foot. Repeat and do it with both sides. Eyes first open, then closed. Rate tremor during heel-to-shin test (Klockgether Score)

0 ____ Absent
1 ____ Slight (slight terminal tremor)
2 ____ Moderate (marked terminal tremor)
3 ____ Marked (kinetic tremor throughout intended movements)
4 ____ Severe (severe kinetic tremor heavily interfering with everyday life)
5 ____ Most severe (maximal form of kinetic tremor making intended movements impossible)

5.6.2 Ataxia - heel-to-shin test

Rate ataxia (Klockgether Score)

0 ____ Absent
1 ____ Slight (slight hypermetria in heel-to-shin test)
2 ____ Moderate (hypermetria and slight ataxic performance of heel-to-shin test)
3 ____ Marked (marked swaying: unable to stand with feet together)
4 ____ Severe (pronounced ataxia in performing heel-to-shin test)
5 ____ Most severe (unable to perform heel-to-shin test)

5.6.3 Sensory disturbances

Sensory disturbances such as sensory impairment of the glove and-stocking type
0 ____ Absent
1 ____ Present
*5.6.3.1 Comments*_____

5.6.4 Bradykinesia

Rate your observation whether there was any sign of bradykinesia during the examination (slower active movements, absent or altered synkinesia of upper extremities during gait)
0 ____ Absent
1 ____ Present

5.7 Hypo-mimia

Rate your observation whether there you observed an hypo mimic expression of the face during the examination)
0 ____ Absent
1 ____ Present

6 Specific Tests

6.1.1 Date of the specific test:.....

6.1.2 Name of the tester:.....

6.1.3 Code of the tester _____

6.2 Memory Disturbances (Wechsler)

6.2.1 Forward digit span test (part of *Wechsler Memory Scale)*

Please repeat each column of numbers. Score longest series correctly repeated forward

	Score	Test
	4	6-4-3-9
	4	7-2-8-6
	3	4-2-7-3-1
	3	7-5-8-3-6
	2	6-1-9-4-7-3
	2	3-9-2-4-8-7
	1	5-9-1-7-4-2-3
	1	4-1-7-9-3-8-6
	0	5-8-1-9-2-6-4-7
	0	3-8-2-9-5-1-7-4

6.3 Match Box Test (from *MOT*)

Put **20 matches** on a table , half of each on one side of an open matchbox, approx. 15 cm away. Take the time until all matches are put into the box. Use left and right hand alternatively.
_____ seconds

6.4 Finger Tapping Test (from *MOT*)

Sitting at a table. Elbows should be placed on the table. Try to do as many points as possible on a piece of paper with a pencil. Count the amount of points within **10 seconds**.
_____ points

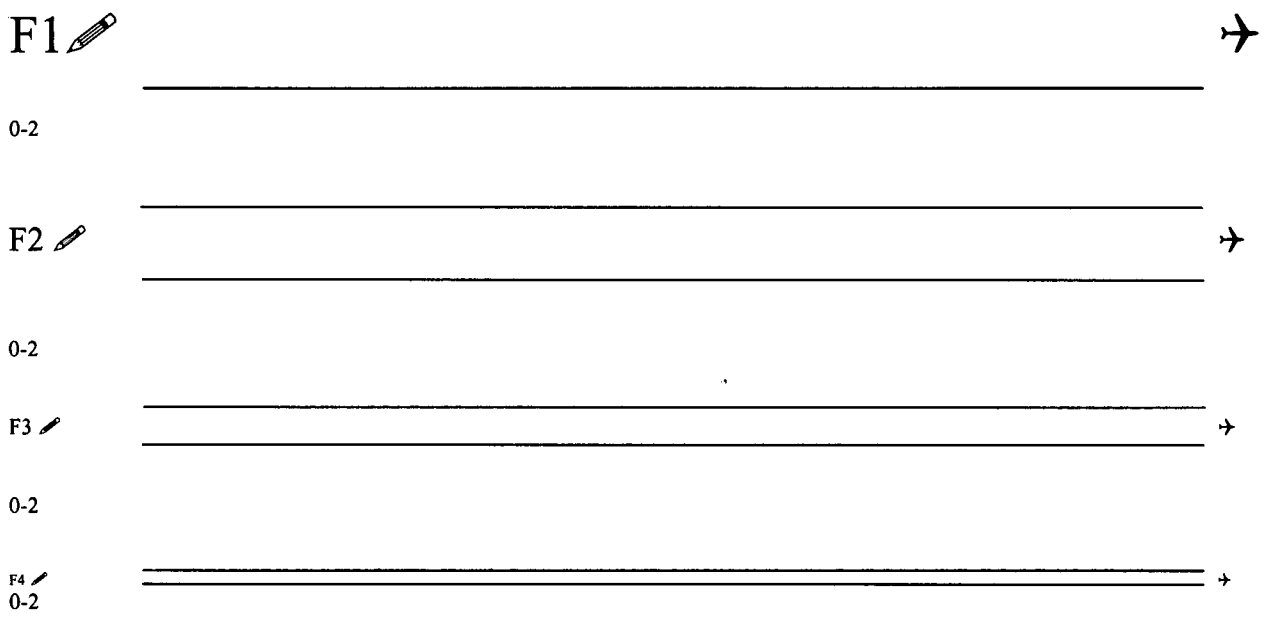
ID Nr:_____

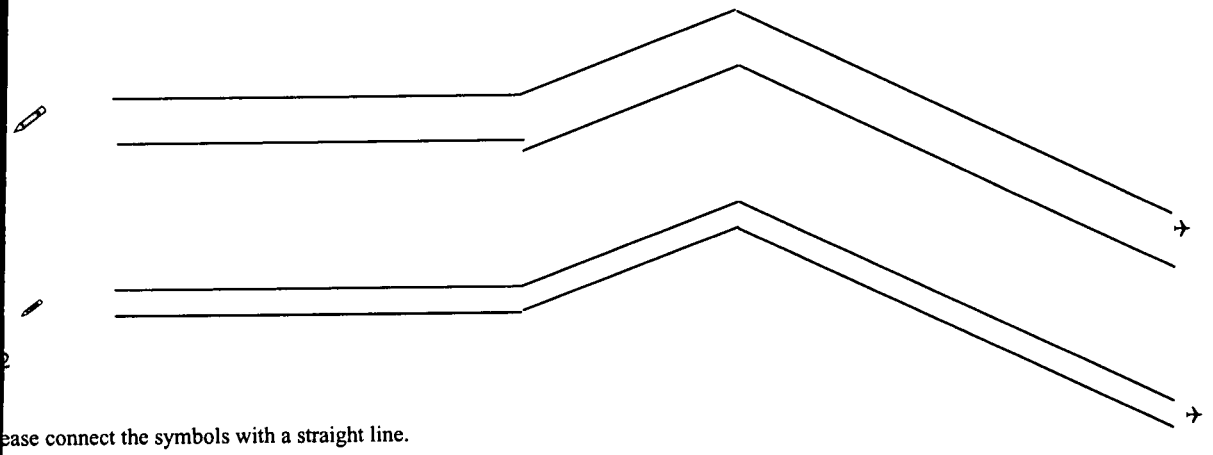
6.5 Frostig Score

Draw a line from one symbol to the other. Do not interrupt while drawing. Do not touch the lines.

Score: _____

Please connect with a pencil the symbols. Please try to stay within the lines. ??





ease connect the symbols with a straight line.

6.6 Visual field test

left ____ cm
right ____ cm
base line ____ cm

6.7 Objective tremor assessment

Result _____

6.8 Weight in _____kg

6.9 Height in _____ cm

7 Specimens

7.1.1 Date of the specimen.....

7.1.2 Time of the specimen sampling.....

7.1.3 Name of the specimen taker:.....

7.1.4 Code _____

7.2 Blood (EDTA-blood 10 ml)

0 ____ Yes
1 ____ No

7.3 Urine (spontaneous urine sample 10 ml)

0 ____ Yes
1 ____ No

7.3.1 Proteinuria

0 ____ negative
1 ____ positive ____ score

7.3.2 Urine total mercury (field test) (additional)

____ Result ____ unit

7.4 Hair

0 ____ Yes, sample collected
1 ____ No

7.5 Others (breast milk)

0 ____ Yes, sample collected
1 ____ No sample