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# Lichens as a Good Bioindicator of Air Pollution by Mercury in Small-Scale Gold Mining Areas, Tanzania

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Environmental impacts and human health risks associated with mercury pollution have prompted numerous studies, worldwide, that are geared to provide better understanding of mercury cycling and bioaccumulation in temperate and tropical ecosystems (Driscoll et al. 1994; Anderson et al. 1995; Akagi 1998). Some of the studies have generated useful mercury databases that provide the basis for modeling and predicting mercury dispersion and accumulation patterns in different ecosystems (Henry et al. 1995). In developing countries, mostly in tropical regions, small-scale gold extraction by mercury amalgamation is a major source of mercury pollution (Appleton et al. 1999, Malm et al. 1990). While there is fair amount of data on mercury pollution levels in tropical aquatic systems due to gold mining, especially in the Amazon region, the data on atmospheric mercury pollution are still scarce, in spite of the fact that more than 55% of mercury used in gold extraction is released to the atmosphere during burning and re-burning of amalgams (Pfeiffer and Larceda 1988; Van Straaten 2000). Complicated field logistics, including difficult access of remote mining areas and equipment security concerns, make modern air sampling techniques unattractive for long term monitoring of atmospheric mercury pollution in the gold mining areas. In the absence of direct air mercury sampling and measurement equipment, the use of locally available plant species in the assessment and evaluation of air pollution patterns in the gold mining areas is desirable. In the present study, lichens were selected for the assessment of mercury dispersion in air from point sources related to gold mining activities in Tanzania.

Lichens have been used successfully in air pollution assessment and management studies for various heavy metal pollutants (Frenzel et al. 1990; Kapu et al. 1991; Nash III and Gries 1995; Quevauviller et al. 1996; Nimis et al. 2001). Recently, Mulgrew and Williams (2000) gave a detailed review on the use of lichens in air pollution monitoring. Lichens exhibit a number of attributes that make them suitable biomonitors for air pollutants. Like other rootless epiphytes, lichens obtain their nutrients directly from the atmosphere, are good accumulators of metals, and show good tolerance to high metal concentrations in their tissues. Many lichen species have large geographical distribution, which makes them suitable for national and international air pollution assessment programmes. Among the lichens found in the Miombo woodlands in the Lake Victoria goldfields in Tanzania, *Parmelia* and *Usnea* species are more abundant and easily amenable to sampling without

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incorporating large amounts of substrate materials in the samples. These two species were used in this study to determine their suitability in the assessment of air mercury pollution from gold mining operations.

## MATERIALS AND METHODS

Two gold mines, Imweru and Mugusu, were selected for the pilot study of mercury levels in lichens for the assessment of air mercury dispersion patterns. Small-scale gold mining at Imweru started in 1988 during the gold rush period in Tanzania, and continued intensively until 1997 before the miners moved to new gold rush areas. The gold mining at Mugusu also began in 1988. Intensive mining took place between 1990 and 1994, when over 7000 miners, gold dealers, and petty traders worked in the area. The mine population had decreased to less than 1000 at the time of this study in August 2000. Unlike the Imweru mine, where active mining nearly ceased around 1997, the mining activities at Mugusu continues to the present time. Therefore the Mugusu mine area has experienced a longer period of mercury exposure from amalgamation and the burning of amalgams than the Imweru mine.

A limited number of lichen samples were collected from the two mining areas for the study. Three samples were collected from the Imweru mine area and 8 samples from the Mugusu area. Out of the eleven samples, two samples were *Usnea sp.* while 9 samples belonged to *Parmelia* species. The relative number of samples for the two species reflects, in one way or another, the field abundance of the species. Both species are found together on trees, but the *Usnea* lichen is less common. The *Usnea*, however, has a fructose or shrub-like form and hence much easier to separate from the substrate than the *Parmelia* that occurs in foliose (leaf-like) or crustose forms. Individual samples were collected from single trees as well as from multiple trees, depending on the abundance of the lichen material on the trees. For the background sample, a composite sample was collected from several trees. All samples were collected at the height of 1.5 to 2 metres above the ground. Each sample was collected in a clean, labeled, polyethylene bag, closed tightly, and kept in a plastic container. The container was kept air tight to avoid contamination during transportation.

The samples were kept in a deep freezer in the laboratory at the University of Dar es Salaam until they were air freighted to Japan for analysis. The samples were processed and analyzed at the National Institute for Minamata Disease (NIMD, Japan). All vessels, including the glassware, were always washed with the potassium permanganate solution just before use to ensure that no mercury contamination occurs during the sample processing. The samples were placed separately in 500 ml glass bottles and soaked overnight in mercury-free water and finally washed twice in the ultrasonic cleaner, to remove any dust and particulate matter adhering on the lichen tissue. After washing, the samples were sorted and cleaned with tweezers to remove wood matter or substrate material sticking on the lichen tissue. The cleaned samples were rinsed with alcohol and then dried on a rotary evaporator with a water bath at 50° C. An aliquot of the dried sample was placed in a 20 ml glass vial and then chopped into fine pieces using a scissor. The chopped sample was placed in agate mortar and pulverized to obtain the powdered sample. A few samples were

split into two aliquots before grinding and the aliquots were processed for analysis in order to evaluate the homogeneity of the raw samples. In addition, duplicate samples of the grinded material were analyzed to evaluate the in-bottle powder homogeneity of the samples.

The powdered samples were analyzed for total mercury using highly precise and accurate analytical technique developed at NIMD by Akagi and Nishimura (1991) and later modified by Akagi (1997). The precision and accuracy of the NIMD analytical techniques for total mercury (THg) and methylmercury (MeHg) have been verified through interlaboratory comparison exercises (Logar et al. 2001) and by participating in the analysis of reference materials issued by the International Atomic Energy Agency (IAEA), such as the IAEA-0140 algae (Coquery et al. 1997) and the IAEA 0391-0393 algae series.

## RESULTS AND DISCUSSION

Results for the raw sample and in-bottle powder homogeneity tests are given in Table 1. Aliquots of the split lichen samples showed almost same mercury concentrations, suggesting that the lichen thalli from a given sampling point have fairly uniform mercury composition. Hence mercury concentrations in the lichen samples reflect average cumulative and temporal mercury exposure levels at a given locality or sampling point. The analysis of duplicate samples (100 mg) of the lichen powder gave nearly same mercury concentrations, which indicated good in-bottle powder sample homogeneity and analytical precision.

**Table 1.** Results for raw sample and in-bottle powder homogeneity tests for total mercury in lichens

| Raw sample splits | THg (μg/g) | Powder duplicates | THg (μg/g) |
|---|---|---|---|
| LC-9 | 0.10 | LC-9A | 0.11 |
| LC-9A | 0.11 | LC-9B | 0.10 |
| LC-6 | 0.47 | LC-6A | 0.47 |
| LC-6A | 0.47 | LC-6B | 0.47 |
| | | LC-6C | 0.48 |

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

Two samples of the *Parmelia* and one sample of the *Usnea* from the Imweru mine area gave mercury concentrations in the range from 0.08 to 0.44 μg/g. The *Unsea* sample had the highest mercury concentration. Given the limited number of samples, it is not possible to deduce air mercury dispersion pattern for the Imweru mine. Further sampling of the lichens is needed in that area to provide a better picture of mercury exposure levels recorded in the lichens.

**Table 2.** Mercury analyses for lichens from Lake Victoria Goldfields, Tanzania

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

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

Lichens are considered useful bio-indicators of air quality since they obtain most of their nutrients directly from the atmosphere; they are good metal accumulators and usually have wide geographical distribution (Mulgrew and Williams 2000; Quevauviller et al. 1996). Biomonitoring studies have demonstrated that the metal concentrations in lichens reflect to the large extent atmospheric trace element levels and/or deposition (Walterbeek et al., 1996). A successful biomonitoring program is feasible when a contaminant burden is readily distinguished from background levels. For example, mercury concentrations in lichens from Arctic regions have been found to vary from 0.40-0.87 μg/g (d.w.) near industrial/urban sites to 0.009-0.101 μg/g in rural areas (Nash III and Gries 1995). Loppi and Bargagli (1993) reported mercury concentrations in the range from 0.053 to 0.555 μg/g and an average concentration of 0.199 μg/g in the *Parmelia* lichen from a geothermal area in central Italy. The concentrations of mercury were significantly correlated with distance from the geothermal sources.

The results from the pilot study of the lichens around the Mugusu mine show that lichens, especially *Parmelia*, could be used successfully for the biomonitoring of mercury air pollution from point sources in the Lake Victoria goldfields. The biomonitoring would help to identify areas and local villages that are being impacted by airborne mercury pollution from the mining centers. The present data indicate that

villages within a distance of 3 km from the Mugusu gold mine in the windward direction experienced elevated air mercury concentrations that were more than 4 times higher than the local background level. It is important to extend the biomonitoring further away from the Mugusu mine, in the westerly direction, in order to determine the locations where mercury gradient in the lichens, and hence in the atmosphere, falls to background levels. It is also important to carry out similar biomonitoring exercise in other mining centers so as to determine areas and villages that are affected by airborne mercury pollution. Impacted areas would need short- and long-term air pollution management and mitigation measures to offset potential human health risks from airborne mercury exposure.

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