IMPACT OF GOLD MINING ON THE ENVIRONMENT AND HUMAN HEALTH: A CASE STUDY IN THE MIGORI GOLD BELT, KENYA

JASON S. OGOLA[1], WINNIE V. MITULLAH[2] and MONICA A. OMULO[3]
[1] *Department of Mining and Environmental Geology, School of Environmental Sciences, Venda University for Science and Technology, Private Bag X5050 Thohoyandou, South Africa*
(e-mail: ogolaj@univen.ac.za)
[2] *Institute for Development Studies, University of Nairobi, P.O. Box 30197, Nairobi, Kenya*
(e-mail: IDS@nbnet.co.ke)
[3] *Department of Environmental Studies, Maseno University, Private Bag Maseno, Kenya*
(e-mail: monicaomulo@hotmail.com)

Received 21 January 2000; accepted in revised form 18 July 2001

Abstract. The study of gold sites in the Migori Gold Belt, Kenya, revealed that the concentrations of heavy metals, mainly Hg, Pb and As are above acceptable levels. Tailings at the panning sites recorded values of 6.5–510 $\mathrm{mg\,kg^{-1}}$ Pb, 0.06–76.0 $\mathrm{mg\,kg^{-1}}$ As and 0.46–1920 $\mathrm{mg\,kg^{-1}}$ Hg. Stream sediments had values of 3.0–11075 $\mathrm{mg\,kg^{-1}}$ Pb, 0.014–1.87 $\mathrm{mg\,kg^{-1}}$ As and 0.28–348 $\mathrm{mg\,kg^{-1}}$ Hg. The highest metal contamination was recorded in sediments from the Macalder stream (11075 $\mathrm{mg\,kg^{-1}}$ Pb), Nairobi mine tailings (76.0 $\mathrm{mg\,kg^{-1}}$ As) and Mickey tailings (1920 $\mathrm{mg\,kg^{-1}}$ Hg). Mercury has a long residence time in the environment and this makes its emissions from artisan mining a threat to health. Inhaling large amounts of siliceous dust, careless handling of mercury during gold panning and Au/Hg amalgam processing, existence of water logged pits and trenches; and large number of miners sharing poor quality air in the mines are the major causes of health hazards among miners. The amount of mercury used by miners for gold amalgamation during peak mining periods varies from 150 to 200 kg per month. Out of this, about 40% are lost during panning and 60% lost during heating Au/Hg amalgam. The use of pressure burners to weaken the reef is a deadly mining procedure as hot particles of Pb, As and other sulphide minerals burn the body. Burns become septic. This, apparently, leads to death within 2–3 years. On-site training of miners on safe mining practices met with enthusiasm and acceptance. The use of dust masks, air filters and heavy chemical gloves during mining and mineral processing were readily accepted. Miners were thus advised to purchase such protective gear, and to continue using them for the sake of their health. The miners' workshop, which was held at the end of the project is likely to bear fruit. The Migori District Commissioner and other Government officials, including medical officers attended this workshop. As a result of this, the Government is seriously considering setting up a clinic at Masara, which is one of the mining centres in the district. This would improve the health of the mining community.

Key words: artisan mining, heavy metals, health hazards, metal contamination, panning sites

1. Introduction

The paper is based on research findings, covering 11 mine sites in the Migori district, western Kenya. The district lies to the southern part of Winam Gulf of Lake Victoria. The mine prospects covered were Nairobi, Kisumu, Ahero and Komito in Rongo division; Shinyanga in Suna West division; Masara, Mikey, Osiri, Macalder, Nyapala and Nyatworo in Macalder division (Figure 1).

Environmental Geochemistry and Health **24:** 141–158, 2002.

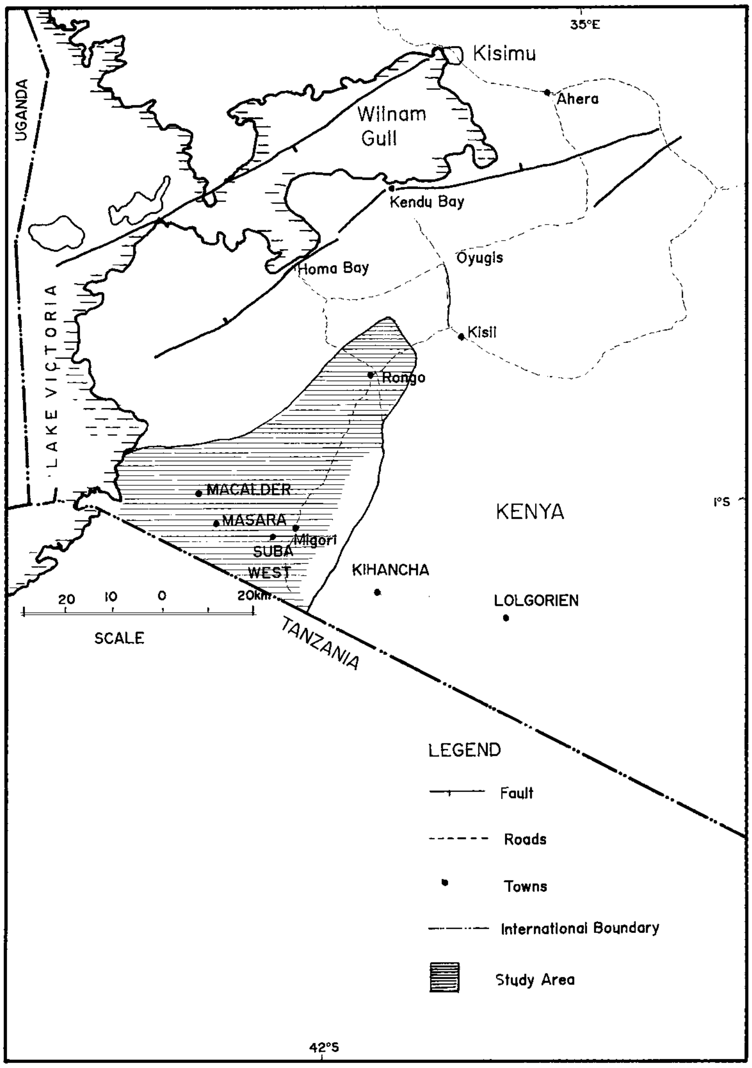

Figure 1. Location map of the mine sites in the Migori district showing Rongo, Suba West and Macalder divisions.

1.1. GEOLOGY AND MINERALISATION

The rocks of the Migori district are Archaean in age, about 2.8 billion years old (Figure 2). They are referred to as the Migori granite-greenstone complex. The Archaean rocks of the Migori district are known to contain gold. Gold occurs in quartz veins within the mafic volcanics of the Nyanzian Group. The host rocks are metabasalt, banded ironstone, shales and andesites. The auriferous quartz veins have a general trend of 320° and a dip of between 65° and 90° to the southwest.

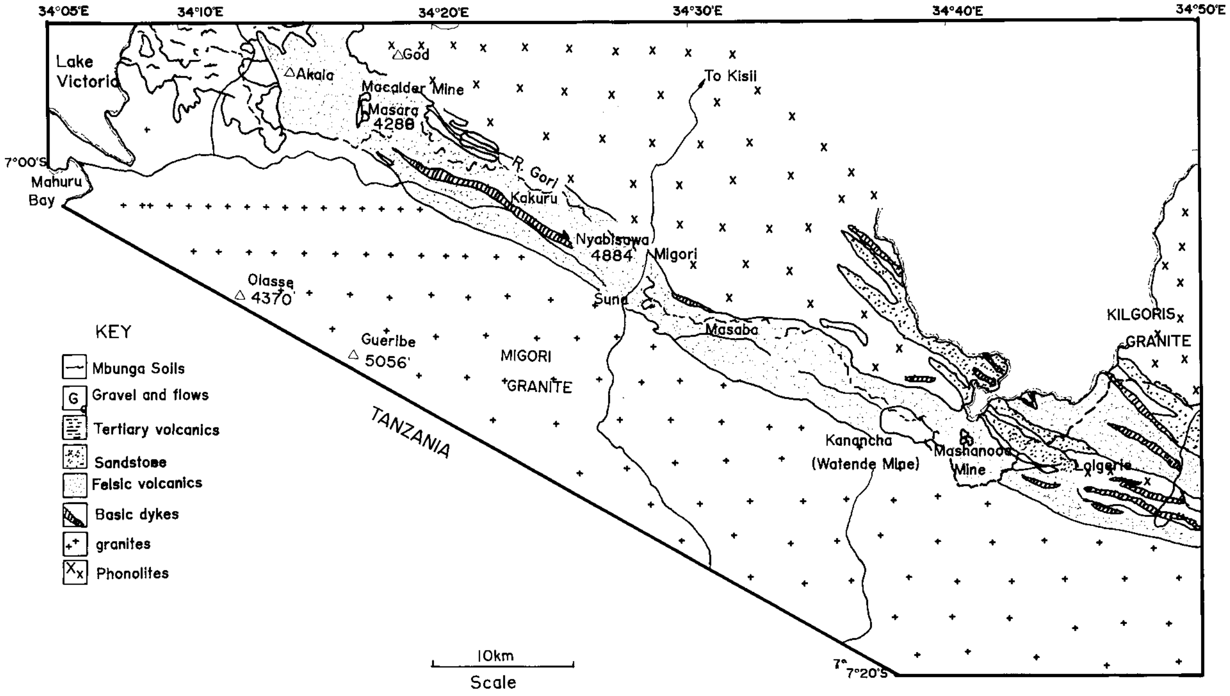

Figure 2. The geological map of the Migori gold belt showing different types of rocks which host gold.

Two hypotheses are advanced for gold-sulphide mineralisation in the region. Shackleton (1946) considered the presence of apophyses and veined ore bodies within the host rocks at Macalder to be indicative of hydrothermal-metasomatic origin. However, Sanders (1964), suggested that gold-sulphide mineralisation in this deposit took place in a pre-existing thrust structure. In contrast, Hutchinson (1981) concluded that Macalder is a deformed volcanogenic massive sulphide deposit of a primitive type, which was formed over a sea floor hydrothermal vent. Factors favouring syngenetic hypothesis include sheet-like ore bodies and concordant bedding of ore bodies within the host rocks. In the Macalder deposit, Ogola (1987) concluded, that emplacement of gold within the host rocks was due to epigenetic vein-type mineralisation and the mode of formation is volcanogenic-hydrothermal. Keays (1982) reckons, that most vein-type Archaean gold deposits probably formed after the deformation and metamorphism of the host rocks, apparently, due to late-stage metamorphic fluids.

The mineralisation fluids apparently, were generated during the granite intrusion. The latter might have played the role of a heat-engine during which there was dissolution of the elements followed by subsequent concentration and redeposition of minerals within tectonically favourable environments. The complex is well studied compared to the rest of the greenstone complexes of western Kenya. This includes the works of Wayland (1931), Kitson (1934), Shackleton (1946), Allum (1951), McCall (1958), Sanders (1964), UNDP (1969, 1988), Hutchinson (1981), Ogola (1982, 1984, 1985, 1986, 1987, 1993, 1995), Kuehn *et al.* (1990), Ogola and Omenda (1991).

Gold was discovered in the Migori Gold belt in 1920 and by 1927 about 100 kg of gold had been recovered. In the 1930s there was renewed gold interest in the district. Discovery of new gold deposits in the district was at Kehancha, Masara and Macalder. Mining involved many companies that exploited relatively small, but rich reefs. By the time of closure of the mines in 1966, a total of 4,284 kg of gold, 1,210 kg of silver and 20 000 tonnes of copper had been recovered from the Migori Gold Belt (Ogola, 1993). After large-scale mining operations came to a halt, shortly after Kenya's independence, artisan miners have been the sole producers of gold in the belt.

Artisan mining is an important economic sector in many developing countries. However, limited resources and training, and the availability of cheap, but potentially hazardous methods of extraction and processing of minerals can cause significant threats to both miners and the local environment. Such a scenario is being experienced in the Migori mining district. It is important to assess the scale of problems and to develop approaches, both technical and sociological, to deal with these.

The main objective of this study was to appraise the environmental impacts and ascertain the levels of Hg, Pb and As and to educate the local communities on safe and environmentally sound mining and mineral processing techniques. This was achieved through on-site training and by organising a workshop for miners.

2. Materials and methods

2.1. FIELD METHODS

The work, which was undertaken in the Migori district, incorporated visual observation, informal interviews, on-site training, sample collection, preparation and analysis.

A reconnaissance survey was undertaken at the 11 mine sites in the district. Fifty soil and water samples for the investigation of heavy metals were collected from the mines and panning sites, dry and wet tailings, river sediments and water from different underground mines and rivers. At each sampling site, 2–3 samples, weighing 2–3 kg were taken. These were labelled and described in the field, packed and transported to Nairobi for laboratory analysis.

2.2. SAMPLE PREPARATION AND ANALYSIS

The collected samples were submitted to the Chemistry Laboratory, Materials Branch, Ministry of Works. Five grams of each sample was digested with 10% HNO_3 to a volume of 250 ml. The samples were analysed for Hg, Pb and As by atomic absorption spectrometer.

3. Environmental impacts and health issues

During peak mining periods, up to 20 000 people invade the district from outside. This has devastating effects on health and environment. Artisan mining in the district conforms to neither mining laws nor regulations governing mining operations and environmental management. The miners are unaware of the effects of metal poisoning during mining and mineral processing. In principle, artisan gold mining in the district is an informal sector with very little Government control.

Haphazard mining in the district has led to health effects ranging from respiratory problems to mental disorders. Studies in a similar region, across the border in Tanzania revealed that symptoms of heavy metal poisoning such as sensory disturbance, hyporeflexia, tremor, gingivitis, metallic taste, neuroasthenia and night blindness are common (Harada *et al.*, 1997).

3.1. LAND DEGRADATION, DEFORESTATION AND SOIL EROSION

Gold mining in the Migori district is transitory. Mining involves both open-cut and underground operations. The ore is then crushed and panned. Waste rock is dumped into heaps as tailings. Mining in the area has left behind dredged out and contaminated streams, disturbed vegetation and littered landscapes, open trenches and gaping pits filled with water. For example, at Macalder mine, one can easily identify the scars remaining from the 1930s to 1960s large-scale mining. The mine site is heaped with featureless flat tailings, which are partly washed on to adjacent land, pulled down buildings and machinery and debris of scrap metal. Artisan miners who have been trying to rework the tailings within the mine dump and old processing plants have worsened land degradation.

Plant growth on the wasteland is inhibited, and this seems to be due to acid mine drainage. Toxic compounds and heavy metals previously locked in the undisturbed strata and minerals are leached to the environment.

During gold rushes to the district, the large number of miners put much pressure on the environment in terms of energy resources; thus large quantities of trees are cut down either as firewood or as timber for support of weak mine workings. This causes deforestation and soil erosion.

Lack of sound mining techniques and procedures often result in the collapse of the wall rock and eventual subsidence of mined areas. This often results in loss of life. For example, in 1999 three miners were buried alive by a collapsed hanging wall at Nyapala prospect near Macalder.

Options for restoration of landscape in the mining areas are not easy. One such option is to refill the mine, using the waste rock once mining is over. However, this option is difficult to implement because most of the miners are not landowners, thus they quickly abandon the exhausted site and move to new productive ones. The landowner is therefore left with wasteland.

3.2. ACID DRAINAGE AND WATER POLLUTION

Pollution of water in the Migori district is significant. Panning is often carried out along river profiles. Evidence of river pollution includes siltation and colouration. The affected rivers are rivers Kuja, Migori and Mickey. River Kuja is adversely affected by the Macalder tailings through a stream that passes at the foot of the tailings. The water in the stream is strongly acidic due to acid drainage from the tailings (Figure 3).

Acid drainage is a legacy of past mining practices and current mining operations, particularly where sulphide minerals are present. Waste rock dumps, tailings, low-grade ore, overburden and run-off mill stockpiles are sources of acid drainage. It is a consequent of the oxidation of sulphide minerals, mainly pyrite (FeS_2), but also pyrrhotite (FeS), marcasite (FeS_2), galena (PbS), sphalerite (ZnS), arsenopyrite (FeAsS), and chalcopyrite ($CuFeS_2$). FeS_2, for example, when exposed to oxygen and water oxidizes to sulphuric acid and ferrous hydroxide as follows:

$$2FeS_2 + 6H_2O + 7O_2 \rightarrow 4H_2SO_4 + 2Fe(OH)_2$$

It is the sulphuric acid that gives the strong acidic property, whereas ferrous hydroxide is responsible for the jelly-like yellowish orange colouration to the stream water (Figure 3). The sulphuric acid attacks other sulphide minerals and thus breaks them down to release metals such as Pb, As, Cd, Cu, Zn, Ni. The stronger the acid solution, the more the metals become soluble in water and this lowers the pH.

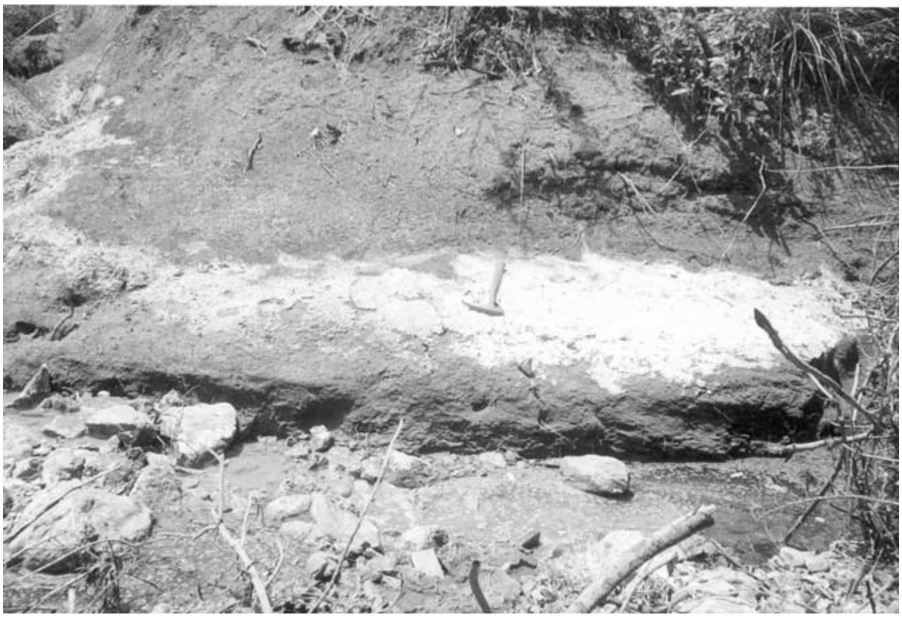

Figure 3. Acid mine drainage from the Macalder tailings. The originally orange colour (dark in this photo) is due to the presence of ferrous hydroxide in water.

During the rainy seasons, much sulphuric acid is produced from the Macalder tailings and this finds its way into river Kuja. Consequently, drainage of contaminated, low pH water into waterways, results in the death of fish, and other elements of aquatic ecosystems, as well as soil and groundwater contamination. Fish do not survive in strongly acidic conditions, generally not below 4.5 pH (Cohen, 2000).

Under natural conditions, the process of acid drainage is rather slow, but once mining of sulphide deposits takes place, the process is accelerated due to exposure of sulphide minerals to oxygen and water. Taylor (1998) notes that whenever new sulphide-rich mineral and coal deposits are mined, the potential liability for acid drainage increases. As an example, he states that annual liabilities for acid drainage in the USA is $ 20 billion, in Germany DM 13 billion for uranium mines and in Australia A$ 60 million.

The aim of the management of sulphide mine wastes is to limit ecological detriment to acceptable levels. Monitoring can provide information on the production and transport of pollutants and data for use in predicting medium to long term behaviour of waste piles. The true success of rehabilitating a site is determined by its long-term sustainability and biological diversity (Tongway, 1998).

3.3. AIR POLLUTION

Air pollution within mine workings is common. Cases of carbon monoxide emissions from water pumps have claimed many lives in the district. For example, in

Figure 4. Ore crushing at Masara. Both young and old are involved in gold processing.

1980 seven miners died due to suffocation from carbon monoxide released from water pump within an old mine working at Osiri mine south of Macalder.

Mining and dust are inseparable. Air pollution comes mainly from silicate dust from ore mining and crushing. The inhaling of this dust is a serious health hazard. Mining is done underground where there is no air circulation, thus there is little air to breathe. Up to 30–50 people work underground, at the same time, within narrow openings. This makes the mine a breeding ground for infectious diseases such as tuberculosis, and dust poisoning results in respiratory ailments.

Ore crushing is, however, done in open structures with only a roof, known locally as 'garages'. Here as young as 12-year-old boys and girls are engaged in ore crushing and panning and are bathed in dust without any preventing measures to reduce the amount of dust being inhaled (Figure 4). The main dust component is silica, which comes mainly from quartz veins, which host gold.

3.4. SILICA

Silica, like asbestos, can result in the development of fibrotic lung disease (Mossman, 1993). Exposure to silica dust may result into a disease known as silicosis, which occurs in three different ways:

(a) chronic or nodular silicosis is a progressive lung disease, characterised by the development of fibrotic (scar) tissue, in response to inhalation of quartz particles in the size of 0.5–0.7 μm, which develop in the region of the small airways and this may lead to heart and respiratory failure;

(b) acute silicosis develops in workers exposed to exceptionally high concentrations of fine particles of silica, usually quartz dust, which damage the linings of the airways so that lungs become heavy and rigid as the air spaces are filled with a finely granular substance; and

(c) accelerated silicosis (intermediate between chronic and acute silicosis), which develops after 5–10 years of heavy exposure to silica dust of almost pure quartz, in which the victim often shows no clinical abnormalities other than breathlessness until the condition becomes acute, resulting in a decrease of lung function. Death often occurs as a result of cardiopulmonary failure within 10 years of onset of symptoms.

3.5. HEAVY METALS AND THEIR TOXICITY

Artisan gold mining is a dangerous activity as the heavy metals, mainly Hg, Pb and As are released to the environment. This study was therefore a rapid assessment of these metals and their presence in soil and water in the district. They were selected because of their known toxicity in similar mining environments.

According to the United States Agency for Toxic Substances and Disease Registry (ATSDR, 1999) As, Pb and Hg top the priority list of hazardous substances. The first two are major metals in gold-sulphide deposits, where they occur as minerals mainly in arsenopyrite (FeAsS) and galena (PbS), respectively. Under natural conditions, they are relatively stable. However, once mining has taken place, the minerals are broken down due to exposure to oxygen and water.

Mercury as a pollutant in artisan mining, is due mainly to gold processing, when mercury is used to amalgamate gold. Cadmium, which is another common toxic metal, occupying position seven in the priority list of hazardous substances (ATSDR, 1999), generally occurs as an isometric trace element in sphalerite. However, in the Migori mining district, sphalerite occurs as a minor sulphide mineral (Ogola, 1988), thus cadmium levels are likely to be quite low.

The main problem for identification of heavy metal poisoning is that typical symptoms of poisoning are often masked by microbial and parasitic infections, malnutrition and poor living conditions and medical care (Harada, 1996).

3.6. MERCURY

Mercury exists in both inorganic and organic compounds. Methylation of inorganic mercury into organic mercury occurs in micro-organisms under anaerobic conditions, for example, in underwater sediments. Organic mercury is highly poisonous and is easily absorbed by the gastric and intestinal organs, and it is carried by blood into the brain, liver, kidney and even foetus.

For centuries, mercury has been used in the amalgamation of gold (Au). It is estimated that about 1.32 kg of Hg is lost for every 1 kg of Au produced (Harada *et al.*, 1997). About 40% of this loss occur during the initial concentration and amalgamation stage of Au. The lost Hg is released directly into the soil, streams and rivers, initially as inorganic Hg, which later converts into organic Hg. This is then taken up into the food chain, mainly by fish and other aquatic life. The remaining 60% Hg is released directly into the air when the Hg–Au amalgam is heated during the purification process and is often inhaled. Mercury is a very volatile element, thus dangerous levels are readily obtained in air. Safety standards require that Hg vapour should not exceed 0.1 mg m^{-3} in air.

Mercury, once taken in, is accumulated into the human body and attacks the central nervous system, resulting in numbness and unsteadiness in the legs and hands, awkward movements, tiredness, ringing in the ears, narrowing of the field of vision, loss of hearing, slurred speech, loss of sense of smell and taste and forgetfulness. Mercury poisoning may lead to a disease known as Minamata.

Minamata disease was first detected in 1956 in Minamata, Japan (Minamata Disease Museum, 1993,1997; UNU, 1993). It was caused by eating large quantities of fish or shellfish, contaminated by industrial discharges of mercury compounds into Minamata Bay.

Harada (1997) noted that 200 mg L^{-1} of Hg in blood and 50 mg g^{-1} in hair are the provisionally established standards and anyone with higher concentrations is considered to be at risk of poisoning. The allowable level of methyl-mercury in fish is 0.3 mg kg^{-1}.

3.7. LEAD

Lead does not dissolve, but water, air and sunlight change its minerals and compounds. It sticks to soil particles and enters underground water or drinking water only if the water is acid or soft. Exposure to Pb takes place mostly through drinking water, breathing polluted air or dust, and eating contaminated food, for example, food grown on soil with high Pb content.

Lead is toxic even at very low levels of exposure. Even the lowest doses can impair the nervous system and affect foetus, infants and young children, resulting in lowering of IQ (UN, 1998). It may also cause cancer and, thus is classified as a possible human carcinogen. Low level Pb exposure leads to encephalopathy, inschaemic heart disease, abnormalities in children, testicular atrophy, anaemia and interstitial nephritis (UN, 1998). In the US, the Environmental Protection Agency (United States EPA, 2000) requires that Pb in air should not exceed 1.5 $\mu g\ m^{-3}$ and the amount in drinking water is limited to 15 $\mu g\ L^{-1}$ (ATSDR, 1993).

3.8. ARSENIC

Arsenic poisoning results in cutaneous symptoms, polyneuritis, bronchitis, gastroenteritis, rhinitis, conjunctivitis and cancer. It can result in skin and lung cancer, 20–30 years after the first occurrence of symptoms (Harada, 1996). Other effects are cardiovascular and cerebrovascular diseases, Raynaud's phenomenon, hepatopathy and nephropathy malignant neoplasm including Bowen's disease.

In the US, the guideline for As level in drinking water is 0.05 mg L^{-1} (United States EPA, 2000). Potential health effects from ingestion of water containing arsenic include skin damage, circulatory system problems, and increased risk of cancer.

4. Results and interpretation

4.1. TOXIC METAL POLLUTION

Chemical analysis of soil and water samples collected from mine workings, mine dumps, pan ponds, tailings and along streams and rivers indicated high levels of Pb, As and Hg (Table I). Tailings recorded values of 6.5–510 mg kg^{-1} Pb, 0.06–76.0 mg kg^{-1} As and 0.46–1920 mg kg^{-1} Hg (Figure 5). Stream sediments had values of 3.0–11075 mg kg^{-1} Pb; 0.014-1.87 mg kg^{-1} As and 0.28–348 mg kg^{-1} Hg (Figure 6). The highest levels of metal contamination was recorded in sediments from the Macalder stream (11075 mg kg^{-1} Pb), Nairobi mine tailings (76.0 mg kg^{-1} As) and Mickey tailings (1920 mg kg^{-1} Hg).

Water samples from Macalder stream indicated values of 13.75 mg L^{-1} Pb and 8.04 mg L^{-1} Hg. This stream empties its waters into Kuja river. Analysis of the sediments from this river showed values of 7.0–317 mg kg^{-1} Pb, 0.08–0.92 mg kg^{-1} As and 5.52–134 mg kg^{-1} Hg. Similarly, the concentrations in sediments from Migori river had a range of 3.0–55 mg kg^{-1} Pb, 0.03–1.87 mg kg^{-1} As and 1.96–220 mg kg^{-1} Hg.

Heavy metal poisoning takes place also during mining. Some of the miners use pressure burners to weaken the reef. This mining practice is deadly as burning of Au-sulphide ore results in the sprinkling of hot particles of Pb, As and other sulphide minerals. As miners work bear-chest, shirts are being removed for fear of them being burnt, hot metal particles land on their skin resulting into burns. Burns later become septic. Such miners rarely survive for more than 2 years.

4.2. SOURCES OF TOXIC METALS

Lead occurs as galena and is associated with gold mineralisation, thus during ore crushing and panning lead is released into the environment. It eventually finds its way into the sediments and surface and underground water.

The mineral arsenopyrite has genetic correlation with, and is generally a pathfinder for gold. During ore crushing and panning, arsenopyrite like lead is released into the environment and it finally finds its way into sediments and underground and surface water.

Mercury does not have a natural source in the district. It is introduced into the environment during gold processing. Mercury is added to the pan towards the end of processing. It attracts micro-gold particles to form Au–Hg amalgam. At this stage, about 40% of mercury is lost into the pan ponds, enters the tailings

TABLE I

Concentrations of Pb, As and Hg in tailings, river sediments and water

Sample no.	Mine	Sample type	Pb ($\mathrm{mg\,kg^{-1}}$)	As ($\mathrm{mg\,kg^{-1}}$)	Hg ($\mathrm{mg\,kg^{-1}}$)
1	Shinyanga mine	Old processed tailings	Nil	5.35	32.6
2	Shinyanga mine	Old processed tailings	7.0	1.32	33
3	Masara village	Unprocessed tailings	475	21.65	578
4	Masara village	Processed tailings	161	3.97	326
5	Masara Kakoth	Processed tailings	221	1.40	802
6	Kamito	Processed tailings	Nil	10.5	3.26
7	Kamito	Tailings	Nil	3.92	2.94
8	Nairobi mine	Tailings	Nil	76.0	0.94
9	Nairobi mine	Tailings	Nil	7.85	1.38
10	Kopuodho	Tailings	6.5	16.05	1.5
11	Kapiyo Masara	Processed tailings	510	2.9	366
12	Kapiyo Masara	Tailings	400	9.25	568
13	Kapiyo Masara	Tailings	285	18.5	360
13a	Masara Kapiyo	Water	Nil	0.0001	0.31
14	Mikey	Tailings	18	2.97	588
15	Mikey	Tailings	24.5	0.06	1920
16	Mikey	Sediments	26.5	0.87	348
17	Mikey	Wet tailings from pond	22.0	12.5	409
17a	River Mikey	Water	Nil	0.002	1.4
18	Osiri	Dry unprocessed tailings	118.5	20.35	152
19	Osiri	Wet processed from pond	Nil	4.0	82
20	Kapiyo Masara	Quartz–control sample	Nil	0.26	66
21	Kapiyo Masara	Water sample–itching	Nil	Nil	10.6
22	Nyatuoro	Tailings	120	1.32	12.8
23	Nyatuoro	Quartz–control sample	Nil	0.31	10.56
24	Nyatuoro	Processed tailings	216	18.0	39.6
24a	Nyapala	Tailings	Nil	10.3	12.2
25	River Migori	Sediment, 200 m from bridge	Nil	1.86	220
26	River Migori	Sediment 300 m down	24.5	1.87	3.08
27	River Migori	Sediment 400 m down	Nil	0.48	6.36
28	River Migori	Sediment 500 m down	3.0	0.03	5.0
29	River Migori	Sediment 600 m down	55	0.12	1.96
30	River Kirwa	Sediments at bridge	8.0	0.02	0.48
31	River Kirwa	Sediment 300 m down	Nil	0.15	0.28
32	Kisumu Site	Tailings	Nil	2.15	0.46
33	Kisumu Site	Tailings	83.0	4.65	1.34
34	Kisumu Site	Tailings	Nil	1.75	1.06

TABLE I

(*continued*)

Sample no.	Mine	Sample type	Pb ($mg\,kg^{-1}$)	As ($mg\,kg^{-1}$)	Hg ($mg\,kg^{-1}$)
35	River W of Macalder	Sediments	258	0.43	36
36	River W of Macalder	Sediments	Nil	0.33	136
37	River W. of Macalder	River water	13.75	Nil	0.04
38	River S. of Macalder	Sediments	11075	0.014	422
39	Macalder Mine	Red tailings	40.5	0.99	399
40	Macalder Mine	Tailings	41.5	0.05	206
41	Kuja river bridge	Dry sediments	317.0	0.32	5.52
42	Kuja river	Sediment 150m upstream	282.0	0.92	134
43	Kuja river	Sediment 250m upstream	49.5	0.33	112
44	Kuja river	Sediment 350m upstream	7.0	0.08	55
45	Migori river–Osiri	Sediments	Nil	0.09	2.3
46	Migori river–Osiri	Sediments	Nil	0.02	1.54

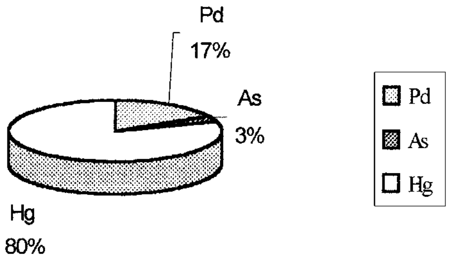

Figure 5. Distribution of heavy metals in tailings.

and, finally, finds its way into the sediments and surface and underground water. Hg may, thus reach rivers and, ultimately, Lake Victoria. The remaining 60% of Hg is released directly into the air when Au–Hg amalgam is being heated during purification.

4.3. WATER CONTAMINATION

The survey revealed that water contamination is associated mainly with panning along streams and rivers. Evidence of possible pollution includes siltation and water coloration due to chemical reactions, resulting in the formation of sulphuric acid and ferrous hydroxide. The streams show orange coloration and the water is acidic, depicting chemical pollution. Rivers that have been affected by pollution include the Macalder and Mickey streams, Kuja and Migori rivers.

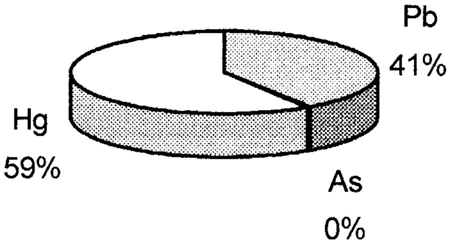

Figure 6. Concentrations of heavy metals in river and stream sediments.

The local community depends on the water from these rivers for domestic use; unaware of the dangers posed by their pollution. Fish is also the main source of food in this area; thus fish is obtained from contaminated rivers. The possibility of heavy metal contamination reaching Lake Victoria, which is only 15 km from Macalder, is quite high.

Groundwater pollution in the mines is partly due to dumping of used batteries within mine workings and partly due to poor sanitation underground. Cases of groundwater causing itching are common. Analysis of such waters gave the following chemical composition: 96.10 mg L^{-1} Na, 26.10 mg L^{-1} Mg, 4.89 mg L^{-1} K and 3.53 mg L^{-1} Ca. The water is strongly alkaline and this can be attributed to alkaline batteries being used in torches underground.

5. Discussion and recommendations

The world community has recently undertaken various environmental projects involving the monitoring of soil, air, water and aquatic life. There is interest in securing harmony between the industry, on one side, and the environment and human health on the other. For example, in 1991 and 1992, the United Nations University in Tokyo sponsored conferences on industry, environment and human health. It was noted that mercury poisoning poses a serious hazard to health, as was seen in Minamata, Japan. To avoid a repetition of such events, the world community is undertaking early surveys and dissemination of information as a basis for timely action.

Action includes international collaborative research on toxic metals. The experience of the Japanese researchers in metal toxicology, particularly in the case of mercury poisoning is most useful to the rest of the world. Uitto (1992) correctly noted that the primary concern is to learn from these experiences so as to avoid similar episodes in future, and where they have not been avoided, to facilitate community rehabilitation.

Relationships between mining and environment are particularly complex and not yet fully understood especially in developing countries. In Kenya, this complexity is due partly to the level of research and lack of adequate analytical capabilities as well as foolproof diagnostic ability for environmentally related health conditions.

The environmental consequences of mining in the Migori district came to the fore only recently when fish and other components of the ecosystem were reportedly being decimated in the Kuja and Migori rivers as a result of suspected heavy metal poisoning. There are few surveys and pertinent data to corroborate these speculations. For instance, whereas the mine water is known to be polluted, details of the fugitive elements (mercury, arsenic, lead, etc.) in terms of the nature and extent of their environmental impact including health implications, are not known.

The main health problems of the mining community in the Migori district include the spread of respiratory ailments and diseases related to impacts of mining. Water logged pits and trenches, are breeding sites for mosquitoes. Inhalation of large amounts of siliceous dust, careless handling of mercury during gold panning and breathing mercury vapour during the heating of Au/Hg amalgam and having a large number of miners sharing poor quality air in the mines are some of the causes of poor health among miners specifically linked to mining and processing of ore.

The concentrations of heavy metals, mainly Pb, As and Hg at the mine sites, stream sediments and water exceed the recommended values of the World Health Organization. For example, the concentration of Pb and As in the Macalder stream is up to $13.75\,\mathrm{mg\,L^{-1}}$ and $8.04\,\mathrm{mg\,L^{-1}}$, respectively. This is several levels above the WHO recommended guidelines of $0.05\,\mathrm{mg\,L^{-1}}$ for Pb and As. Lead is toxic at any level and it does not break down naturally until it is removed from dust, soil, drinking water and food. Even the lowest doses can impair the nervous system and affect foetus, infants and children, resulting in lowering the IQ. Children can get Pb poisoning by simply crawling on the floor or wiping their hands with dust.

Mercury from panning sites may find its way into the rivers and finally into Lake Victoria, where it is likely to be taken up by fish. Once in the human body, it attacks the brain, liver, kidney and even the foetus. Mercury attacks the central nervous system and eventually leads to Minamata disease, which has no cure. In the Migori district, many miners have symptoms similar to this. However, clinical investigation is necessary in order to eliminate other similar symptoms.

On-site training of miners in protective measures was conducted to reduce the effects of mining on human health. During training, the importance of dust masks, air filters and heavy-duty industrial chemical gloves were emphasized. This protective gear was distributed to the miners who, on using them, appreciated their effectiveness. They were further encouraged to purchase such protective gear, and to continue using them for the sake of their health.

Notwithstanding this, concerted effort is still required in order to improve the health standards of the mining community in the Migori district. Measures to be taken include:

(a) providing technical and professional assistance for artisan miners so as to improve their skills in mining and gold processing;

(b) encouraging the use of protective gear at all times during gold mining and processing;
(c) formation of strong mining committees with the task of planning and managing mine sites and working hand in hand with the Government authorities on health and pollution control, for example, on protection of water sources;
(d) strict observation of sanitation within the mines, including provision of pit latrines, boiled water, and hot meals;
(e) Campaigns on sexually transmitted diseases (STDs) including HIV/AIDS, which spreads at an alarming rate among the mining communities in the district.

Acknowledgements

The present paper is based on research findings of a project in the Migori district, which was sponsored by the Netherlands Embassy in Nairobi, in 1999. We therefore express our sincere thanks to the Embassy for the financial support. We are also indebted to the Kenya National Academy of Sciences (KNAS) for the coordination of the project. Particular thanks go to the Chairman of KNAS; Prof. S.O. Wandinga for continued support during the period of the project.

We are most grateful to the organisers of the workshop on Geomedicine in Nairobi, in 1999, for having given us the opportunity to present our findings at the workshop and for the publication of this paper. Sincere thanks are expressed to the Publishers, Kluwer Academic Publishers, for peer review of the draft and publication of this paper.

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