Impact of the disused Kilembe mine pyrites on the domestic water quality of Kasese town, western Uganda

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Abstract

This study investigates the impact of the disused Kilembe mine pyrites on the domestic water quality of Kasese town in western Uganda. Surface water samples were collected from 8 sampling stations around Kasese town and were analysed using an atomic absorption spectrophotometer for 6 heavy metals: cadmium, nickel, copper, cobalt, lead and zinc. The results showed that the mean concentrations of the measured heavy metals did not conform to the maximum permissible limits of the WHO standards for drinking water quality. Lead, nickel and cadmium had mean concentrations well above the maximum permissible limits : 0.016 μg mL^{-1} for lead, 0.024 μg mL^{-1} for nickel and 0.61 μg mL^{-1} for cadmium. In general, the total mean concentration, in μg mL^{-1}, of the metals in all the samples decreased in the order: Co > Cu > Zn > Ni > Pb >> Cd. The results indicated that the total heavy metal content in the water was greater in the Kilembe mine valley followed by the area before the mine (near river sources) and least in the water after the Kilembe mine valley. Nevertheless, the heavy metal concentration in the domestic water remained high for human domestic usage at a number of the sampling stations. It is therefore recommended that working bioremediation projects need to be put in place to resolve the problems of heavy metal contamination and other potential pollutants in the environment in the area.

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Keywords:

Mine pyrites, Kilembe disused copper mine, Contamination, Surface water, heavy metals, Kasese town, bioremediation

1. Introduction

Kasese town is one of the fastest growing municipalities in Uganda. The district is endowed with various water resources, which cover about 12% of the total land area, including lakes, rivers and streams. The rivers include Mubuku, Rwimi, Nyamba, Ssebore (that harbours the Mubuku Irrigation Scheme), Nyamugasani and Lhubiriha (housing the Bwera Water Scheme at the Uganda-Congo border). The lakes include Lake George, Lake Edward and Lake Katwe, while the crater lakes on the top of Mt. Rwenzori provide extra in-drainage. Generally, the district is endowed with quite a number of other water sources, including boreholes, protected wells and springs as well as piped water in the municipal areas.

The average safe and clean water coverage in the district is currently estimated at 84.1%. By December 2005, there were 1,106 protected springs, 1,557 Gravity Flow Scheme (GFS) taps (including illegal connections) and 170 boreholes in the district. From January 2006 to date, 178 water points have been built. These are serving an estimated 31,350 people. These water points are from the following water sources: 78 protected springs – serving 15,600 people, 5 boreholes - serving 1,500 people, 95 tap-stands of gravity flow schemes.

A large percentage of the domestic water supply facilities in the district utilise ground water. These include springs, gravity flow schemes and boreholes. It is currently estimated that there are 1,167 protected springs up from 1,136, 183 boreholes and about 1,450 GFS taps available for rural water supply with an average access to safe water coverage being estimated at between 80 – 85%. The average functionality of safe water sources in the district stands at 63% down from 76%. There are numerous reports of drying water springs which are a real threat to the domestic water supply and in general water resources in the district. Water supply systems that use surface water include: the National Water and Sewerage Corporation plant, which supplies mainly Kasese Town Council; the Katwe-Kabatooro Urban water supply system which supplies Katwe Town Council, and Bwera water supply which serves the 3 sub-counties of Bwera, Karambi and Nyakiyumbu. All the three systems have treatment processes with Bwera having the simplest treatment process consisting of roughing filters, sedimentation and rapid sand filters; the other two have chemical treatment processes.

Copper was mined at Kilembe between 1956 and 1979, and during this period, a lot of pyrites, estimated at 15 million metric tonnes, were generated during the processing of the copper-cobaltiferous pyrite ores. The cobaltiferous pyrites which were a by-product were dumped in settling ponds in Kasese about 11km east of the mine. Flotation tailings were dumped in various areas in the Kilembe valley. The mine was forced to close owing to fluctuating price of copper on the international market, and the political turmoil prevailing in the country at the time. This disused Kilembe copper mine in western Uganda may therefore be a source of contamination for the domestic water sources of Kasese town mainly due to acid mine drainage, weathering, leaching and erosion of waste rock, flotation tailings and cobaltiferous stock-piles.

Some research was carried out on the establishment of plant propagules in the acid-mine polluted soils of the pyrite trail in Queen Elizabeth National Park [1]. The results from this study indicate that the pH values of the pyrite trail ranged from 1.6 to 3.5. Seed germination of all plant species except *Bidens pilosa* L. was not possible in the pyrite soils (pH 1.6–4.0) in laboratory germination trials. Under field conditions, seed germination was possible in all the plots with amended pyrite soils at pH 5.5 ± 0.2 and 7.0 ± 0.2. Seed germination in the uncontaminated soil was much higher than in the amended pyrite soil. Further, work done on Lake George acting as a sink of the contaminants derived from the abandoned Kilembe copper mine [2] points out that Lake George is a highly resilient system that efficiently immobilsizes the contaminants. This was because sequential extraction experiments on the Lake Sediments and Lake Water analyses suggested low bioavailability of the heavy metals. However information on how these pyrites might have contaminated the domestic water of Kasese town is limited.

The arising environmental problems from defunct mining activities are receiving increasing attention particularly in the industrialised nations. Much less similar attention has been accorded in developing countries like Uganda which, nevertheless, still continue to be the world's major producers of raw materials. This could perhaps be attributed to these countries having poorly developed or insufficient environmental monitoring strategies to identify potentially detrimental concentrations of toxic heavy metals in the environment [3].

Although the Kilembe copper mines closed more than three decades ago, metals still contaminate the water bodies around. Studies elsewhere have shown that even after cessation of the contamination source, heavy metals from sediments can be cycled into natural aquatic systems [4]. Natural immobilisation and removal processes of heavy metal contaminants may be outpaced by cycling and the continued loading of metals into the ecosystem. If so, this could adversely affect the ecological dynamics of the water bodies.

The exposure of sulphidic components in the tailings to an exotic environment (especially under tropical weathering conditions) leads to complex oxidation processes resulting in a marked increase of acidity and mobilisation of metallic elements towards the surrounding water bodies and soils arising from acid mine drainage (AMD) and possibly also acid rock drainage (ARD).

The high levels of mobilised metallic elements from their deposit sites in Kilembe and large stockpile of cobaltiferous pyrites at Kasese may consequently contaminate domestic water sources of Kasese town due to such acid mine drainage, weathering, erosion of waste rock and flotation tailings. Despite all these, there is no information available whatsoever as to what extent of contamination these pyrites might have had on the domestic water sources of Kasese town.

The aim of this study was to establish the extent to which the domestic waters of Kasese town may be contaminated with toxic heavy metals due the leachates from the pyrites obtained from the abandoned Kilembe mines. It was therefore necessary to identify and quantify the presence of a selection of trace metals: Cd, Pb, Zn, Ni, Co and Cu.

2. MATERIALS AND METHODS

2.1 Study Area

The district of Kasese in western Uganda is located along the Equator (00 11N, 30 05E). It is bordered by the districts of Kabarole to the north, Kamwenge to the east, Rubirizi to the south. The western border is shared with the Democratic Republic of the Congo. The district headquarters at Kasese are located some 360 kilometres, by road, west of Kampala, Uganda's capital and largest city.

Figure 1: Showing the stock-pile of the copper-cobaltiferous pyrites along the Kasese-Kilembe road.

The town borders the Rwenzori mountain ranges (popularly known as the mountains of the moon), which have heights of up to 5,109m. The highest Rwenzori peaks are permanently snow-capped, and they, along with Kilimanjaro and Mount Kenya are the only such in Africa. The range is about 120 km long and 65 km wide. It consists of six masses separated by deep gorges: Mount Stanley (5,109m), Mount Speke (4,890m), Mount Baker (4,843m), Mount Emin (4,798m), Mount Gessi (4,715m) and Mount Luigi di Savoia (4,627m) [2]. Mount Stanley is the largest and has several subsidiary summits, with Margherita peak being the highest point. The underlying rock is metamorphic, and the mountains are believed to have been tilted and squeezed upwards by plate movement. They are in an extremely humid area, and frequently engulfed in white clouds.

The Rwenzoris are known for their unique mountainous vegetation, ranging from tropical rainforest, through alpine meadows to snow; and for their diverse fauna, including forest elephants, several primate species and many endemic birds. The range supports its own species and varieties of Giant groundsel and Giant lobelia and even has a six-metre high heather covered in moss that

lives on one of its peaks. Most of the range is now a World Heritage Site and is surrounded jointly by The Rwenzori Mountains National Park in Uganda and the Parc National *des* Virunga in Congo [2].

2.2 Sampling
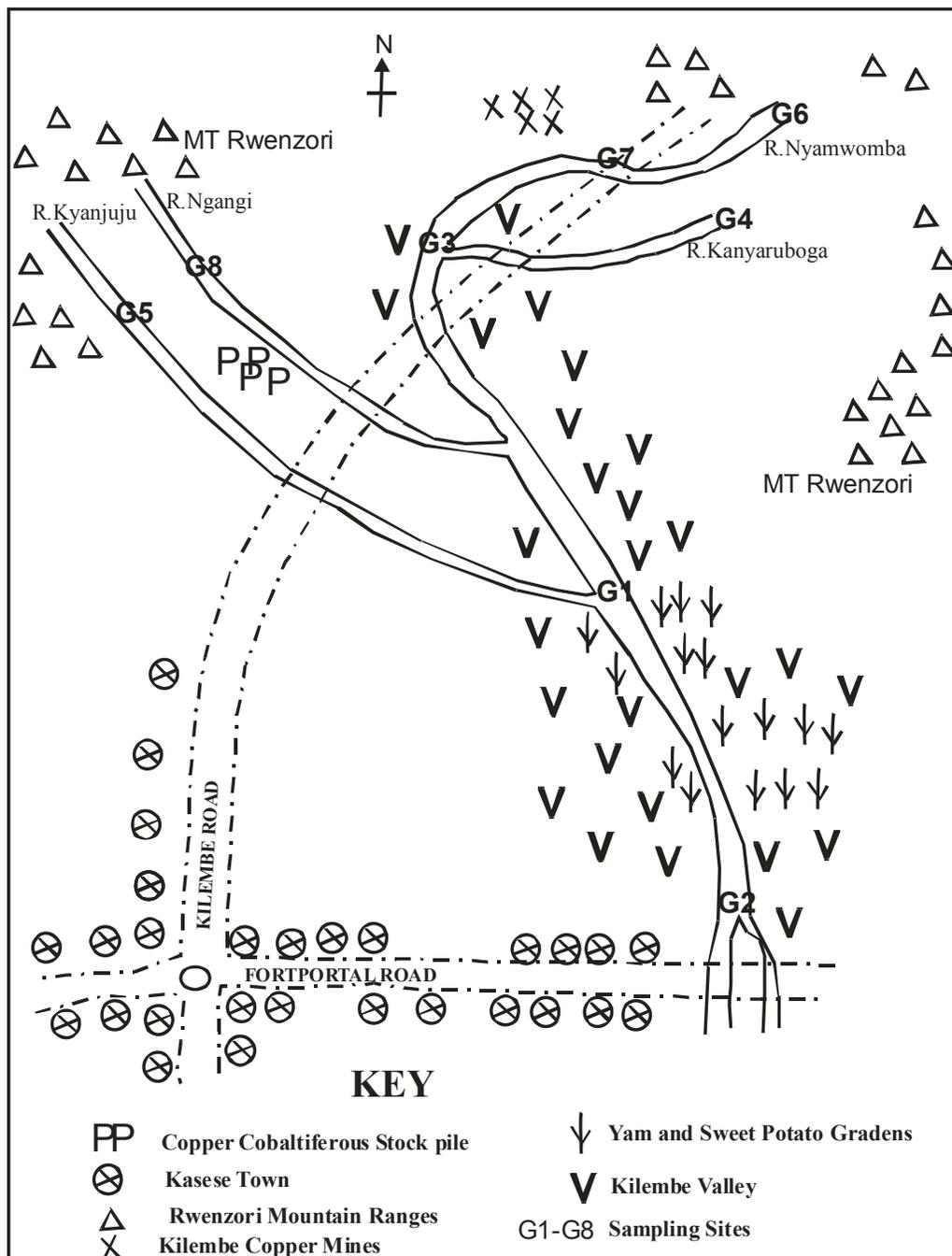
Figure 2. Sketch map of major domestic water sources and where the water samples for the study were collected

KEY TO MAP

G1 **-** water samples taken in down the mine valley at a site after River Kyanjuju joins River Nyamwamba

G2 - water samples takes as River Nyamwamba just exits the Kilembe Valley

G3 - water samples from the Kilembe valley (just adjacent to the disused mine machinery)

G4 - water samples from River Kanyarubogo before it joins the mine valley

G5 - water samples from River Kyanjuju before joining River Nyamwamba

G6 - water samples from near the source of the Nyamwamba River

G7-water samples from River Nyamwamba before it enters the Kilembe mine valley

G8 - water samples from River Ngangi before joining River Nyamwamba

Eight sites (Fig.2) were selected to represent the major physiographic regions of the water sources. Physico-chemical water parameters were determined using procedures certified by the International Standards Organisation (ISO). Sampling was during December 2010. Water (24 samples) from the different water sources of domestic water were collected into a 1000 ml plastic container. The samples were carried to the laboratory for analysis at the Departments of Chemistry and Geology of Makerere University.

2.3 Analytical procedures

The pH of water was determined with the WTW pH 315i meter (ISO 10390: 2005), which is an

electronic device with a probe. The electrolytic conductivity was determined using a TDS

conductivity reader and recorded in µS cm^{-1} All the chemicals named and used in this study,

including the deionised water, were supplied by British Drug Houses (BDH) and were of

analytical reagent (AnalaR) grade, that is, of the highest purity.

The water was analysed for major trace metals (Cd, Co, Cu, Ni, Pb, and Zn) using an Atomic

Absorption Spectrophotometer (AAS, Model 2380; Perkin-Elmer GmbH, Uberlingen, Germany).

 Control samples of water from the source of the main river which is a life-line of Kasese town (River Nyamwamba) were collected and correspondingly analysed.

The heavy metals were investigated for comparison and completeness. Several different methods for analysis were used so as to obtain values that would yield more meaningful and representative means. The filtered samples were analysed directly [5], without any treatment, for copper Cu, zinc Zn, cadmium Cd and lead Pb, using a flame atomic absorption spectrophotometer (FAAS). To 250 ml of filtered water sample 5 ml of concentrated hydrochloric acid were added and evaporated to 25 ml. The concentrate was then transferred to a 50 ml flask and diluted to the mark with distilled water. Metal contents were then determined using the FAAS [6]. As an alternative variation to this method, to 500 ml of the filtered water sample was added 10 ml of concentrated hydrochloric acid (analytical reagent grade) and evaporated under gentle heat to 50 ml. The concentrate was quantitatively transferred to a 100 ml flask and made up to the mark with deionised distilled water. The resultant aqueous solution was analysed for each of the heavy metals Zn, Cu, Ni, Co, Cd and Pb. Further, at the time of analysis, 1 litre of the water samples from each site was evaporated to dryness. To the residue, the triple acid system, *viz*. concentrated nitric acid (10 ml), perchloric acid (2 ml) and hydrofluoric acid (4 ml) were added. Then this was reheated to dryness. The final residue was be reconstituted in 2 ml of hydrochloric acid (2M), transferred to a 25 ml volumetric flask and made up to the mark with distilled water. The solution was analysed using the FAAS. This gave the total metal concentration in the sample, which here is reflected as the mean of the various methods employed.

3. **RESULTS AND DISCUSSION**

The pH of the filtered water samples at 25°C was in the range 6.14 to 7.35 (Table 1), an indication of the relative neutrality of the domestic waters. The water had its highest pH of 7.28 at sampling site G4 and the lowest pH of 6.14 at sampling site G1.

Table 1. Showing the mean pH

Sampling site	G1	G2	G3	G4	G5	G6	G7	G8
pH	6.14	7.06	6.82	7.28	7.27	7.07	7.35	7.05

Electrolytic conductivities, however, were comparatively high, with values ranging up to 1000 μS cm^{-1} (Table 2), compared with 5.5 x 10^{-2} μS cm^{-1} of pure distilled deionised water. This suggested a presence of more soluble ionic substances, among them metallic hydroxides, carbonates and hydrogencarbonates that would in turn tend to buffer the waters against any excessive intrusive acidities and alkalinities.

Table 2. Showing the mean electrolytic conductivities in μS cm^{-1}

Sampling site	G1	G2	G3	G4	G5	G6	G7	G8
E.C. / μS cm^{-1}	108	104	1000	150.2	120	72	76	74

Solubilisation of heavy metals in the water may occur as cationic, anionic, non-ionic and non-ionic modifications. The existence of the metals in non-ionic forms may be attributable to metal associations with high relative molecular mass (RMM) organic matters [7,8]. Distribution among the different forms or modifications varies widely according to the nature and the coordination chemistry of the metal. The total heavy metal levels at various domestic water sources (Fig. 2) were sampled in December 2010, the concentration was recorded as the mean total concentrations (±SD) in the water sources. Table 3 shows the total sum of heavy metal composition of the filtered water samples as analysed through the four analytical procedures indicated above. In general, the total concentration, in μg ml^{-1}, of the metals in all the samples decreased in the order: Co > Cu > Zn > Ni > Pb >> Cd.

Table 3. Total heavy metal levels in the domestic water at various sampling sites, Kasese town – Western Uganda

Sampling site	Concentration (μg ml^{-1})					
	Zn	Ni	Cd	Pb	Co	Cu
December 2010						
G1 (*n*=3)	0.05±0.01	0.10±0.00	0.01±0.01	0.00	0.10±0.00	0.12±0.01
G2 (*n*=3)	0.01±0.00	0.00	0.00	0.00	0.10±0.03	0.09±0.01
G3 (*n*=3)	0.56±0.02	1.00±0.20	0.05±0.01	0.20±0.07	3.90±0.36	2.60±0.11
G4 (*n*=3)	0.31±0.01	0.20±0.02	0.02±0.01	0.25±0.20	0.30±0.02	0.61±0.02
G5 (*n*=3)	0.78±0.02	0.10±0.00	0.03±0.00	0.00	0.10±0.11	0.16±0.01
G6 (*n*=3)	0.19±0.01	0.10±0.06	0.00	0.49±0.08	0.10±0.02	0.12±0.00
G7 (*n*=3)	0.36±0.03	0.30±0.09	0.01±0.01	0.00	0.00	0.19±0.03
G8 (*n*=3)	0.35±0.01	0.10±0.03	0.01±0.00	0.30±0.05	0.30±0.01	0.79±0.05
Mean	0.33±0.01	0.24±0.06	0.13±0.01	0.16±0.05	0.61±0.07	0.59±0.04

All the tolerances in the observed metal levels were computed and quoted as standard deviations (±*s.d.*).

Copper in the samples (Table 4) gave mean total concentrations of 0.59 μg ml^{-1}. Copper was more or less evenly distributed among all the sites (1–8), with the total metal concentrations lying in the range 0.9–2.6 μg ml^{-1} over the entire study period. The total zinc concentration (Table 8) in the filtered water was found to be the highest (0.78 μg ml^{-1}).

Table 4. Concentration of copper at various sampling sites

Site	I	II	III	Concentration
G1	0.11	0.13	0.12	0.12±0.01s.d.
G2	0.09	0.10	0.08	0.09±0.01
G3	2.50	2.70	2.60	2.60±0.11
G4	0.62	0.59	0.62	0.61±0.02
G5	0.16	0.15	0.17	0.16±0.01
G6	0.12	00.12	0.12	0.12±0.00
G7	0.18	0.22	0.17	0.19±0.03
G8	0.77	0.84	0.76	0.79±0.05

The linear comparison of copper concentrations at various sampling sites with World Health Organization (WHO) maximum acceptable concentration levels (Fig. 3) shows that the concentration of copper at various sampling sites occurred in tolerable limits, *i.e.*, < 2 µgml^{-1} except at sampling site G3 where the copper concentration was unsafe for human consumption.
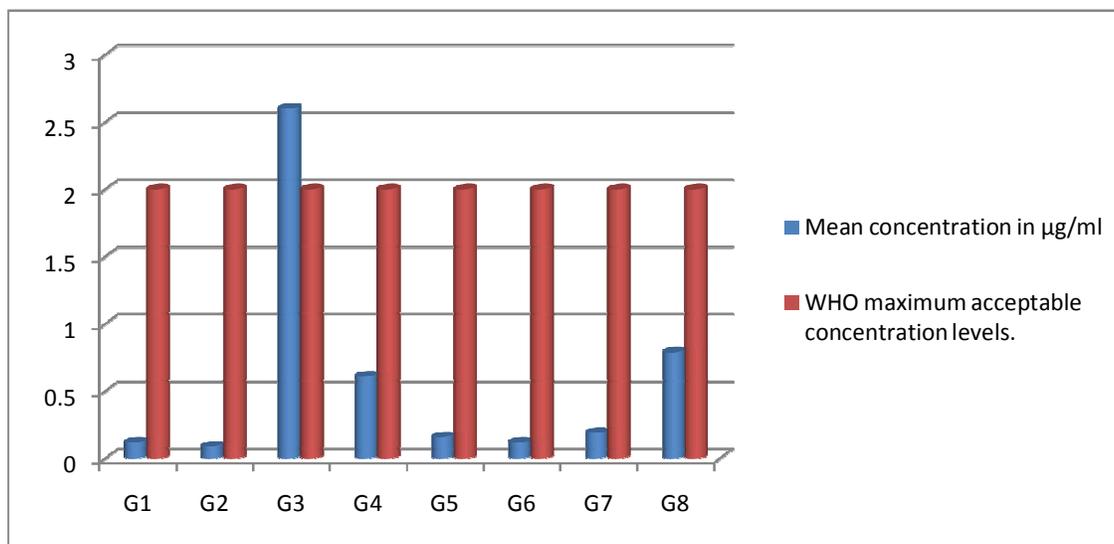
Figure 3. Showing a linear comparison of copper concentration at various sampling sites with WHO maximum acceptable concentration levels.

The total lead concentrations in the samples were in the range 0.2-0.49 µg ml^{-1}, for four samples. However lead was undetected in four other samples. Lead was the least detected trace metal element, that is, it was not detected at sites G1, G2, G5 and G7 making it a metal with the lowest probable rate of detection among the six trace metals investigated. It had its highest concentration of 0.49 µg ml^{-1} at G6 (Table 5).

Table 5. Concentrations of lead at various sampling sites

Site	I	II	III	Mean	Concentration
G1	0.00	0.00	0.00	0.00	0±.00s.d.
G2	0.00	0.00	0.00	0.00	0±0.00
G3	0.26	0.14	0.20	0.20	0.20±0.07
G4	0.04	0.33	0.37	0.25	0.26±0.18
G5	0.00	0.00	0.00	0.00	0±0.00
G6	0.51	0.41	0.54	0.49	0.49±0.07
G7	0.00	0.00	0.00	0.00	0±0.00
G8	0.26	0.32	0.31	0.37	0.30±0.03
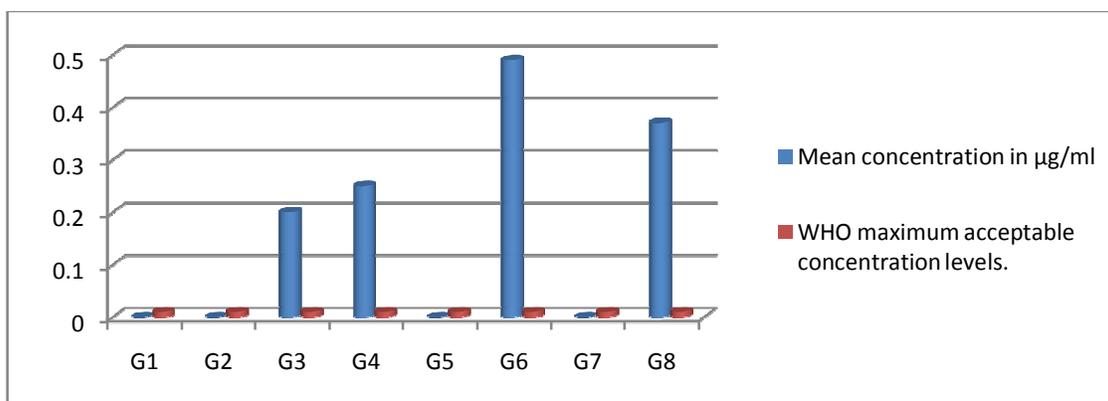
Figure 4. Showing a linear comparison of lead concentration at various sampling sites with WHO maximum acceptable concentration levels.

The linear comparison of lead concentrations at various sampling sites with WHO maximum acceptable concentration levels (Fig. 4) shows that the concentration of lead at sampling sites G3, G4, G6 and G8 was well above WHO acceptable the maximum concentration limit of 0.01 $\mu g\ ml^{-1}$ and is therefore considered unsafe for human consumption. In spite of this, water from sites G1, G2, G5 and G7 was within the acceptable limit for human consumption of below 0.01 $\mu g\ ml^{-1}$.

Sampling sites G6 near the source of River Nyamwamba and above the Kilembe mine valley exhibited the highest lead concentration followed by sampling site G8 which is also above the Kilembe mine valley along River Ngangi (Fig. 2). The results show that the rather high concentrations of lead at these sites could be attributed to background contamination since they are above the mine valley.

The total concentration of cadmium in the water samples ranged between 0.1-0.5 $\mu g\ ml^{-1}$, indicating that cadmium was the second rarest element of the six elements investigated (Table 6).

Table 6. Concentration of cadmium at various sampling sites

Site	I	II	III	Mean	Concentration
G1	0.01	0.01	0.01	0.01	0.01±0.00*s.d.*
G2	0.00	0.00	0.00	0.00	0.00
G3	0.04	0.06	0.05	0.05	0.05±0.01
G4	0.01	0.02	0.03	0.02	0.02±0.01
G5	0.03	0.03	0.03	0.03	0.03±0.00
G6	0.00	0.00	0.00	0.00	0.00
G7	0.00	0.02	0.01	0.01	0.01±0.01
G8	0.01	0.01	0.01	0.01	0.01±0.00
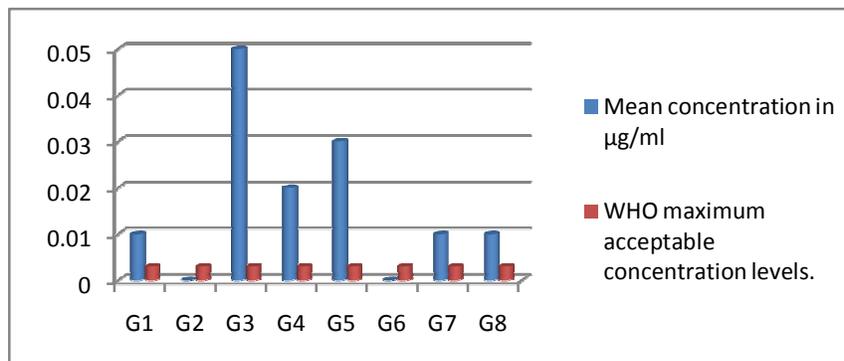
Figure 5. Showing a linear comparison of cadmium concentration at various sampling sites with WHO maximum acceptable concentration levels.

The linear comparison of cadmium concentrations at various sampling sites with world health organization (WHO) maximum acceptable concentration levels (Fig. 5) shows that the concentration of cadmium at sampling sites G1, G3, G4, G5, G7 and G8 is well above the WHO limit of 0.003 μg ml^{-1} cadmium in drinking water. Consequently, water from such sources is considered unsafe for human consumption, with the highest contamination occurrung at sites G3 and G5. Water from sites G2 and G6, however, has no detectable cadmium concentrations. Cadmium having a high concentration at G3 indicates the contamination due to the leachates from the abandoned Kilembe mines while the high concentration at G6 is due to the background contamination since site G6 is above the mine valley.

The total nickel concentrations in the samples were in the range 0.1-0.3 μg ml^{-1}. Nickel and cobalt where not detected at only one sampling site (Table 7).

Table 7. Concentrations of nickel in μg ml^{-1}

Site	I	II	III	Mean	Concentration
G1	0.10	0.10	0.10	0.10	0.10±0.00*s.d.*
G2	0.00	0.00	0.00	0.00	0.00±0.00
G3	0.80	1.00	1.20	1.00	1.00±0.20
G4	0.18	0.20	0.22	0.20	0.20±0.02
G5	0.10	0.10	0.10	0.10	0.10±.00
G6	0.10	0.20	0.10	0.10	0.10±0.06
G7	0.26	0.24	0.40	0.30	0.30±0.09
G8	0.08	0.09	0.13	0.10	0.10±0.03
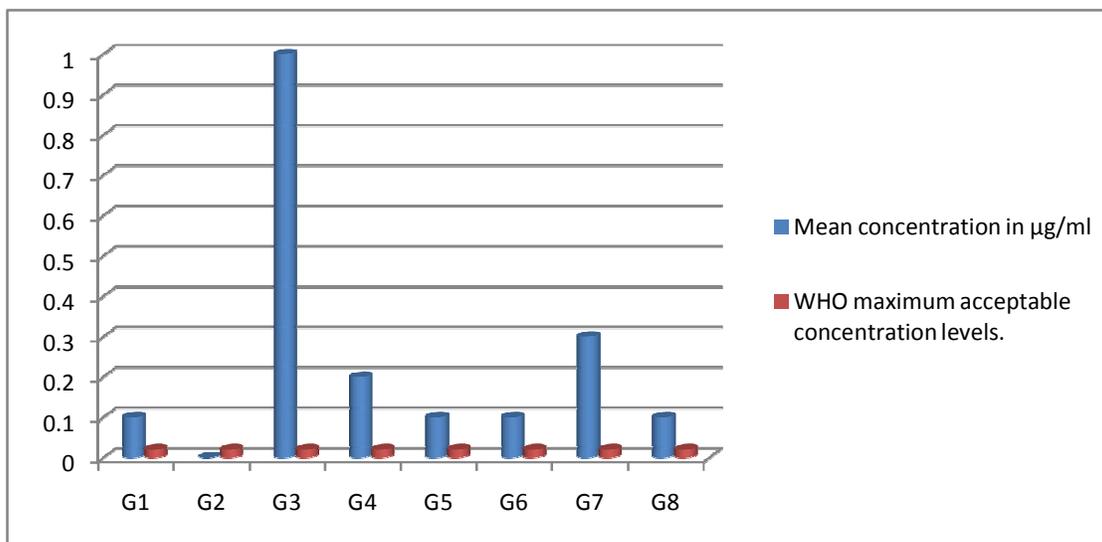
Figure 6. Showing a linear comparison of nickel concentration at various sampling sites with WHO maximum acceptable concentration levels.

The linear comparison of nickel concentrations at various sampling sites with WHO acceptable concentration levels (Fig. 6) shows that the concentration of nickel at all sampling sites except G2 is well above the WHO limit of 0.02 μg ml^{-1} of nickel in drinking water and water from such sources is unsafe for human consumption, with the highest contamination occurring at site G3 followed by G7. The presence of elevated concentrations of nickel at G3 may be accounted for if background contamination is taken into consideration.

Copper and zinc were the only trace metal elements out of the six investigated that were present in all the sampling sites.

Table 8. Concentration of zinc at various sampling sites, in μg ml^{-1}

Sampling Site	I	II	III	Mean Concentration
G1	0.45	0.44	0.46	0.45±0.01*s.d.*
G2	0.01	0.01	0.01	0.01±0.00
G3	0.56	0.54	0.58	0.56±0.02
G4	0.32	0.30	0.31	0.31±0.01
G5	0.79	0.76	0.78	0.78±0.02
G6	0.19	0.20	0.18	0.19±0.01
G7	0.39	0.35	0.34	0.36±0.03
G8	0.36	0.34	0.35	0.35±0.01
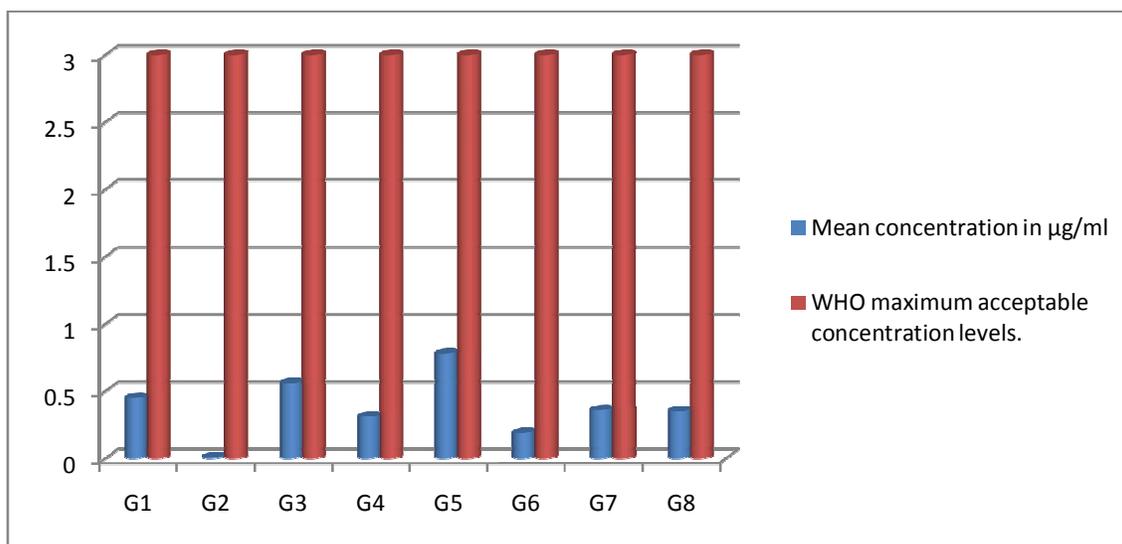
Figure 7. Linear comparison of zinc concentration at various sampling sites with WHO maximum acceptable concentration levels.

The linear comparison of zinc concentrations at various sampling sites with WHO concentration levels (Fig. 7) shows that the concentrations of zinc at all sampling sites were within the WHO acceptable concentration limit of 3 μg ml^{-1} of zinc in drinking water.

The total cobalt concentrations in the samples were in the range 0.1-3.9 μg ml^{-1}. There were no WHO reference acceptable levels for cobalt so a linear comparison with the WHO acceptable limits and cobalt concentrations at various sites could not be made. Yet cobalt frequently occurs concomitantly with copper in copper seams, and is currently being extracted from the pyrites at Kilembe.

Table 9. Concentration of cobalt at various sampling sites in μg ml^{-1}

Site	I	II	III	mean	Concentration
G1	0.10	0.10	0.10	0.10	0.10±0.00*s.d.*
G2	0.08	0.09	0.13	0.10	0.10±0.03
G3	3.70	3.80	4.30	3.90	3.90±0.36
G4	0.31	0.31	0.28	0.30	0.30±0.02
G5	0.10	0.00	0.20	0.10	0.10±0.11
G6	0.12	0.08	0.10	0.10	0.10±0.02
G7	0.00	0.00	0.00	0.00	0.00±0.00
G8	0.29	0.31	0.30	0.30	0.30±0.01

The study showed that cadmium concentrations were the least of the six trace metals investigated. Although a large percentage of the metals are believed to occur in the free, hydrated cationic form, the existence of the metals in non-ionic modifications may be viewed in the light of associations with high RMM organic matters. Lead on the other hand had the rarest occurrence, followed by cadmium. Nickel and cobalt where not detected at only one site. Cobalt had the highest standard deviation of 0.07, the order of standard deviations being: Co > Ni > Pb > Cu > Zn=Cd. The site with the highest mean trace metal concentration was G3 with cobalt as the element with the highest mean concentration of 3.90 µg ml^{-1}.

The relative magnitudes on a linear percentage scale of the heavy metal levels in the domestic water before Kilembe mine valley, within Kilembe mine valley and after the Kilembe mine valley are as shown (Fig.8).
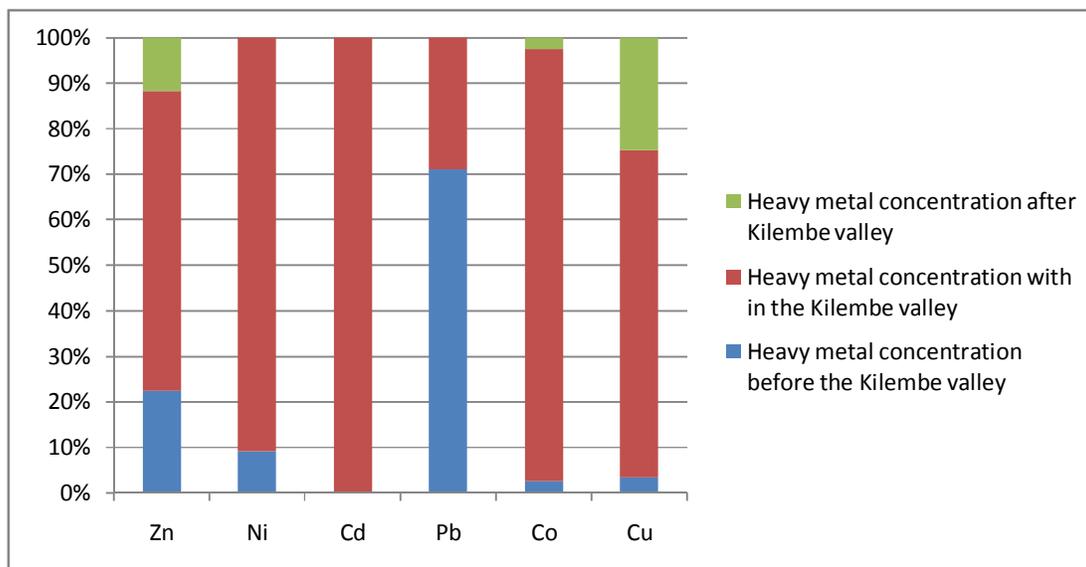
Figure 8. Variation in heavy metal concentrations before the Kilembe mine valley, within the Kilembe mine valley and after the Kilembe mine valley.

The results indicate that the total heavy metal content in the water was greater in the Kilembe mine valley followed by that before the mine (near river sources) and least in water after the Kilembe mine valley. The heavy metal concentration in the domestic water however remains relatively high for human consumption at most of the sampling sites. The high concentration of heavy metals in the Kilembe valley was attributed to a number of factors, notable among others the dissolution and mobilisation of metallic elements from their deposit sites, owing to acid mine drainage, weathering and erosion of waste rock. These mobilised metallic elements plus associated waste-water output from Kilembe Hospital and the nearby township find their way down the surrounding water sources.

The decrease in heavy metal concentration after Kilembe valley was attributed to a number of factors among which is the different types of plants both grown and wild within the Kilembe valley (Fig. 2). These plants included sweet potatoes (*Ipomoea batatas)*, yams (*Dioscorea alata)* and the wildly growing elephant grass (*Pennisetum purpureum)*. Secondly, the heavy metal concentration may have also decreased due to the dilution from other rivers such as Ngangi and Kyanjuju flowing through the Kilembe valley joining River Nyamwamba (Fig. 2). This increases the volume of the water and decreases the concentration of the metal elements. These latter rivers carry a lower heavy metal concentration than River Nyamwamba at the site the rivers meet it in the mine valley.

There was a significant difference in concentration of lead in the waters around Kasese Town, the concentration being zero in the control waters collected 5 km away due east of the town. Average concentrations of 0.16 µg ml^{-1} in the mine area and 0.00 µg ml^{-1} 5 km away from the mine exhibited an average increase in lead in the town domestic waters. There was no significant difference in concentration of zinc, and its average concentrations remained well below the acceptable limits in drinking water by WHO (Fig. 8). Concentrations of lead from three sampling sites lie within the WHO guideline values in drinking water (0.01 µg

ml^{-1}), namely sites G1, G5 and G7, while the rest have lead concentrations well above the WHO guideline values for drinking water, indicating that ingestion of raw water from this river site, as is usually the case, exposes one to the harmful effects of lead.

There was a significant difference in concentration of copper as there was a visible increase in concentration from near the water source of 0.12 to 2.6 $\mu g\ ml^{-1}$ in the Kilembe mine valley. This is clearly a contribution of the leachates from the drilling wastes which contain copper pyrites ($CuFeS_2$). The chemistry of the leaching may not be well understood, but it seems likely that the fluctuating pH of the rain water may be responsible for the leaching out of copper in whatever form, cationic or anionic, from the pyrites. We may wish to remind ourselves that during the extraction of copper from its ores, some copper is extracted by leaching, usually with sulphuric acid or ammonia.

There were the non-detectable cadmium concentrations in the control samples 5 km east of the mine. However, cadmium has a concentration range between 0.00 to 0.05 $\mu g\ ml^{-1}$ and a mean concentration of 0.02 $\mu g\ ml^{-1}$. The mean concentration of 0.01 $\mu g\ ml^{-1}$ is well above the WHO guideline of acceptable values in drinking water of (0.003 $\mu g\ ml^{-1}$), which may consequently pose a threat to people using this water directly.

Distribution of the metals in the water varies widely according to the nature of the metal. Table 3 shows the total sum of heavy metal composition of the filtered water samples as analysed through the various digestion procedures. The table also displays the average total heavy metals from all the digestion procedures. The fairly good agreement among the total heavy metal values from Procedures (a - c) suggests that the methods used were reliable. The total concentration, in $\mu g\ ml^{-1}$, of the metals in all the samples decreased in the order: Co > Cu > Zn > Ni > Pb >> Cd. It is anticipated that a considerable percentage of copper in the Kilembe valley water is as a result of leaching of the copper pyrites, $CuFeS_2$, in the pyrites brought to the surface from underneath the mountain range. This is augmented by the observation that the copper concentrations are much less in all the other samples with an average of 0.59 $\mu g\ ml^{-1}$ and the concentration of copper around Kilembe valley water hovers around 2.6 $\mu g\ ml^{-1}$. It is also worthy of note that the rather elevated levels of heavy metals in the sources of domestic water within and around Kasese town may as well arise owing to the uncontrolled industrial and anthropogenic pollution introduced by untreated effluent from the highly residential township that also empties into the poor drainage systems after passing through a depleted landscape.

Background contamination aside, the levels of cadmium in the municipality waters may be attributable to the activities of small-scale metal works in the town, which process even scrap metal and run the remaining waste directly into the drainage channels. Increased use of artificial fertilisers in the agricultural land basin further enhances the presence of Zn and Cd in the waters as a result of drainage, arising from heavy equatorial as well as relief rainfall. Further, cadmium is widely used in plastics and paints, like zinc, and, owing to the booming construction in the town, there may be some release of the metal into the environment via the associated painting and face-lifting of buildings. The presence of toxic cadmium in the water (Table 3) may also be traced to the volume of small metal processing industries that has sharply increased owing to increased demand for welding iron and steel bars needed for the booming building construction in the town and elsewhere in the countryside. Not possessing nor importing iron ore, Uganda relies heavily on scrap metal from old cars, rusty steel doors, windows, corroded roofing iron and, occasionally, rail steel girders. Traces of cadmium embedded in the scrap iron and steel are released to the environment in the effluent and run-off. Cadmium has been blamed for large-scale poisoning incidents in industrial workplaces, particularly where any ore is being processed or smelted and among welders who have unsuspectingly welded on cadmium-containing alloys or working with silver solders [9].

As expected zinc is a naturally occurring metal and was present in all sampling sites and at relatively low levels in surface water within acceptable limits by WHO (Table 3). The increase in the concentration levels may due to the fact that zinc is extensively used in the manufacture of dry cells that are commonly used as chemical sources of electrical energy to operate radio sets, electric searchlights, remote controls, calculators, microphones, loudspeakers, *etc.* When they are spent, these dry cells are simply discarded into the environment and this may increase the zinc availability.

The average lead level in the domestic waters of Kasese township was found to be 0.16 $\mu g\ ml^{-1}$. The presence of this toxic metal in the waters, either as free cations or as associations with organic matters, could be attributed to several factors, which include the continued use of lead-based paints for face-lifting buildings in the town and their inappropriate disposal. In addition, there is poor management of industrial and municipal waste, not forgetting the background contamination. Car washing and emptying of dead lead-acid accumulators regularly takes place directly along the streams and channels around the domestic water sources. The untreated Pb- laden effluent discharges into the soil and, with continuous annual rainfall, ultimately into the water.

Perhaps rather surprisingly, the copper concentration levels at various sources of water in Kasese municipality are relatively low and within the acceptable limits by WHO (Table 3). Only one sampling site G3 exhibited a slightly higher that the tolerable value. This relatively high concentration within the mine valley may be due to floatation tailing and waste rock along the slopes of the Ruwenzori mountain which have undergone leaching, acid mine drainage, weathering and abrasive erosion for centuries. It is presumed that the leachates produced might have found their way into the sources of domestic water, consequently contaminating it.

The WHO maximum permissible levels of Cu, Pb, Zn, Ni and Cd in drinking water are: Cu =2; Pb = 0.01; Zn = 3; Ni= 0.02; Cd = 0.003 $\mu g\ ml^{-1}$ [10]. The corresponding limits for the heavy metals, according to the Uganda environment management statutes [11], are, respectively, Cu, 1; Pb,0.1; Zn, 5; Cd, 0.1 $\mu g\ ml^{-1}$. Our results show that whereas Cu (0.978) and Zn (1.216 $\mu g\ ml^{-1}$) levels (Table 2), although undesirable, are still within the permissible limits, those of Pb (0.942) and Cd (0.079 $\mu g\ ml^{-1}$) are in the higher range. Under Ugandan Law[12], the Uganda National Environment Management Authority (NEMA) requires, under Statutory Instrument (S.I.) No. 153-4 (NEMA, 2004), that (1) 'Every industry or establishment shall install at its premises anti-pollution equipment for the treatment of effluent chemical discharge emanating from the industry or establishment', and that (2) 'Antipollution equipment installed, under Regulation 1 shall be based on the best practicable means, environmentally sound practice or other guidelines as the Executive Director may determine.' Under S.I.153-6 [25] of the same law, 'Any person who contravenes these Regulations commits an offence and is liable, on conviction, to imprisonment for a term not exceeding eighteen months or to a fine not less than one hundred and eighty thousand shillings and not more than eighteen million shillings or both' (US$1 = USh2500). In spite of this, however, only the Nile Breweries Industry at Jinja seems to be taking serious steps towards pre-treatment of effluent before discharge into a water body.

The forms in which heavy metals exist in a given environment are of key importance in understanding their uptake and release, as well as their toxicological properties. Most studies of the toxicity of heavy metals in fish have indicated that the free metal-ion (hydrated) is the most toxic form [13]. In fairly recent findings, it is indicated that the predominant form of the heavy metals is the cationic species (80–83%). This percentage value may be a good indicator of the bioavailability of these metals in the river water. Considering that no such metals were detected in the bottled mineral water commonly consumed in Kasese town, there is therefore a need for the relevant urban authorities in Uganda to apply measures for water pollution control, particularly from industries. Informed urban dwellers may be well advised to drink only mineral water and use it only for their cooking. Rejecting the river water because of its pollution could then be publicised to expedite the process of environmental improvement.

4. CONCLUSION

The town of Kasese relies heavily on the water from the foothills of the Ruwenzori Mountains majorly from River Nyamwamba and River Ngangi for its domestic use and sustenance. The results obtained from the investigation show that the levels of heavy metals in the river water are significant, perhaps reflective of background contamination and the growing anthropogenic pollution. Although this might in time pose a threat to the fresh water sources for domestic and industrial use, the levels, particularly those of copper and zinc, are still within the concentration values laid down by the WHO. However some sampling sites have concentrations of cadmium and lead well above the guideline concentration values. Therefore it appears that the waters of Kasese town are safe for domestic use at some points and unsafe at others especially with in the Kilembe mine valley and along river Nyamwamba. It also seems that leaching of heavy metals from the pyrites extracted from the defunct Kilembe mines is still minimal, or is yet to have a noticeable effect. It however remains imperative upon the relevant municipal authorities to stress the need for treatment of effluent at the source before release into the environment. In addition, tougher laws should be put in place as a deterrent against urban landscape encroachers.

REFERENCES

1. Oryem-Origa, H., Makara, A., & Tusiime, F.M. (2007). "Establishment of plant propagules in the acid-mine polluted soils of the pyrite trail in Queen Elizabeth National Park, Uganda". African Journal of Ecology, 45(1): 84-90.

2. Owor, M., Hartwig, T., Muwanga, A., Zachmann, D. & Pohl, W. (2006). "Impact of tailings from the Kilembe copper mining district on Lake George, Uganda". International Journal of Geosciences. Available online at http://web.archive.org/web/20080305014225/http://www.rwenzoriabruzzi.com/mountains.html.

3. Denny, P. (1987). "Monitoring of Heavy Metals–A Proposed Strategy for Developing Countries". In Hutchinson, T. C. & Meema, K. M. (eds), Lead, Mercury, Cadmium and Arsenic in the Environment. John Wiley and Sons Ltd.

4. Kelderman, P., Drossaert, W. M. E, Min, L. S. Z., Galione, L., Okonkwo, C. & Clarisse, I. A. (2000). "Pollution assessment of the canal sediments in the city of Delft (The Netherlands)" Water Research, 34: 936–944.

5. Kisamo, D. S. (2003). "Environmental hazards associated with heavy metals in Lake Victoria Basin (East Africa), Tanzania." African Newsletter on Occupational Health and Safety, 13: 67–69.

6. Olowu, R. A., Ayejuyo, O. O., Adewuyi, G. O., Adejoro, I. A., Denloye, A. A. B. & Babatunde A. O. (2010). "Determination of heavy metals in fish tissues, water and sediment from Epe and Badagry lagoons, Lagos, Nigeria". E-Journal of Chemistry, 7(1): 215 - 221.

7. Gao, K. & Pearce, J. (1999). "Interaction between peat, humic acid and aqueous metal ions". Environmental Geochemistry and Health, 21(1): 13-26.

8. Mbabazi, J., Twinomuhwezi, H., Wasswa, J., Ntale, M., Mulongo, G., Kwetegyeka, J. and Schroder, K.H. (2010). "Speciation of heavy metals in water from the Uganda side of Lake Victoria". International Journal of Environmental Studies, 67: 9–15.

9. Wendelaar Bonga, S. E. & Lock, R.A.C. (2003). "Metal toxicity to fish". Aquaculture, 217(1): 686–686.

10. [10] WHO (2008). "Guidelines for drinking-water quality" [electronic resource]: incorporating 1st and 2nd addenda, Vol. 1, Recommendations. 3rd edn. ISBN 978 92 4 154761 1 (web version).

11. National Environmental Management Authority (2004). "Standards for discharge of effluent in water," in: Environmental Legislation of Uganda (NEMA), §7: 1–4. National Environmental Management Authority (2004). The National Environment (Standards of discharge of effluent in

12. National Environment Act, Cap.153 Laws of Uganda 2000 Revision.

13. FAO/WHO (1993). Evaluation of certain food additives and contaminants (Geneva: FAO/WHO).