The Distribution of Toxic Metals in Sediments: Case study of New Union Gold Mine Tailings, Limpopo, South Africa

C. Mitileni[1], J. R. Gumbo[1], C. Muzerengi[2], F. A. Dacosta[2]

[1]Department of Hydrology & Water Resources, jabulani.gumbo@univen.ac.za; jabulani_gumbo@yahoo.co.uk, [2]Department of Mining and Environmental Geology, University of Venda, P/Bag x5050, Thohoyandou, 0950, South Africa

Abstract The study revealed that the toxic metals (Mn, Cu, Cd, Co, Zn and Ni) were distributed in the upper part of the river and stream sediments (0—20 cm). The concentration of the heavy metals were arranged in descending order where Manganese> Copper> Nickel> Zinc> Cobalt> Cadmium. The range of toxic metals in the top and bottom layer was: Mn (99.1 ± 0.1 to 203.5 ± 2.1 mg/kg); Cu (8.9 ± 0.1 to 65.7 ± 4.0 mg/kg); Ni (6.1 ± 0.1 to 63.5 ± 1.2 mg/kg); Zn (12.5 ± 0.6 to 36.2 ± 0.3 mg/kg); Co (4.1 ± 0.1 to 18.8 ± 0.5 mg/kg); Cd (0.2 ±0.00 to 1.3 ±0.1 mg/kg) respectfully. The pH of top soil profile ranged from 3.25 ± 0.01 to 6.28 ± 0.02 whereas the bottom soil profile ranged from 3.75 ± 0.01 to 6.45 ± 0.03. The electrical conductivity of top layer sediments in the stream and the Mandzoro River ranged from 8.5 ± 0.20 to 16.3 ± 0.1 mS/cm and the bottom layer ranged from 8.4 ± 0.20 to 15.3 ± 0.23 mS/cm. The increase of these toxic metals in the bottom profile has the potential to contaminate groundwater supplies, which is a source of drinking water for the rural community. Also the presence of the toxic metals in top profile in river sediments has the potential to impact negatively on aquatic organisms.

Key Words rural communities, toxic metals, groundwater, sediments

Introduction

Mining activities at New Union Gold Mine occurred from 1934 to 1995 when the mine stopped due to depletion of gold ores (Ward and Wilson 1998). During the same period the waste material arising from the processing of gold was stockpiled in mine tailings dams close to the mine. Other studies else in South Africa indicate that some of toxic materials are rich in mercury and cyanide and that these are hazardous to the environment and the nearby communities due to the wind dispersal of dust and water erosion of sediments to streams that drains the tailings (Naicker *et al.* 2003). Also the mine tailings are rich in heavy metals such as Mn, Cu, Cd, Co, Zn and Ni (Mulugisi *et al.* 2009). During heavy rains these heavy metals are washed and deposited into streams and rivers as sediments and accumulate more such that they pose danger to aquatic ecosystem and have the potential to contaminate water sources, surface and groundwater (Wright and Welbourne 2002). Other studies in Spain have indicated that the mine tailings are a source of heavy metals in sediments due to water erosion (Meza-Figura *et al.* 2009).

Though other studies have indicated the presence of heavy metals in the mine tailings, Cynodon dactylon and Hyparrhenia grasses grass species at New Union Gold Mine (Mulugisi *et al.* 2009) there is no data on the distribution of heavy metals in sediments. These heavy metals are likely to be emerging pollutants with the potential to contaminate and contribute to surface water and groundwater pollution. In addition to this, toxic metals may have a long term effect to local ecosystems since they are accumulative and are non-biodegradable.

The general objective of this study was to determine the distribution of heavy metals in stream and river sediments that drain the New Union Gold Mine tailings. The specific objectives were: to analyze the vertical and horizontal distribution of heavy metals in the sediments and to determine the pH and electrical conductivity of the sediments.

Materials and Methods

Sample collection

The sediment samples were collected from five locations in streams that drain New Union Gold Mine tailings dams (longitude 23°01'24"S, latitude 30°43'36"E) and Mandzoro River (Figure 1). The sediments were collected at the top soil profile (0—20). The collected sediment samples were sealed in plastic sachets, labeled with date of sampling and then sent to University of Venda laboratory for further processing.

pH and EC determination and analysis of heavy metal content of mine tailings and grass samples

The sediments were processed following the procedure that was used by Mulugisi *et al.* (2009).

The flame atomic absorption spectrometry (Varian Spectra AA 220/880) was used to measure the concentration of heavy metals (Mn, Cu, Cd, Co, Zn and Ni) in the sediments.

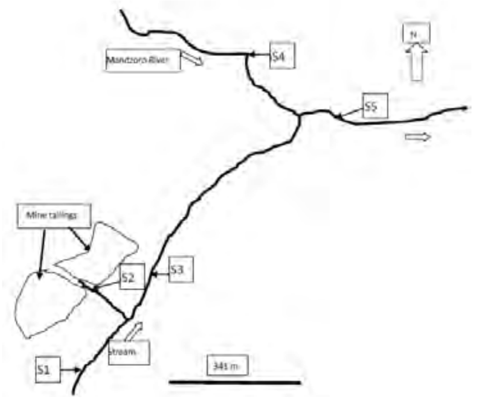

Figure 1 *The location of sediment sampling points (S1) is upstream of tailings dams; (S2) is a stream draining the New Gold Mine tailing dams; (S3) is a stream downstream of tailings dams; (S4) is upstream of Mandzoro River and (S5) is downstream of Mandzoro River.*

Data analysis

The analytical raw data was processed as per procedure of Mulugisi *et al.* (2009) and statistical analysis was carried out with single factor ANOVA.

Results and Discussion

The location of study area

Location shown in Fig. 1.

The effect of pH and electrical conductivity on sediments

The pH and electrical conductivity of sediment samples indicated an inverse relationship and the direction changed from the streams that drain the New Union Gold Mine tailing dams towards Mandzoro River (Figure 2).

The pH of the top profile (0 – 20 cm) of increased from the acidic values of the 3.25 ± 0.01 to the slightly acidic values of 6.28 ± 0.0 (Figure 2). The improvement in the pH values downstream of mine tailings may be attributed less sediments from mine tailings that were deposited downstream. Correspondingly the electrical conductivity decreased downstream.

The distribution of heavy metals in the sediments

The levels of Mn were mainly distributed in the lower profile (20 cm) with the exception of sample point 4 (Figure 3A). The ANOVA test showed that the Mn values were significantly difference ($p < 0.0$) between the upper top profiles (0 and 20 cm). This may be explained by increased migration of Mn into the lower layer (20 cm) as a result of increased of water flows from the tailings dams from sample points 1 to 3. For sample point may be the high levels may have originated from Mn discharged from Malamulele sewage plant (Baloyi 2009). The highest value recorded for Mn (250.8 mg/kg) were higher than the recommended standard of Australian and New Zealand and Environment and Conservation Council guidelines of 21 mg/kg (ANZECC, 2000) but lower than the United State Environmental Protection Agency Sediments quality guidelines of 640 mg/kg (USEPA, 2000).

The levels of Cu were mainly distributed in the bottom profile with exceptions of sample point 3 and 4 (Figure 3B). The ANOVA test showed that Cu values were significantly different ($p < 0.0$) for all sample points with the exception of sample point 3 ($p > 0.58$). This may be explained by increased migration of Cu into the bottom layer as results of increased of water flows from the tailings dams. The effect of pH on the solubility of the heavy metal at sample point 3 increases from the acidic to slightly acidic arranges (Figure 2). The recorded Cu value of 65.7 mg/kg was higher than the recom-

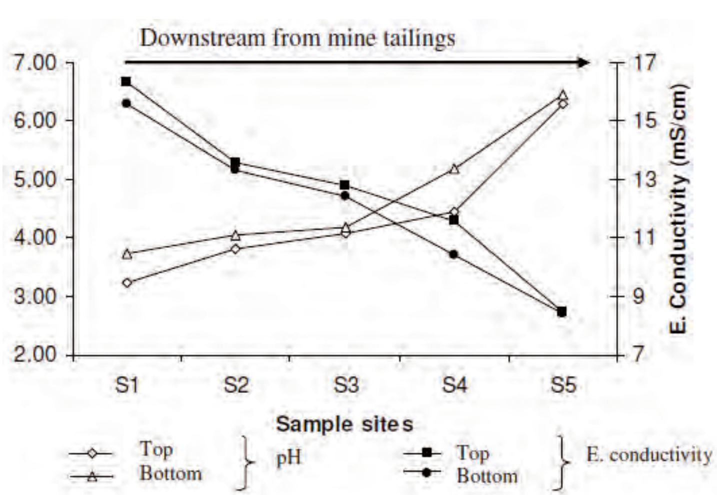

Figure 2 *The effect of pH and electrical conductivity on vertical and horizontal profile of the sediments.*

mended standard of the United State Environmental Protection Agency Sediments quality guidelines of 32 mg/kg (USEPA, 2000).

The levels of Ni were mainly distributed in the lower profile (20 cm) with the exception of sample point 3 (Figure 3C). The ANOVA test showed that Ni values were significantly different ($p < 0.0$) for all sample points. This may be explained by increased migration of Ni into the lower profile as results of increased of water flows from the tail-

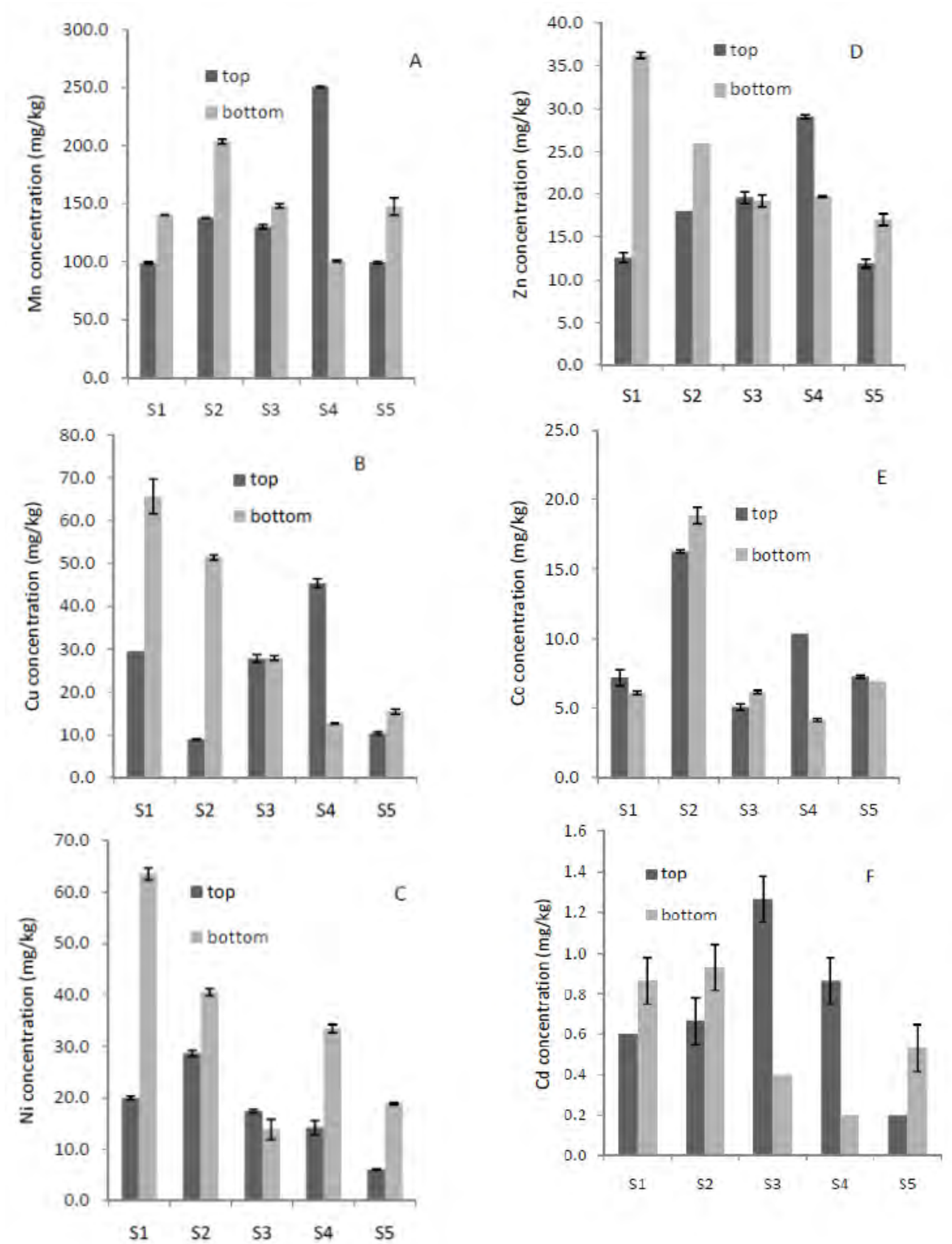

Figure 3 *The distribution of metals (A) manganese, (B) copper, (C) nickel, (D) zinc, (E) cobalt and (F) cadmium in the upper sediments profiles (0 – 20 cm)*

ings dams. The effect of pH on the solubility of the heavy metal at sample point 3 increases from the acidic to slightly acidic arranges (Figure 2). The highest value recorded for Ni (63.5 mg/kg) was slightly higher than the recommended standard of Australian and New Zealand and Environment and Conservation Council (ANZECC, 2000) guidelines of 60 mg/kg but lower than the Switzerland sediment Quality guidelines of 75 mg/kg (Steyn *et al.* 1996).

The levels of Zn were mainly distributed in the lower profile with the exception of sample point 4 (Figure 3D) and followed a similar profile to Cu (Figure 3B). The ANOVA test showed that Zn values were significantly different ($p < 0.0$) for all sample points with the exception of sample point 3 ($p > 0.52$). This may be explained by increased migration of Zn into the lower profile as results of increased of water flows from the tailings dams. The highest value recorded for Zn (36.2 mg/kg) was lower than the recommended standard of South African Sediment Quality Guidelines of 185 mg/kg (Steyn *et al.* 1996), Canadian Sediment Quality Guidelines of 123 mg/kg and Australian and New Zealand and Environment and Conservation Council (ANZECC, 2000) guidelines of 200 mg/kg and United States Environmental Protection Agency Sediments quality guidelines of 120 mg/kg (USEPA, 2000).

The levels of Co were mainly distributed in the top profile (0 cm) with the exception of sample points 2 and 3 (Figure 3E). The ANOVA test showed that Co values were significantly different ($p < 0.0$) for all sample points. This may be explained by increased migration of Co from sample point 2 (close to the mine tailings dams) towards sample point 3 and also migration into the lower profile as results of increased of water flows from the tailings dams. The mean concentration recorded for Co (18.8 mg/kg) was higher than the recommended standard of the United State Environmental Protection Agency Sediments quality guidelines of 3 mg/kg (USEPA, 2000) and lower than the South African guidelines of 20 mg/kg (Steyn *et al.* 1996).

The levels of Cd were mainly distributed in the lower profile with the exception of sample points 3 and 4 (Figure 3F). The ANOVA test showed that Cd values were significantly different ($p < 0.0$) for all sample points. This may be explained by increased migration of Co from sample point 2 (close to the mine tailings dams) towards sample point 3 and also migration into the bottom layer as results of increased of water flows from the tailings dams. The highest value found for cadmium (1.3 mg/kg) was lower than the recommended standard of South African guidelines of 2 mg/kg (Steyn *et al.* 1996) but lower than the United States Environmental Protection Agency Sediments quality guidelines of 2.5 mg/kg (USEPA 1999) and higher than the United State Environmental Protection Agency Sediments quality guidelines of 1 mg/kg (USEPA 2000).

The presence of heavy metals in the upper top profiles (0 – 20 cm) of sediments is a major cause of concern. In the lower profile these heavy metals have the potential to contaminate groundwater supplies since the pH is alsmost ideal (around 6) most suitable for metals going into solution. Also the presence of these heavy metals in top profile has a potential to contaminate surface water sources and may affect aquatic ecosytems. For example Cd element can be detrimental to humans because it can cause diarrhea, nausea, vomiting, renal failure, muscle cramp, salivation, sensory disturbances, convulsions, shock and liver injury (Hazards Centre and People's Science 2005). Too much intake of cobalt can cause health effects such as vomiting and nausea, vision problems, heart problems, thyroid damage. It also affects the lungs, including asthma, pneumonia, and wheezing (Frank *et al.* 1976). Zinc can be detrimental to human health because it can cause loss of appetite, decreased sense of taste and smell, slow wound healing and skin sores (Heyneman, 1996).

Conclusion

The study found that the heavy metals were mainly distributed in the upper top profile (0 cm) of sediments at toxic levels. The presence of heavy metals in the lower profile (20 cm) has the potential to contaminate the groundwater supplies since the pH is almost ideal for metal solubility. Lastly the presence of heavy metals in the top profile has the potential to affect the aquatic ecosystems and contaminate surface water sources.

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