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Zimbabwean mine dumps and their impacts on river water quality – a reconnaissance study

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Abstract

Zimbabwe has a substantial number of mines and 67 minerals have been mined in the country since 1900 but at present only 30 different minerals are being mined. Exploitation of a variety of ores, in rocks of diverse composition, provides the potential for a range of pollution problems. The severity and extent of contamination differs with the type of minerals mined.

This paper presents part of the results of a broad study, carried out across Zimbabwe, which assessed the potential of different mine tailings dumps to cause environmental problems. The dumps considered in the study were divided into six dump types, namely: gold-mine dumps, base-metal mine dumps (dumps associated with the mining of nickel, zinc, copper and lead), minor-metals mine dumps (dumps associated with mining of antimony, arsenic, and selenium), platinum-group metal mine dumps, chromite and asbestos mine dumps, and sulphur (pyrite) mine dumps. The elemental chemistry of the dumps and physical characteristics (pH, total dissolved solids) of the dumps, tailings' leachates, and stream waters around the dumps were used to assess the potential of the dumps to pollute water bodies. Samples were collected in both the dry and wet seasons. The dispersion and pollution patterns were derived from Eh-pH conditions around the dumps after considering the mobility of the elements present in these dumps under different Eh-pH conditions. In this paper potential to pollute is considered as the likelihood of the elements to disperse under the prevailing conditions at the dump. The concentrations of elements, type of elements and the potential dispersion and pollution patterns from each dump were used to characterise potential risk of water pollution associated with the different dump types.

The results showed a slight increase in concentrations of most elements studied in downstream waters compared to upstream waters. The dump conditions varied from acidic to alkaline, and so the elements studied have different mobilities in different dumps. The elements that pose environmental risks differed from one dump type to another thus different dumps have different potentials to pollute the water bodies. From the study it emerged that the minor metals dumps show the worst pollution risk, followed by base metal dumps, gold-mine dumps, platinum group metals mine dumps, chromite asbestos mine dumps and sulphur mine dumps.

The pH values of 79% of the waters sampled in streams both before and after the dumps were neutral, though the pH values of the leachates themselves was frequently very acidic ($\text{pH} < 4$). The low pH levels in leachate are associated with elevated metal and metalloid concentrations in the leachate and in adjacent streams. From this study, a decrease in stream water pH is only expected when there is severe contamination. However, most streams were sampled near the dumps, and results from such samples would not represent entire stream profiles. The general trend from the results is that pH increases downstream as the leachate and run-off from a dump are diluted. Although concentrations of elements are affected the pH for streams did not show significant changes as near the dumps the overall pH of the stream water was not affected. The dumps rarely dry up, and leachate continues to seep from dumps throughout the year, suggesting that AMD is a continuous process.

Keywords: Environmental geochemistry; Mine dumps; Water quality; Mine drainage; Water pollution; Waste management

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1. Introduction

Zimbabwe has a substantial number of mines, from which 67 minerals have been mined since 1900. Thirty-seven minerals are currently being mined. The greater part of mining production comes from ancient Archaean (>2.5 Ga) terrain. These rocks have been worked for gold, silver, iron, copper, nickel, lead, zinc, magnesite, manganese, arsenic, antimony, tungsten, tin, barites, pyrite, corundum, limestone, beryl, tantalum, niobium, lithium, emerald and pollucite. Rocks of Proterozoic age (2.4–0.7 Ga) also host substantial amounts of mineral wealth such as copper, lead and zinc. The 2500 Ma Great Dyke is host to chromium, platinum, nickel, copper, gold, graphite, talc and tungsten. Exploitation of such a variety of ores, in rocks of diverse composition, provides the potential for a range of pollution problems. The severity and extent of contamination differs with the type of minerals mined and thus the type of waste produced. The severity depends on the physical characteristics (pH-Eh environment) around which determines the equilibrium chemical species and dispersion characteristics. The extent depends on the mining methods and dispersion characteristics of the element in question as well as the physical environment which includes the adjacent land use and land covers.

Mining activities in Zimbabwe is predominantly on the highveld. Therefore it usually takes place in the source areas of river catchments, giving rise to conflicts between the need for mines to dispose of large volumes of waste and the water quality needs of the environment and of agricultural and other water users (e.g. Ashton et al., 2001; Lupankwa et al., 2004a,b; Musiwa et al., 2004; Ravengai et al., 2004a,b). These areas are also highly productive for agriculture, and can thus give rise to conflicts between miners and farmers as the disposed wastes negatively affects the soil and water quality which can impact on the agricultural productivity and quality of produce. Work by Engdahl et al. (1998), Maponga (1995), Mohiddin (1997), Roberts (1996) and Thixton (1999) have shown evidence of the negative effects associated with mining activities in Zimbabwe. Acid mine drainage has been shown to be associated with many mine types (Lupankwa et al., 2004a; Ravengai et al., 2005a), alkali mine drainage with chrome mining (Ashton et al., 2001; Roberts, 1996) and base metal pollution with base metal and some gold-mines (Lupankwa et al., 2004b; Musiwa et al., 2004). However there is lack of information that compares different mining waste types making it difficult to gauge the prevalence and severity of mining related pollution of one waste dump type compared to another.

This paper is based on a broad study to provide baseline geochemical information regarding the nature of different mine dumps, which can be used to gauge the prevalence of geochemical mining-related pollution in Zimbabwe. The specific objectives of this study were to:

- categorise different types of waste;
- investigate the geochemistry of each category/group;
- assess the potential toxic elements released by each group;
- assess the likely impact of each group on river water quality.

This paper presents the outcomes of the last objective where the potential impact of the different mine wastes on water bodies was assessed.

The study was carried out at 68 mine dumps throughout Zimbabwe. The mines visited for the purpose of this study are marked in Fig. 1. Most of the mines are situated in the Midlands province, which forms part of the Archaean craton, which is the major producer of minerals in Zimbabwe. It is host to over 75% of the country's gold-mines.

2. Materials and methods

The study deals with levels of potential toxic elements in mine dumps across Zimbabwe with the aim of assessing the potential impact of these levels on river water quality. The parameters considered on choosing the representative mines include geographic setting, geological setting, host rock-type, processing method, ore type and commodities being mined. The dumps visited were divided into six dump types, namely: gold-mine dumps, base-metal mine dumps (dumps associated with the mining of nickel, zinc, copper and lead), minor-metals mine dumps (dumps associated with the mining of antimony, arsenic, and selenium), platinum-group metal mine dumps, chromite and asbestos mine dumps, and sulphur (pyrite) mine dumps. Thus the mine dumps were subdivided into different waste type groups.

To investigate the geochemistry the physical characteristics and element concentrations of the dump and stream water around it were measured, in two sampling campaigns: a dry season campaign (May–October) and a wet season campaign (November–April). A portable Hanna pH meter (model HI 9023C) was used for measuring pH on site. Around each dump, samples of leachate, tailings, downstream water, and upstream (control) water were collected. After collection, samples were stored in a cool place and analyses were performed at the Geology Department, University of Zimbabwe laboratory, using an Atomic Absorption Spectrophotometer (AAS) (model – VARIAN SPECTRAA 200HT). The following metals were analysed: Cu, Ni, Zn, Sb, Pb, Cd, Co and Cr. Arsenic was not determined in leachate and stream samples due to an equipment problem but were determined in the tailings.

Based on the list by McBride (1994) which prioritises toxic elements, a list of potential toxic elements released by each group was tabled. In order to evaluate the impact each group of mining waste is likely to have on river water quality, the level of concentrations of potential toxic elements was evaluated in the dumps, tailings' leachates, and stream waters around the dumps. The dispersion and pollution patterns were derived from Eh-pH conditions around the dumps after considering the mobility of the elements present in these dumps under different Eh-pH

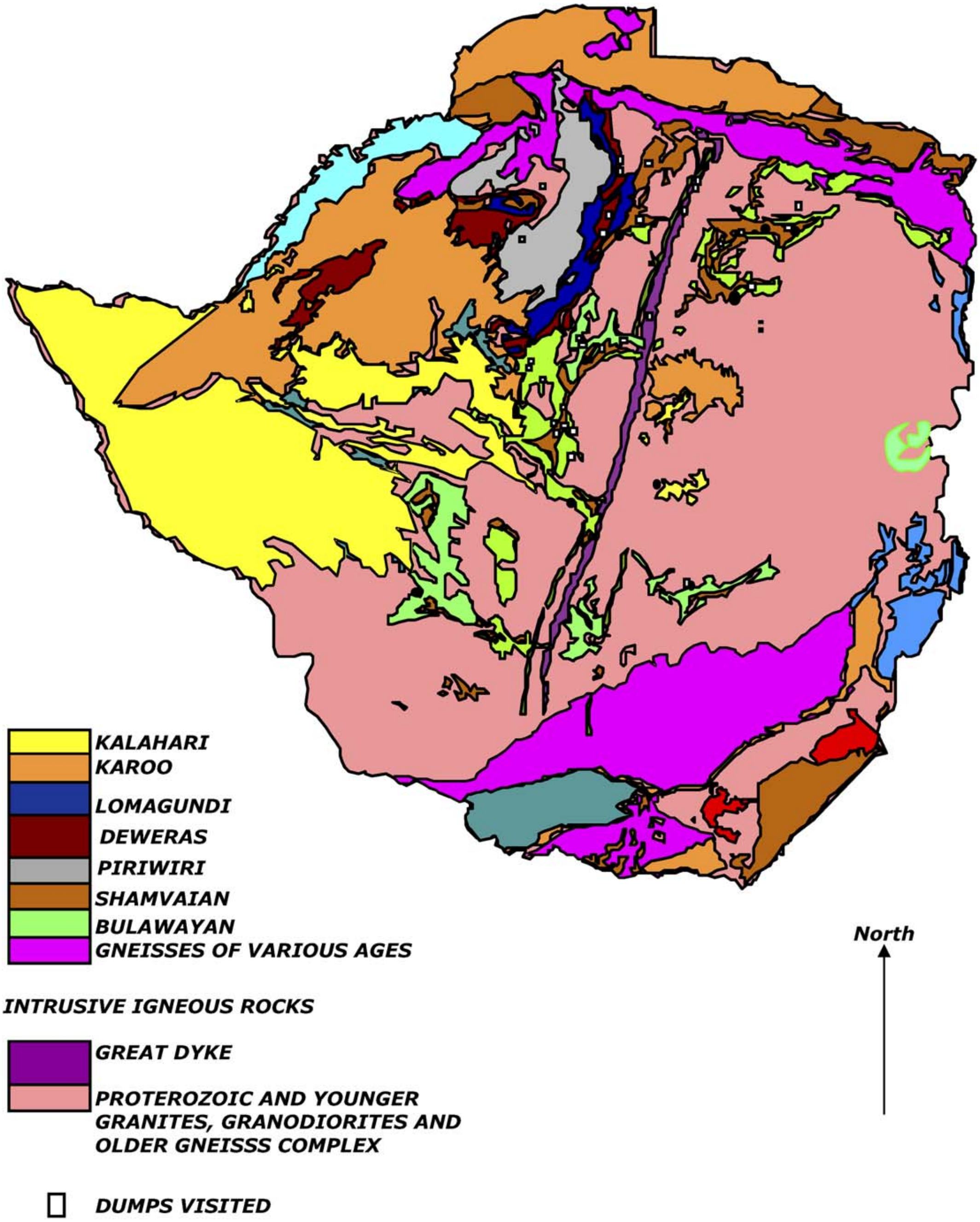

Fig. 1. Geological map of Zimbabwe, showing the location of the mine dumps sampled (show the study area namely Midlands Province!).

conditions. Potential to pollute in this paper is considered as the likelihood of the elements to disperse under the prevailing conditions at the dump. The concentrations of elements, type of elements and the potential dispersion and pollution patterns from each dump were used to estimate the potential to pollute water bodies. The risk associated with the different dump types was then ranked.

3. Results

The results showed that the leachates being released by all dump types were higher than the maximum allowed effluent discharge limits set in Zimbabwe, for at least one parameter per mine type. Table 1 shows these results and from the table it can be seen that levels of nickel, antimony, lead, cadmium and chromium were above discharge limits in all dumps studied. Levels of copper and cobalt were above discharge limits for only some mine types (base metal and minor metal mines for cobalt and minor metal mines for copper). National discharge limits for zinc were not exceeded at any of the sites studied.

Analysis of the stream waters downstream of the mine dumps showed that most metals exceeded WHO guidelines

Table 1
Average metal levels in leachate from different dump types, compared to Zimbabwean effluent disposal limits (MRRWD, 2000)

Dump type/group	Statistic	Metal level							
		Cu	Ni	Zn	Sb	Pb	Cd	Co	Cr
Gold-mine dumps	Average	2.48	*3.12*	0.76	7.68	*0.84*	0.07	*2.08*	*2.83*
	Std dev	5.38	3.89	1.52	9.51	1.33	0.04	2.34	0.76
Minor metals mine dumps	Average	*5.86*	*3.72*	0.12	2.48	*1.83*	0.08	*2.54*	*2.72*
	Std dev	9.70	5.09	0.09	1.49	1.93	0.04	3.85	1.36
Sulphur mine dumps	Average	0.46	1.10	1.69	1.58	*0.66*	0.06	1.23	*3.33*
	Std dev	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Base metals mine dumps	Average	0.03	1.24	0.05	4.62	0.36	0.06	1.08	*2.17*
	Std dev	0.00	1.69	0.02	4.21	0.21	0.00	1.13	0.03
Zimbabwe effluent limits		**5.00**	**1.50**	**15.00**	–	**0.50**	**0.30**	**2.00**	**0.50**

Table 2
Metal levels in streams downstream of different dump types compared to WHO drinking water guidelines (WHO, 2004)

Dump type/group	Statistic	Metal level							
		Cu	Ni	Zn	Sb	Pb	Cd	Co	Cr
Gold	Average	*3.39*	*2.37*	3.70	*3.44*	*1.02*	*0.12*	1.95	*2.48*
	Std dev	0.10	0.26	0.05	0.36	0.25	0.00	0.09	0.20
Minor metals	Average	0.02	*0.10*	0.04	*1.63*	*0.18*	*0.05*	0.21	*2.38*
	Std dev	0.01	0.03	0.00	0.25	0.16	0.00	0.04	0.41
Sulphur	Average	0.06	*0.40*	0.06	*0.85*	*0.25*	*0.05*	0.13	*2.34*
Base metals	Average	0.04	*0.25*	0.05	*1.24*	*0.21*	*0.05*	0.17	*2.36*
	Std dev	0.04	0.52	0.02	0.22	0.08	0.00	0.11	0.18
Platinum group	Average	0.06	*0.82*	0.07	*0.91*	*0.11*	*0.06*	0.26	*2.37*
	Std dev	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromite and asbestos	Average	0.13	*0.16*	0.03	*0.96*	*0.08*	*0.04*	0.06	*2.20*
	Std dev	0.092	0.115	0.018	0.679	0.057	0.029	0.043	1.553
WHO guidelines		**2**	**0.02**		**0.02**	**0.01**	**0.003**		**0.05**

(WHO, 2004) for drinking water in most samples (Table 2). Except for copper, the levels of metals in streams at all the different dump types were found to be higher than the WHO guidelines for drinking water. Yet many rural communities in Zimbabwe use stream water for drinking purposes.

The results also show that for 90% of the dumps, concentrations of elements are higher downstream of the mines than upstream. This is depicted in Fig. 2. Cobalt from chromite and asbestos dumps, and zinc from minor metals dumps are lower downstream than upstream (Fig. 2). Thus most mine dumps are sources of contamination of streams, which could be a source of conflicts between mine and farmers.

The stream waters around different dump types have similar signatures in terms of element concentrations, although the leachates from different dump types have varying concentrations for all elements. Levels of most of the potentially toxic elements were high in leachates, except for cobalt and nickel which were conspicuously low in both the leachate and stream waters. This is despite the fact that analyses of the dumps showed higher levels (Mabvira-Meck et al., 2004). This may be because the two elements do not readily form aqueous phases, which are dominant in waters and leachate solutions.

Seventy nine percent of the waters sampled in this study both before and after the dumps had a neutral pH, yet the pH values of the leachates were either very acidic (mean pH value = 2) or alkaline (mean pH value = 8) (Fig. 3). The alkaline leachates are associated with chromite and asbestos dumps as well as several gold-mine dumps. The acidic leachates are associated with gold, base-metal, minor-element and sulphur dumps.

Though arsenic was not determined in water and leachate, the levels of arsenic in the dumps and soils indicated which mine types are at risk of releasing arsenic in mobile form (Mabvira-Meck et al., 2004).

The study showed that the potentially toxic elements likely to be released by different mine dumps vary from one dump waste type to the other. The elements that might

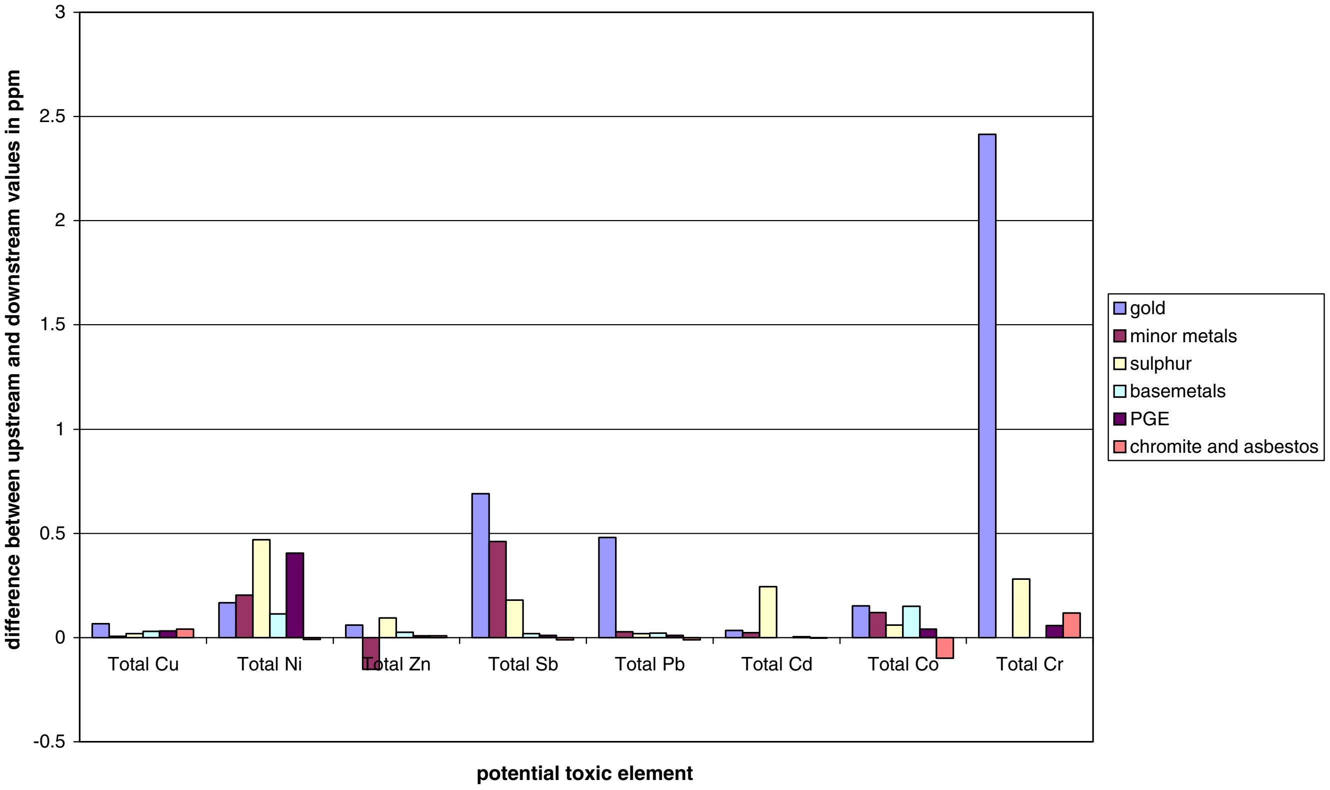

Fig. 2. Difference of metal levels in downstream and upstream waters of different dump types: statistics gold $n = 20$; minor metals $n = 5$; sulphur $n = 4$; base metals $n = 15$; PGE $n = 4$; chromite and asbestos $n = 3$.

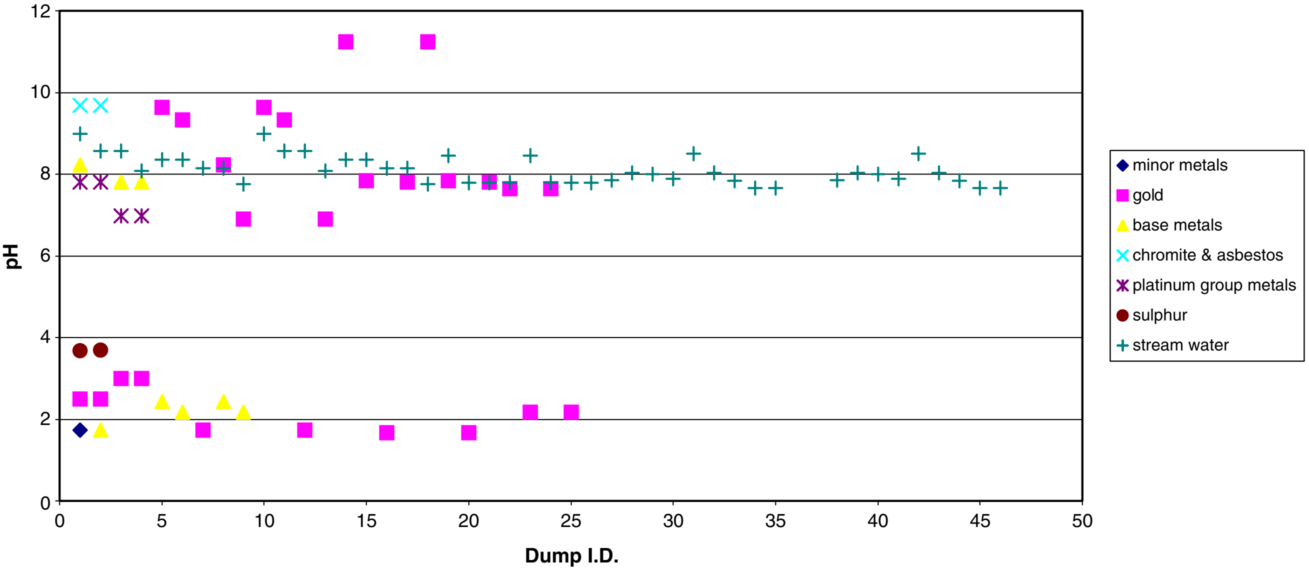

Fig. 3. pH of leachate from different dump types: statistics gold $n = 19$; minor metals $n = 3$; sulphur $n = 3$; base metals $n = 8$; PGE $n = 3$; chromite and asbestos $n = 1$.

be a risk to water quality is summarised in Table 3 for the different dump types. As such the different dumps have different potentials for polluting water bodies.

From the study it emerged that the order of dumps in terms of dumps with worst to least risks is minor metals dumps, base metal dumps, gold-mine dumps, platinum

Table 3
Zimbabwean mine dumps and major metals likely to pose geochemical risks

Mine dump type	Risks to water quality
Minor metals	Arsenic, nickel, zinc, copper, acidity
Gold	Arsenic, zinc, copper, nickel, acidity
Base metals	Copper, zinc, nickel, cobalt, arsenic, acidity
Chromite and asbestos	No major risks
Platinum Group metals	Copper, nickel, cobalt, zinc, arsenic
Sulphur and arsenic	Arsenic, acidity

group metals mine dumps, chromite and asbestos mine dumps and finally sulphur mine dumps.

4. Discussion

The concentrations of metals in the leachates reflect the amount of dissolved material being carried by water from the dump into water bodies. Concentrations in the leachates also showed that the six different types of dumps contribute differently to the pollution of soils and waters, since the leachate values were different from dump to dump. Levels of transition metals are problematic in leachates from all dump types and the receiving streams, as can be observed by a slight increase in concentrations of elements downstream of most dump types.

The low pH values of the leachates are due to acid mine drainage (AMD) from the oxidation of sulphides in the dumps. This is a continuous reaction as long as there is water in the dumps, which, this study has shown, is the case during both wet and dry seasons. The existence of sulphate on most dumps encountered in this study is an indication that acid mine drainage is continuing. The possibilities of accelerated AMD due to the presence Fe (III) sulphate is also anticipated, since all dumps visited contained appropriate levels of this species of iron. The pH data for streams suggest that contamination in most rivers near dumps is localised. This is supported by secondary signs seen in the field: withering vegetation, yellow, amber, bright orange and red-coloured water and stained rocks along the banks of rivers near dumps. However in all the streams studied pH levels soon rise again downstream.

The range of pH values in stream waters encountered in this study suggests that river waters generally dilute mine waters within 1 km of the dumps. Despite this the metal concentrations are slightly elevated. Though there is a possibility that water, gravity and wind can disperse the pollutants from the dumps, water is the major dispersing agent of pollutants as it can physically carry particles as well as dissolving most elements efficiently. In so doing the water gets polluted.

Acidity was not a problem in asbestos and chromite mine dumps and platinum group elements mines but it was with the other four dump types. Effluents from some of the gold-mines were alkaline which can be explained in terms of neutralisation due to lime addition which is one of the methods used as part of the rehabilitation efforts being undertaken by mine operators.

5. Conclusions

The different mine dump types have varying geochemistries. All the six dump types studied are possible sources of pollution to water bodies. The potentially toxic elements likely to be released by different mine dumps types are similar but different dumps have different potentials for polluting water bodies.

From this study it can be concluded that management of mine dumps is a real necessity if water quality around mine dumps is to be protected from further deterioration in Zimbabwe. There are a wide variety of technologies available that can mitigate releases from active mine dumps. These include constructed wetlands (Lupankwa et al., 2004), grouting (Ravengai et al., 2004b), anoxic limestone drains, bactericides, run-off diversion, and the introduction of sulphate-reducing bacteria. Many mining companies are introducing several of these technologies. Zimbabwe however faces another challenge in that many mines and mining areas, such as the Beatrice Gold Belt, are now abandoned, but are still releasing contaminants into the local environment (Ravengai et al., 2005b). These abandoned mines and dumps require attention, possibly from central government. The dumps need to be rehabilitated with engineered covers, and revegetated, either with fast-growing exotic timber trees such as *Eucalyptus* or metal-tolerant indigenous trees such as *Acacia* (Mabvira, 2003).

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