THE USE OF INDIGENOUS GRASS SPECIES AS PART OF REHABILITATION OF MINE TAILINGS: A CASE STUDY OF NEW UNION GOLD MINE

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ABSTRACT

Mining has enormous global impacts on both the environment and human health and most of these impacts are due from mine tailings. Using local indigenous grass species for *in situ* mine dump rehabilitation is both environmentally friendly and cheaper. It is attractive to use local plants since these are adaptable to local climatic conditions and are able to strive under adverse conditions that are prevalent at mine tailings sites. In this study, mine tailings at New Union Gold Mine, Limpopo, South Africa, five grass species were analysed for their uptake of heavy metals. The total metal mean concentrations were high (329.5 mg/kg for *Cynodon dactylon*, 318.0 mg/kg *Cyperus esculentus;* 307.0 mg/kg *Hyparrhenia tamba*; 294.5 mg/kg *Hyparrhenia hirta* and 290.7 mg/kg *Paspalum dilatum*). *C. dactylon* was widespread and absorbed more of the following mean metal concentrations: 232.5 mg/kg for Mn; 39.8 mg/kg for Zn; 48.5 mg/kg for Cu; 5.7 mg/kg for Pb; 1.0 mg/kg for Cd and 1.9 mg/kg for Co. *P. dilatum* absorbed the least of the heavy metals (290.7 mg/kg). The tailings were highly acidic with a pH range of 3.28-3.64 and 3.78-4.84. *C. dactylon* species absorbed these heavy metals and was able to grow under the acidic conditions. Thus *C. dactylon* was found suitable for re-vegetation of mine tailings and was able to hold together the soil and stabilized the tailings against wind and water erosion.

Key words: Environmental remediation, acidity, re-vegetation, *Cynodon dactylon*, mine tailings rehabilitation

1. INTRODUCTION

Mine tailings sites are a source of environmental problems throughout the world and are on the increase (Bell et al., 2001; Ogola et al., 2002; Naicker et al., 2003; Mendez et al., 2007; Schuwirth et al., 2007). The mine tailings dams arise mostly from waste products from ore processing. Thus mine tailings are acidic (source of acid mine drainage) and rich in heavy metals such as Cu, Mn, Zn, Cd, Ni, Fe, As and Hg. Most development projects, including mine projects were undertaken with foreign and domestic capital without impact assessment studies (Appiah-Opoku, 2001). Startlingly most of these environmental problems are associated with defunct mines since no environmental impact assessments were not done as part of environmental management plan (EMP). The EIA process was introduced in introduced in 1969 in United States of America (Sandham et al., 2006) and in Ghana in 1995 (Appiah-Opoku, 2001). In South Africa, EIA was practiced on a non-mandatory (voluntary) basis as an input to decision-making from the mid-1970s and but this was legal formalized in 1997 with enactment of the first set of EIA regulations was published in the *Government Gazette,* of which activities that impact on the environment were regulated in terms of section 21 of Environmental Conservation Act (Act no. 73 of 1989) (du Pisani and Sandham, 2006).

Naicker et al. (2003) reported the results of an investigation into contamination of surface and ground waters by gold mine tailings from the centre of Johannesburg. Typical results of the water quality of the groundwater (line 2) indicated that it was acidic (pH range 3.46 to 3.78) and this was attributed to oxidation of pyrite (FeS_2) within the mine tailings. Some of the heavy metals that were present in groundwater and their concentration levels were: Cr (2.15 to 14.38 mg/l); Zn (2.85 to 21.24 mg/l); Cd (0.02 to 2.05 mg/l); Fe (14.85 to 379.00 mg/l); Pb (0.30 to 1.03 mg/l); Mn (6.78 to 168.91 mg/l); As (3.25 to 13.78 µg/l); Hg (0.19 to 18.00 µg/l). The top soil profile (20 cm) was also acidic and contaminated with heavy metals due to capillary rise of groundwater. The polluted groundwater discharged to nearby streams in the environs and contributed to 20% of stream flow and thus contaminating the surface water with heavy metals and acidity.

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In a study of a pyrite mine in Spain, Moreno-Jiménez et al. (2009) observed that Mn had the highest concentration followed by Zn, Cu and Cd with lowest concentration. The concentration of Cd has been reputed to be harmful to the environment even in low concentration because they have no biological function to plants and animals (Ogola, 2002; Moreno-Jiménez et al., 2009). Of particular concern is the high levels of Mn in the tailings and other studies have linked Mn toxicity to Parkinson-like symptoms in humans (Gerber et al., 2002; Erikson and Aschner, 2003; Li et al., 2007), infertility in mammals and malfunction of the immune system (Li et al., 2007).

In the study of Mendez et al. (2007) they demonstrated the suitability of indigenous qualibush [*Atriplex lentiformis* (Torr.) S. Wats], a perennial halophytic subshrub, in colonizing lead-zinc mine tailings. The halophytic subshrub improved the pH of mine tailings due to compost formation. Also the subshrub shoot-accumulated some metals such as Mn (400 to 1000mg/kg), Pb (30 to 100 mg/kg) and Zn (100 to 1000 mg/kg). Though qualibush was effective in heavy metal removal, the concern that may arise is the hazard the shoot may pose to foraging wildlife.

For example mining occurred at New Union Gold Mine until from 1934 to 1995 when the mine stopped due to depleted gold bearing ores (Ward and Wilson; 1998). During the processing of gold, mercury and cyanide were used and the mine wastes were dumped in tailing dams (Naicker et al., 2003). These tailing rich in heavy metals including mercury and cyanide pose a danger to local ecosystems and human health due to the dispersal of dust and sediments by water erosion and dust storms. During the rainy season there is water erosion of the mine tailings which are washed off and get deposited in the nearby Mandzoro River and finally get into Shingwedzi River which flows towards the world renowned Kruger National Park (Nkuna, 2007). Other studies have documented the spread of heavy metals to crops and vegetables brought about by the dust storms (Meza-Figura et al., 2009). Conesa et al. (2009) reported high levels of metal concentrations in soils and lettuce in an agricultural area that was situated close to La Union mine in Spain. The presence of toxic metals in the soils was attributed to wind erosion of the less vegetated mine tailings. Also according to Winde et al. (2004), the contamination of the streams by adjacent mine tailings dams poses a risk for the health of people in the informal settlements where polluted streams, water is consumed without appropriate treatment. Thus it is important use indigenous grasses in an effort to rehabilitate the tailings dam in order to mitigate against water and wind erosion.

Thus it is important to rehabilitate the mine tailings by establishing a permanent vegetative cover to contain toxic metals by accumulation in root tissue, leaves and stem (Mendez et al., 2007). The main aim of the study was to assess which indigenous grass species are suitable for use as part of a rehabilitation plan for the mine tailings dams at New Union Gold Mine. The use of indigenous grasses has advantages such the demonstrated tolerance of local adverse environmental conditions and thus minimum interventions for natural ecological succession. The specific objectives were: to determine the heavy metal composition of mine tailings; to determine the pH of the mine tailings; to identify grass species that were growing at the mine tailings and to determine the heavy metal uptake by these grass species.

2. MATERIALS AND METHODS

Study and Sampling Areas

The New Union Gold Mine tailings dams (A is south-west and B is north-east) are located at longitude 23°01’24”S, latitude 30°43’36”E, are located 90 km south east of Thohoyandou in Ka-Madonsi village at Malamulele, Limpopo province in South Africa. Mine tailings and grass samples were collected from the tailings dams for a period of six months (September 2008 to February 2009). A total of 50 mine tailing samples and 50 grass samples were collected during the study period.

The Analysis of Heavy Metal Content of Mine Tailings and Grass Samples

The collected samples (mine tailings and grass) were sealed in plastic sachets, labeled with date of sampling, sample number that corresponded to a GPS coordinate. The samples were taken to the University of Venda for further physical and chemical analysis.

The samples were subdivided into two (2kg of each) and dried overnight at 110 ºC using a bench mounted Vacutec laboratory oven. 1 kg of samples were then removed from bench mounted oven and allowed to cool. The samples were then milled by the Retsch RS 200 grinding mill machine for 2 minutes to 80 % fine or < 75 µm. Then 5 g of each milled sample was weighed on an AS 220/C/2 balance and transferred to a 250 ml glass beaker and then acid digested in a fume cupboard with 20 ml of nitric acid and 60 ml of HCl on an oven hotplate HPE 30184 for at least 30 minutes. The final volume of 10ml was then transferred to a 100 ml volumetric flask and filled to the mark with deionized water. The flask was shaken to ensure homogenous mixing.

These were stored in the refrigerator at 0°C before analysis. All mine tailings and grass samples were analysed by Varian Spectra AA 110 Flame Atomic Absorption Spectrometer (220/880 series) with deuterium background corrector was used to determine the total concentration of Mn, Pb, Zn, Cu, Co and Cd. A fuel lean air-acetylene flame was used for all heavy metal analysis. 1000ppm standard solutions (Mn, Pb, Zn, Cu, Co and Cd) were prepared according to procedures of Standard Methods for the Examination of Water and Wastewater (APHA, 2006). Dilute working solutions were prepared daily. All chemical analyses were conducted in replicates.

The Determination of PH of Tailings Samples

A pH meter (Eutech Instruments, Singapore) was used to determine the pH of samples. These samples were weighed (50g) with a BP 1200 balance and then transferred to a 250ml glass beaker and 50ml of distilled water was added. The contents were stirred for 5 seconds with a glass stirring rod and allowed to stand for 30 minutes.

Data Analysis

The recorder output of the Varian Spectra AA 110 Flame Atomic Absorption Spectrometer (220/880 series) gave the heavy metal concentration of Mn, Zn, Cu, Pb, Cd and Co in ppm. The results were then expressed as mg/kg with Microsoft Excel 2003 spreadsheet and the preparation of graphs. Data with replicates were presented as mean± standard deviation (SD). The procedure by Li et al. (2007) and Moreno-Jiménez et al. (2009) for the bioaccumulation coefficient of the grass species was followed.

3. RESULTS AND DISCUSSION

PH and Heavy Metal Distribution of Tailings at New Union Gold Mine

The pH of the tailings soils at New Union Gold Mine were acidic (Table 1). With the tailing dam A the pH range was 3.28 to 3.64 and the pH range at tailing dam B was 3.78 to 4.84. These pH values are probable due to high levels of pyrite and sulphide minerals which undergo chemical process (oxidation) when they are exposed to oxygen and water which result in acid mine drainage (Naicker et al., 2003; Petrik et al., 2007). These findings are in agreement with typical pH values that range from 2 to 4.4 that are prevalent in acid mine drainage areas that are dominated by coal and gold mine and old underground workings (Naicker et al., 2003).

The following heavy metals Mn, Zn, Cu, Pb, Cd and Co and their levels were determined at the tailings dams of New Union Gold Mine (Table 1). The concentration of Mn was the highest followed by Cu and the Zn. The concentrations of Pb, Cd and Co were the lowest in all cases, below 5 mg/kg. The concentration of Cd remained stable with a concentration of 1 mg/kg. The toxic heavy metals may be transported to mammals including humans through a variety of routes. The transportation routes are varied and maybe via contamination groundwater, contamination of surface water following a rainfall event or a dust event blowing in the direction of human settlements or mammals consuming grasses and plants that colonize the tailings dams.

Table 1: pH and Metal concentrations in tailings soils at New Union Gold Mine

	Tailings dam A					Tailings Dam B				
	Mean	(SD)	Median	Min	Max	Mean	(SD)	Median	Min	Max
pH	3.47	0.11	3.51	3.28	3.64	4.19	0.47	3.88	3.78	4.84
Total metal concentration (mg/kg)										
Mn	123.0	29.9	125.0	72.0	202.0	118.1	34.1	120.0	77.0	216.0
Zn	21.3	6.3	22.0	12.0	33.0	25.3	7.2	24.0	15.0	36.0
Cu	26.5	6.4	27.0	15.0	38.0	29.4	7.3	29.0	16.0	41.0
Pb	4.8	1.0	5.0	3.0	7.0	4.1	0.8	4.0	2.0	5.0
Cd	1.0	0.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0
Co	1.8	0.7	2.0	1.0	3.0	1.7	0.6	2.0	1.0	3.0
	Mean, (Standard deviation), n = 105					Mean, (Standard deviation), n = 45				

The Heavy Metal Uptake by Grass Species at New Union Gold Mine

There were five types of grass species that were observed growing among the mine tailings at New Union Gold Mine and were identified as follows (Russell et al.,1991): *Paspalum dilatatum* (common paspalum), *Hyparrhenia tamba* (blue thatching grass), *Hyparrhenia hirta* (common thatching grass), *Cynodon dactylon* (Bermuda grass) and *Cyperus esculentus* (yellow nutsedge) (Figure 1).

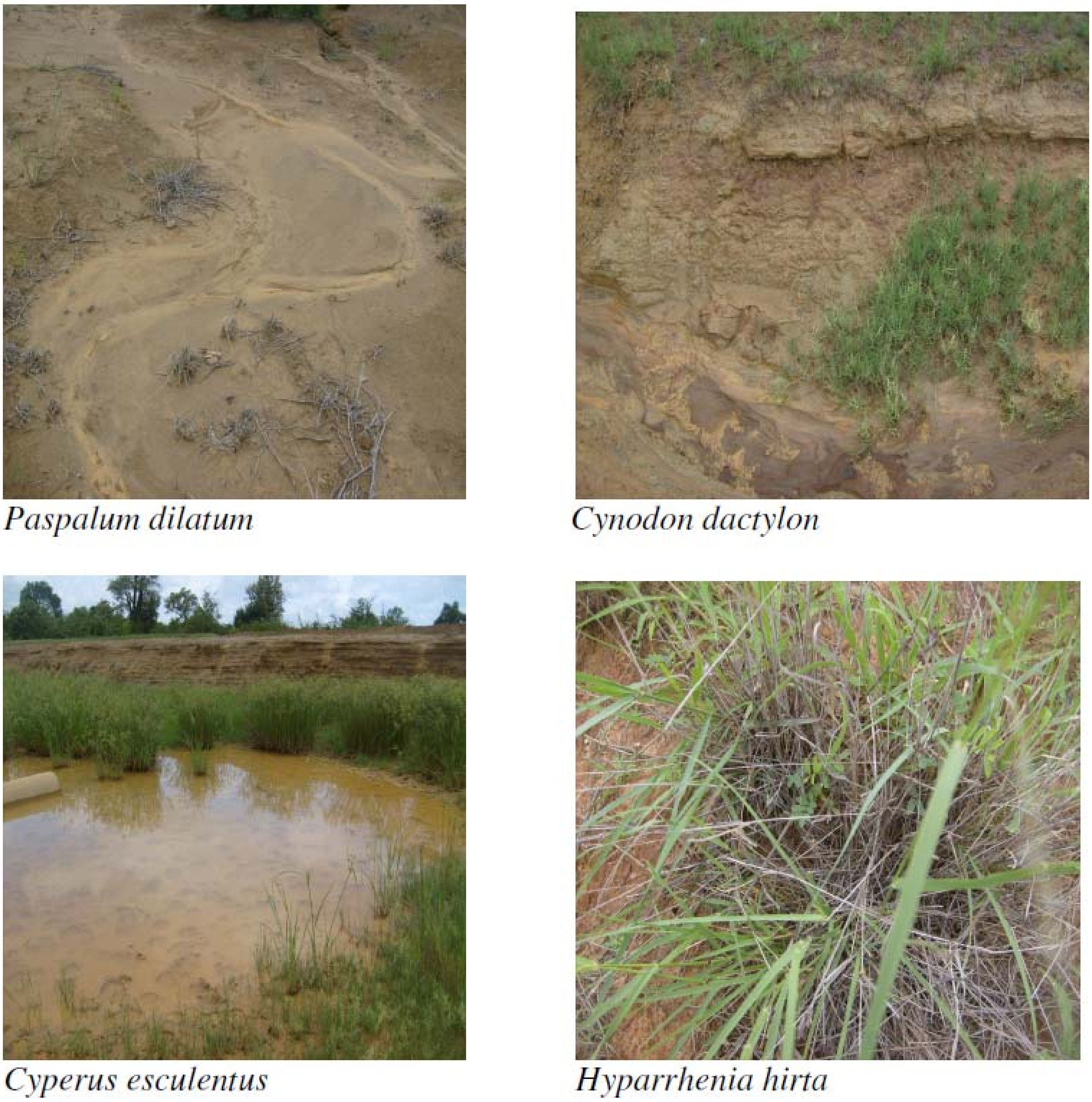

Figure 1. Some of the grass species that were found growing at New Union Gold Mine

The total heavy metal uptake of different grass species are indicated in Table 3. The results showed the grass species *Cynodon dactylon* accumulated the most of heavy metals and was widely distributed at the both tailings dams. *C. dactylon* absorbed more of the following heavy metals (mean total from tailings A & B): 232.5 mg/kg for Mn; 39.8 mg/kg for Zn; 48.5mg/kg for Cu; 5.7mg/kg for Pb; 1.0mg/kg for Cd and 1.9mg/kg for Co. The *Cyperus esculentus* was ranked second in the heavy metal accumulation and its distribution was restricted to tailings dam A. The third position was the *Hyparrhenia* species of which *H. tamba* colonised tailings dam A and *H. hirta* colonised tailings dam B. On heavy metal accumulation the results showed that *H. tamba* species was accumulated more than the *H. hirta* species and the reasons for this distribution and different metal uptake are unknown at this stage. The *Paspalum dilatum* species accumulated the least heavy metals (mean total of 290.7 mg/kg) in comparison to other grass species. This may be attributed to factors such heavy metal toxicity since other grass species were able to grow under the adverse pH conditions of 3.41 to 3.58.

Table 3. Heavy metal uptake by different grass species from mine tailings

		Tailings dam A							Tailings Dam B				
Species	**Metal**	**Mean**	**(SD)**	**Median**	**Min**	**Max**	**Species**	**Metal**	**Mean**	**(SD)**	**Median**	**Min**	**Max**
Cynodon dactylon	**Mn**	227.3	96.9	239.0	111.0	334.0	*Cynodon dactylon*	**Mn**	237.6	61.8	237.5	147.0	333.0
	Zn	31.7	5.8	30.5	26.0	40		**Zn**	48.0	11.8	48.0	28.0	70.0
	Cu	50.0	12.1	46.5	37.0	67		**Cu**	47.0	9.9	46.5	33.0	63.0
	Pb	6.8	1.2	7.0	5.0	8.0		**Pb**	4.6	1.7	5.0	2.0	7.0
	Cd	1.0	0.0	1.0	1.0	1.0		**Cd**	1.0	0.0	1.0	1.0	1.0
	Co	2.0	1.1	2.0	1.0	4.0		**Co**	1.8	0.7	2.0	1.0	3.0
	Total	318.8						**Total**	340.1				
Hyparrhenia tamba	**Mn**	219.2	55.2	206.5	147.0	304.0	*Hyparrhenia hirta*	**Mn**	164.0	51.2	145.0	122.0	240.0
	Zn	41.2	4.9	41.0	35.0	48.0		**Zn**	56.2	15.2	56.0	34.0	75.0
	Cu	38.8	10.1	37.5	28.0	54.0		**Cu**	66.3	10.9	65.5	50.0	81.0
	Pb	4.8	1.2	5.0	3.0	6.0		**Pb**	5.2	1.7	5.5	2.0	7.0
	Cd	1.0	0.0	1.0	1.0	1.0		**Cd**	1.0	0.0	1.0	1.0	1.0
	Co	2.0	1.1	2.0	1.0	4.0		**Co**	1.8	1.2	1.5	1.0	4.0
	Total	307.0						**Total**	294.5				
Paspalum dilatatum	**Mn**	207.7	22.8	208.5	170.0	254.0							
	Zn	35.6	7.9	36.0	17.0	47.0							
	Cu	40.3	8.1	38.0	31.0	61.0							
	Pb	4.2	1.0	4.0	3.0	6.0							
	Cd	1.0	0.0	1.0	1.0	1.0							
	Co	1.8	0.9	2.0	1.0	5.0							
	Total	290.7											
Cyperus esculentus	**Mn**	223.8	34.7	206.0	192.0	302.0							
	Zn	38.7	12.6	34.0	23.0	64.0							
	Cu	46.7	8.8	47.5	35.0	65.0							
	Pb	6.1	2.0	6.0	4.0	11.0							
	Cd	1.0	0.0	1.0	1.0	1.0							
	Co	1.75	0.6	2.0	1.0	3.0							
	Total	318.0											
		Mean (Standard deviation), n = 105							Mean (Standard deviation), n = 45				

The research findings are in disagreement with Conesa et al. (2007) on the Cu accumulating ability of *Hyparrhenia* species. The research findings indicate that *Hyparrhenia hirta* can accumulate up to 10 times of the metal Cu but this depends on tailings pH of 3.78 to 4.84. In the studies of Conesa et al. (2007) the pH range was from strong acid to slightly alkaline (pH 4.6 to 7.6). Thus the bioavailability of Cu might be linked to solubility of Cu which is highly dependent the organic content of the soil (easily forms complexes) and to lesser extent the pH (Reichman, 2002). The *C. dactylon* species absorbed these heavy metals and was able to grow under the acidic conditions. Thus *C. dactylon* was found suitable for re-vegetation of mine tailings and was able to hold together the soil and stabilized the tailings against wind and water erosion. The highest concentration of heavy metals at the tailings dams was the concentration of Mn, the concentration of Mn was followed with the high concentration of Cu, and Zn, and was also followed by the low concentration of Pb and Co, and the lowest was the concentration of Cd which remains stable in all the samples with the concentration of 0.001 mg/g.

Other researchers have determined that the bioaccumulation coefficient is a better tool to determine the phytoaccumulation potential of plants and grasses (Li et al., 2007; Moreno-Jiménez et al., 2009). This evaluates what aspects of the plant structure are likely to bioaccumulate the metals and has important implications for phytoremediation and health implications to other mammals including humans.

Phytoaccumulation of Heavy Metals and Implications for Phytoremediation and Environmental Transfer

There were wide variations of heavy metal phytoaccumulation among the five grass species. Of the five grass species, all had BAC above 0.5 with *Cynodon dactylon* and *Hyparrhenia hirta* species leading in the 2.0 BAC categories for the accumulation of Mn, Zn and Cu (Figure 2). *Hyparrhenia hirta* is a great hyperaccumulator for Cu and Zn. This is important in the selection of grasses species in order to target toxic metals such as Mn which have severe health hazards to mammals and humans (Li et al., 2007). This aspect of phytoremediation includes the removal of metals through hyperaccumulation and stabilization of tailings soils and binding such that soil erosion is minimized.

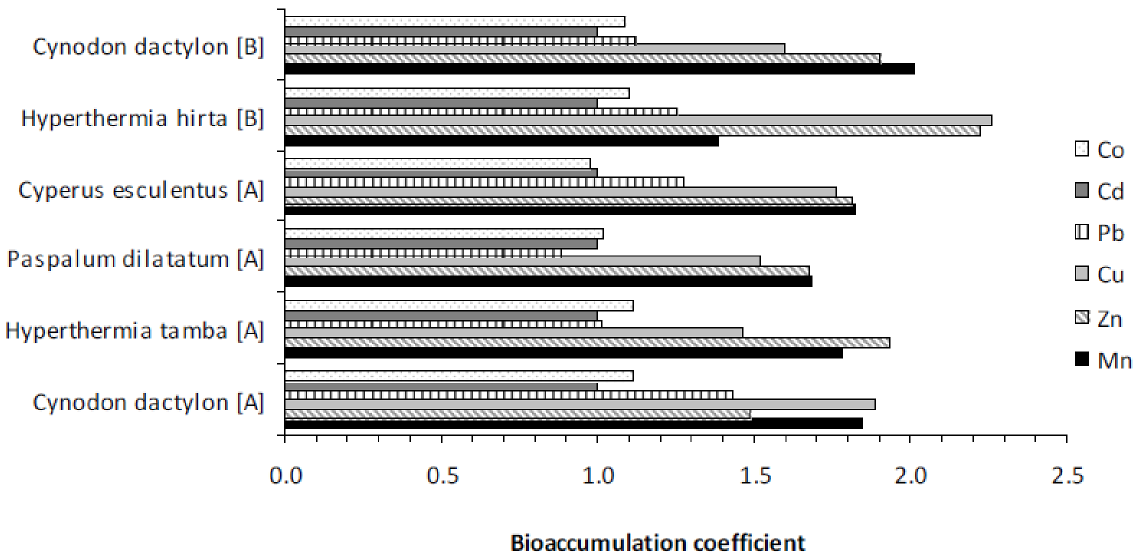

Figure 2. The bioaccumulation coefficient (BAC = [metal]leave/[metal]tailings) for heavy metals for different grass species growing at tailings dam [A] or [B] at New Union Gold Mine.

According to Li et al. (2007) hyperaccumulators must have the Biological accumulating coefficient (BAC) and Biological transfer coefficient (BTC) that is greater than 1. It appears that the some of the grass species qualify for this definition to be classified hyperaccumulators such as *Cynodon dactylon* for all the heavy metals (Co, Cd, Pb, Cu, Zn and Mn); *Hyparrhenia hirta* qualifies for all the heavy metals; *Cyperus esculentus* for all the metals; *Hyparrhenia tamba* qualifies for all the metals and *Paspalum dilatatum* qualifies for the removal of Co, Cd, Cu, Zn and Mn. The studies of Li et al. (2007) and the research findings it appears that different plants (*Phytolacca acinosa*, Li's study) and grasses (*Cynodon dactylon,* this study) have a greater affinity for the phytoaccumulation of Mn metals in tailings originated from different mine wastelands. Thus Mn is a potential hazard to mammals and humans and must be therefore be removed from the environment.

The grasses at New Union Gold Mine are grazed upon by domestic animals such as goats, cattle and wild animals such as rabbits and wild dogs that prey on the rabbits as indicated by visual observation of animal droppings at the tailings dams (Mothetha, 2009). This may be the transportation route in which the heavy metals are transferred from the tailings to mammals and humans.

The grass with the highest concentration of heavy metals was the *Cynodon dactylon*, and it was growing very well. Visual observation indicated that the *Paspalum dilatum, Hyparrhenia tamba* and *Hyparrhenia hirta* absorbed the heavy metals from the soil but it grew only when there was no heavy rainfall. The *Cyperus esculentus* absorbed the heavy metals during the wet season. The research findings indicate that tropical species such as *Cynodon dactylon* and *Cyperus esculentus* are strong candidates for use in post mine rehabilitation. The visual observation showed that the *Cynodon dactylon* grass grew in dry season and wet season but also grew in times of heavy rainfall when the toxic tailings were eroded and deposited on the grass. It was also growing very well on low pH at the tailings dams. Thus *Cynodon dactylon* grass may be suitable for rehabilitation of the tailings dams because it can survive in the harsh condition of the tailings dams at New Union Gold Mine.

4. CONCLUSION

- The study showed that the tailings dams [A; B] and grass contained the heavy metals mean concentration, mg/kg, (Mn [123.0; 118.1], Zn [21.3; 25.3], Cu [26.5; 29.4], Pb [4.8; 4.1], Cd [1.0; 1.0] and Co [1.8; 1.7]) with an adverse pH range of 3.28 – 4.84 that may impose health hazard to the community and the environment.
- Five grass species were observed growing at the tailings and were identified as *Paspalum dilatatum, Hyparrhenia tamba, Hyparrhenia hirta, Cyperus esculentus* and *Cynodon dactylon* and all have the potential of being classified as hyperaccumulators.
- Thus the *Cynodon dactylon* grass was suitable for rehabilitation of the tailings dams. The reason for choosing the *Cynodon dactylon* grass was because it could cover the soil very quickly (rhizome characteristics) and can also hold the soil together so that the erosion and dust problem are solved. The C*ynodon dactylon* grass grows at the harsh conditions of New Union Gold Mine.
- During the times of heavy rainfall the soil erosion occurred at the tailings dams, the eroded materials maybe transported and deposited to a nearby stream. The winds may also transport the dust containing the heavy metals to the wider environment.

5. ACKNOWLEDGEMENT

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