An Interdisciplinary Response to Mine Water Challenges - Sui, Sun & Wang (eds)
©2014 China University of Mining and Technology Press, Xuzhou, ISBN 978-7-5646-2437-8

Environmental Risk Assessment and Risk Management Strategies for Abandoned New Union Gold Mine in Malamulele, Limpopo, South Africa

Ndivhudzannyi Rembuluwani[1], Francis Amponsah Dacosta[1], Jabulani Ray Gumbo[2]
1Department of Mining and Environmental Geology, 2Department of Hydrology and Water Resources; University of Venda, P/Bag x5050, Thohoyandou, 0950, South Africa
E-Mail: Ndivhudzannyi.rembuluwani@univen.ac.za

Abstract Abandoned mines and mine tailings pose a hazard to communities that live around these sites. Here we report on the environmental risk assessment and risk management strategies of an abandoned New Union Gold Mine that is located in Ka-Madonsi village, Malamulele district, South Africa. The visual assessment was done through visits to the mine sites and the levels of heavy metals in the mine tailings soil and stream sediments was analysed with atomic absorption spectrometry. The hazards were then rated based on the probability of reoccurrence and the severity of the impact. The risk management strategies were suggested based on the severity and the probability of the impacts and the geographical setting of the area. The heavy metals: Cu, Co, Cd, As, Zn, Ni and Mn were found in the mine tailings soil and in the stream sediments. The mine tailings soils and stream sediments were acidic, within pH ranges of 3.93 to 4.45 and 4.18 to 6.28 respectfully. The acidic soils can pose as a problem to the growth of plants and grass should they be used for revegetation of the mine tailings.Environmental impacts identified at the mine site were: soil erosion, sedimentation, land subsidence deep open voids and land scarification. Thus for each of the environmental impact that was identified, risk management strategies were then proposed. The re-vegetation of the exposed mine tailings was found to be the most practical way of solving the problem of soil erosion and sedimentation. Presence of plants and grass on the mine tailings may reduce the rate of soil erosion caused by either water and/ or wind. The deep openings need to be safeguarded and backfilled. The drainage lines and storm water infrastructures need to be established to channel water in order to prevent storm water from transporting sediment to the stream.
Keywords risk management, environmental impacts, abandoned mine, post mining impacts, risk assessment

Introduction

Mining is the breaking up and extraction of minerals of economic importance from the earth's crust for humans' benefit. It also involves operations such as transportation of ore as well as downstream beneficiation processing of minerals and disposal of waste. The waste disposal through dumping on mine tailings creates serious environmental and health problems to communities that live close to the abandoned mines and mine tailings (Miller, 1992). These mine tailings are rich in heavy metals and potential source for acid mine drainage (Brnich and Mallett, 2003). The degree of impact depends on the scale of mining, mining methods and chemicals used to recover the valuable minerals (Ogola, 1995).The New Union Gold Mine was abandoned in the 1990s when the gold ore was exhausted (Steenkamp and Clark-Mostert, 2012). The New Union Gold Mine is situated in the northern part of the Giyani Greenstone Belt where gold mineralization occurs within intensely folded and sheared banded iron-formation (BIF), which forms part of the Giyani Formation of the Sutherland Group. These rocks are considered to be similar to those found in the lower part of the Onverwacht Group in the Barberton Mountain Land (Potgieter and De Villiers, 1986). The exposed mine tailings contribute to erosion and sedimentation due to absence of vegetation cover (Wright et al. 2004). The main objective of the study was to identify and assess post mining environmental impacts and to develop environmental management strategies to address these impacts.

Materials and methods

Sampling and sample analysis

The field visits where conducted in order to carry out environmental characterization and risk assessment. The mine tailings' soil and stream sediments samples were collected at random in the study area (Figure 1). The procedure of Nelushi et al. (2013) was followed in sample treatment and sample analysis and the heavy metals Mn, Zn, Cu, Cd, As and Co were analysed with Varian Atomic absorption spectrometer. Sample sites S5 and S6 are stream sediments.

Fig. 1 *The sampling points at the abandoned New Union Gold Mine site*

Risk assessment and evaluation of risks

The risk assessment process consisted of five steps which are delimitation of the study area, identification of all possible hazards, risk evaluation, hazard rating and suggested risk management strategies. The procedures of DeVaul (1992) and Hau (1993) were followed in risk assessment and evaluation. These hazards that would lead to situations with the greatest probability for occurring and the greatest severity to the operation were being considered as high-risk hazards. The high risk hazards will be given first priority when coming up with the risk management strategies. The medium then low risks will take the least priority.

Data analysis

The heavy metal content was calculated as follows: (concentration × dilution) ÷ weight to give the concentrations in ppm.

Results and discussion

The pH and presence of heavy metals in mine tailings soil and stream sediments

The pH of mine tailings soils and the stream sediments at New Union Gold Mine was found to be acidic and the pH range was 3.93 to 6.28 (fig. 2). The acidic nature of the mine tailings would provide adverse conditions for the growth of plants and grass that may be used for the re-vegetation of the mine tailings. Also the low pH, below 5, would encourage the availability of heavy metals at sample sites S1 to S5. At the sample site S6, the pH was 6.28

and the heavy metals were found to be lower in comparison with other sample sites S1 to S5 (figs. 2 and 3). The heavy metals, Zinc Copper, Cadmium, Nickel, Cobalt, Arsenic and Manganese were found in abundance at the mine tailings soils and in the stream sediments (fig. 3). The highest Zinc (Zn) value of 33 ppm was found in sample site S3 and this was lower than the recommended standard of Canadian Sediment Quality Guidelines of 123 ppm (CCME 2001) and Australian and New Zealand and Environment and Conservation Council guidelines of 200 ppm (ANZECC 2000) and United State Environmental Protection Agency Sediments quality guidelines of 120 ppm (USEPA 2000). Zinc is a micro-nutrient for plants and grasses (Pahlsson 1989). The highest copper (Cu) value of 66 ppm for sample site S3 was higher than the recommended standard of the United State Environmental Protection Agency Sediments quality guidelines of 32 ppm (USEPA 2000). Cu is also a micro-nutrient for plants and grass. However the Cu levels of 60 to 125 ppm are known to be toxic and inhibitory to the growth of plants and grass (Alloway and Ayres 1999). The study of Shu et al. (2002) at Fankou and Lechang lead/zinc mine tailings in Guangdong Province in China showed that Cynodondactylon and Paspalumdistichum grasses were tolerant of high Zn and Cu levels and were able to strive, thus making these potential candidates for mine tailings revegetation. The highest cadmium (Cd) value of 0.5 ppm for sample site S1 was lower than the recommended standard of United State Environmental Protection Agency Sediments quality guidelines of 1 ppm (USEPA 2000). Cadmium is naturally very toxic in trace concentrations (Gordon and Hannan, 1986). The exposure to cadmium can result in toxic acute and chronic effects. The highest Nickel (Ni) value 64 ppm, was higher than the recommended standard of Australian and New Zealand and Environment and Conservation Council guidelines of 21 ppm (ANZECC 2000). Nickel has been known to cause phytotoxicity to plants at elevated concentration of 63.6 ppm and this affected mainly the development of roots (Stellman 1998, Zornoza et al. 1999). However the study of Ye et al. (2002) at Fankou and Lechang lead/zinc mine tailings in Guangdong Province in China showed that the vegetable crop Brassica chinensis and Cynodondactylon grass were tolerant of high Ni levels and were able to strive thus making these potential candidates for mine tailings revegetation.

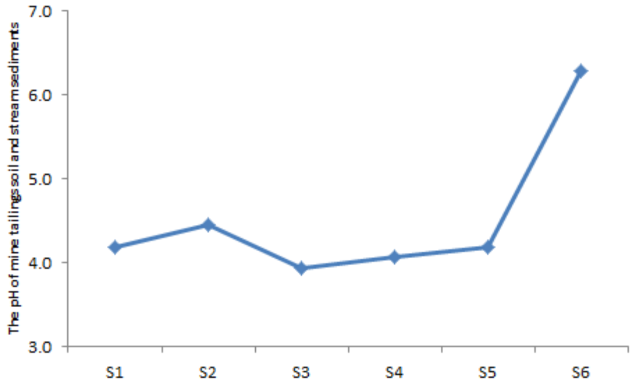

Fig. 2 *The pH of the mine tailings soil and stream sediments*

The highest cobalt value of 10 ppm for sample site S5 was higher than the recommended standard of the United State Environmental Protection Agency Sediments quality guidelines of 3 ppm (USEPA 2000). Trace levels of cobalt are essential for human health development but concentration of 40 ppm or greater are considered toxic (Powel 1980). The highest manganese (Mn) value of 249 ppm for sample site S5 was higher than the recommended standard of Australian, New Zealand and Environment and Conservation Council guidelines of 21 ppm (ANZECC 2000) but lower than the United State Environmental Protection Agency Sediments quality guidelines of 640 ppm (USEPA 2000). Manganese is an essential element for both plants and animals but higher levels it is toxic (Millaleo et al. 2010). The level of Arsenic in the soil samples was found to be ranging between 0.4 to 3.9 ppm. Arsenic is well known to be toxic to plants (Meharg and Hartley - Whitaker 2002).

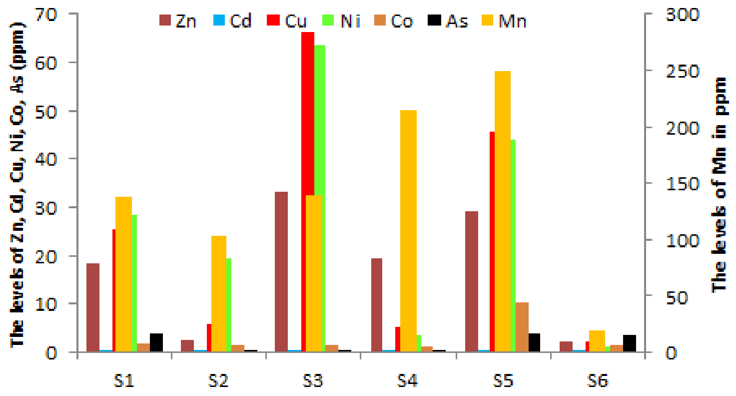

Fig. 3 *The levels of heavy metals in the mine tailings soil and stream sediment*

Risk assessment

The risks that were identified at New Union Mine are soil erosion, sedimentation, subsidence, open unsafe voids and shafts, vacant buildings and land scarification. Sedimentation was identified as one of the major problems due to water and wind erosion. Sedimentation refers to material or sediments that are carried from one area and are then applied up in another area. Sedimentation will also result in the destruction of habitat for aquatic species and thus disrupting the natural ecosystem. It will reduce the level of water in the steams and results in the deterioration of the water quality thereby posing a health risk for the people and animals drinking such water. Soil Erosion at New Union Mine is taking place at a very high rate at both tailings dump. This erosion is being influenced mainly by the slope angles and lack of any vegetation cover (fig. 4). The mobility of the tailings material to the environment is elevated by rainfall and wind actions. The severity of the erosion is high and the probability of the erosion occurring again is also high due to the rainwater and wind actions.

Land subsidence

The land subsidence was clearly visible at the mine site (fig. 5a). This may be caused by the collapse of underground mine tunnels since these are no longer supported internally (Xie and Liang 2010). Land subsidence is associated with the risk of surface structures such as houses cracking or failing into the ground this may result into people getting injured. In this area people reside next to this abandoned mine and chances of their houses subsiding into the ground increases every day when this voids remain opened. Children and animals are also at a greater risk of falling into these holes since the area is not fenced.

Open voids

The open shaft at the mine was not covered or protected to prevent the access by community members (fig. 5b and c). The minimum health hazard associated with these shallow openings at this mine is pollution as a result of the community throwing domestic wastes in the open voids; this waste includes diapers. The open voids can also cause a problem during rainfall season due to flooding. The flooding poses a health hazard and may also infiltrate and contaminate ground water with heavy metals.

Land scarification

The former mining area is littered with abandoned equipment and buildings (Figure 5d). The natural biodiversity is completely lost and both the people and animals can longer enjoy the natural ecosystem.

Fig. 4 *Devastating effects of erosion in the tailings dump*

Fig. 5 *(a) land subsidence; (b)unprotected or unfenced open shaft; (c)An open hole being used as a dump site and (d) derelict equipment littering the former New Union Minesite*

Conclusion

The mine tailings soil and stream sediments were found to be acidic and also contained heavy metals as Cu, Co, Cd, As, Zn, Ni and Mn at elevated levels. Based on the identified problems, risk management strategies were proposed for each impact. Revegetation of the tailings was found to be the most practical way of solving the problem of erosion and sedimentation. It will assist in limiting the rate of erosion thereby slowing down the speed of water and wind actions. Deep openings need to be safeguarded and backfilled. Drainage lines and storm water infrastructures have to be established to channel water in order to prevent storm water from transporting sediment to the stream.

Acknowledgement

The Chief of Madonsi village, community and Triangle cc for giving us permission to have access to the New Union Gold Mine. The University of Venda for financial support used in the study project (I431) and travel costs (IP60) to attend and present at the 12th IMWA congress in Xuzhou, China.

References

Alloway BJ, Ayres DC (1997) Chemical Principles of Environmental Pollution: champ and Hall, London.

Australian and New Zealand and Environment and Conservation Council (ANZECC) (2000) Australian and New Zealand Guidelines for Fresh Water Quality National Water Quality Management Strategy Paper No 4. Australian And New Zealand And Environment And Conservation Council And Agriculture And Resource Management Council Of Australia And New Zealand, Canberra, Australia

Brnich MJJr, Mallett LG (2003) Focus on prevention: conducting a hazard risk assessment. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2003-139

Canadian Council of Ministers of the Environment (CCME) (2001) Canadian Sediment Quality Guidelines for Protection of Aquatic Life: Summary Tables. Canadian Environmental Quality Guidelines, (1999). Canadian Council of Ministers of Environment, Winnipeg, Canada

DeVaul RE (1992) Emergency response plan formulation and implementation. In: Proceedings of the 23rd Annual Institute on Mining Health, Safety and Research. Blacksburg, VA: Virginia Polytechnic Institute and State University, p 67-74

Gordon RM, Hannan JC (1986) Metals from old mine tailings deposit, rehabilitation of surface coal mines in Hunters valley an innovative approaches to mined land reclamation, New South Wales

Hau ML (1993) Coordinating your facility's emergency response. Port Clinton, OH: M. L. Hau and Assoc., Inc., p. 1-17

Wright MA,White S,Baker P, Burton P, Davidson R, Falvey S, Gallegos T, Harden R, Hunt G, Jensen D, Krueger R, Malin L, Rol D, Smith J, Suflita M, Wyatt K (2004) The Practical Guide toReclamation in Utah

Meharg AA, Hartley-Whitaker J (2002) Arsenic uptake and metabolism in arsenic resistant and nonresistant plant species. New Phytologist 154(1): 29-43

Millaleo R, Reyes-Diaz M, Ivanov AG, Mora ML, Alberdi M (2010) Manganese as essential and toxic element for plants: transport, accumulation and resistance Mechanisms.J. Soil Sci. Plant Nutr 10 (4): 470 - 481

Miller GT. (1992) Environmental science sustaining the earth, 4th edition Wadsworth Publishing Company

Nelushi K, Gumbo JR, Dacosta FA (2013) An investigation of the bioaccumulation of chromium and uranium metals by Cynodon dactylon: A case study of abandoned New Union Gold Mine Tailings, Limpopo, South Africa. African Journal of Biotechnology 12: 6517-6525

Ogola., JS (1995) Environmentally Sound and Sustainable Development, A Case Study of Artisan Gold Mining and Processing in the Migori District, Kenya, Proceedings of the Workshop on Environmentally Sound Management and Exploration of Mineral Resources, Entebbe, Uganda, p64-80

Pahlsson Anna-Maj B (1989) Toxicity of heavy metals (Zn, Cu, Cd, Pb) to vascular plants.Water, Air and Soil Pollution 47:287-319

Potgieter GA, De Villiers JPR. (1986) Controls of mineralization at Sutherland Greenstone Belt. South African Journal of Geology 1: 197- 203

Powel JM (1980) Environmental Management in Australia Mineral and Energy Sonet Pty Limited 1304 Malvem Road, Australia

Steenkamp NC, Clark-Mostert V (2012) Inferred historic gold mining approaches, Giyani Greenstone Belt, South Africa. 9th International Mining History Congress 17-20

Stellman JM (1998) Enclopedia of occupational health and safety fourth edition Volume 3. General International Labor Organization
Shu WS, Ye ZH, Lan CY, Zhang ZQ, Wong MH. (2002) Lead, zinc and copper accumulation and tolerances in populations of Paspalum distichum and Cynodon dactylon. Environmental Pollution 120: 445-453
Zornoza P, Robles S, Martin N (1999) Alleviation of nickel toxicity by ammonium supply to sunflower plants. Plant and Soil 208: 221-226
Xie ZW, Liang XY. (2010) Gom-Svm predictor for land subsidence at finished underground mining. Advances in Environmental Geotechnics 49-554
United State Environmental Protection Agency (USEPA) (2000) Sediments quality guidelines values for metals in the environment in Japan: levels Wisconsin Department of natural resources, Washington, D.C.217
Ye ZH, Shu WS, Zhang ZQ, Lan CY, Wong MH. (2002) Evaluation of major constraints to revegetation oflead/zinc mine tailings using bioassay techniques. Chemosphere 47: 1103-1111