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Review

Impacts of mining on water resources in South Africa: A review

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Acid mine drainage is recognized as one of the more serious environmental problems in the mining industry. Acid mine drainage is a major problem on coal and gold mines throughout the world and in South Africa, the main focus of this study, is no exception. Various studies that have been undertaken in South Africa have shown that the water decanting from the mine companies is highly acidic and as such cannot be released into the natural watercourse (streams and rivers). Some form of water treatment and prevention to nullify or neutralise the acid levels of the mine water is necessary. The water quality of the Blesbokspruit, klip and wonderfontein in the test area was below standard due to the presence of acid mine drainage. The aim of this review is to raise awareness of the environmental risk associated with acid mine drainage in our environment.

Key words: Blesbokspruit, acid mine drainage, klip, water quality.

INTRODUCTION

Water supplies continue to dwindle because of resource depletion and pollution, whilst demand is rising fast because of population growth, industrialisation, mechanisation and urbanisation (Falkenmark, 1994). This situation is particularly acute in the more arid regions of the world where water scarcity and associated increases in water pollution, limit social and economic development and are linked closely to the prevalence of poverty, hunger and disease (Falkenmark, 1994)

Over 70% of the water used in both rural and urban areas in South Africa is surface water drawn from rivers, streams, lakes, ponds and springs (DWAF, 2004). Water and soil contamination caused by acid mine drainage (AMD) is a significant environmental problem in some parts of the world, particularly in densely populated developing countries where human habitats are usually in close proximity to mine sites (Lee, 2003). Water draining from coal and base metal mines frequently contains sulfuric acid and heavy metals at high levels which could contaminate streams and agricultural lands, when the mine water or mine water-affected stream water is used for irrigation purposes. Entry of mine-originated contaminants into agricultural soils and streams may also occur during heavy rainfall events that cause over-bank flooding. Elevated concentrations of heavy metals in the soils and streams, accompanied with acidic pH, are likely to enhance uptake of heavy metals by plants and man, which poses a high health risk to the people who consume the contaminated agricultural products (Boularbah et al., 2006). Increasingly, human activities threaten the water sources on which we all depend. Coal mining is one such activity. In fact, according to the Environmental Mining Council of British Columbia (2001), water has been called “mining’s most common casualty”. There is a growing awareness worldwide of the environmental legacy of mining activities that have been undertaken with little concern for the environment (EMCBC, 2001). Mining by its nature consumes, diverts and can seriously pollute water resources (Miller, 1999) Changes in laws, technologies and attitudes have begun to address some of the most immediate threats posed by coal development, but there are still many areas of coal mining practices and regulations that need to be addressed both in South Africa and on a worldwide scale

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(Younger, 2001). While there have been improvements in coal mining methods, practices and technologies in recent years, significant environmental risks, such as environmental degradation, soil, air and water pollution, still remain (EMCBC, 2001).

According to the Environmental Mining Council of British Columbia (2001), for the sake of current and future generations, there is a need to safeguard the purity and quantity of water against irresponsible mineral development. Such irresponsible mineral development can result in a reduction of the quality of water, through increased pollution and sedimentation loads, leading to a reduced quantity of water being available for us by current and future generations. This falls in line with the principal of sustainable development (IIED, 2002). There is, therefore, a need to ensure that the best pollution prevention strategies are employed, especially in case where the environmental risks can be managed.

This scenario thus calls for efficient and effective treatment of water from such sources before use, to avoid instances of water–borne and water related diseases such as typhoid fever and cholera. It has also been known that inadequate water supply both in terms of quantity and quality coupled with poor sanitation globally account for approximately 30, 000 deaths daily, many of them infants and 80% of such cases occur in rural areas (Nkwonta and Ochieng, 2009). The aim of this review is to raise awareness of the environmental risk associated with acid mine drainage in our environment.

IMPACT OF MINE WATER ON WATER QUALITY OF SOUTH AFRICA

Pollution has been identified as one of the many pressures affecting freshwater systems and resources in South Africa (Younger, 2001). Mine water is a growing concern in water quality management. Mine water impacts negatively on the water environment by increasing the levels of suspended solids, leading to mobilization of elements such as iron, aluminum, cadmium, cobalt, manganese and zinc and also decreasing pH of the receiving water. The overall effect of mine water is the deterioration in water quality in many surface water sources that may impact on the domestic, industrial and agricultural users (Wamsley and Mazury, 1999).

Types of mining activities and methods

Mining methods vary widely and depend on the location, type and size of mineral resources. We have two types of mining namely surface mining and underground mining. Surface mining methods are most economical in situations where mineral deposits occur close to the surface (such as coal, salts and other evaporite deposits or road quarry material) or form part of surface deposits (such as gold and diamonds and heavy mineral sands). Typical surface mining methods include: strip mining and open pit mining, as well as dredge, placer and hydraulic mining in riverbeds, terraces and beaches. These activities always disrupt the surface and this, in turn, affects soils, surface water and near-surface ground water, fauna, flora and all alternative types of land-use (Fuggle and Rabie, 1994).

Shallow underground mining, up to about 50 m below the surface, includes bord (room) and pillar mining (often used in coal mines), where pillars of the mineral seam are left to support overlying material. In some of the older South African coalmines in the Witbank area, roof collapse has occurred after the mines were closed, allowing air to enter the old workings and promoting spontaneous combustion in the residual coal. Some of the abandoned workings in the Witbank area have continued to burn for many years and have resulted in unplanned surface collapse as well as ground and surface water contamination through acidification and salinisation of local aquifers and streams (Fuggle and Rabie, 1996).

Acid mine drainage

Acid mine drainage is the single most significant threat to South Africa's environment (Younger, 2001). Acid generation and metals dissolution are the primary problems associated with pollution from mining activities. The effect of mining on the environment includes the release of many chemical contaminants into water resources turning them into acidic which is referred as acid mine drainage. The chemistry of these processes appears fairly straightforward, but becomes complicated quickly as geochemistry and physical characteristics can vary greatly from site to site (Younger, 2001). Acid mine drainage is metal-rich water formed from chemical reaction between water and rocks containing sulfur-bearing minerals. The runoff formed is usually acidic and frequently comes from areas where ore or coal mining activities have exposed rocks containing pyrite, a sulfur bearing mineral (Younger, 2001). In some acid mine drainage systems temperatures reach 117°F (47°C) and the pH can be as low as 3.6 (Younger, 2001).

Pyrite (FeS_2) is responsible for starting acid generation and metals dissolution in coal and hard rock sites. When pyrite is exposed to oxygen and water it will be oxidised, resulting in hydrogen ion release-acidity, sulfate ions and soluble metal cations. This oxidation process occurs in undisturbed rock but at a slow rate and the water is able to buffer the acid generated. Mining increases the exposed surface area of these sulfur-bearing rocks allowing for excess acid generation beyond the water's natural buffering capabilities.

$$2FeS_2\,(s) + 7O_{2\,(aq)} + 2H_2O \rightarrow 2Fe^{+2} + 4SO_4^{-2} + 4H^{+} \quad (1)$$

Further oxidation of Fe^{+2} (ferrous iron) to Fe^{+3} (ferric iron) occurs when sufficient oxygen is dissolved in the water or when the water is exposed to sufficient atmospheric oxygen.

$$2Fe^{+2} + ½\, O_2 + 2H^{+} \rightarrow 2Fe^{+3} + H_2O \quad (2)$$

Problems with Acid mine drainage are contamination of drinking water, contamination of agricultural lands and disrupted growth and reproduction of aquatic plants and animals if untreated.

THE NEED FOR ACID MINE DRAINAGE TREATMENT

Through out history, water has played an important role because of its use for domestic, industrial, agricultural and environmental purposes. Some of the major effects on the environment owing to acid mine drainage in the water include the following:

(1) Depletion of aquatic life including Fish, salamanders, frogs and other aquatic species will begin to dwindle in number, as the acidity and heavy metal content of their habitat increases.
(2) Contamination of food chain by way of heavy metals in the water accumulating in the tissues of fish and other creatures. If enough metals collect, it can be toxic to the fish or to a creature that eats the fish.
(3) Contamination of drinking water supply via the toxic heavy metals that remain dissolved in the acidic water from the mines. These metals can be ingested by humans through drinking water supplies, causing severe health problems.
(4) Deterioration of ecosystems: This can occur as damage to wildlife and water systems in drier regions due to toxic mining drainage which will impact all aspects of the ecosystem. Arid regions have delicate and fragile balances, with very little buffering for increased levels of acidity in the water supply (USGS, 2000).

ECONOMIC IMPACT OF ACID MINE DRAINAGE

AMD has become a very visible and highly political issue in South Africa (Akcil and Koldas, 2006). Mine closure and the associated increase in AMD also have serious consequences for communities previously supported by the mining sector (Akcil and Koldas, 2006). Mine closure results in loss of job opportunities and increased unemployment. In addition, informal settlements with associated social pathologies are on the increase. Subsistence farming is often the last resort for such communities, also AMD may render the available water resources unfit for agricultural use (Warhurst and Noronha, 2000). A region impacted by acid mine drainage often has a decline in valued recreational fish species such as trout as well as a general decline in outdoor recreation and tourism along with contamination of groundwater drinking supplies.

Thus, from the foregoing explanation, acid mine drainage can have severe impacts on aquatic resources and can stunt terrestrial plant growth and harm wetlands (USGS, 2000). Systems devised to treat such mine waters can be described as either active or passive. Active treatment is the use of conventional mine water treatment unit processes, which is pre-treatment steps of chemical coagulation, rapid mixing and flocculation, followed by floc removal via sedimentation or flotation.

MINE WATER PROBLEMS IN SOUTH AFRICA

South Africa has a long history of mining and has limited natural water resources, leading to a situation where it also has a number of significant mine-water related challenges. With over 10, 000 km^2 of hydraulically-interlinked coal mines and over 300 km of interlinked gold mines, mine-water challenges are not only at local mine level but at regional level too (Vureen, 2009). A study by Naicker et al. (2003) revealed that the groundwater in the mining district of Johannesburg, South Africa, is heavily contaminated and acidified as a result of oxidation of pyrite contained in the mine tailings dumps and has elevated concentrations of heavy metals. Where the groundwater table is close to surface, the upper 20 cm of soil profiles are severely contaminated by heavy metals due to capillary rise and evaporation of the groundwater. The polluted groundwater is discharging into streams in the area and contributes up to 20% of the stream flow, causing an increase in the acidity of the stream water. The effect of the contaminated water from the mines can persist for more than 10 km beyond the source (Naicker et al., 2003). Evidence of AMD was found in the blesbokspruit catchments and this is shown in Figures 1, 2 and 3 (Wade et al., 2002).

AMD is the most difficult mine waste problem to address (Durkin and Herrmann, 1994). Post-closure decant from defunct coal mines is estimated at 62 mℓ /d (DWAF, 2004), and in the order of 50 mℓ /d of acid mine water discharges into the olifants river catchment (Maree et al., 2004). It is clear, therefore, that significant volumes of polluted water need to be managed on a continuous basis for decades to come. Currently the groundwater levels in most operating coal mines in Gauteng and Mpumalanga are kept well below ground level to allow for the effective operation of the mines and to allow access to the coal reefs (Durkin and Herrmann, 1994). When mining ceases, pumping of the water will stop and groundwater levels will rise (Scott, 1995). AMD from coal mining is problematic in the highveld coalfield in Mpumalanga and has been reflected by media attention on the consequences of severe pollution seen in the Loskop dam and the olifants river catchment (Naiker, 2003). It is likely that new coal mining in the Waterberg coalfield (Limpopo Province) will lead to similar problems in the area in the future, if precautions are not taken. If

Figure 1. Partially treated mine water from the Grootvlei Dam enters the Blesbokspruit (Nkwonta and Ochieng, 2009).

Figure 2. Water pollution in wonderfontienspruit resulting in mine water effulent from nearby stream (Nkwonta and Ochieng, 2009).

the mines are reflooded to an uncontrolled level, this will result in the discharge of untreated acid mine water into surface streams and wetlands, leading to the contamination of these sensitive areas. It may also affect groundwater aquifers below surface particularly if they are dolomitic. This process is already happening in parts of the Witwatersrand. In the Randfontein area, water is decanting from an abandoned shaft and flowing Northwards towards the Krugersdorp game reserve and the cradle of humankind world heritage site. There is also evidence of ground water contamination in this area, extending at least into the game reserve (Scott, 1995). In the Natalspruit area in South-east of Johannesburg, water is decanting from abandoned mine near surface mining operations (Naicker et al., 2003). According to Tutu (2008), in the areas surrounding the Witwatersrand goldfields, tailings dumps are the main source of pollution since they are generally composed of elevated proportions of pyrite and other minor metallic sulfides. Oxygenated water percolating down the dump produces a visible oxidation. The elevated water table within the dump or its associated capillary fringe may impinge on the sides of the dump, where evaporation takes place forming efflorescent crusts of metal sulfates .The colour of these crusts is very variable and depends on the composition of the dissolved salt load in the groundwater. White crusts, dominated by gypsum (derived from partial neutralisation of AMD by lime), are the most common, but colours ranging from pale pink (Co, Mn) to various shades of green (Ni, Fe), and even yellow have been observed (Tutu, 2008). Many of the streams passing through the mining areas of the Witwatersrand and

Figure 3. Mine water pollution in west rand area of Johanesburg (Garth, 2010).

Mpumalanga are perennial and derive their base flow from groundwater seepage (Tutu, 2008). The stream samples include streams flowing through tailings footprints and reprocessing areas, distributaries and natural streams near or distal to pollution sources. In the vicinity of dumps, polluted groundwater emerges at surface and contributes to stream flow (Jones, 1998). The capillary fringe above the water table impinges on the land surface on the stream banks and evaporation of the groundwater results in efflorescent crusts (Naicker et al., 2003). Occasionally, polluted groundwater may enter dams directly where such exist on streams flowing between dumps, in which acidification of lake water may also occur.

The Vaal river barrage catchment is not only unique in terms of user's requirements, but also with regard to impacts on water quality. It is estimated that approximately five million people live within the catchment (DWAF, 2004). Whilst the Vaal river barrage reservoirs relies heavily on return flows from domestic, industrial and agricultural users, its catchment is also characterised by a large number of gold and coal mines. Gold and coal mine in the west of Johannesburg are probably the largest contributors to diffuse water pollution in the Vaal barrage catchment (DWAF, 2004).

TYPES OF ACID MINE DRAINAGE TREATMENTS

It can be classified as either passive or active treatment. According to Fripp et al. (2000), active treatment can be successful; however it necessitates a long-term and continuous commitment to treatment. Equipment failure and budget restrictions can result in lapses in treatment, which in turn, can result in biological and physical degradation of the streams (USGS, 2001). An advantage of active treatment system is that less area is needed to construct an active treatment system than is necessary for construction of a passive treatment system such as constructed wetland. Most of the common methods used for active treatment of mine water are lime neutralization, ion exchange and carbonate neutralisation. This method is quite demanding in chemical use, energy input and mechanical parts as well as skilled manpower that are often unavailable, especially in rural areas of developing countries such as South Africa. This scenario calls for appropriate technologies that utilize locally available materials, skills and other resources in accessing quality and effective treatment systems.

While passive treatment involves the developing of a self-operating system that can treat the effluent without constant human intervention (IIED, 2002). The basis for passive treatment is to let nature purify itself over time (Younger, 2001). An example would be passing the water through linked ponds (Barton and Karathansis, 1999) or an artificial wetland in which organic matter, bacterial and algae work together to filter, adsorb, absorb and precipitate out the heavy metal ions and reduce the acidity (IIED, 2002). The surface area required is generally significant, well into the hundred-hectare range, as compared to active treatment systems which require, in general, less than 70 ha for treatment of 100 m/ℓ of mine water per day (Barton and Karathansis, 1999). There are, however, also several advantages to using passive treatment systems. These systems, once constructed, can treat the mine water for 15 to 25 years with minimal routine maintenance costs (Barton and Karathansis, 1999). They generally require less operational attention than active treatment systems but require large area of land for effective treatment. Currently, the three most common types of passive technologies used in South Africa are: wetlands, Rhodes biosure process, roughing filters.

Wetlands

Wetlands utilise naturally available energy sources such as topographical gradient, microbial metabolic energy, photosynthesis to precipitate out the heavy metal ions, and reduce the acidity of the water (IIED, 2002). The effectiveness of this system has been very variable, they were conceived to promote the activity of sulphate reducing bacteria that generate alkalinity, raise the pH, and result in the precipitation of heavy metals as sulphides, which have a smaller bulk volume than ferric hydroxide (IIED, 2002).

Wetlands generally use an imported inorganic substrate of 400 – 700 mm deep, for which spent mushroom compost has proved effective, overlaying a limestone base layer of 100 – 200 mm. The base layer of limestone raises the pH and generates alkalinity to supplement the role of sulphate reduction in pH neutralisation. This system requires large area of land for effective treatment, which may not be available in some developing countries (IIED, 2002).

Rhodes biosure process

Polluted waters, arising from extensive past and ongoing mining operations in South Africa, pose serious environmental threats to the limited fresh water resources (Neba, 2007). History was made in South Africa on 18th January, 2005 with the launch of the first full scale plant in the world using the Rhodes Biosure process, a locally-developed, first-of its kind solution for treating acid mine water drainage (Neba, 2007). The Rhodes Biosure process is the most cost-effective biological treatment option developed to date for reducing sulphates in acid mine water without the external addition of chemicals. The new plant construction at Ancor sewage works, near springs, was developed by Rhodes University's environmental biotechnology research unit over the past eight years with the support of the Water Research Commission (WRC), East Rand Water (ERWAT) and Biopad. The Rhodes biosure process removes sulphate from acid rich mine water. Instead of expensive carbon and electron donor sources, primary sewage sludge, a by product from ERWAT, is being used. Together, the two waste products ensure improved water quality before being discharged into the Blesbokspruit site. At the same time, safe and stable biosolids are produced. This process also requires skilled manpower for effective treatment.

Roughing filtration

Roughing filters can be considered as a major pretreatment process for mine water, since they efficiently separate fine solid particles over prolonged periods without addition of chemicals. Roughing filters are simple and efficient mine water pre-treatment technology compared to the conventional system. This is in terms of technical labour requirement, daily operation, maintenance and treatment efficiency and effectiveness. The first horizontal roughing filter was developed in delmas coal in Mpumalanga province of South Africa to treat heavy metals and increase the pH of the mine water. Gravel was used as a control medium. The filter was divided into three parts namely the inlet structure, the outlet structure and the filter bed. The inlet and outlet structures are where flow control installations are required to maintain a certain water level and flow along the filter as well as the establishment of an even flow distribution along and across the filter. In order to improve the performance of roughing filters, this process was modified by applying local available material like charcoal as the filter media. The pilot plant was monitored for a continuous 90 days from commissioning till the end of the project. The overall function of the filter in removing parameters that were put to test was accepted using charcoal. Achieved results in this study showed that roughing filters may be considered as a packed, low-cost and efficient pre-treatment process for mine water treatment.

CONCLUSION

From the foregoing analysis it is evident that the increase of AMD presence in the streams/rivers threatens the scarce water resources of South Africa, and as a result also human health and food security in mining areas, it also presents an opportunity to provide usable water through appropriate treatment technologies such as passive or active treatment. The water qualities of the grootvlei sample area as well as the water quality discharged by the mine into the spruit both exceed the standards set by DWAF. From this, it is concluded that the water discharged into the Blesbokspruit by the mine, is deteriorating the water quality of the spruit and concomitant benthic faunal assemblages. The conclusion of the analysis was that the pumping of the extraneous water from underground mine workings into the Blesbokspruit had a major impact on the deterioration of water quality of the Blesbokspruit. It was indicated that the discharge of untreated acid mine drainage into Wonderfonteinspruit and Klip River has a negative impact on the water quality in these rivers.

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