Evaluation of the applicability of the passive treatment for the management of polluted mine water in the Witwatersrand Goldfields, South Africa.

Ntshengedzeni Obed Novhe

Council for Geosciences, Environmental Geosciences Unit, 280 Pretoria Road, Silverton, 0001

Abstract

Acid mine drainage in the Witwatersrand Goldfields threatens scarce water resources, the social welfare and the environment. Current management involves the use of active treatment with lime which is considered to be expensive and has limited efficiency. A study was conducted to review and evaluate the potential application of the passive treatment. The applicability of these systems is limited by the presence of large volume of polluted water, but may be successfully implemented to treat small streams of polluted water in the area, such as minor seepages from the flooded underground workings and leachate from the old mine residues.

Keywords: acid mine drainage, passive treatment, Witwatersrand Goldfields

Introduction

From over 120 years ago, the economy of South Africa is largely dependent on mining. Formal gold mining activities commenced in 1886 on the farm Langlaagte, near Johannesburg (Fig.1) and most of the mines have ceased to operate in the 1970s (Swart, 2003). Prior to the adoption of environmental legislations, mining companies used irresponsible methods with no regard for protecting the environment. Most of the abandoned mines are not rehabilitated and the owners cannot be traced and hence there is a negative legacy of environmental problems.

Acid Mine Drainage (AMD), from abandoned mine sites of the Witwatersrand Goldfields is the major environmental challenge which threatens the scarce water resources in South Africa. In the presence of oxygen and water, sulphide minerals (especially pyrite) that are present in the mine residues and on the exposed rock surfaces within the open pits and underground mine workings oxidizes to form AMD. The resulting AMD is responsible for the most costly environmental and socio-economic impacts in South Africa (Oelofse et al 2007). A study conducted by Naicker et al (2003) in the West Rand and Central Rand goldfields also indicated that acidified water seeping from the mine residues contributes an average of about 20% of stream flow. In addition, a study conducted by Tutu et al (2008) also revealed the deterioration of surface and groundwater quality in the immediate vicinity of mine residues.

AMD resulting from the abandoned underground mines was first noticed in 2002 August in the West Rand, west of Johannesburg. As an emergency solution the polluted mine water is currently being pumped and neutralised with lime to precipitate toxic metals such as iron (Fe), manganese (Mn) and sulphate before discharged into a nearby streams. This active treatment option is considered to be very much expensive and has limited efficiencies in removing other contaminants such as sulphates. No management measures are currently implemented in respect of polluted mine water contained in the old pits and seepages from the mine residues, and hence this is posing continuous substantial impacts on the environment.

A lot of studies have been conducted in the area to characterise the nature and occurrence of AMD, but there is still a challenge/gap in respect of development of possible sustainable management measures. Passive treatment systems are increasingly gaining favours over active treatment technologies internationally for the management of the polluted mine water due to their efficiency in removing contaminants at a lower cost, but their applicability in the Witwatersrand Goldfields is limited and not well understood. However, a study by Coetzee et al (2002) indicated that wetlands have a potential to attenuate pollution from Witwatersrand gold/uranium mines. Therefore, there is a need to explore the potential application of these systems for a long-term management of polluted mine water. This study involved a review of available passive treatment technologies and making recommendations in terms of their applicability in the Witwatersrand environment, with special reference to the West Rand, Central Rand and the East Rand Goldfields (Fig.1). The objective was to contribute towards sustainable management of polluted mine water in the Witwatersrand Goldfields.

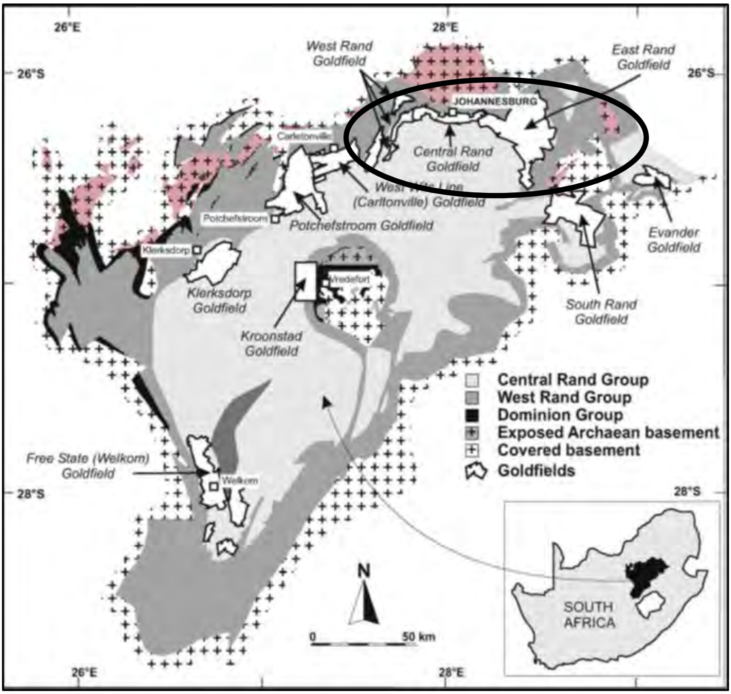

Figure 1 *Schematic geological map of the Witwatersrand Basin, indicating among others the West Rand, Central Rand and East Rand Goldfields (modified after Pretorius et al 1986)*

Material and methods

The contaminated water areas were identified using a combination of past data collected by Council for Geosciences (CGS), previous operated and current operating mines as well as data contained within the Department of Water Affairs (DWA) monitoring database. In addition, fieldwork observation and sampling were conducted in the study area (West Rand, Central Rand, and East Rand) to identify the point sources of pollution, with special emphasises on the characterisation of leachate resulting from the mine residues. Onsite water parameters analyses were conducted in respect of the identified areas and water samples were collected and analysed at CGS laboratory. The applicability of passive treatment was evaluated based design criteria of the available technologies and the identified site characteristics of the polluted mine water in the Witwatersrand Goldfields.

The East Rand, situated east of Johannesburg is typically characterised by near neutral pH of mine water, whereas other Goldfields such as the Central Rand and West Rand are characterised by acidic mine water. This has been observed in various mine water pumping sites (Table 1). According to Scott 1995, the alkalinity in respect of the East Rand mine water is associated with the presence of dolomite (Scott 1995). The author also concluded that the high flow rates, as indicated in Table 1 below are associated with the following sources: direct ingress from rainfall through major geological structures and open pits, groundwater, and surface streams that loose water directly into the mine openings. Mine residues, in particular tailings, are seen as areas of enhanced seepage where the volume of water entering the mine void is relatively high. The interactions between water and tailings can lead to contamination of the water and AMD production, resulting in the flow of contaminated water into the mine voids. In addition, the field observation conducted in the area revealed that poor quality leachate resulting from the mine residues is also responsible for the pollution of the water resources. Generally, the overall leachate from the mine residues in the study area is acidic with elevated amount of sulphate and toxic metals (such as Manganese, Aluminium, Cobalt, Nickel and Arsenic), and in most cases it directly discharges into the nearby water resources. The results of water quality parameters in respect of the identified seepage areas are summarised in Table 2.

The amount estimated by Harmony Gold/Rand Uranium as part of their continuous pumping and monitoring. Onsite analysis during site visit conducted on 27 January 2012. Medium value of at least 200 samples collected by Harmony gold/Rand Uranium (Ramontja et al, 2010). Estimated flow rate based on the daily pumped water during active mining at ERPM, after Scot 1995. Modelled inflow water chemistry after Scott, 1995 (Ramontja et al, 2010). Median of data collected since 2008, provided to Council for Geosciences (CGS) by Grootvlei Mine (Ramonjta et al, 2010). Department of Water Affairs and Forestry 1996a.

Table. 1 *Typical water Parameters in the West Rand, Central Rand and East Rand pumping sites.*

Parameter	West Rand	Central Rand	East Rand	Guideline for category 4, industrial processes
Flow rate (m^3/day)	15 000[(a)]	60 000[(d)]	75000 -108 000[(f)]	_
pH	2,72 [(b)]	2.8[(e)]	6.65[(f)]	5-10[(g)]
Ec (mS/m)	427 [(b)]	467 [(e)]	246[(f)]	250[(g)]
Dissolved oxygen (mg/l)	5,7[(b)]	_	_	_
Total dissolve solids (mg/l)	6580 [(c)]	4936 [(e)]	2041[(f)]	1600[(g)]
Sulphate (mg/l)	4010 [(c)]	3700[(e)]	1037[(f)]	500[(g)]

Applicability to Witwatersrand Basin

There is a number of passive treatment technologies that can be implemented in various polluted mine water sites in the Witwatersrand. Both acidic and alkaline mine water can be accommodated using suitable passive systems. The selection of a suitable passive treatment system is a function of the chemistry of the polluted mine water (pH, Acidity, alkalinity, Fe^{2+}/Fe^{3+}, sulphate (SO_4), dissolved oxygen), flow rate and topography (Hedin et al 1994) (Figure 2). Table 3 shows generic categories of passive treatment technologies and their potential applicability as a function of polluted water chemistry. In general, aerobic wetlands can treat net alkaline water. Anoxic limestone drains can treat water with low Al, Fe^{3+}, and dissolved oxygen (DO). SAPS, anaerobic wetlands, and open limestone drains (OLD) can treat net acidic water with higher Al, Fe^{3+} and DO.

Table 2 *Typical seepage quality in the West Rand, Central Rand and East Rand*

Parameter	West Rand	Central Rand	East Rand	Guideline for category 4, industrial processes
pH	4.7	2.9	3.73	5-10
Ec (mS/m)	675	323	328	250
Sulphate (mg/l)	3083	2712	1638	500
Fe (mg/l)	1 57	134	91	0-10
Mn (mg/l)	279	12	25	0-10
Al (mg/l)	8.90	100.02	44.40	_
Ni (mg/l)	10.50	6.04	4.94	_
Co (mg/l)	4.52	2.87	1.65	_
As (mg/l)	0.81	0.1	0.1	_

East Rand Goldfields

As indicated in Table 1, the typical mine water in this goldfield is near neutral but with elevated concentration of sulphate and metals (especially Fe). The passive systems that are more likely to be implemented include aerobic wetlands for metal removal and bioreactors for the reduction of sulphate. Aerobic wetlands are designed to provide sufficient residence time to allow metal oxidation and hydrolysis thereby causing precipitation and physical retention of metals (Fe, Al, and Mn) hydroxides (Ziemkiewicz et al 2003). Considering the large volume of polluted net alkaline water, the applicability of this system in the Witwatersrand will require a large surface area and therefore the availability of surface area is likely to be a limiting factor in this regard. Sulphate reducing bioreactors also have potential applicability but the presence of high volume of water is the limiting factor. A study by Gusek et al 1998 in respect of a lead mine in Missouri indicated that at high flow rate the efficiency of sulphate reducing bioreactors is more likely to decrease.

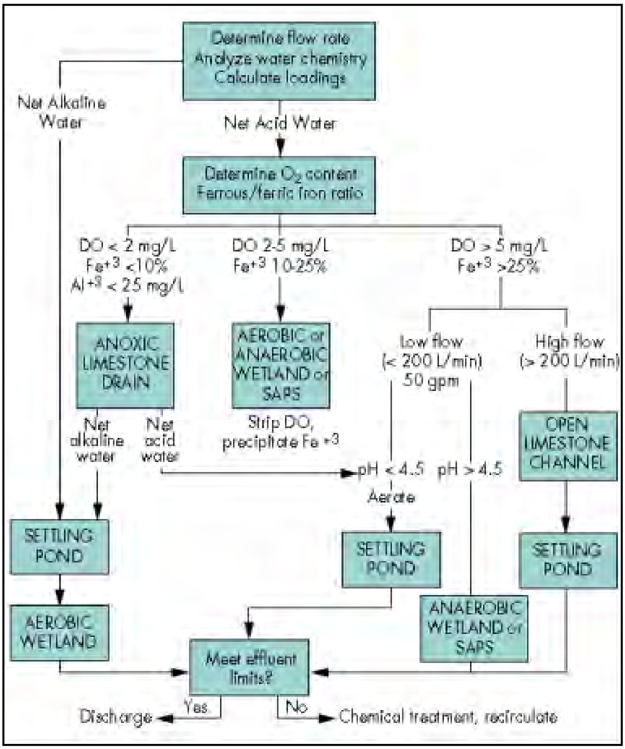

Figure 2 *Flowchart to assist in the selection of a passive treatment technology for acid mine drainage (adapted from Hedin et al 1994)*

Central and West Rand

The likely passive treatment systems for net acidic water (such as in the Central Rand and West Rand) include: Anoxic limestone drains (ALDs), Open limestone drains (OLDs), Anaerobic wetlands and Successive Alkalinity Producing Systems (SAPS), and Sulphate reducing bioreactors (SRB). In these goldfields the acidic mine drainage is characterised by elevated concentration of Fe, SO_4 and dissolved oxygen (Table 1), and hence the applicability of ALDs may not be suitable due to potential clogging/armouring of limestone with oxides or gypsum, reducing the rate of limestone dissolution or plugging the system. In either instance, the ability of the ALDs to generate alkalinity may be significantly reduced, and failure of the system may occur. On the other hand, anaerobic wetlands must have substantial retention time and therefore requires large surface areas to treat large volumes of acid mine drainage, hence their applicability is also limited by large volume of water in the study area. Nevertheless, SAPS have a potential applicability to treat acid mine drainage in the Witwatersrand Goldfields. They are considered to be suitable for net acidic water even if it contains elevated concentration of metals and dissolved oxygen (Skousen 2001). SAPS combine the mechanisms of anaerobic treatment wetlands and anoxic limestone drains (Kepler and McCleary 1994). Younger et al 2002 indicated that these systems can be accommodated in an area of 15 to 20% of that needed for an anaerobic wetland, and therefore this is an added advantage for the potential applicability of SAPS in the area. Open limestone drains also have potential applicability in the net acidic water as pre-treatment systems. A study by Ziemkiewicz et al 1994 indicated that the use for open limestone channels/drains can be very useful in the initial raising of the pH and removal of metals before the water enters the constructed wetlands or SAPS. In addition the authors also suggested that the velocity/flow rate of the water be high enough in order to prevent possibly armouring or coating of the limestone. The applicability of SRB is also limited by the presence of large volume of water.

Conclusions

There are available passive treatment technologies that have a potential applicability to treat both acidic and alkaline drainages, but the presence of large volume of polluted mine water that requires treatment presents a major challenge for the applicability of passive treatment technologies in the Witwatersrand Goldfields. However, suitable passive systems can be successfully implemented to treat small streams, such as seepages from mine residues that are currently not being managed. Successive Alkalinity Producing Systems (SAPS) have a potential applicability to treat acid mine drainage in the Witwatersrand. The applicability of anoxic limestone drains is limited by the presence of high concentration of metals (such as Fe) and dissolved oxygen.

***Table 3** Generic categories of Passive Treatment systems*

Passive Treatment Technology	Application Niche in Mine Drainage	Potential applicability in the Witwatersrand
Aerobic wetlands	Net alkaline drainage, low flow rate	East Rand, but may be limited by surface area availability.
Anoxic limestone drains (ALD)	Net acidic , low Al^{3+}, low Fe^{3+}, low dissolved oxygen	Central Rand and West Rand, but limited by the presence of high metal loads, sulphate and dissolved oxygen
Anaerobic wetlands	Net acidic water with high metal content, low flow rate	Central Rand and West Rand, but may be limited by surface area availability
Successive Alkalinity Producing Systems	Net acidic water with high metal content	Central Rand and West Rand, more likely to be implemented due to reduced surface area requirements
Open limestone drains (OLD)	Net acidic water with high metal content	Central and West Rand, more likely to be implemented for the pre-treatment of net acidic water
Sulphate reducing bioreactors (SRB)	Net alkaline or acidic, low flow rate	More likely to be implemented in all the goldfields, but application is limited by presence of large volume of water

Recommendations

A further extensive research and site visit is recommended for more precise identification of suitable passive treatment systems that can be implemented in the Witwatersrand Goldfields for the management of polluted mine water. Measures to prevent/minimize the ingress of water (both surface and groundwater) must be investigated and implemented with the aim to reduce the volume of water in the old mine workings.

Acknowledgement

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