Evaluation of the Changes in Mine Water Quality in the Witwatersrand Basin: Basis for Proactive Long-term Solution

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Abstract

After mining ceased in the Witwatersrand goldfields various risks were identified due to flooding of the mine voids. In response to these challenges, it was recommended that the water level must be maintained below a set environmental critical level. The water has since risen above the set level. However, the water quality in the mine voids has shown a gradual improvement over time. Therefore, rational planning for the remediation of mine water pollution should involve intensive treatment of initial discharges to deplete vestigial acidity, followed by long-term in-situ and/or passive treatment of the juvenile acidity.

Keywords: Mine Voids, Acid Mine Drainage, Acidity, Environmental Critical Level

Introduction

Mining is a vital contributor to economic, social and environmental sustainability in South Africa. Economically, mining attracts investors while, socially, it improves people's quality of life by creating employment. Mines began to close as accessible resources were depleted. Pumping ceased around 2000 in the Central basin of the Witwatersrand Goldfields. Water levels recovered after the cessation of pumping.

Mining is associated with profound environmental impacts and continues to negatively affect the environment. Coetzee *et al* (2011) have identified risks owing to the flooding of mine voids in the Witwatersrand Goldfields. The risks identified in the Witwatersrand Goldfields include; contamination of shallow groundwater, geotechnical impacts, seismic impacts and ecological impacts. In response to these challenges, the Team of Experts on Acid Mine Drainage recommended that the water be maintained at a certain environmental critical level (ECL). Currently, the mine void water is being managed through pumping and treating the water as well as ingress control measures (fig. 2).

Younger (1997) explained how mine water in the mine voids changes over time by analysing water quality records for major abandoned mine discharges in Scotland, Wales and Cornwall. It was established that long-term acidity generation in mine voids

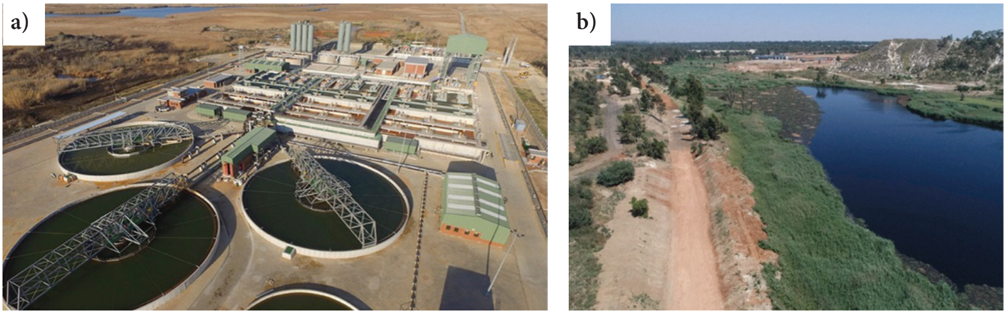

Figure 1 *High-density sludge acid mine drainage treatment plant (a) and a canal for ingress control (b).*

comprises two components: vestigial and juvenile.

The vestigial component occurs as abandoned mine voids fill with water for the first time, dissolving intermediate products of pyrite oxidation into a solution such as ferrous and ferric hydroxy sulfate salts. Depletion of vestigial acidity is primarily controlled by the hydraulic retention time of the flooded mine system and usually lasts for less than 40 years.

Juvenile acidity arises from ongoing pyrite oxidation in the zone of water table fluctuation within the mined system. This can be expected to continue for many hundreds of years until the supply of pyrite is finally exhausted (Younger (1997)).

In summary, the duration of mine water pollution is a function of the rate of depletion of vestigial acidity and the scope for the generation of juvenile acidity. Vestigial acidity is primarily controlled by hydraulic factors, such as:

1. The volume of the interconnected, flooded, mine system (depletion being fastest where systems are small and flow paths short);
2. Hydraulic connectivity and conductivity of the mine system (depletion being fastest in the most highly connected and highly conductive systems);
3. Rate of recharge (hydrological residence times will be shorter where recharge is higher).

The generation of juvenile acidity is very important when pyrite oxidation can occur above a fluctuating water table. In the context of the Witwatersrand, above the water level, other soluble iron minerals (siderite, ankerite etc.) are present. This will diminish over time if acid-producing mineral sources are depleted by dissolution in the shallow workings. This may require several centuries in typical systems (Strömberg and Banwart 1994).

This study assessed the changes in mine void water in the Central basin of the Witwatersrand Goldfields for appropriate long-term management of mine water to be recommended.

Methods

Water in the mine voids is being managed through pumping and treatment using high-density sludge technology. The resultant sludge is placed back into the mine voids. The daily water levels and water chemistry data from the treatment plants in the Witwatersrand Basin were analysed and plotted on a time series graph to obtain clear pictures of the changes in the water quality as the water levels changed in the mine voids. The water quality and level data before the treatment plant was constructed in 2014 is not available.

Results and Discussion

The evolution of the water chemistry in the mine voids situated in the Central Basin has been gradually improving between 2014 and 2020 (fig.2). This resulted due to main reasons:

1. During the treatment of mine water through the high-density sludge treatment system, the resultant sludge is disposed of into the mine voids. This has residual alkalinity that causes in-situ neutralisation of the pH and results in the improvement of the water quality.
2. According to (Younger, 1997) long-term acidity generation is shown to have two components (vestigial and juvenile acidity). The vestigial component relates to the geochemical processes that occur as abandoned mine voids are allowed to fill with water for the first time, taking ferrous and ferric hydroxy sulfate salts (intermediate products of pyrite oxidation) into solution.

The dissipation of vestigial acidity is primarily controlled by the hydraulic retention time of the flooded mine system, and will generally be accomplished in less than 40 years. The mines in the Central basin stopped mining around 2000 and were left to flood. The secondary products of pyrite oxidation ($FeSO_4.7H_2O$, $FeSO_4.4H_2O$, $FeSO_4.H_2O$ and $Fe^{2+}.Fe_4^{3+}(SO_4)_6(OH)_2.20H_2O$) were dissolved resulting in the water quality characterised

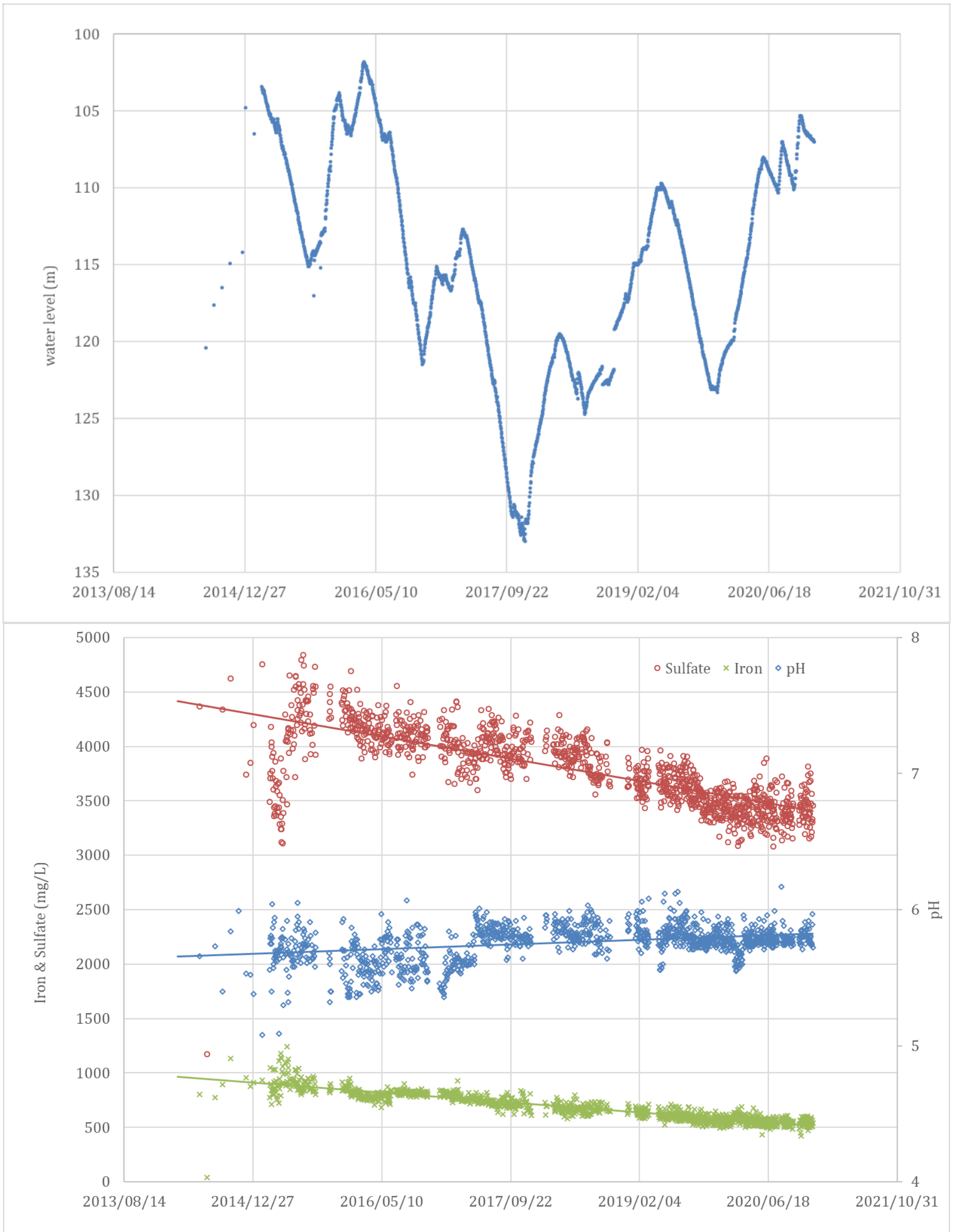

Figure 2 *The trends of the water levels and water chemistry in the mine voids in the Central Basin*

by low pH and high sulfate and metal concentration. In 2014, when the treatment plants were built, vestigial acidity has been exhausted. The ongoing juvenile acidity (from ongoing pyrite oxidation) remained the only source of pollution in the water.

The generation of this kind of acidity is very slow as it requires O_2 availability and bacterial catalysis. In the flooded mines means that O_2 ingress to facilitate pyrite oxidation was minimised. In conjunction with in-situ neutralisation from the disposed of sludge back into the mine void resulted in improved water quality.

The treatment plant in the Central basin was designed to handle acidic water containing high concentrations of metals. The water quality in the mine voids is showing gradual improvement (with circumneutral pH and low concentration of metals). Therefore the treatment plants will become inappropriate as the water continues to improve. Long-term sustainable mine water management such as passive treatment needs to be considered if the trends that were observed in this study continue.

Conclusions

There is a gradual improvement in the water quality in the mine voids in the Central Basin of the Witwatersrand Goldfields. This could be due to exclusion of O_2 due to flooding. and in-situ neutralisation of the mine water owing to the disposal of the sludge from the high-density sludge treatment plants into the mine voids. The current pH of the mine void water is around 5 and 6.

In this regard, continuous monitoring of the water quality is required to inform long-term sustainable mine water management in this area.

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