Evaluation of the Water Quality Impacts Associated with Relaxation of Environmental Critical Levels: A Case Study in the West Rand Basin, South Africa

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Abstract

To respond to the challenges posed by mine water discharging from mine voids, a recommendation to maintain a certain level called environmental critical levels (ECLs) was made. Currently, in the Western Rand Basin, the water level in the mine voids is above the recommended ECL. The focus of this study was to understand how the current water level in the basin is affecting surface and groundwater resources. Both surface and groundwater showed a dominance of Ca-Mg-SO_4 and Ca-SO_4 water type. Surface water shows high SO_4^{2-}, low Fe and low pH, while groundwater shows high SO_4^{2-}, high Fe and high pH.

Keywords: Environmental Critical Level, mine void, water level, water quality, surface and groundwater

Introduction

Mining has long been a cornerstone of South Africa's economy, in particular, gold mining in the Witwatersrand has been a key sector since 1886 (McCarthy 2010). Mining made Johannesburg 'the City of Gold' and helped make Gauteng a wealthy province. A century of mining has had many positive economic impacts, however, mining has also had large negative environmental effects (McCarthy 2010).

Underground mining in the Witwatersrand Basin led to the excavation of a series of large interconnected voids (Ramontja *et al.* 2011). During mining operations, as part of water management, water was pumped out of these voids to allow mining operations to continue. However, when mining stopped in several mines, the remaining few had to carry the burden of the pumping operations. This became extremely costly for the remaining mines. Ultimately, the remaining mines also stopped operations and pumping, which led to the flooding of mine voids. In the West Rand Goldfield, pumping ceased in 1998 (Ramontja *et al.* 2011). In 2002, acidic water began to discharge from the West Rand Goldfield's underground working, negatively impacting the downstream environments (Coetzee 2016). The polluted water characteristically showed low pH, high total dissolved solids (TDS), high SO_4^{2-} and may contain high amounts of metals including uranium (Ramontja *et al.* 2011).

The main risks associated with flooding of mine voids with mine water as identified by a Team of Expects (Coetzee *et al.* 2010), are; contamination of shallow groundwater resources, geotechnical impacts, such as the flooding of underground infrastructure in areas where water rises close to urban areas and increased seismic activity. Furthermore, risks associated with the discharge of mine water to the environment may lead to serious negative ecological impacts, regional impacts on major river systems and localised flooding in low-lying areas.

This study aims to understand the impacts of the mine water on the groundwater and surface water resources. This is because the water has risen above the set ECL for the basin.

Site setting

The study site is in the Western Basin of the Witwatersrand Goldfields, (Figure 1).

Methodology

Water samples were collected from surface water bodies, boreholes and shafts for water chemistry analyses. The samples were filtered through a 0.45 µm filter paper. Samples (100 ml) to be analysed for metals and metalloids were preserved by adding 3 drops of concentrated HNO_3, whilst an unpreserved sample was collected for the analysis of anions. These were analysed using inductively coupled plasma mass spectrometry (ICP-MS) and ion chromatography (IC) for metals/metalloids and anions respectively.

Electrical conductivity (EC), pH, iron (Fe) and sulfate (SO_4^{2-}) were chosen for observation purposes in this study. ArcGIS 10.4.1 was used to create the concentration maps. AquaChem 3.70 was also used to process the data into water types.

Results and discussions

Water types

Figure 2 shows the Piper diagram created using samples from boreholes, surface water and shafts in the study area. In the cation triangle, the samples show a dominance of Ca^{2+} and Mg^{2+} over Na^+ and in the anion triangle most samples show a dominance of SO_4^{2-}. The majority of the samples show Ca-Mg-SO_4 and Ca-SO_4 water types. These SO_4^{2-} water types have been established to be mine water signatures in the study area, which is also evident in the samples from the mine void water. This water type most likely represents the mixing of dolomitic groundwater (Ca-Mg-HCO_3) with acidic mine water, consuming alkalinity and replacing it with SO_4^{2-} as the dominant anion. Most of the samples generally show elevated levels of SO_4^{2-}, this is with the exception to boreholes A2N0576 and GP00308 which show a freshwater signature with low EC

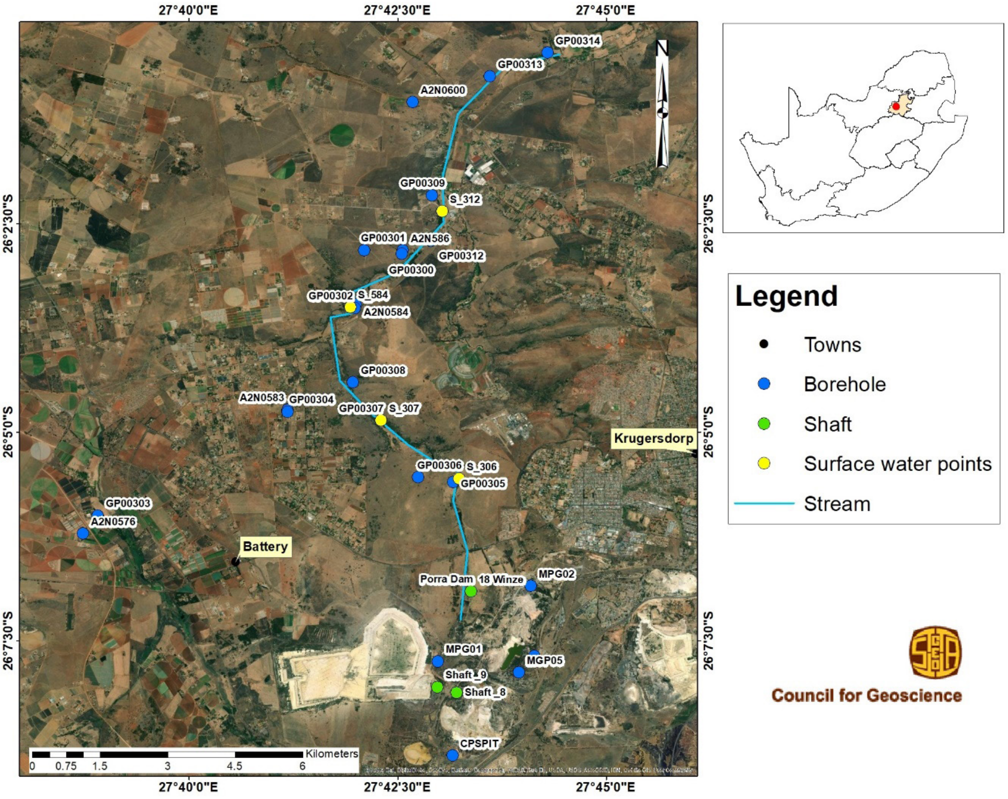

Figure 1 Study area

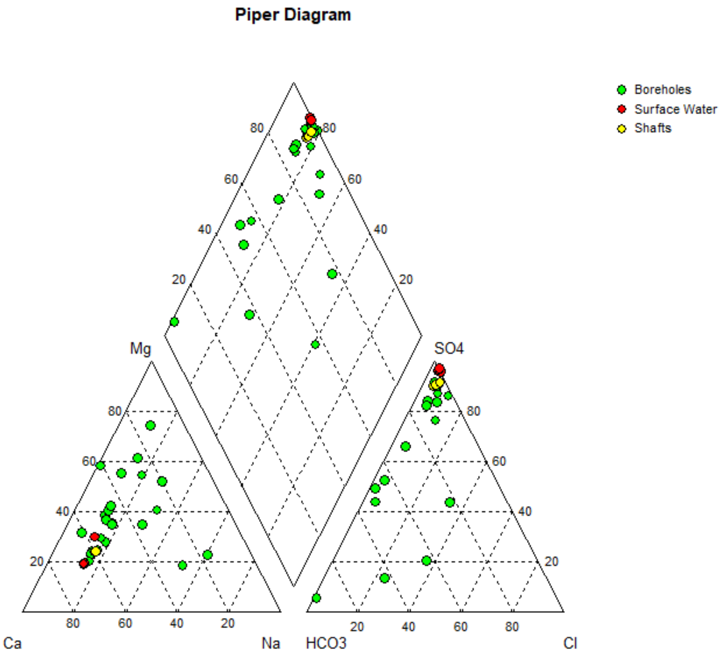

Figure 2 *Piper diagram showing major ion chemistry for the sample in the study area*

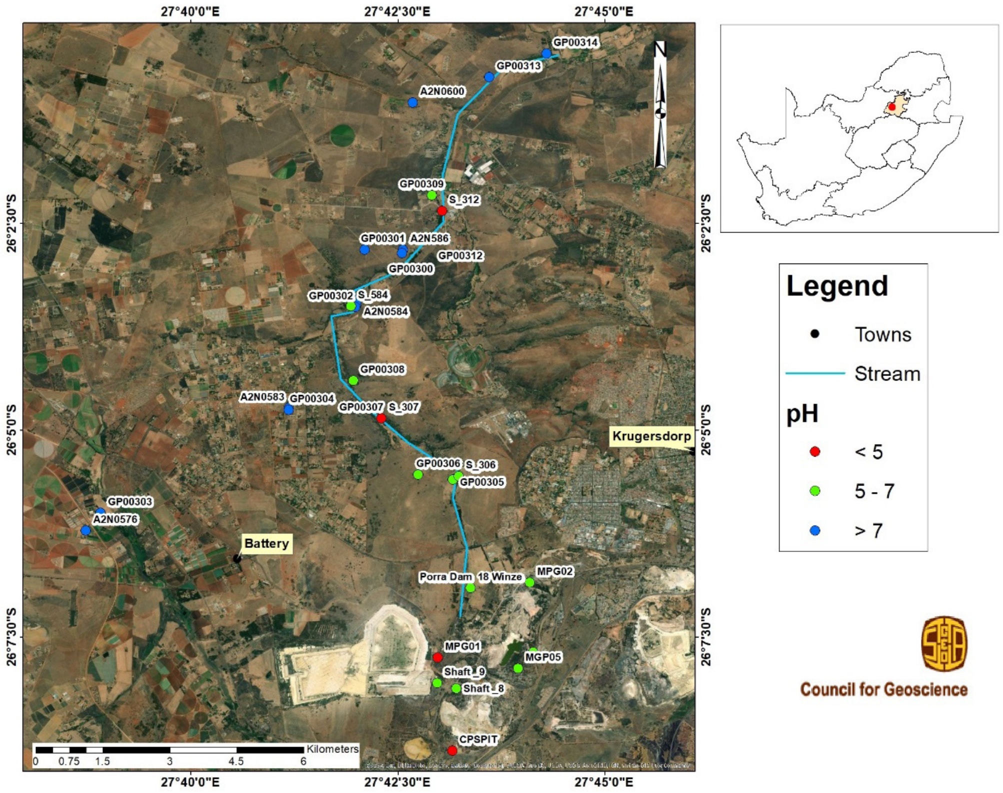

Figure 3 *Spatial distribution of pH*

and low SO_4^{2-}. This indicates that these boreholes sample a different aquifer to the other boreholes and that this aquifer is not connected to the mine void.

Water Chemistry

The variation in pH levels in the study area is shown in Figure 3. The pH for groundwater samples varies from 3.4 to 8.2, in surface water samples 3.2 to 4.8 and in shafts, it ranges from 6.4 to 6.6.

The groundwater in the study area is mostly circumneutral to alkaline, this is with the exception of two samples CPS Pit and MPG01 which showed pH of 3.4 and 4.8 respectively. The water in the mine voids is circumneutral. Surface water samples show low pH levels, this is possibly due to surface reactions that occur due to the exposure of Fe to oxygen (Equation 1).

$$2Fe^{2+} + O_2 + 4H_2O \rightarrow 2Fe(OH)_3 + 2H^+$$

Equation 1

The EC in the groundwater samples ranges from 74.5 to 1398 mS/m, in surface water it ranges from 1292 to 1439 mS/m and in the shafts it ranges from 1371 to 1391 mS/m. The spatial distribution of EC concentration in the study area is shown in Figure 4. The high EC levels in all the samples correlate with high SO_4^{2-} as shown in Figure 4. This indicates that SO_4^{2-} is the main anion contributor to high EC levels in the study area.

Sulfate levels in groundwater range from 10.71 to 2064.44 mg/L, in surface water it ranges from 1877.09 to 2169.38 mg/L and in the shafts it ranges from 1934 to 2184 mg/L. The majority of the samples exceed the recommended limit of 500 mg/L as per 2015 South African national drinking standards (SANS) (Figure 5). High SO_4^{2-} in the study area indicates that the surface and groundwater resources were impacted by the water from mine voids and leachates from mine waste in the area.

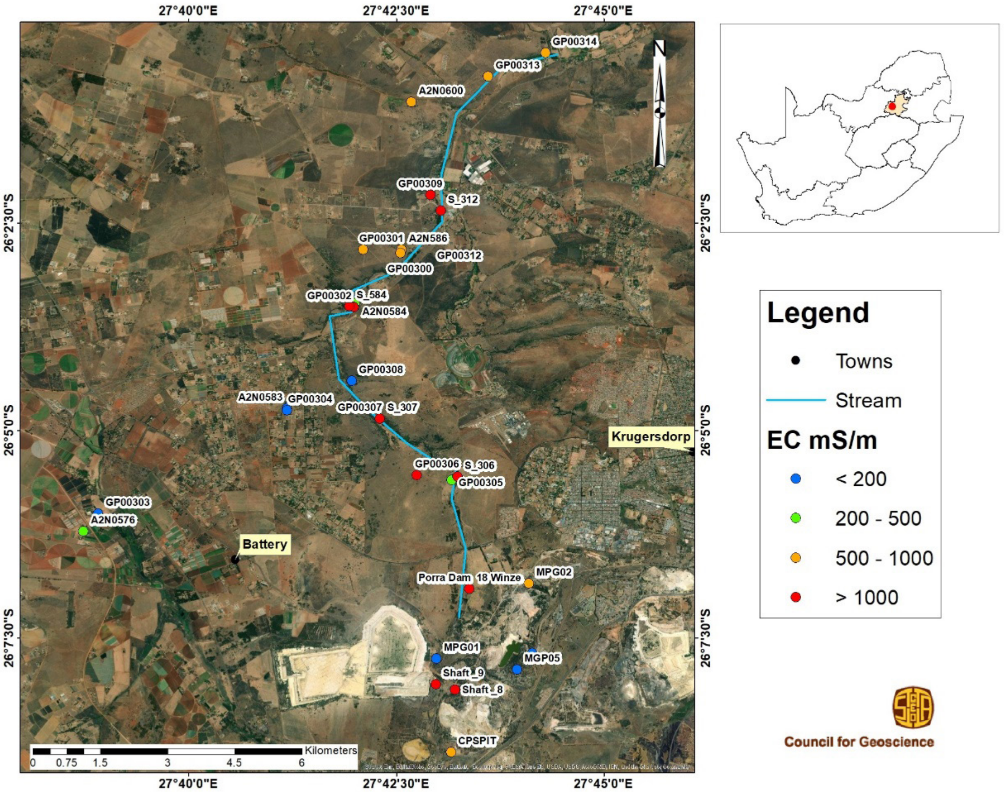

Figure 4 *Spatial distribution on Electrical conductivity*

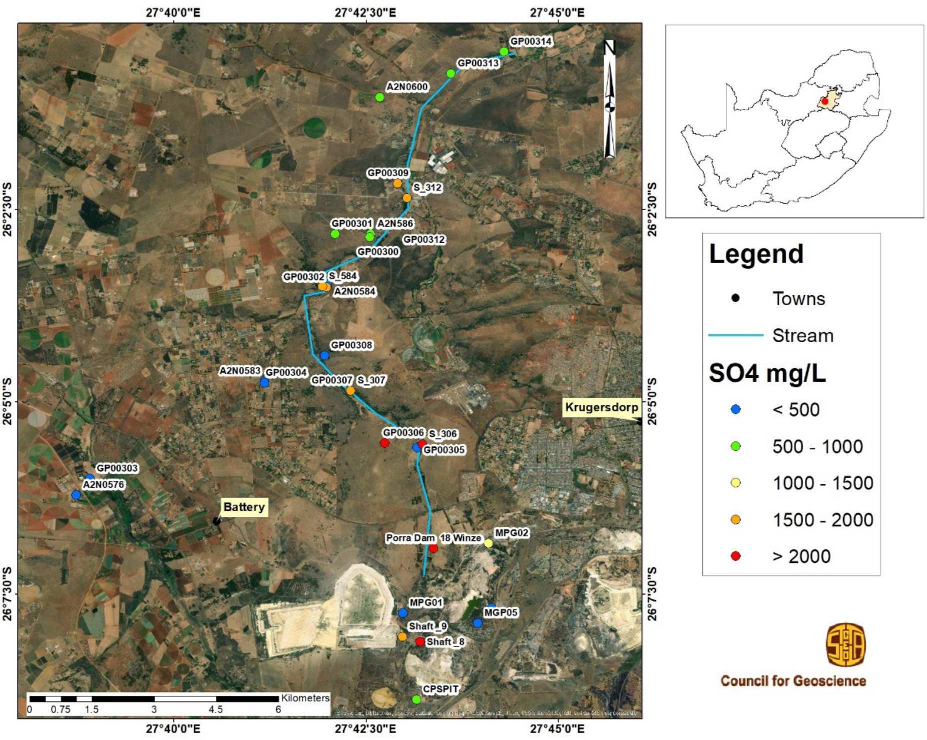

Figure 5 *Spatial distribution of Sulfate*

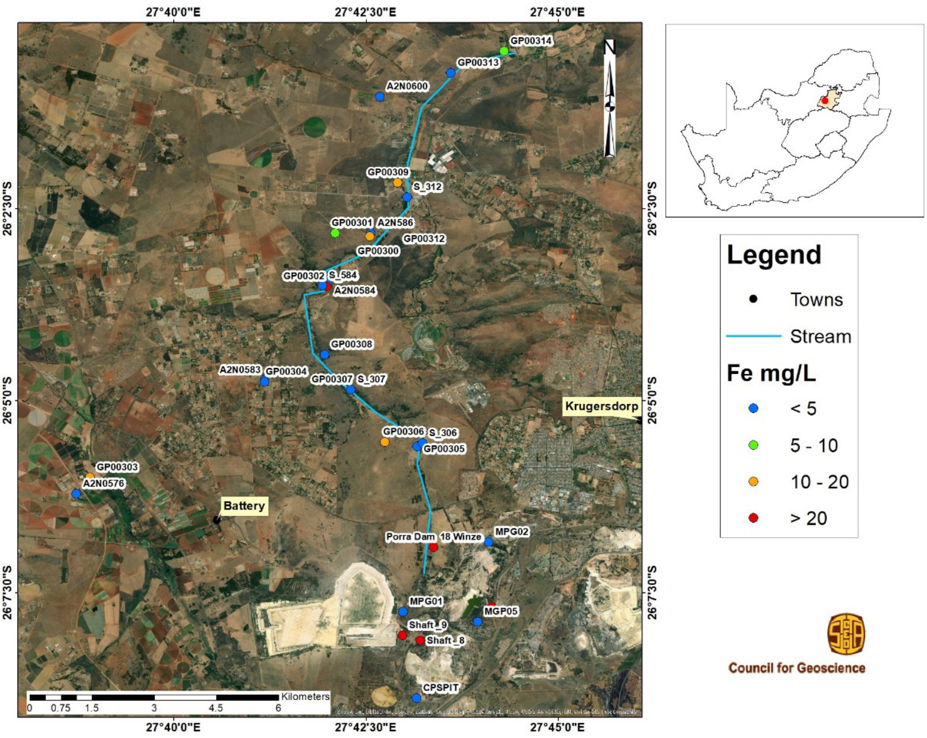

Figure 6 *Spatial distribution of Iron*

According to the SANS 2015 drinking water limits, the permitted amount of Fe is 2 mg/L. Fe levels in groundwater range from 0.23 to 42.02 mg/L, in surface water it ranges from 0.03 to 6.76 mg/L and in the shafts it ranges from 25 to 172 mg/L. The Highest Fe levels are found in the boreholes along the stream and mine void water (Figure 6).

However, the boreholes located farther from the stream showed low Fe levels. This indicates that the leachates from the mine tailings flow into the streams and impacting the groundwater resources.

Conclusions

The results show that both surface and groundwater interact with mine water due to the current mine void water level (higher than ECL). Surface water shows high SO_4^{2-}, low Fe and low pH levels, while the groundwater shows high SO_4^{2-}, high Fe and high pH. High EC in the samples is related to high SO_4^{2-} concentrations, while the low Fe concentration in the surface water identifies it as water discharged from the treatment plant, where most of the iron, but not all of the dissolved sulfate is removed.

High SO_4^{2-} concentrations were observed in the stream and shallow boreholes along the stream as compared to those farther away from the stream and deeper (> 100 m). The iron concentration in the water, both stream and shallow groundwater decrease from upstream to downstream. This could be due to mixing along the flow paths. The main water type signature in the study area is Ca-Mg-SO_4 and Ca-SO_4, which are associated with the mine water. This is corroborated by high Fe levels is an indication of contamination from mine water or mine waste.

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