Hydrochemical characterisation of mine drainage discharging into the UNESCO Fossil Hominid Site of South Africa

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Abstract

Mine drainage affects waters locally and regionally and can have far reaching environmental and economic impacts. Therefore, it is important to be able to quantify the changes in hydrochemistry and to be able to measure the extent of the impacts of mine waters to be able to assess when mitigation steps need to be taken, and to decide on the best methods of mitigation and remediation based on scientific baseline studies.

We present findings from a study area that extends from the West Rand Goldfield of the Witwatersrand, South Africa, to Hartbeespoort Dam in the North and that encloses protected national spaces, including the internationally recognised UNESCO site known as the Fossil Hominid Site of South Africa (FHSoSA), locally referred to as the Cradle of Humankind World Heritage Site (COH WHS).

The research results highlight a need for further investigations to provide realistic solutions that can be implemented to mitigate potential negative outcomes that mine drainage discharges have on the environment and economy, in-line with national and global legislation to preserve and protect world heritage areas. The findings have implications for mine water legislation and monitoring in areas of active and historic mining, and for water resource management, in particular where UNESCO sites are located.

Keywords: ICARD, IMWA, Hydrochemistry, mine water, acid mine drainage, gold mining, West Rand, Witwatersrand, Crocodile River, Cradle of Humankind World Heritage Site, Fossil Hominid Site of South Africa, UNESCO.

Introduction

Mine waters exhibit a range of pH and dissolved solutes, where waters with pH less than 6 are referred to as acid mine drainage (AMD), and waters with pH greater than 6 are classified as saline drainage (SD) or neutral mine drainage (NMD) depending on the concentration of dissolved solutes (Ficklin et al., 1992; Verburg et al., 2009).

Gold mining in the Witwatersrand Goldfield started in 1886 and over 130 years of mining history, more than 150 mining companies have mined gold from the Witwatersrand Goldfield (McCarthy, 2006, 2010). The Witwatersrand collectively hosts the world's largest gold deposits and gold mining across the Witwatersrand has shaped the South African economy (McCarthy, 2010; Durand, 2012). Gold mining has also left many mine shafts and tunnels across the Witwatersrand exposed to air and water so that oxidation and secondary mineralisation along the wall rock has been allowed develop over many decades. Although there is not connectivity between the various Goldfields of the Witwatersrand, there is connectivity within a single Witwatersrand Goldfield (e.g. the West Rand Goldfield). Gold ore deposits in the West Rand Goldfield were the first to become uneconomic to mine and the mining companies in this goldfield ceased underground mining operations and groundwater pumping in 1998. The mine void space was allowed to completely flood, and as the groundwater levels rebounded, reactions between the water with primary sulfide and secondary minerals in the presence of air formed an acidic mine drainage, that has been permitted to reach the ground surface in 2002 (Hobbs and Cobbing, 2007).

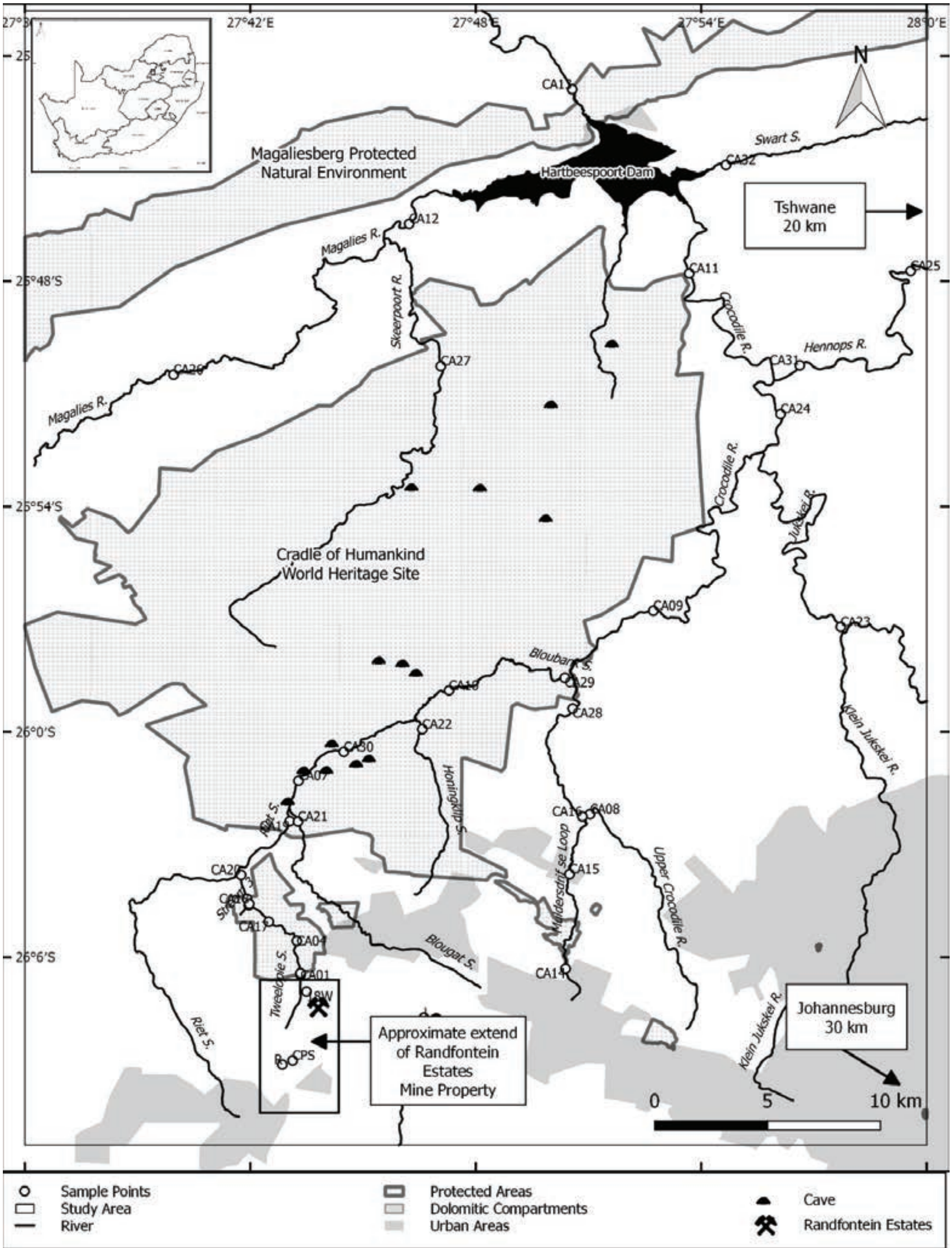

Figure 1: *Map showing study area with major rivers and sampling points used for this study as well as the protected areas and points of interest. Inset map showing the Water Management areas of South Africa, and the location of the study area.*

The volumes measured by various authors over the past 16 years has varied between 18 – 36 ML/day and continued to discharge into the Tweelopie Spruit at the boundary between the Randfontein Estates Mining Property with the Krugersdorp Game Reserve (KGR) (Figure 1) (Hobbs and Cobbing, 2007, Department of Water Affairs, 2013). In 2007, it was reported that the Tweelopie Spruit had been transformed from a non-perennial to a perennial river (Hobbs and Cobbing, 2007). The acidic mine drainage has continued to discharge into the Tweelopie Spruit for a further five years, as observed during this study in 2011-2012.

Water resources and water quality are important economic and social drivers necessary to sustain and develop the economy, and meet the supply demands for residential, health, environmental and cultural uses of a population (Price, 2003; Hobbs and Cobbing, 2007; McCarthy, 2010).

Increased solute loads in surface waters, coupled with increased precipitation of "yellow boy", or ochre, downstream from the mines presents environmental consequences that modify channel stability, channel width and bank morphology. This affects the ecosystems and agricultural land use immediately adjacent to the river e.g. cultivation of crops, water abstraction and recreational activities (Goudie and Viles, 2016). River bed armouring from the precipitation of 'yellow boy' may influence infiltration rates and aquifer recharge downstream of mines (Goudie and Viles, 2016).

The UNESCO site known as the Fossil Hominid Site of South Africa (FHSoSA) is locally referred to as the Cradle of Humankind World Heritage Site (COH WHS), is located approximately 10 km north east of the West Rand Goldfield (Figure 1). Only one of the four mine properties that make up the West Rand Goldfield drains northward, while the other three collectively drain south westward into the Vaal River catchment. All mine drainage received by the downstream UNESCO site is therefore contributed from Randfontein Estates mine property only.

The UNESCO site is a globally important cultural heritage area that hosts some of the oldest discovered hominid fossils and is a major contributor to our understanding of the evolution of modern hominids over the past 3.5 million years. The COH WHS hosts many fossiliferous sites, including the famous Sterkfontein caves where "Mr Ples" was discovered (Hobbs and Cobbing, 2007; Unesco.org, 2015; Maropeng - Official Visitor Centre, 2018; Tawane and Thackeray, 2018).

This study characterises the West Rand mine drainage to define the chemistry of the mine drainage and to determine the extent of the hydrochemical interaction within the UNESCO cultural site and beyond.

Methodology

36 locations were sampled, collected quarterly for an annual cycle during 2011/2012. Physical parameters pH, EC and temperature were recorded in the field, and samples were analysed by IC and q-ICP-MS techniques.

Median values were used to determine the hydrochemistry of surface waters across the sub-catchment draining the West Rand, using two available mine discharge classification schemes, namely the Global Acid Rock Drainage Guide (Verburg et al., 2009) and the deposit-based classification developed by the USGS (Ficklin et al., 1992; Plumlee et al., 1999). This is the first time this type of quantitative and comparative study has been performed in South Africa.

Data are described and compared with other published datasets. Surface waters are classified according to existing classification systems for mine waters, followed by the characterisation of a 'West Rand highly metalliferous AMD signature' (WR AMD) and a 'baseline signature' for the study area. The quantity of acid and metals in mine waters are presented here.

To identify and characterise the baseline signature for river water in the study area, data for each sample collected for the baseline rivers for the duration of the sampling period were plotted on GARD sulfate vs pH and Ficklin ΣMetals vs pH. Based on these figures, there exists a cluster of rivers with hydrochemistry defined with a pH greater than 6.2, sulfate concentrations less than 50 mg/L and ΣMetals < 201 µg/L. This cluster defines the baseline hydrochemistry signature for the study area during the sampling period.

Results and Discussion

Binary mixing curves were calculated between the average baseline and the 'WR AMD' signature (the first water sample taken outside of the Randfontein Estates Mine Property). This allows quantification of the WR AMD component at various points downstream of the point source to be quantified (Fig 2).

Trends associated with precipitation between Randfontein Estates Mine Property and the exit of the Tweelopie Spruit from the Krugersdorp Game Reserve plots sub-parallel to the binary mixing curve, whereas CA07 and downstream of this location within the COH WHS plot away from the mixing curve. This indicates that a more complex set of processes is occurring within the COH WHS other than mixing of two end-member compositions. The mine drainage component at CA19 is quantified at ~75% which confirms that only a small reduction in the AMD signature occurs between Randfontein Estates Mine Property and the entry into the COH WHS (a length of 10.4 km). Yet there exists only an ~10% mine drainage signature at CA07 (adjacent to the Sterkfontein Caves), which is offset to the mixing curve. This indicates that within the first 2.2 km of entry into the COH WHS there is a ~65% decrease in the AMD signature.

The mine drainage signature is observable between sampling position CA09 and CA24 (a maximum distance of 54.2 km from source) according to the sulfate concentrations which are persistent (Figure 2), whereas the mine drainage signature is observable until CA07 (12.6 km from source) according to ΣMetals (Figure 2).

Conclusions

The results of this work with the use of these classifications shows that the mine drainage generated from the WR AMD can be described as an acidic (pH = 3.19 to 3.36), highly metalliferous (ΣMetals = 2564 to 3141 µg/L) mine drainage, and with (SO_4^{2-} = 3217 to 3532 mg/L). This mine drainage has been allowed to discharge continuously into the environment for the past sixteen years following the flooding of mine voids in the West Rand Goldfield. The results confirm that the WR AMD signature is traceable through the

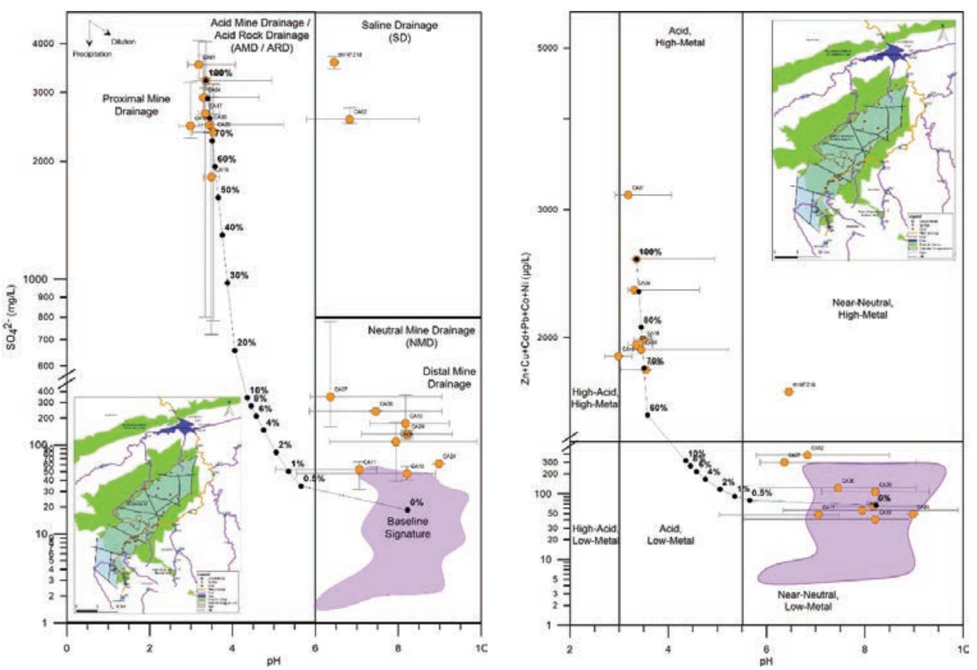

Figure 2: *2a (GARD Classification showing SO42- vs pH load evolution of the main tributary from its source in the West Rand to the outlet with Hartbeespoort Dam, map shown in inset. Binary mixing curve superimposed between the AMD point source (CA03) and an average baseline signature composition, see map shown in inset.) 2b (Ficklin Classification showing ΣMetals vs pH load evolution of the main tributary from its source in the West Rand to the outlet with Hartbeespoort Dam, map shown inset. Binary mixing curve superimposed between the AMD point source (CA03) and an average baseline signature composition, see map shown in inset.)*

COH WHS with a maximum of up to 54 km (based on sulphate that persistently remains in the dissolved phase) downstream of the Randfontein Estate Mine Property, which is the sole source of mine discharge to the area. In addition to the surficial contamination, there is evidence of groundwater – surface water interactions within the karstic terrain of the UNESCO FHSoSA mostly from recorded evidence of previously non-perennial rivers becoming perennial rivers.

The findings highlight the need for mitigation of WR AMD discharge into the environment and appropriate remediation to be performed along the affected river courses. On-going monitoring and further research is needed to determine the possible consequences that the WR AMD discharge has on the environment and on yet undiscovered fossils within the cave systems of the karstic UNESCO cultural site. Research is needed to provide realistic solutions that can be implemented to mitigate potential negative outcomes identified and that are in-line with national and global legislation to preserve and protect this world heritage area.

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