Stream sediment geochemistry of the areas impacted by mining around Emalahleni (formerly known as Witbank), South Africa: Fingerprinting AMD potential point sources

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Abstract Emalahleni is located within the province of Mpumalanga, and is where most of the coal mining activities dominate the southern part of the Olifants catchment area. This paper presents the findings of the study of the severity of the mining impacts on the water resources and the ecosystem of the areas around Emalahleni, using SXRF, ABA, ICP-MS and IC analytical techniques. Based on 39 sediments samples, four AMD hotspots areas (PCA 1 to 4) were identified and fingerprinted using the Principal Component Analysis. The main pollution point sources were the coal mines (abandoned and operating) and the ferrochrome processing plant..

Keywords Stream sediments, AMD, Principal Component Analysis, Emalahleni, South Africa

Introduction

The subject of this study is a B1 sub – catchment of the primary Olifants River catchment. The Olifants River catchment has an area of approximately 87000 km^2 and is located in the northern part of South Africa straddling the border with Mozambique. It is one of the most polluted catchment in South Africa because of anthropogenic activities which include, coal mining activities in Emalahleni, industrial activities such as ferrochrome processing for vanadium extraction together with agriculture. The Council for Geoscience in collaboration with the Department of Mineral Resources launched a project to investigate the severity of the mining impacts on the water resources and the ecosystem of the country, using a catchment-based approach.

Stream sediments and water samples are used in this study for identifying the potential mine polluted areas with an objective of remediation/rehabilitating the impacted areas. Stream sediment geochemistry is commonly used for mineral exploration and in assessing the environmental concern areas. This is because sediments are sink of trace metals and can also act as a source of metals depending on the change of environmental conditions. In addition, stream sediment geochemistry can be used to estimate point source of contaminants that upon being discharged to surface waters are rapidly absorbed by particulate matter, thereby escaping detection by water monitoring (Forstner 2004, Salminen *et al.* 2005, Segura-Munoz *et al.* 2006). The screening study revealed anomalous values of Fe, Mn, Cr, Pb, Zn, U and Al in sediments in B1 catchment areas A and C, which forms part of the drainage area of the Emalahleni. The sediments from the screening level study revealed the sediments had a potential to generate acid (Netshitungulwana and Yibas 2012). Chrome signatures were thought to be associated with the processing of ferrochrome in and around the Witbank and Middelburg towns (Netshitungulwana and Yibas 2012).

According to Ashton *et al.* (2001), water bodies containing high levels of sulfate, iron, aluminium, cadmium, cobalt and radioactive elements such as uranium as those identified in the Olifants River catchment suggest that

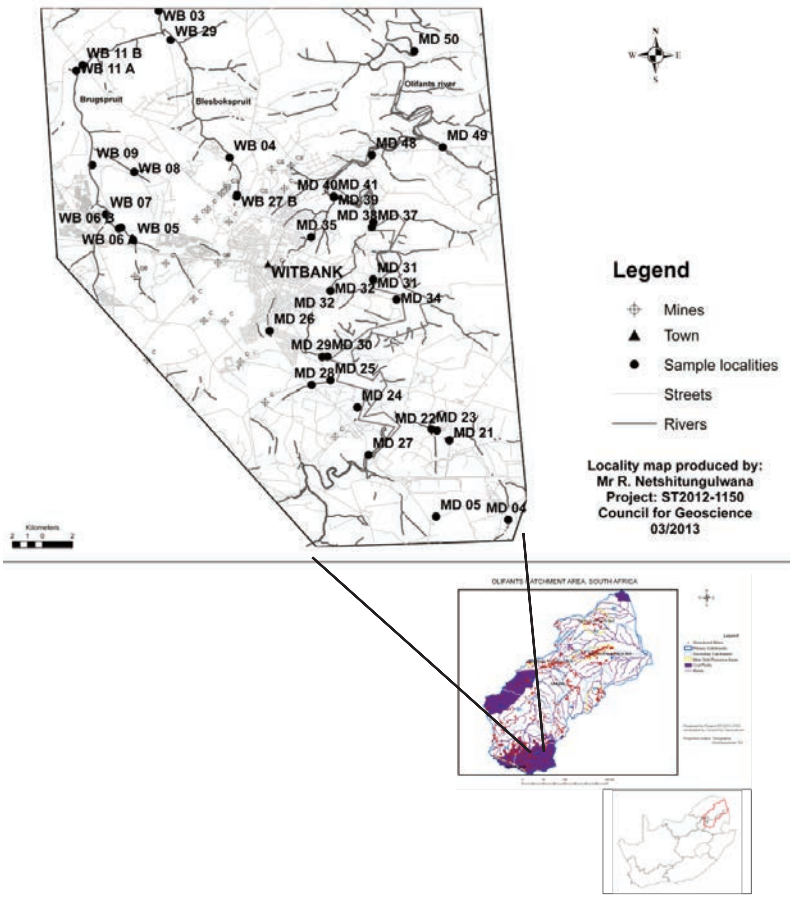

Fig. 1 *Sample locality map of the Emalahleni study area, within the Olifants river catchment area in South Africa.*

contamination could be associated with mine polluted water, especially AMD. Surplus metals that escape to the environment as a result of mining or agriculture have devastating consequences including degrading the quality of water systems, destruction of heritage sites and endangering human health. McCarthy and Pretorius (2009) raised environmental concern for the future of the Witbank Coalfield once the coal reserves have been fully exploited. To date some of the abandoned mines are flooded and leaking acid water and the rivers are loaded with toxic metals in sediments and water.

Methods

A total of 39 stream sediment and 30 water samples were collected for various analyses and tests which include SXRF in chemical composition, ICP-MS and IC analyses of metal loadings of sediments, ICP-MS and IC cations and anions, XRD and SEM for mineralogical composition and, ABA for AMD potential assessment. ABA was done only on WB’s samples. For sediments metal loadings, the data were plotted to understand the stream sediment compositional variation within the catchment and its relationship with the various mining activities in the catchment. Areas of elevated concentrations of selected metals are then identified for further investigations on environmental issues.

Results and Discussion

The entry of Al, Fe, Mn, Cu, Cr, V and As of the sediment chemistry to the Principal Component Analysis (PCA) has fingerprinted and discriminated the Emalahleni areas into PCA 1 to PCA 4 (Fig. 2).

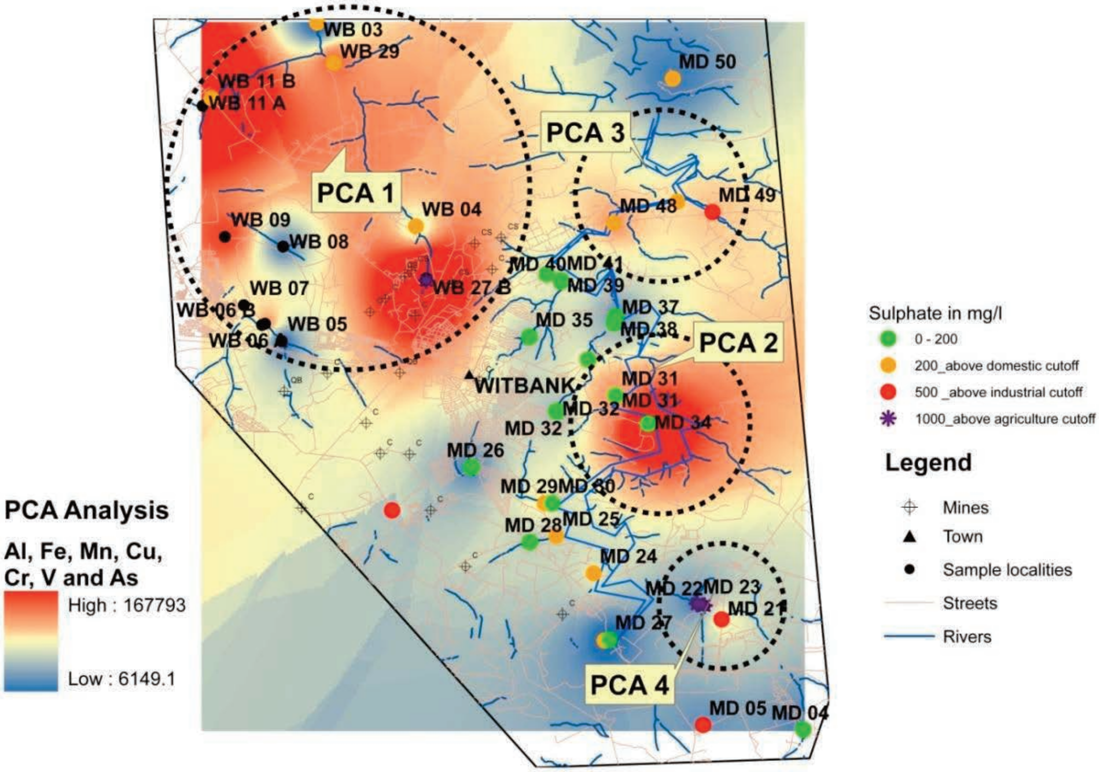

***Fig. 2** Area PCA1 to PCA4 discriminated by the Principal Component Analysis, the metals entered are Al, Fe, Mn, Cu, Cr, V and As.*

Area PCA 1

The 14 samples collected from this area are distributed within the Brugspruit and Blesbokspruit rivers which are both tributaries to the Klipsruit River. The upstream activities include ferrochrome processing plant and abandoned underground coal mine. Based on acid base accounting results, the majority of the samples (except WB04, WB06 and WB07) is classified as potentially acid generating (Fig. 4). The acid potential of most of the samples exceeds the neutralization potential. The acid potential (AP) ranges from 1.2 kg $CaCO_3$/ton to 123.7 kg $CaCO_3$/ton, whereas neutralization potential (NP) ranges from -15.3 kg/ton $CaCO_3$ to 28.1 kg $CaCO_3$/ton. These samples show average paste pH value of 4.86, paste EC of 2613 and 1.09 % of sulfur content. The Paste pH and the EC indicate the status of the pore water which in this area is of low quality. This observation is further supported by the high concentration of Mn, Pb, Mg, Na, Cd and SO_4^{2-} in the water samples which exceeds the South African drinking water quality and industrial limit guidelines. This result indicates that the previous water pollution control works constructed by the Department of Water Affairs (DWA) around 2004 following the report that AMD seeps from an abandoned mine into nearby Blesbokspruit and Brugspruit streams by Bell *et al.* (2002), does not seem to improve the situation.

Blesbokspruit

Samples collected upstream on the outflow side of the constructed AMD ponds on the Blekbokspruit have paste pH ranging from 2.83 to 3.16, paste EC range from 840 to 1171, total sulfur content range from 0.35 % to 0.4 % and have acid producing potential (Fig. 4). The downstream sediments show paste pH range from 4 to 5, paste EC range from 1934 to

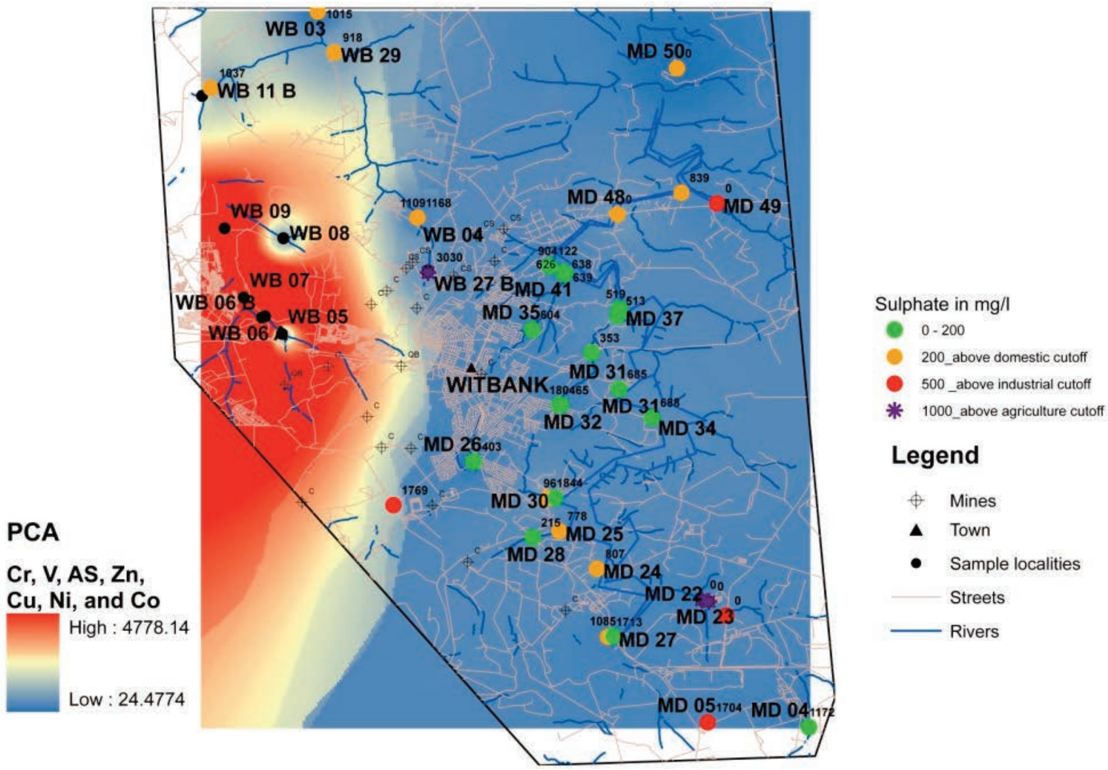

Fig. 3 *Principal Component Analysis, the metals entered are Cr, V, As, Zn, Cu, Ni and As.*

2210, and total sulfur content range from 0.04 to 2.47 %, and have acid producing potential. For the water quality, the SO_4^{2-} concentration range from 459 mg/L to 3030 mg/L, which is above South African water quality guidelines for the domestic, industrial and irrigation uses (Fig. 2). Fe, Al, Mn and Mg are above the South Africa drinking water quality guidelines. The data suggest that Blesbokspruit stream water as well as sediments are severely contaminated and has not improved since Bell *et al.* (2002), reported the poor water quality status of the streams. The sediments are rich in Fe, Al, Mn, Cu, As, Cd and Pd metals. The acid generating potential sediments can be attributed to AMD sources that are situated upstream as a result of runoffs of coal spoils and precipitates. The sediments either generated AMD and released metals into the stream or are in the process of generating AMD and releasing metals. The relatively low concentrations of these metals downstream may be attributed to a possible adsorption of the metals into the wetland of the Blesbokspruit.

Brugspruit

Stream sediment samples collected upstream (WB11A) and downstream (WB11B) of the Brugspruit show sulfur content of 2.24 % and 0.05 %, paste pH values of 5.82 and 5.7, paste EC values of 262 and 6620. This data clearly shows the negative impact of the mining in the area. The samples with higher sulfur content show relatively low EC, whereas the samples with low sulfur content show higher paste EC, suggesting their current state in the oxidation and metal release processes. The high EC value reflects the upstream AMD sources. The elevated concentrations of Cr, Ni, V and As in Fig. 3 can be attributed to the Bushveld PGE mining, which is represented by the Vanadium processing plant. For the Bushveld PGE material,

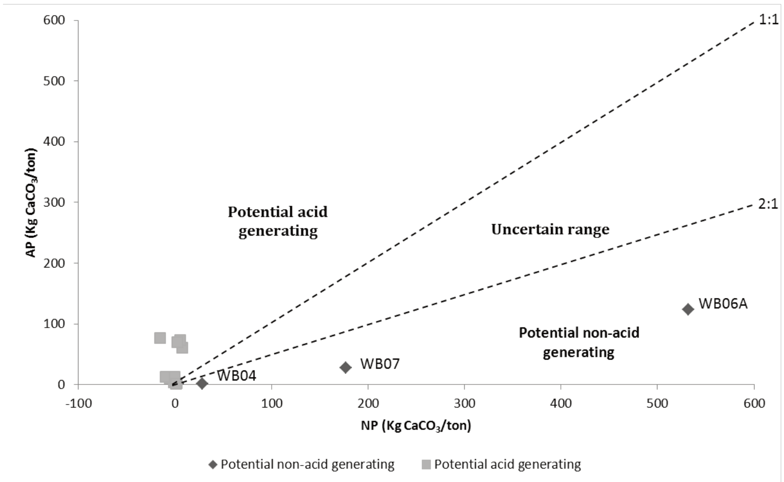

Fig. 4 *Acid Potential (AP) vs. Neutralization Potential (NP) graph for PCA 1 area indicating areas of likely acid generation and unlikely acid generation for open system; the line 1:1 means above this acidification is likely and 2:1 line means below this acidification unlikely.*

the highest Cr, Ni and V concentrations in the sediments were 978, 430, 1738 mg/kg respectively with As concentrations range from 2 to 22 mg/kg. Poor water quality marked by SO_4^{2-} level of 362 mg/L in downstream sample is above the acceptable South African drinking water and above industrial category 3 quality standards. This reveals the severity of the pollution by mining activities of the Brugspruit. The main pollution sources are probably the coal mines (abandoned or operating) and the ferrochrome processing plant.

Area PCA 2 and 4

PCA 2 area is located within the Witbank Dam and PCA 4 in the southeast of the dam. The metal loadings in the sediments are marked by high levels of Al, Mn, Fe, As, Cu and radioactivity metals such as Pb, Th and U.

The water samples (MD24, MD25, MD30, MD31 and MD34) collected from within the dam have an average pH of approximately 7.5 and the SO_4^{2-} level range from 19 to 235 mg/L, with two samples above the current South Africa water quality drinking water and industrial category 3 quality guidelines.

Brown, (1997), observed that approximately 70–80 % of the SO_4^{2-} load in the Witbank Dam catchment emanates from diffuse sources and can be attributed to coal mining. This increase in diffuse pollution has resulted in a gradual decline in water quality in the Witbank Dam catchment. Water quality in the dam itself has declined from 50 mg/L SO_4^{2-} and 100 mg/L TDS in 1997 to over 150 mg/L SO_4^{2-} and 400 mg/L TDS to date. The dam does not show any signs of improvement since 1997. The TDS value (calculated from the EC) from the 5 samples in the dam range from 438 mg/L to 540 mg/L, showing no signs of improvement since 1997. Pollution in the Witbank Dam emanate from the nearby coal mines (*e.g.* Area discriminated as PCA4), since SO_4^{2-} is a good indicator of salinity arising from this form of pollution.

Area PCA 3

PCA3 is an area downstream of the Witbank Dam (MD47, MD48 and MD49). The metal loadings on the sediments include Fe, Al, Mn, As, Cr, Cu and Mg. The water samples have SO_4^{2-} concentration range from 242 mg/L to 860 mg/L, which were found above the South African water quality drinking (MD47 and MD48) and industrial (MD49) guidelines. The metals of Mg, Mn, Pb, F, Cu, and Ca in the area were also found above the South African drinking aquatic ecosystem and industrial limit guidelines. The main pollution source in the area may be attributed to the coal mines upstream, and probably the coal mines west of the PCA3.

Conclusions

The use of stream sediment and water chemistry (ICP-MS, IC and ABA) of samples collected systematically upstream and downstream of potential pollution source mine infrastructures and metallurgical plants is found to be a useful tool to fingerprint and quantify the severity of pollution impacts. In this study, a pollution resulting from the coal mines and ferrochrome processing plants is clearly and characterised. Four impacted areas (hot spots) have been identified around Emalahleni area. The approach adopted herein suggests that the stream sediment chemical data can be accredited in characterising or fingerprinting impacted areas to an extent that liability in future can be apportioned. The main pollution point sources were the coal mines (abandoned or operating) and the ferrochrome processing plant located around the Emalahleni areas. For the affected areas, the SO_4^{2-} level exceeds that of the South Africa industrial and domestic water quality guideline, whereas Mg, Mn, Pb, F, Cu, and Ca were also found exceeding the aquatic ecosystem guideline.

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