Stream sediment geochemistry of the Olifants catchment, South Africa: Implication for acid mine drainage

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Abstract

The Olifants primary catchment area, which straddles the border between South Africa and Mozambique, has a total area of approximately 87000 Km^2. The South African portion makes up 60 % (60000km^2) of the Olifants and in turn straddles the provinces of Mpumalanga and Limpopo. Although industrial and agricultural activities are also important, the contribution of pollution from the mining activities within the catchment is significant as the result intense mining activities of various mineral commodities such as coal, gold, base metals and other mineral commodities with in the catchment area and yet not fully quantified. A multi-disciplinary project is underway to investigate the severity of the mining impacts on the water resources and the ecosystem of the Olifants catchment area. One of the techniques adopted at the screening level pollution assessment to identify hotspot sites with respect to mine pollution is stream sediment and water analysis. Based on SXRF data of 118 stream sediment samples, 19 potentially impacted areas have been identified for further detailed investigation. The approach adopted herein suggests XRF data of stream sediment samples can be used as a preliminary screening tool for identifying potentially impacted areas for detailed investigation.

Keywords: stream sediments, acid mine drainage, Olifants primary catchment area, South Africa.

Introduction

The Olifants primary catchment area in South Africa which straddles the provinces of Mpumalanga and Limpopo is a home of intense mining activities of various mineral commodities such as coal, gold and base metals in South Africa. It is subdivided into nine sub-catchments (Figure 1).

Recently, environmental issues in the Olifants catchment area have been the subject of intense public scrutiny. Despite obvious signs that water quality in the Olifants River has been deteriorating as a result of industrial, mining and agriculture activities, the trigger for episodic fish and crocodile deaths in the river system remains elusive (de Villiers and Mkwelo, 2009). Although industrial and agricultural activities are also important, the contribution of pollution from the mining activities within the catchment is significant as the result intense mining activities of various mineral commodities such as coal, gold, base metals and other mineral commodities with in the catchment area and yet not fully quantified. The impacts are more evident in the Witbank area where active and derelict coal mines are abundant. The other areas within the catchment where environmental damage has occurred on a significant scale include the asbestos mining areas of the Penge and other areas in Mpumalanga, the alluvial heavy mineral sand operations and areas of extensive smaller-scale mining such as the Barberton and Giyani Greenstone Belts and the Pilgrims' Rest Goldfield.

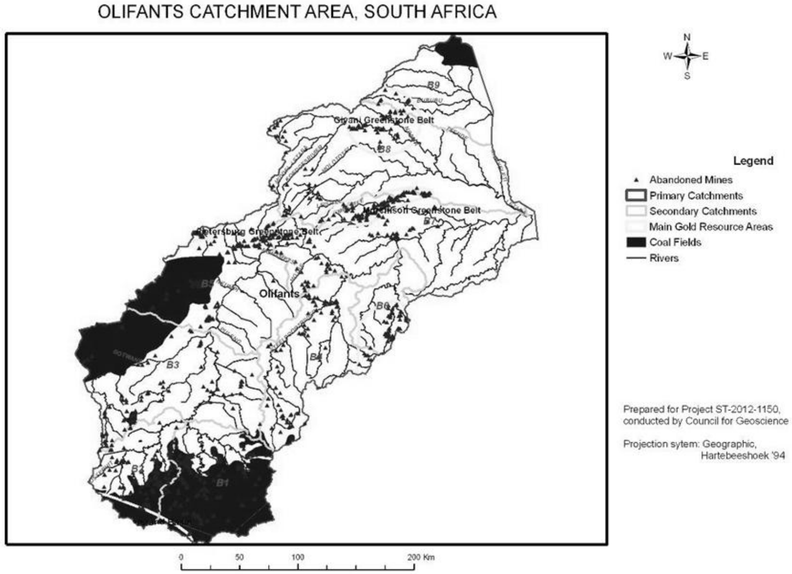

Figure 1 *The Olifants catchment area, South Africa.*

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 on catchment by catchment based approach. The Olifants primary catchment area has been identified to be studied priory due to the density of mining activity within its territory.

Stream sediments samples are commonly used for mineral exploration and in assessing the environmental concern areas (see for example Salminen *et al*., 2005). They are also considered as a sink for trace metals, but they can also act as source of metals depending on the change of environmental conditions (Segura-Munoz *et al*., 2006). Stream sediment analysis can be used to estimate point source of contamination that, upon being discharged to surface waters, are rapidly absorbed by particulate matter, thereby escaping detection by water monitoring (Forstner, 2004).

Stream water and sediment sampling for metal loads and ecotoxicological impact analysis, hydrological and hydrogeological investigations, among other tasks, have been conducted with the aim of assessing metal loading and losses and understand the interactions of metals in stream water and bed sediment as well as to compare stream water with national water quality standards. The information from all these tasks will be used to identify appropriate remedial action/s.

This paper discusses the use of stream sediment chemical data as a tool to assess metal loading from the mining activities and to identify the mining pollution sources through metal signatures.

Methods

A total of 118 stream sediment samples were collected for various analyses and tests which include XRF for chemical composition, ICP-MS and IC analyses of leachates for potential water leachability, XRD and SEM for mineralogical composition and, ABA for AMD potential assessment This paper, however, discusses only the XRF data generated using Philips PW 1606 Simultaneous X-ray Fluorescence Spectrometer (SXRF). The SXRF 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 concentration of selected metals are then identified for follow up studies.

Results and Discussion

On the basis of the SXRF data 19 areas of concerns have been delineated throughout the Olifants primary catchment area and grouped in terms of the nine catchment areas.

- Metal signatures and AMD generating potential of stream bed sediments
- B1 (Little Olifants and Riet) catchment area

The Little Olifants catchment drains largely on the Witbank Coalfields and surroundings with many active and abandoned coal mines. Three areas with in this catchment are identified as potentially impacted areas. These three areas show elevated concentrations of Fe Mn, Cr, Pb, Zn and U. As and Al are elevated only in areas A and B whereas Co is elevated only in Area C (Figure 2). The stream sediment that makes up Area A can be classified as potentially acid-producing based on the ABA results which showed NNP values of -8.65 and -8.24 and paste pH of 5.8 and 5.1. Area B shows elevated signatures of similar metals as that of Area A except differences in the order of relative concentration of certain elements. It is also potentially acid-generating in terms of its ABA potential in spite of alkaline paste pH. The chrome signature may be associated with the processing of the ferrochrome in and around the Witbank and Middleburg towns in addition to possible contribution from sulphide minerals in the coal seams and in the over- and inter-burden lithologies.

Arsenic is considered the most toxic element even at concentration as low as 3 ppm (Irwin et al. 1997 and references therein). As a result the arsenic concentration of between 8 and 55 ppm in this study can be considered a severe pollution in the sediments.

B2 (Wilge) catchment

In the Wilge catchment, four anomalous areas are identified. Two of these areas (A and D) show elevated concentrations of Al-Fe-Mn-Ti-Ni-Co-Cu-Zn-V-Pb whereas Area-B registers elevated signature of Al-Mn-Cr-Cu whereas Area C is characterised by elevated signature with respect to Mn-Ni-Zn-Co (Figure 3). Mn is elevated in all the four areas, whereas Al, Ni, Co, Cu, Zn are elevated in three of the four areas. Fe, Ti, V and Pb are elevated in areas A and D; whereas U is elevated only in area D. The source of the stream sediment of the Wilge catchment area are Witbank coalfield in the east and small scale mines of the heavy mineral sand and their host rocks according to South African minerals data base (SAMINDABA) of the Council for Geoscience.

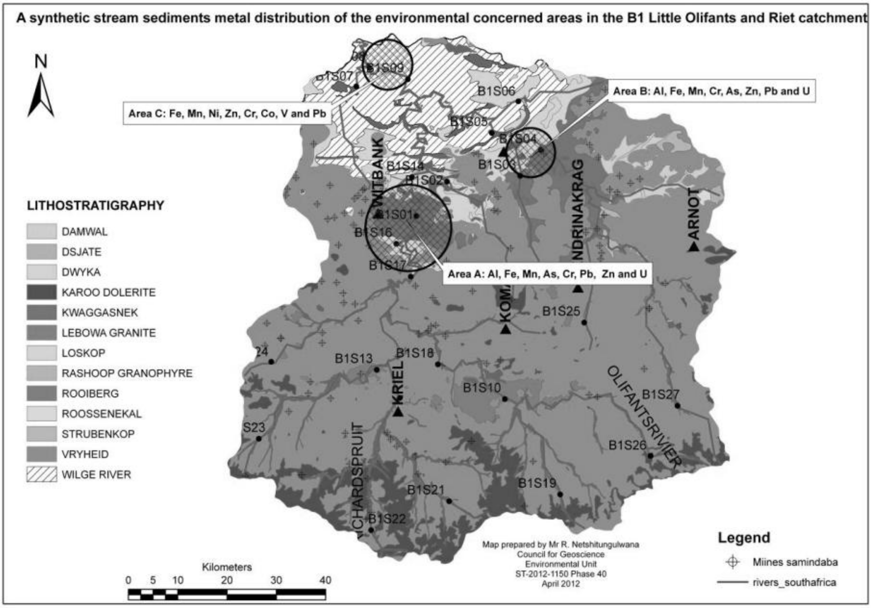

Figure 2 *Synthetic stream sediment metal distributions of the environmental concern areas.*

The B4 (Steelpoort catchment)

Areas A and B in the Steelpoort show elevated signatures of Ni-Zn-As-Co-Fe-Mn and Ni-Zn-Pb-U-Co-Cr-Fe-Mn respectively. Area- C shows elevated signature of Ni-Zn-Pb-U-Co-Cr-Fe-Mn whereas Area D registered elevated signatures of Zn-Co-Cu-Ni-V-Fe-Mn. Area- E shows elevated signatures of Ni-Zn-U-Co-Cr-Fe-Mn. Ni, Zn, Pb, Co, Fe and Mn are elevated in all of the five areas. Cr is elevated in areas B, C and D whereas U is elevated in areas B, C and E. Pb is elevated in areas B and C. High concentration of As is found only in Area A.

The underlying geological formations beneath the Steelpoort catchment consist predominantly of mafic rocks of the Bushveld Igneous Complex and the Transvaal Supergroup (Figure 4). The elevated metals in Area A and particularly As could be attributed to the gold mines in the Sabie Pilgrim’s Rest area, since. Area A of

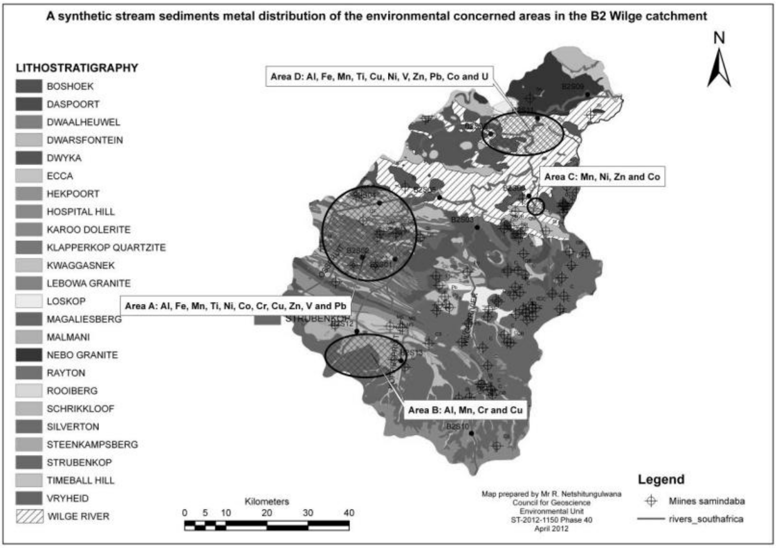

Figure 3 *A synthetic stream sediments metal distribution of the environmental concerned areas in the B2 Wilge catchment.*

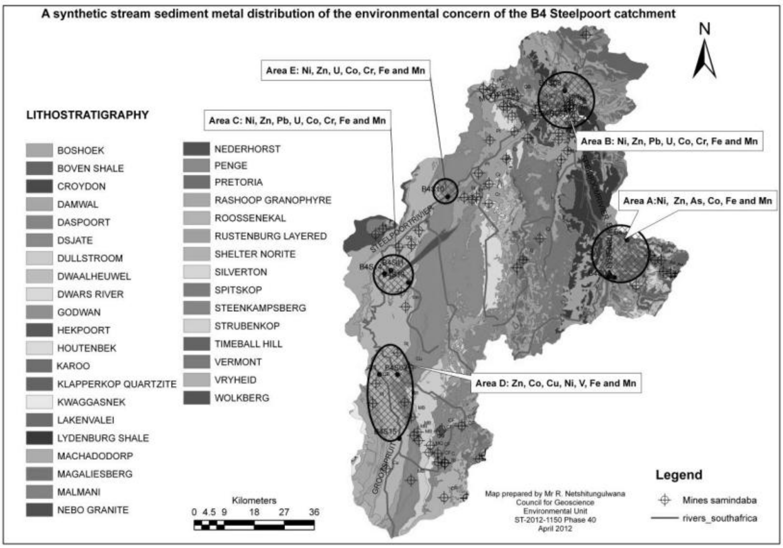

Figure 4 *A synthetic stream sediment metal distribution map of the environmental concern areas of the B4 Steelpoort catchment.*

B5 (Middle Olifants) catchment area

Steelpoort catchment shows NNP value of -3.83, -9.55 and -1.02 respectively, and can be classified as acid producing though with alkaline paste pH. The presence of Cr in area C could be from the mines associated with the Critical Zone of the Bushveld Complex.In the Middle Olifants catchment, Area-A has elevated signatures of Al-Pb-Zn associated with the Sn and Cu mines of the Rooiberg Felsites. Area-B has elevated metal loadings of Al-Cu-Ti-Pb-Zn (Figure 5). NNP value of -14.03 though with alkaline paste pH of 8.8 can be classified as potentially acid generating.

B6 Blyde catchment area

The Blyde catchment drains the rocks of the Timeball Hill Formation of the Transvaal Supergroup. Area-A has elevated metals of Al-Fe-Mn-Ti-As-Cu-Ni-V-Zn-Pb-Co-U. Many of the gold mines are hosted in Malmani dolomites, and to a lesser extent in the Timeball Hill Formations. The presence of As and other sulphide metals probably points to the gold source upstream. The presence of probable toxic Pb and U in the sediments may points to the use of lead concentrated fertilizers by agricultural activities.

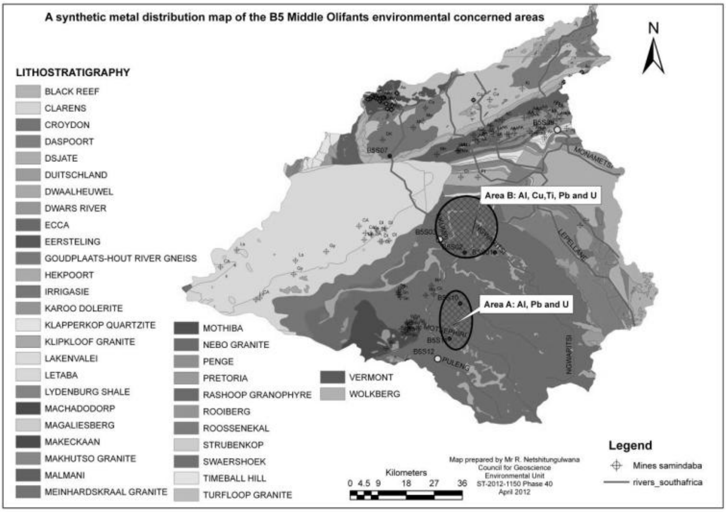

Figure 5 *A synthetic metal distribution map of the B5 Middle Olifants environmental concerned areas.*

B7 (Selati, Timbavati-Klasserie) catchment area

Area-A, in the B7 catchment, which is underlain by the Murchison Greenstone rocks shows elevated signature in Al-Cr-As-Cu-Ni-Co. The presence of As may point to the gold mines upstream as source. Area-B which is underlain by the rocks of the Phalaborwa Carbonatite Complex where the world class copper deposit is mined shows elevated signature in Al-Cu-Pb (Figure 6).

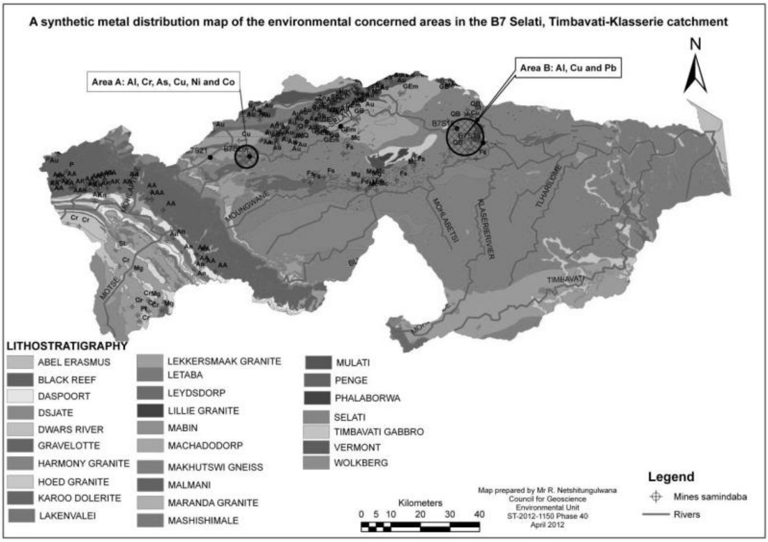

Figure 6 *A synthetic metal distribution map of potential impacted areas in the Selati, Timbavati-Klasserie catchment.*

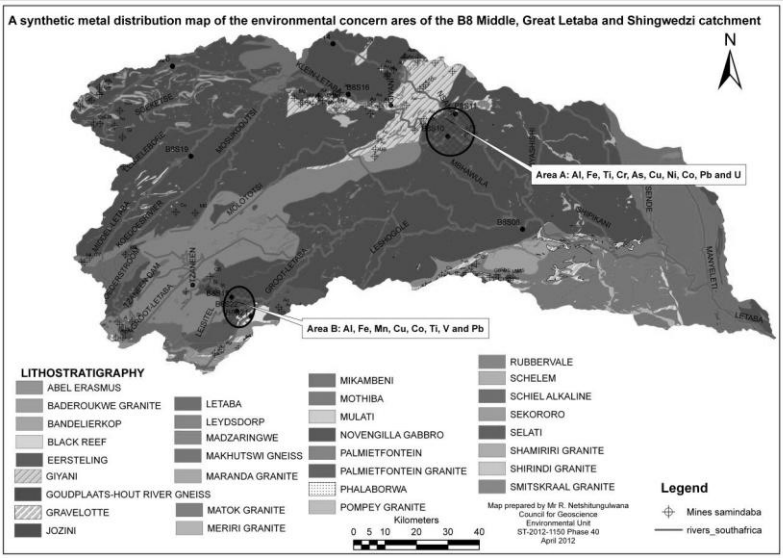

Figure 7 *A synthetic metal distribution map of potentially impacted areas of the B8 catchment area.*

The Cr and Ni signature may be associated with the mafic or ultramafic rocks of the Murchison Greenstone Belt. NNP value of -0.26 and -3.83 may suggest potential AMD generating capacity though the paste pH of 8.2 and 7.2 dilutes this suggestion.

B8 (Middle, Great Letaba and Shingwedzi) catchment area

In the B8 catchment, Area-A, underlain by the rocks of the Giyani greenstones which hosts Klein Letaba and Nsama gold mines, is characterised by elevated Al-Fe-Ti-Cr-As-Cu-Ni-Co-Pb-U (Figure 7). The presence of As and other sulphide metals points to the gold mine areas as source. The Lusunzi Ultramafic complex and the Giyani Greenstone Belt may have contributed to Cr, Ni and Cu concentrations. Area-B shows elevated signatures of Al-Fe-Mn-Cu-Co-Ti-V-Pb.

Conclusions

Based on SXRF data of stream sediment samples in the Olifants primary catchment area, 19 potentially impacted areas have been identified for further detailed investigation. This suggests the XRF major and trace element data of stream sediment samples can be used as a preliminary screening tool for identifying potentially impacted areas for detailed investigation.

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