Current impact of mining alkaline rocks on Save River water quality in Zimbabwe

M. Meck a,b,*, J. Athopheng b, W.R.L. Masamba c

a Department of Geology, University of Zimbabwe, P.O. Box MP187, Mt. Pleasant, Harare, Zimbabwe
b Environmental Science Department, University of Botswana, Private Bag 80004, Gaborone, Botswana
c Harry Oppenheimer Okavango Research Centre (HOEORC), University of Botswana, Box 285, Mabata, Botswana

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ABSTRACT

Alkaline rocks (phosphate deposits in particular) of igneous origin are currently being mined in Zimbabwe. Exploitation of these deposits, which are associated with metals and non-metals, provides a potential for changing the river water quality in the surrounding areas by increasing metal and phosphates levels in the water, thereby endangering the beneficial use of the river. The aim and objectives of this paper are to enumerate the current impacts associated with mining alkaline rocks on Save River water quality in Zimbabwe using the Dorowa mine as a case study. Though there are several impacts associated with the mining of alkaline rocks, this paper deals only with impacts on water quality.

A preliminary assessment of the water quality in the Save River downstream of the Dorowa phosphate mine showed an increase in conductivity, iron content, manganese content, nitrates and hardness when compared to those taken before mining activity began. However, there was no notable increase in phosphate and metals except for Fe and Mn. A plausible explanation for the low phosphate values in the water is that the phosphates are precipitating and settling as sediments. Phosphate is known to effectively remove metals from the surface water through the formation of metal–phosphate minerals. Thus, various pollutants may be adsorbed into sediments accumulated on the bottom of the river. These sediments may accumulate pollutants over long periods and act as new pollutant sources to the overlying water when phosphate desorbs from sediments due to changes in water conditions. Therefore, the sediments can act as a source of water pollution in the future.

1. Introduction

This study evaluates the impact of mining alkaline rocks on the Save headstreams in Zimbabwe. Mining is known to impact the environment in several ways and different types of mines impact the environment differently (Mawira, 2003). Most mining activities in Zimbabwe take place in Achous greenstone belts, spread throughout the country. Consequently, most of the work to assess mining impact has concentrated on these rock types. Zimbabwe also hosts mineral deposits in other rock types of other geological ages. Of particular interest (and discussed in this paper) is the occurrence of alkaline igneous rocks of Mesozoic age. Though Walsh et al. (2001) describe several carbonatites, there are only six alkaline ring complexes in Zimbabwe of which four (Matundza, Chishanya, Shawa and Dorowa) are host to phosphate deposits and occur in the Save catchment area. Three of these complexes are currently being mined and there are plans to start mining the fourth one. Exploitation of these phosphate deposits provides a potential for changing the water quality of surrounding areas (Modesti et al., 2001; Mallaunsky et al., 2002). The alkaline rocks being mined in the Save catchment are associated with elements (Cu, Ga, W, Mo, Mg, F, Co, Fe and Zn) that can affect water quality. Table 1 shows the alkaline greenstone complexes in the Save catchment, their sizes, the associated ore minerals and the elements likely to impact on water quality.

Each ring complex is located less than a kilometer from the Save River or its tributaries and so run-off from the mines and their dumps can easily reach the main river system. This is of concern because the communities around the Save River have no or few alternative water sources to the Save River for their uses which include domestic use, stock watering, recreation, fishing and irrigation.

There are several impacts associated with mining of alkaline rocks on water quality in the Save basin in Zimbabwe and literature indicates that there is potential for other future impacts. This paper aims to enumerate the current impact associated with mining alkaline rocks on Save River water quality in Zimbabwe by bringing to light the current water quality problems at the Dorowa mine. The scope of the paper is limited to impacts on water quality. Data for sediments were acquired for the sole reason of explaining...
Table 1
Approximate size, ore and accessory minerals of the alkaline ring complexes in the Save catchment with a list of potential risk elements derived on the basis of the classifications by Middle (1994) and that of Dallas and Day (1995).

<table>
<thead>
<tr>
<th>Complex</th>
<th>Diameter (km)</th>
<th>Ore and accessory minerals</th>
<th>Elements that can impact water quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matandaie</td>
<td>6</td>
<td>Chalcocite, chalcopyrite, wolframite, scheelite, calcite, brucite, magnesite, talc, galena, siderite, amianite, fluorite, molybdenite, pyrite, pyrrhotite</td>
<td>Ca, C, Fe, Cu, Zn, Mg, Mn, Pb, S, W, As, carbonates and bicarbonates, F, Mo</td>
</tr>
<tr>
<td>Gishane</td>
<td>5.5</td>
<td>Magnetite, pyrite, sphalerite, calcite</td>
<td>Fe, Ca, Co, Mg, Cu, W, Al, Pb, CO3</td>
</tr>
<tr>
<td>Shona</td>
<td>5.5</td>
<td>Vermiculite, mica, calcite, magmaticite, magnetite</td>
<td>Fe, F, P, W, Ca, Mg, Al, CO3</td>
</tr>
<tr>
<td>Dorowa</td>
<td>5.5</td>
<td>Magnesite, apatite, vermiculite, carbonates (calcite and magnesite)</td>
<td>Fe, F, P, W, Ca, Mg, Al, CO3</td>
</tr>
</tbody>
</table>

The possible partitioning of elements between water and sediments for use in interpreting the water quality. Discussions in this paper are based on a reconnaissance study of the mine. Additional and more conclusive work is currently being undertaken.

2. Study area – Save River

The study area is in one of the seven catchment areas of Zimbabwe known as the Save catchment. The location of the area is shown in Fig. 1. The study area is part of the upper Save sub-catchment and the Save River, which passes through the Dorowa phosphate mine, is the major river. The area is located in the Bulawayo District of Zimbabwe at 19°45'S, 31°46'E. The mine is exploiting a carbonatite that is associated with foyaitite, ijolite and pulaskite rocks (Barber, 1991). The rocks are mineralized with phlogopite, vermiculite and apatite. The major risk being mined at Dorowa is fluorapatite (Ca₁₀(PO₄)₆(OH)₂(FO, F, Cl), which is associated with a number of elements. The Save River, the upper portion of which is being evaluated in this paper, is approximately 640 km long and has a catchment area estimated to be 43,000 km² (Marunda, 2001). The river rises as the Save about 80 km south of Harare and flows southeast from the Zimbabwean highveld to its confluence with the Odzi. It then turns south, drops over the Chivi Falls, and is joined by the Runde River at the Mozambique border. The river then follows an east-northeast course to its mouth near Mambone on the Mozambique Channel of the Indian Ocean. Around the study area (Dorowa), most villagers use the Save river as their primary drinking water source.

3. Materials and methods

Sampling for the study area was carried out during the dry season (September). During this time the water level was very low and flowing very slowly. Both sediment and water samples were...
collected along the Save, upstream and downstream of the mine, which is located on the igneous ring complex. The sediments were surface composite samples collected from areas considered to be natural sediment traps, where the net effect is deposition rather than erosion. The sampling was carried out on the river bank on the same side as the mine. The sediment samples were collected in triplicate, as grab samples using polyethylene spoons to avoid contamination. Water from the river was collected from, or close to, midstream. The water samples were collected using plastic sample bottles rinsed prior to use with distilled water. Two subsets of each sample were taken with each sample fitted to the bottom of the bottle to exclude oxygen. One set was acidified with 65% nitric acid (HNO₃) to a pH below 2 and another was left unacidified to allow for the analysis of nitrates. Three samples were collected at each site for each of the subsets to allow statistical verification of differences. The sampling locations are shown in Fig. 2. Measurements for pH and electrical conductivity were taken in the field using an electronic HANNA pH/EC meter (model HI 9023 C).

McBrine (1994) has prioritized the following elements as the most toxic from the standpoint of potential hazard to plants, animals and human health: As, Be, Sb, Cd, Cr, Cu, Pb, Hg, Ni, Sn, Se, Ag and Zn. Dallas and Day (1993) classified metals according to toxicity and availability into three categories namely: non-critical; toxic but insoluble or very rare; and very toxic and relatively accessible. The very toxic and relatively accessible category contained Be, Ca, Ni, Zn, Sn, As, Se, Te, F, Ag, Cd, Pt, As, Hg, Ti, Pb, Sb and Bi in specific forms. On the basis of the classifications by McBrine (1994) and that of Dallas and Day (1993), a list of potential risk elements around Dorowa, given the mineralogy of the area (Table 1), was constructed. Elements accordingly analyzed in the water samples were phosphates, nitrates, cobalt, iron, nickel, zinc and manganese. For sediment samples only the elements which had shown changes were analyzed to compare how these elements were proportioned between water and sediment. Analyses for metals were performed at the Zimbabwe National Water Authority (ZINWA) laboratory using an Atomic Absorption Spectrophotometer (AAS) (model-¦VARIAN SPECTRAA 200HT). Nitrates and phosphates were analyzed at the same laboratory using a Jenway UV spectrophotometer. Hardness of water was calculated from the values obtained from major cations analysis by AAS as the total Ca²⁺ and Mg²⁺, with Fe²⁺ and Fe³⁺ present in the sample. Phosphates were, however, not analyzed for sediments due to technical problems at the lab at the time of analysis.

4. Results

4.1. Waste rock dumps

At the mine, the rock dumps are heavily eroded, with material being redeposited in the direction of run-off (mainly eastwards). The Save River passes through the ring complex less than 1 km from the mine dump and some of the effluent from the waste rock dumps enters the river through small streams that drain the dump and mine area.

The small streams draining the mine area are clogged with Bulrush (Typha latifolia), also known as the broad-leaf or common cat's tail.

4.2. Water chemistry

The water and sediment chemistry data are presented in Table 2. The data show that downstream water samples have a higher level of iron, manganese, nitrates and phosphates. Conductivity and total hardness also increases downstream. However, there is no notable variation of other parameters such pH, cobalt nickel and zinc within the study area (Table 2).

The level of metals in the sediment is higher than in the water both upstream and downstream (Table 3). The metal levels
Table 2
Water chemistry results compared to WHO drinking water guidelines.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>pH</th>
<th>EC (μS/cm)</th>
<th>SiO2 (mg/l)</th>
<th>CaCO3 (mg/l)</th>
<th>Ca (mg/l)</th>
<th>Mg (mg/l)</th>
<th>Fe (mg/l)</th>
<th>Mn (mg/l)</th>
<th>Ni (mg/l)</th>
<th>Zn (mg/l)</th>
<th>NO3 (mg/l)</th>
<th>PO4 (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>7.0</td>
<td>245</td>
<td>92</td>
<td>-0.01</td>
<td>0.59</td>
<td>6.10</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.1</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Downstream</td>
<td>7.4</td>
<td>960</td>
<td>314</td>
<td>-0.01</td>
<td>1.34</td>
<td>6.59</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.5</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Wet Effect</td>
<td>NO3</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>NO3</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>WD/WG</td>
<td>NHC</td>
<td>NHC</td>
<td>NHC</td>
<td>NHC</td>
<td>NHC</td>
<td>NHC</td>
<td>NHC</td>
<td>NHC</td>
<td>NHC</td>
<td>NHC</td>
<td>NHC</td>
<td></td>
</tr>
</tbody>
</table>

IC: electrical conductivity; WD: hardness; WD/WG: WHO drinking water guideline; NHC: not of health concern but may affect acceptability of water according to WHO, 2004; +: value not available in the WD/WG.

Table 3
Metals concentration (in ppm) in sediments upstream and downstream compared to metal levels in water (an increase is denoted by +, a decrease by - and where the element is not detected it is shown by N).

<table>
<thead>
<tr>
<th>Metal</th>
<th>Sediment upstream ppm</th>
<th>Sediment downstream ppm</th>
<th>Water upstream</th>
<th>Water downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni</td>
<td>0.027</td>
<td>0.015</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>Mn</td>
<td>0.197</td>
<td>0.012</td>
<td>0</td>
<td>0.10</td>
</tr>
<tr>
<td>Co</td>
<td>0.003</td>
<td>0.003</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>Fe</td>
<td>16.165</td>
<td>21.10</td>
<td>1</td>
<td>1.34</td>
</tr>
<tr>
<td>Zn</td>
<td>1.36</td>
<td>2.29</td>
<td>D</td>
<td>0.01</td>
</tr>
</tbody>
</table>

increase downstream in the water for those that were detected. However, metal levels for the sediments increase for nickel, cobalt, and iron, whilst manganese and zinc decrease.

5. Discussion

The results show a general trend of metal increase in the water downstream. There is no other major activity taking place around this area that is likely to release iron, manganese, and nickel in the lake. The results thus made is that the increase is a result of the mining of alkaline rocks.

Though phosphate is being mined, the levels are observed to be within the WHO, 2004 guidelines. A plausible explanation for the low phosphate values in the water is that the phosphates are precipitating and settling as sediments. Phosphate is known to effectively remove metals from the surface water through the formation of metal-phosphate minerals, thus a concomitant increase of metals in sediments is expected. Though there is no general trend for sediments, it was noted that the sediments contain higher levels of the elements compared to the water, further suggesting that metals are likely to be adsorbing to sediments.

Thus various pollutants may be adsorbed to the sediments accumulating on the bottom of the river. These sediments may accumulate pollutants over long periods and act as new pollutant sources to the overlying water when phosphates desorb from sediments due to changes in water conditions. Therefore, the sediments can act as a source of water pollution in the future.

5.1. Current problems

5.1.1. Bulrush growth

The excessive growth of bulrush observed in the stream that drains from the Dorowa mine to the Save river is an indicator of high levels of phosphates and if not checked out may lead to eutrophication. This excessive growth can lead to choking of the ecosystem, light reduction and extreme oxygen fluctuations, reduced habitat diversity and ultimately nutrient and fish deaths in the streams. Sampling in this stream will be carried out for future work.

5.1.2. High electrical conductivity

The observed high conductivity can be explained in terms of the material being dissolved from the ring complex. The dissolved ions likely to give the high electrical conductivity in this case are iron, manganese and inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates), because the rocks being mined contain high levels of alkaline earth metals. WHO (2004) does not give a drinking water guideline for electrical conductivity but high electrical conductivity is undesirable in drinking water. The value of 950 μS observed downstream compared to 205 μS upstream is an indicator of a potential problem.

5.1.3. Hardness

Hardness in water is caused by dissolved calcium and, to a lesser extent, magnesium. Calcium is a major constituent of apatite which is the main ore mineral for phosphate in the Save catchment area and thus can be used to explain the increase in hardness in the water at the study site. Hardness caused by calcium and magnesium is usually indicated by precipitation of soap scum and the need for excess use of soap to achieve cleaning. The degree of hardness is provided by the ratio of hardness to scale deposition, depending on pH and alkalinity, hardness above 200 mg/l is the case downstream of the mine, which hardness is 314 mg/l, can result in scale deposition, particularly on heating. When the water is used for irrigation, carbonate deposits may clog pipes and coat the inside of water holding tanks. For domestic purposes, hard water is objectionable because of the formation of scale in boilers, water heaters, radiators and pipes. This results in the decrease in rate of flow and heat transfer and increased corrosion. In addition to its effect on soap consumption, excessive hardness can shorten the lifespan of fabrics and toughen cooked vegetables (Urban Watershed Project - UWP, 1995).

5.1.4. Manganese and iron content

The Save river water is contaminated with respect to manganese and iron. The manganese value of 0.59 mg/l downstream of the mine is above the WHO guidelines (0.4 mg/l) for drinking water (0.4 mg/l), yet the water in the river is used for drinking purposes by some villagers around the area (Maranda, 2001). At levels exceeding 0.1 mg/l, manganese in water supplies causes an undesirable taste in beverages. High manganese in drinking water may lead to the accumulation of deposits in the distribution system forming a coating on pipes (black precipitate) and staining sanitary ware and laundry.

The iron content observed (1.34 mg/l) downstream of the mine is also a source of concern, considering that upstream of Dorowa
the iron content value was 0.59 mg/l, which is within the median iron concentration in river, reported to be 0.7 mg/l (WHO, 2002). The elevated iron levels can be explained in terms of magnetite (Fe₃O₄), which is associated with apatite in the rocks that are mined. Though WHO does not give a guideline value for iron, on the basis that it is usually not of health concern at concentrations normally observed in drinking-water, levels above 0.3 mg/l, iron causes staining of laundry and plumbing fixtures, changes taste and develops colour (WHO, 2004) which affects the water users. High concentrations of iron (above 0.3 mg/l) in water causes reddish-brown stains on white porcelain, enamelled ware, fixtures and fabrics. Iron also promotes undesirable bacterial growth (“iron bacteria”) within a waterworks and distribution system, resulting in the deposition of a slime coating on the piping. Small quantities of iron are essential for plant growth and development; however, toxicity occurs when concentrations exceed 5 mg/l (UWW, 1999).

5.15. Nitrates
Nutrient enrichment and eutrophication are of concern since high concentrations of nitrogen can lead to periodic phytoplankton blooms and an alteration of the natural trophic balance. The current nitrate and phosphate levels are, however, not high enough for eutrophication. Nevertheless, these levels still need to be monitored. The observed value in the water of 0.5 mg/l is above the WHO guideline value of 0.3 mg/l. The primary health concern regarding nitrate and nitrite is the formation of methaemoglobinemia, so-called “blue-baby” syndrome.

6. Conclusions
The water samples downstream of Ilorwa show an increase in conductivity, iron content, manganese content, nitrates and hardness, when compared to those taken upstream of the mine. Though the geological environment indicates a possible release of metals from both mined areas of the complex and also unmined areas, the latter by natural rock–water interaction processes (Kimball et al., 2002), the local water in the streams is not contaminated with heavy metals in the vicinity of the alkaline complexes. The metals are likely to be adsorbed to the sediment. Thus, the sediment can act as a source of pollution when the overlying water conditions are changed. The release of phosphate will depend on, among other factors, pH, sediment size, catons present and oxygen. Therefore, further work is recommended to be done around the mine to assess the fate of the phosphates and associated pollutants in the Save River, so that the necessary proactive steps in guarding the water quality of the Save River are taken. The authors also recommend that water and sediment samples within the alkaline rock complex itself should also be analyzed thoroughly.

The paper reports a local problem, but the implications are transferable to other areas.

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