Effects of Coal Mining on the Lower Zambezi Basin, Tete Province, Mozambique

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Abstract

Recent discoveries of coal in Mozambique have attracted international mining companies to the area. Large amounts of groundwater and surface water are abstracted for coal mining drainage and coal processing. All wastewater is discharged to tributaries of the Zambezi River, which are used for irrigation, domestic purposes, and drinking water supply. A water quality assessment was done of two mines in the Zambezi basin through observations, chemical analysis and measured field parameters. Fieldwork was conducted in April 2019, revealing that both mines lack sufficient treatment of wastewater and one of tailing storage as it is led straight to the tributary.

Keywords: Coal Mining, Mine Drainage, Mine Water, Tete Moatize-Mozambique, Zambezi Basin

Introduction

In the beginning of the 2000's, geological surveys found vast seams of high-value coal in Mozambique which attracted some of the world's largest mining companies to the area. The most affected areas are located in Moatize district in Tete province which has no history of mining. Multinational mining companies such as Vale (Brazil), Jindal (India), ICVL (India), Minas de Moatize (UK) now extract coal there (Pondja E. 2017). It is particularly the high-quality coking coal and metallurgical coal for steel production that is dominating the Mozambican mining sector, where the Permian Karoo formation reserves are estimated to have 23 billion tonnes of exportable coking coal (Resource Sector Mozambique 2018).

The coal mines are extracting large amounts of groundwater and surface water from Zambezi river to meet the needs of the plants. Wastewater is released to tributaries, which downstream are used for irrigation, domestic purposes, and drinking water supply. The aim of this study was to investigate the water quality in the Zambezi basin in Moatize district. It was known that communities around the mines were complaining about deteriorating water quality. By finding out the water components and see what pollution are encountered, prevention and precautions can be developed in a more effective way.

Methodology

The field work was completed the 15th–21st of April, 2019. Field measurements and samples were conducted from five locations: Nhanstanga, Catete, Mbirimbe, Cachoeira and Luenha. The first two are located close to coal mines. Catete is upstream the mines and the last two are in association with small scale gold mining and will not be discussed further in this report. The exact location and number of sampling points were determined when in field. The coordinates for each site were logged in-situ. Photographs and notes were taken during the visits. Collected water samples were sent to a laboratory for analysis. To obtain a better understanding of how the water can affect communities that are using the tributaries for domestic purposes, the results were compared with WHO-drinking water guidelines and the Mozambican standards for water regulations from Ministério Da Saúde (MISAU).

The mines are called Mine A and Mine B on the next page.

Sampling

The sampling process proceeded similarly at each sampling point. A 2L bucket was used to collect water as a grab-samples. Immediately after sampling, the field parameters were measured in the bucket to limit external influences. While collecting water, particles were avoided as much as possible. The measured parameters were pH, electric conductivity, dissolved oxygen, total dissolved solids, salinity, redox-potential and temperature. All measurements were repeated five times. The mean value of the parameters at each point was determined as well as the standard deviation. At each sampling point, two bottles of 100-500 mL with water samples were retrieved. One for analysis of major ions and one for trace elements or metal. All water samples taken for metals analysis were filtered with 0.2 µm filters using a funnel. Four drops of nitric acid per 100 mL sample was then added to the bottles with filtered water to lower pH below 2 and preserve the samples.

Laboratory analysis

Collected samples were kept in cool until sent to a laboratory for analysis. Mbirimbe samples were analysed at Laboratório de Engenharia de Mocambique with an X-ray fluorescence spectroscopic (XRF). The following metals and ions where analysed: Fe, Al, Mn, Zn, Cu, K, Ca, Mg, CL, NH_4^+, SO_4^{2-}, NO_3, CO_3^{2-}, HCO3-. Nhanstanga samples were sent to Instrumental Chemistry at Lund University, where an Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) was used for determination of Na^+, K^+, Li^+, Ca^{2+}, Mg^{2+}, Fe, Al, Mn, Zn, Cu, Hg, As, Cd, Pb, and Co. Ion chromatography for analysis of Cl, NO_3^-N and SO_4^{2-} and flow injection analysis (FIA) for analysis of NH4-N.

Water demand

The current size and locations of the mines in Moatize district was found by using google earth satellite images and compared with the conditions 2012, 2015 and 2019. Presently the mines cover an area of approximately 47 km2 altogether. The mines have a lifespan of at least 20 years whereas about 10 has passed. Hence, the mines will continue to grow and cover even larger areas for at least 10 more years.

A rough estimation of the water demand from the mines was made based literature values suggesting an average demand of 250 L of freshwater per tonnes of coal produced (Moon E. 2017) and related to the annual mean flow rate in Zambezi of 3242 m3/s (World Bank 2010). The four main mines have currently a production capacity of extracting almost 40 million tonnes of coal per year or 1.2 tonnes per second (Resource Sector Mozambique 2018), resulting in a water demand of 10 M(m3)/year or 0.32 m3/s. This is equal to 0.1 ‰ of the total average flow in Zambezi River.

Results and discussion

A general picture of the water quality in Tete province was gained, even though conclusions about variations in time and space are rather limited. It has been possible to see some effects on the water quality caused by the mining activities in the area.

Mbirimbe River

Mbirimbe River is a small tributary to Zambezi. It discharges south of Moatize River and Tete City. The water samples were taken a couple of kilometres upstream from the outlet to Zambezi where Mine A has a well-hidden outlet. The community collecting water from the river were complaining about the bitter taste and strange colour that changed over the last two years.

At the first sampling point, left figure 1, the water was brown-red. This could indicate a high content of manganese, iron or aluminium which can give this colour. Degradation of organic matter may also change colour of the water but should not have changed over two years since the mine got operational.

The oily floating layer at sampling point 2, middle photo figure 1, assumingly come from washing the machineries at the mine site with inadequate or no wastewater treatment. An oil-separator could be used to minimize this kind of effluent together with more sufficient waste management.

At sampling point number 3, where the mines wastewater is discharged to the river, the musty smell implied bad water quality as

Figure 1 From left: sampling point 1, 2 and 3 in Mbirimbe River.

Table 1 Measured field parameters in Mbirimbe River.

Mbirimbe	T °C	pH	DO %	DO mg/L	EC µS/cm	TDS mg/L	PSV	Std H2 mV
Point 1	27.7	7.5	109	8.3	8197	5328	4.5	306
Point 2	28.1	7.5	98.5	7.4	7018	4562	3.8	316
Point 3	32.4	7.8	130	9.1	5537	3599	3.0	297

well as the shifting colours and turbidity. It was obvious that the wastewater affected both the water and the biological activity as the type of algae, right picture figure 1, was only found on this spot and in the leakage water.

As in table 1, the high electric conductivity, total dissolved solids and salinity reveal a huge problem with the quality. These parameters all increase downstream in the river from the discharge point. An explanation could be that wastewater coming from the mine dissolve minerals in the rock along the river and thus increasing the metal concentration downstream.

When analysing the water samples several elements were found in large contents, see figure 2 and 3. The high salinity and especially magnesium could explain the bitter taste. The concentrations of Na, Ca, Mg, Cl, SO42-, Fe and Mn all exceeds the drinking water regulations and can cause serious health consequences for the communities that are using the river as a source of water. The community close to Mbirimbe River already noticed problem with agricultural growth and it will probably get worse if no actions are taken.

The reason for the high concentrations is most likely the mining, the use of chemicals in the coal mining process and weathering of rocks. Limestone was observed in the area which might have been neutralizing the acid mine drainage giving the high levels of Ca and Mg. When the limestone is consumed, the pH increases and thereby neutralizing the drainage. SO42-and Fe as well as Al and Mn can all be attributed to acid mine drainage.

Mbirimbe River does not have the capacity, neither flowrate nor quantity

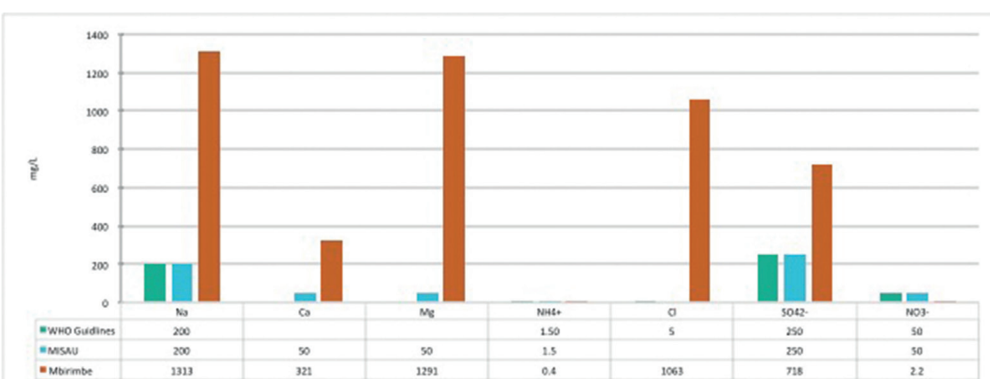

Figure 2 Observed ion concentrations in Mbirimbe River (red) in comparison with WHO-drinking water guidelines (green) and MISAU regulation (blue).

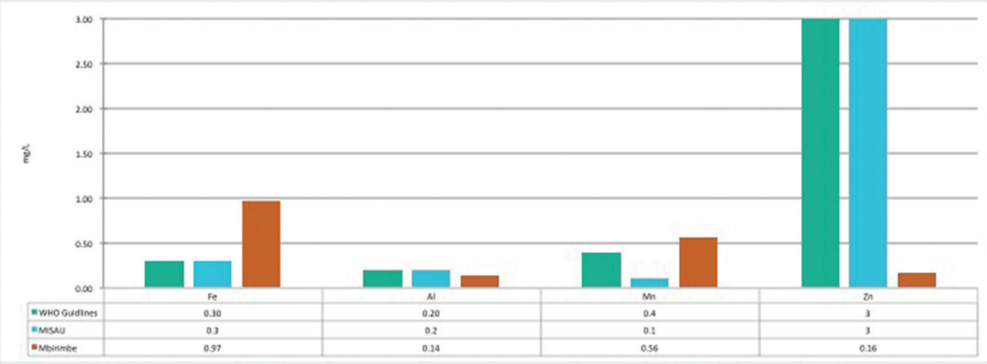

Figure 3 *Observed metal concentrations in Mbirimbe River (red) in comparison with WHO-drinking water guidelines (green) and MISAU regulation (blue).*

to dilute the mine discharge. The mine wastewater needs better treatment and storage for flow equalization.

Nhanstanga River

Nhanstanga River lies in Marara district, north east of Tete City. The river first merge into Chirodzi River, then Sanangua River which flows to the Zambezi River. Mine B discharge wastewater to this tributary and Nhanstanga River has been strongly influenced by the coal mine. What used to be a river that provided whole communities with good drinking water just a couple of years ago is now a black river of tailing from the coal mine. This is not sustainable and directly affects hundreds of people. The depth of coal was about 0.4 m where the river passes the community, left figure 3, about a kilometre from where the mine discharge. Due to low permeability in the coal and recent rain, the surface water found in the river was assumed to be rainwater. At the discharge point, right figure 3, tailing was going straight into the river and will later end up in the Zambezi river.

The borehole measurements in table 2 come from a dug well, 30 m from Nhanstanga river from where the community got their water supply. Another water source in the community was untreated water transported from Zambezi River, referred to as tap water in table 2. Measured field parameters in table 2 shows a significant difference between the discharge water and borehole water compared to the tap water and the water from the river that assumingly was rainwater. In the borehole samples, the water showed similar values to the discharge water with high electrical conductivity and TDS. Water from the river probably infiltrates to the groundwater and thereby affecting the quality of the borehole.

Figure 4 *Left Nhanstanga River, right Mine B discharge point.*

Table 2 Measured field parameters in Nhanstanga River area.

Nhanstanga	T °C	pH	DO %	DO mg/L	EC µS/cm	TDS mg/L	PSV	Std H2 mV
Discharge 1	31.9	8.1	117	8.2	1513	983	0.7	-
Discharge 2	32.4	7.8	120	8.3	1486	966	0.7	294
Discharge 3	32.3	7.7	119	8.2	1468	954	0.7	295
River	32.4	6.9	101	7.0	872	567	0.5	300
Borehole	28.7	6.9	56.7	4.2	1317	848	0.6	333
Tap water	29.3	7.9	112	8.2	143	92.0	0.0	295

The mine effluent at the discharge point contain high levels of Cl, Fe, Al and Hg that exceeds health regulations, figure 6. These are typical elements in mine drainage. While the high contents of Ca and Mg, figure 5, could be a result of weathering rocks, neutralizing acid mine drainage as limestone was observed in the area. Even if the inhabitants in the community did not drink water directly from the river anymore, the cattle still did. Contaminants can be transferred to humans from the cattle through meat and milk or trough crops, if irrigated with unsafe water.

Environmental impact

The timescale it will take for a water quality problem in the tributaries to evolve to Zambezi is difficult to predict. The dilution rate highly depends on the flow which varies between the seasons. The highest concentrations of contaminants will be found in the end of the dry season when the flow is low. Higher

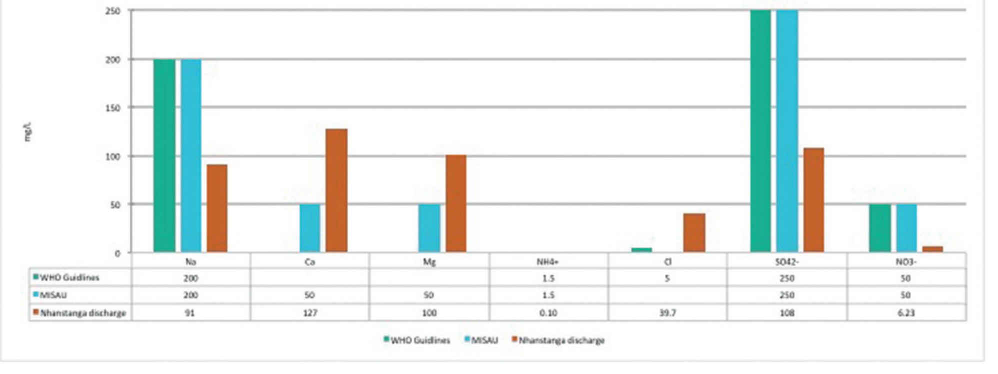

***Figure 5** Detected ion concentrations in Nhanstanga River (red) in comparison with WHO-drinking water guidelines (green) and MISAU regulation (blue).*

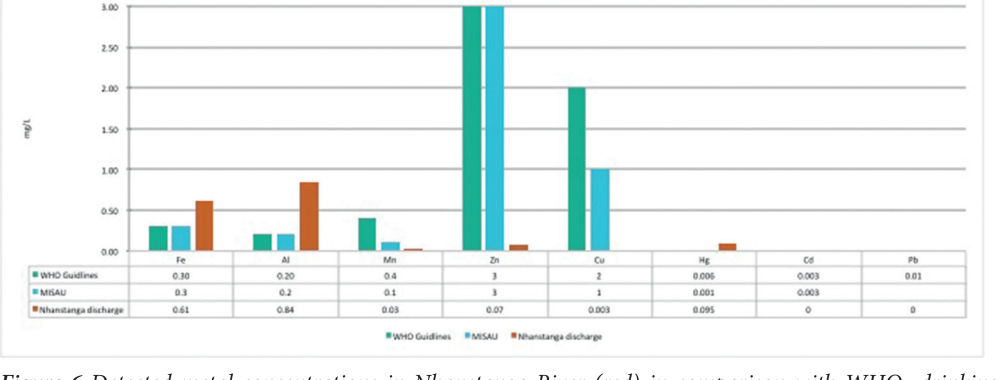

***Figure 6** Detected metal concentrations in Nhanstanga River (red) in comparison with WHO- drinking water guidelines (green) and MISAU regulation (blue).*

flows, on the other hand, gives more dilution and more erosion but less infiltrates and so the contaminates will spread over a larger area. Hence, the time of the field work is very important and effects the results. The field work was carried out in the end of wet season/ beginning of dry season. To fully understand the situation, more measurements are needed over the year, not only in April.

While the mines are growing, more coal is extracted, and larger areas affected, resulting in a higher freshwater use and larger pollution discharge. The composition of the emissions might change as the mining moves through different layers in the ground.

The pH was during both surveys rather neutral and by this the conclusion could be drawn that acid mine drainage has not been and is currently not a problem or that magnesium and calcium carbonates are dissolved by the mine water, thus neutralising it. Elevated sulfate and iron in the drainage indicates a pyrite oxidation process.

Conclusions

The coal mining in Tete province have negative environmental impact. Not only by colouring the ground black and changing the topography, it deteriorates the groundwater and surface water quality. Hundreds of people have already been affected as their drinking water sources are polluted by the mining activity. The local communities noticed that the water changed colour, taste got bitter and crops do not grow as it used to a couple of years ago. The comparison with WHO and MISAU drinking water limits made it clear that the water is not safe for human consumption. The water demand from the mines and areal magnitude has increased over the years. Since not even half of the permitted lifetime has passed yet, the mines will continue to grow with increased water demand and greater emissions. Although, the composition of the emissions might change as the mining moves through different layers in the ground. The large flows within the Zambezi River Basin provide extensive natural dilution but the small tributaries are more vulnerable to pollution. It is of most importance to highlight this problem as the pollution will spread downstream.

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