

Influence of the Daberas Mine on Groundwater Quality and Vegetation at the Orange River

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The dying of trees on the northern bank of the Orange River is restricted to the area of the Daberas diamond mine. Water samples were taken from upstream and downstream of the mine to determine the influence of the mine on the ground water quality. The mining operations cause an increase in salinity of the groundwater from 8000 to 15800 mg/L, mainly due to an increase in NaCl but also due to increasing amounts of K, Ca, B, Br and Sr. Other major constituents of the groundwater, like Mg and SO₄, are only increasing slightly. The fingerprint of the mining operation in the groundwater is characterized by an increase of nitrate (by 346%), nitrite and ammonia as well as chromium (by 160%). The increase in salinity traces back to dissolution of continental evaporates in the river sediments by seepage from the tailings dump, and to an increased evaporation in the mining area, especially at the surface of the tailings dump. To prevent the further dying of trees and to trigger re-vegetation, the flow of highly saline groundwater from the mining area to the river banks has to be prevented. It is recommended to collect the saline groundwater in trenches downstream of the tailings dump. A potential source of groundwater contamination is ferrosilicon (for dense media processing), which is released in significant amounts with the tailings material. It contains higher concentrations of heavy metals than ferrosilicon used by other diamond mining companies in Namibia.

Introduction

Dying of trees has increased between the Daberas mine and the Orange River over the last years. Trees and some bushes have died along the northern river bank over a distance of more than one kilometre. This problem was discussed with the management of the Daberas Mine during a field trip to mining operations of NAMDEB. Two water samples were taken at Daberas to determine the nature of the influence of the mining operation on the groundwater.

This study is part of the training-on-the-job program within the framework of the technical cooperation project between the Federal Institute for Geosciences and Natural Resources (BGR, Germany) and the Geological Survey of Namibia to establish the Division of Engineering and Environmental Geology at the Geological Survey of Namibia. The field work was carried out in cooperation with the Division of Geohydrology of the Department of Water Affairs (DWA). Through cooperation of the two Namibian institutions, a higher degree of efficiency in environmental inspection is created from the governmental side. The finalization of the report took place in a joint workshop of Geological Survey of Namibia and DWA, with broad participation of young scientists of both institutions.

Geological Situation

The bedrocks of the Daberas area consist mainly of schist, amphibolite and metaquartzite of the Neoproterozoic Gariep Belt. The rocks were subjected to greenschist facies metamorphism during the Pan-African event at about 530 Ma (Frimmel and Frank, 1998).

The origin of the Orange River can be traced back to the break-up of Gondwana, when during a humid peri-

od in the late Cretaceous and early Tertiary, erosion was at its peak in central southern Africa (Schneider, 2004). Fossils recorded from its sediments can be dated back from the early Miocene to the basal middle Miocene (Pickford and Senut, 2000).

The area of the lower Orange River experienced an arid climate during the Cretaceous and Tertiary leading to the formation of continental salt pans along the river. The formation of evaporites in pores cemented the coarse clastic material (Partridge and Maud, 1987).

Very limited volumes of groundwater are available in the fractured aquifer of the basement rocks, due to a very low recharge north of the Orange River in the Daberas area.

Water Sampling

Two sampling points, one upstream and one downstream of the mining area, were selected. The first sample (DW1) was taken from a spring at the northern edge of the Daberas Mine Zone 10, on level 42. The bedrock consists of slightly weathered shale of the Gariep Complex and forms the typical fractured aquifer. This sample serves as a background sample, as the groundwater in that area is not influenced by mining.

The second sample (DW2) was taken 50 m south of the slimes dam from a trench in the river terrace, which is filled by groundwater.

On site measurement of the physico-chemical parameters of the water samples was carried out at each individual sampling point with the "MultiLine Kid" of Technische Werkstätten Weilheim, Germany, to determine temperature, pH and electric conductivity.

Two types of water samples were taken:

- 250 ml PE bottle for major cation and trace element analysis, filtered with a 0.45µm filter, acid-

ified with 5% HNO₃ to pH<2

- 250 ml PE bottle for anion analysis, unfiltered, unacidified

Analytical Methods

The samples were analysed in the laboratories of BGR (Bundesanstalt für Geowissenschaften und Rohstoffe) in Hannover, Germany, using the following methods:

- Concentrations of main components Na, K, Ca, Mg, B, Al, Si, Mn and Fe were analysed from acidified solution with Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES) based on standard DIN EN ISO 11885 (1998).
- Concentrations of trace elements As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Pt, Sb, Sn, Tl and Zn were analysed from acidified solution with magnetic sector field Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Rh was used as an internal standard.

For the determination of the anions F, Cl, Br, NO₃, SO₄ ionic chromatography was used based on DIN EN ISO 10304-1 (1995). The anion peaks were detected by electrical conductivity following neutralization of the alkaline KOH-eluent with a membrane suppressor technique; H₂SO₄ was used for regenerating the system.

Nitrite, phosphate and ammonium were determined photometrically as a complex, based on standards DIN EN 26777 (1993), DIN EN 1189 (1996) and DIN 38406 (1983), respectively.

For the determination of alkalinity (acid neutralizing capacity) of a water sample, a 10 ml aliquot of the unfiltered sample was titrated with 0.02 N HCl down to pH 4.3 (DIN 38409, 1979), with the final point determined potentiometrically using a 2-cell pH-glass electrode.

The complete analytical results of the water samples are shown in appendix 1.

Interpretation of results

Major elements/salinity

Water from both sampling points is not suitable for human consumption due to high salinity. Sample DW1 is very hard and brackish water with total dissolved solids of about 8000 mg/L. This salinity is caused mainly by sodium chloride and magnesium sulfate. Sample DW2 is very hard salty water with total dissolved solids of 15800 mg/L dominated by sodium chloride.

The salinity of the groundwater almost doubles after passing the mining area, mainly due to an increase of chloride by 174% and sodium by 136%. The concentrations of calcium and potassium are almost doubled though potassium concentration is generally low. Sulfate and magnesium are increased by a quarter, with sulfate being a major component in both waters.

Some plant species along the banks of the Orange

River are adapted to brackish water. A salinity increase of about 100% from brackish to salty water, is however not tolerable to most species. The high salinity of effluent water from the Daberas Mine is the most probable reason for the intolerable conditions for the vegetation.

B, Br, Sr

The concentrations of boron, bromine and strontium increase between 70% and 133% from the upstream sample to the downstream sample. These elements are typical for continental evaporates. The doubling of the concentration of these elements combined with the high increase of the concentration of Na, Ca, K and Cl points to the dissolution of easily soluble evaporites of continental origin from the sediments, caused by the mining operation.

NO₃, NH₄, NO₂

Nitrate concentration more than triples between the sampling points DW1 and DW2. Upstream of the mine the nitrate concentration is within the range of drinking water of excellent quality (23 mg/L), but it reaches 103 mg/L downstream (DW2) and, thus, exceeds the guideline values for drinking water of acceptable quality and for livestock watering. Nitrite and ammonium concentrations are generally low. Groundwater beneath forest or permanent pasture generally has less than 1 mg/L nitrate; under heavily fertilized ground, less than 10 mg/L nitrate. An agricultural contamination can definitely be excluded. The increasing contaminations of NO₃, NH₄ and NO₂ point to a source from the mining operation. Typical sources of those contaminations are septic tank effluents or explosives.

Fe²⁺, Cr

The iron-II-concentration increases from DW1 to DW2 by 1100% (DW2: 0.012 mg/L) but is well inside the limits of the guideline value for drinking water of excellent quality. Chromium concentration is more than doubling and exceeds the guideline value for acceptable drinking water downstream (DW2). This indicates a source of contamination which is related to the mining operation. A source of both elements might be ferrosilicon (FeSi), which is used in the dense media separator to enrich the heavy minerals fraction. Three samples of ferrosilicon from NAMDEB's stores were taken and analysed for major, minor and trace metals. The analyses show chromium contents between 0.57 and 0.69 % as well as higher nickel and copper contents compared to ferrosilicon used by Samicor (table 1).

Ba, F

Barium and fluorine occur in relatively low concentrations at both sampling points. Concentrations from

Table 1: Analysis of ferrosilicon samples

Sample	Fe %	Cr %	Mn %	Ni ppm	Cu ppm
NAMDEB FeSi 1 (June 2006)	65.6	0.68	1.00	4152	1724
NAMDEB FeSi 2 (June 2006)	64.5	0.57	0.94	3693	2187
NAMDEB FeSi 3 (June 2006)	65.6	0.69	1.05	2700	1811
Samicor FeSi (February 2008)	62.0	<0.004	0.70	<40	1450

DW1 to DW2 decrease by a quarter. An increasing evaporation of natural groundwater usually causes an increase in Ba and F concentration. Thus, the results for these elements support the idea of an extensive but only partial dissolution of evaporates from the river sediments by processing water. The salts of barium (barite, BaSO₄) and fluorine (fluorite, CaF₂) are stable and remain in the sediments. The original concentration of barium and fluorine becomes diluted by the processing water.

Metals: As, Cd, Co, Cu, Mo, Pb, Zn

The water samples show very low concentrations of arsenic, cadmium, cobalt, copper, molybdenum, lead and zinc. These concentrations are often below the detection limit of the laboratory equipment and far below the Namibian guideline values for drinking water. Thus, heavy metals cannot give any information about the process of the salinity increase in the groundwater. On the other hand no environmental hazards are expected to be caused by those heavy metals.

Conclusion

The dying of trees along the Orange River bank is restricted to the area downstream of the Daberas Mine. Its mining activities cause an increase in salinity of the groundwater by almost 100%. The increase in salinity traces back mainly to dissolution of continental evaporates in the river sediments by processing water and to a lesser extend to an increased evaporation on the surface of the tailings dump. Furthermore, the mining operation releases significant amounts nitrate into the groundwater.

Recommendations

To prevent further dying of trees and to trigger re-vegetation, the flow of highly saline groundwater from

the mining area to the river bank has to be stopped. It is recommended to collect the saline groundwater in trenches downstream of the tailings dump. Subsequently, the water could be pumped onto the tailings dump for evaporation or released into the Orange River. The high salinity of the water in the tailings dump may cause instability of certain clay minerals in the walls of the tailings dam, which might cause a steadily increasing seepage from the dump into the groundwater. Therefore the fine fraction of the tailings dam walls has to be analysed for clay mineralogy.

The potential impacts of the latter disposal method have yet to be further investigated.

NAMDEB is advised to control minor and trace element concentration, such as refractory derived chromium, copper and other heavy metals in ferrosilicon (FeSi), to exclude a potential source of groundwater contamination. FeSi is used for the dense media separation and released in significant amounts onto the tailings dump. FeSi used by other diamond mining companies (e.g. Samicor) contains the heavy metals of concern in only very low concentrations.

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