Groundwater Use and Protection as Part of the Namibian Mining Application

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Abstract Water is a scarce commodity in semi-arid Namibia. Therefore water supply for towns, industry, and mines can often only be ensured through the utilization of groundwater resources. Conflicting interests between farmers and bulk users often cause severe problems. Two emerging mining projects are used as examples on how a timely transparent approach involving all stakeholders at an early stage of mine development and based on thorough scientific but easy to understand investigations, can result in a proper project implementation. This constructive participation during an early stage caused less negative effects during the process of mine development and construction later on.

Keywords groundwater use, groundwater protection, Namibia, flow and transport modeling, mining application, Omitiomire Copper Mine, Otjikoto Gold Mine

Introduction

The mining sector in Namibia has significantly increased during the past ten years. Groundwater quality and quantity impacts of mining projects are affected by a progressive rise of public awareness. This paper presents predictions of potential impacts on groundwater and delivers management plans designed to meet legal requirements and minimize impacts on groundwater associated with mining in a rural area. Special attention has been paid to reasonable applying numerical groundwater flow and transport models prior to the mining start. These models were developed as decision making tools, forecast and planning instruments, to initially describe the groundwater conditions for a Copper- and a Gold mine project that are located in commercial farming areas. Both models aim at synergizing groundwater abstraction for mining purposes with the water demand of local stakeholders.

The proposed Omitiomire copper mine is located approx. 150 km north-east of the Namibian capital Windhoek (Fig. 1). The regional geology dominated by a series of dome structures such as the Ekuja Dome, a structurally controlled 'window' of Irumide-age rocks (Steven *et al.* 2000) flanked by younger rocks of the Damara Orogen (900 Ma to 450 Ma pan-African rocks). The Ekuja Dome covering an area of approximately 15 by 12 km is economically important as it hosts the Omitiomire chalcocite deposit (Speiser 2010). Rainfall in the area of Omitiomire is extremely variable, but the mean annual precipitation since 2000 is 442 mm/a (cp. Zingelmann 2012). The model domain is characterized by shallow groundwater levels (< 10 m below ground level) in the vicinity of the Black Nossob River and its tributaries and relatively deep regional groundwater levels (on average 35 m below ground level), according to Bittner and Marx (2012). Groundwater recharge causes significant rising water levels during and after occasional floods in ephemeral rivers. The groundwater quality in the project area is generally good and classified to class B according to Namibian drinking water standards (Steven

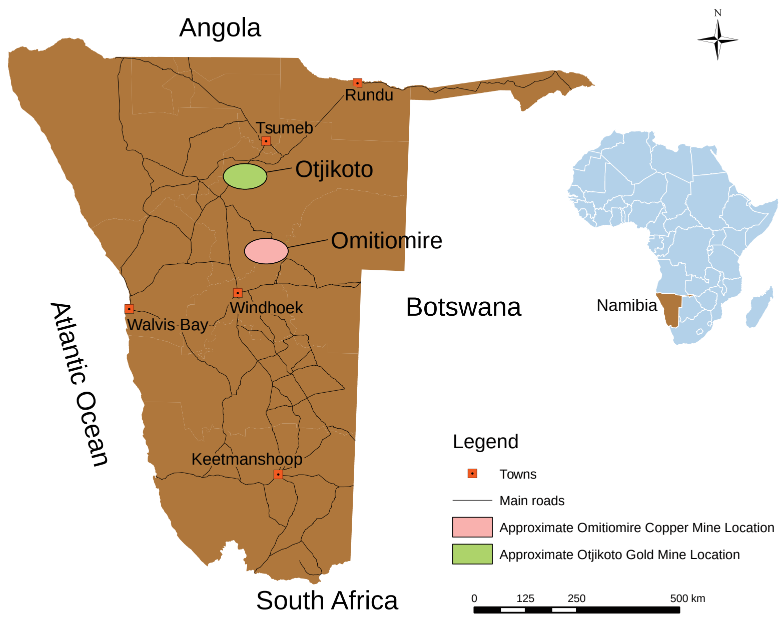

***Fig. 1** Locations of the proposed Omitiomire Copper Mine and the Otjikoto Gold Mine Projects in central Namibia.*

2010). A proposed mining phase 1 will consist of three small test mine pits with a depth of approximately 50 m. During the mining phase 2 a larger mine pit with a total depth of 340 m will be created.

Another project example, the proposed Otjikoto project, is located 300 km north of Windhoek (Fig. 1). Schist and quartzite of the Damara Sequence in alternating sequences with marble and ortho-amphibolite of the Karibib Formation are dominating local geological conditions. The project area is situated on the eastern margin of the Platveld Basin, which is dipping to the Northern Zone of the northeast trending limb of the Damara Orogen extending from Swakopmund to Grootfontein (Klock 2001). Rainfall distribution follows an irregular pattern with a mean annual average of approximately 475 mm/a (Bittner & Winker 2012). The aquifer systems of the study area are consisting of three major units: 1) marbles of the Karibib Formation, 2) the surrounding and underlying quartz biotite and graphitic schists of the Okonguarri Formation, and 3) the calcrete layer covering the Okonguarri Formation (Klock 2001). Groundwater levels in the project area range between 10 and 50 m below ground level. Most groundwater samples taken within the study area are characterized as predominantly Ca-bicarbonate water types.

Methods

Public meetings were held during the initial phases of the mining application process, following the protocol of the Environmental Impact assessment process. Stakeholders such as surrounding commercial famers, water supply utilities, environmental groups and municipalities were invited to express their concerns and recommendations. This public participation process together with groundwater specialist investigations and in consideration of mining interests were taken as basis to develop numerical groundwater flow simulations and subsequent groundwater abstraction and mine pit dewatering scenarios (Fig. 2). The stakeholders were involved in the development of a groundwater monitoring network, and were informed on a regular basis on the outcome of the studies. For both projects, mitigation measures were implemented according to the recommendations derived from model based risk assessments.

Numerical groundwater flow and transport models were utilized to calculate water

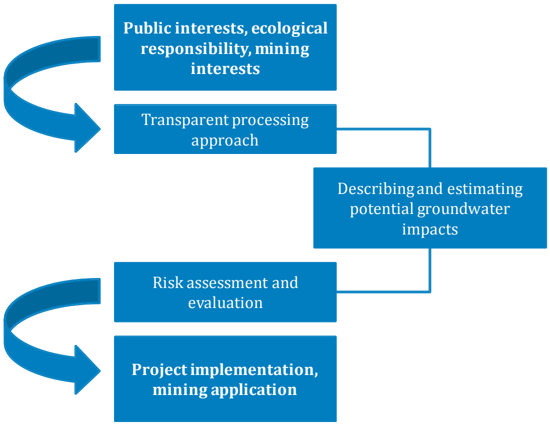

Fig. 2 *Work flow and progress of groundwater issues for a transparent mining application as part of an Environmental Impact Assessment process.*

volumes, determine flow paths, and estimating groundwater characteristics. Both projects are located within fractured basement rocks with major linear structures such as faults and ephemeral rivers, but different hydrogeological units. To thoroughly consider this environment and to acceptably display the permeable and groundwater relevant layers, a finite element modeling approach using FEFLOW has been selected for both projects. Both flow models were calibrated as a steady-state solution and were expanded to transient models later.

For the Omitiomire project in a first step a conceptual model has been developed to describe the baseline conditions and create a basis for the numerical flow solution. Manifold data, such as monitoring results, existing hydrogeological reports (Simmons 2008), and aquifer testing data (Bittner 2007), were integrated into a project database. Efficiently realized calibration of the transient flow solution produced a variety of different flow scenarios. Each scenario is computing a 10-year transient flow solution (Table 1), simulating: 1) a conservative dry period with 25 % less rainfall, 2) a conservative wet period with 25 % of additional rainfall, 3) a wet period with 50 % of additional rainfall, and 4) a period with no rainfall. Table 1 shows fluxes of the entire model domain.

Recharge (indirect and direct) has been simulated as 0 to 5.5 % of the calculated rainfall, depending on hydrogeological units (Zingelmann 2012). Due to the fact that rainfall and subsequent recharge in Namibia is extremely variable but sometimes zero, a conservative approach simulating a period of no rainfall has been chosen. Predictions were given on how much groundwater could be assumed as maximum inflow into the mine pit. Simulated water levels show rising tendencies in scenarios 2 and 3, on average by 3.5 m and 12.0 m, respectively. Scenario 1 and 4 are showing dropping water levels during the 10-year period.

Shallow water levels can be observed shortly after recharge/runoff events in the ephemeral Black Nossob River and in underlying basement aquifers. It is evident that the porous alluvial aquifer acts as leakage or recharge channel (Bittner & Marx 2012). The radius of influence from the river channel is variable and depends on the local geology but is usually not larger than 1,000 m (Fig. 3). Recharge in the vicinity of the Black Nossob River changes the local groundwater flow pattern, especially after flood events as can be seen in Fig. 3. Intensely fissured zones, fractures and faults influence the general groundwater flow conspicuously. To avoid over ab-

No.	Scenario	Flux out [m^3/a]	Flux in [m^3/a]	Recharge [m^3/a]	Mine pit dewatering [m^3/a]
1	25% less	49,498,450	48,385,321	1,234,928	146,540
2	25% more	84,914,777	77,917,645	7,345,260	214,983
3	50% more	103,273,637	94,436,734	9,849,383	285,927
4	no rainfall	41,948,390	41,827,285	0	109,262

Table 1 *Groundwater fluxes of scenarios 1, 2, 3, and 4 for the Omitiomire project.*

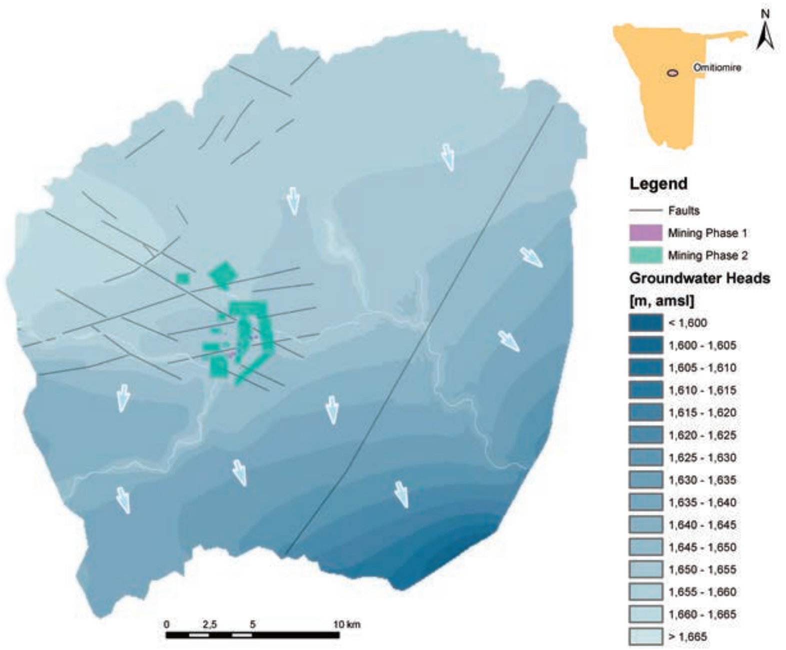

Fig. 3 *Computed groundwater heads of scenario 1 (Omitiomire project).*

straction and to keep impacts on groundwater levels as low as possible, it is recommended to utilize mainly groundwater from mine pit dewatering for production, unlike originally planned. The water demand for the Omitiomire project is estimated at 4 L/s or approximately 0.13 GL/a at the beginning. In summary, it was recommended to use mainly groundwater from the open cast pit and to avoid abstraction from water supply boreholes located in the vicinity of neighboring farms. In other modeling scenarios the best locations of potential dewatering wells were determined, in order to avoid negative groundwater drawdown effects. The generally low permeability of the local basement rocks and subsequently confined drawdown around the mine pit and water abstraction wells further reduces possible negative impacts on nearby groundwater users.

The Otjikoto project lies amidst commercial farmland, where substantial volumes of groundwater are abstracted to allow for cattle breeding and irrigation (Fig. 4). The water demand of the gold mine with an estimated 10 years life of mine was calculated at approximately 38 L/s or 1.2 GL/a. Subsequent groundwater model abstractions scenarios took this in consideration. Like for the Omitiomire Copper Mine project a combined mine pit dewatering and water supply well abstraction strategy was recommended as most efficient.

After a consultation process as part of the Environmental Impact Assessment and in cooperation with the main Namibian bulk water utility and other stakeholders, a mine water management plan has been developed to carefully ensure construction and production during the first years. The marble aquifer (Fig. 4) is one of the most efficient and productive but also vulnerable aquifers in the region and numerical modeling results showed that increasing the abstraction volume by 1.2 GL/a is acceptable for the medium term (Bittner & Winker 2012). To keep impacts on local freshwater sources as low as possible, a phased abstraction strategy was recommended changing from initially 100 % supply from water wells in the first years of mine development to recycled groundwater from mine pit dewatering after mine pit excavation progresses below the water table. One of the most important issues of the future numerical groundwater solution for the Otjikoto Gold Mine project shall

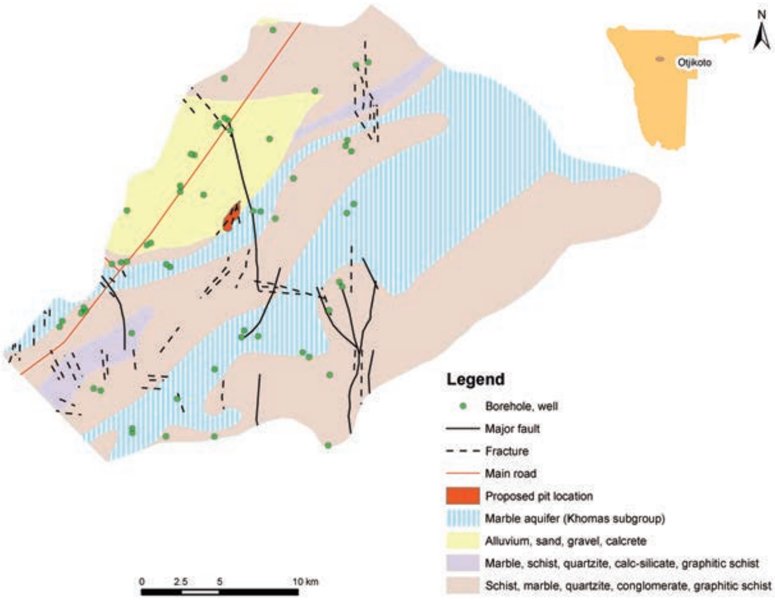

***Fig. 4** Otjikoto aquifer scheme with proposed mine pit.*

be the prediction of groundwater quality impacts. The mass transport model solutions and scenarios will consider potential seepage from mine infrastructure such as the tailings storage facility in order to avoid negative impacts on precious groundwater resources.

Conclusions

Groundwater dependent mining projects, like the Omitiomire copper and the Otjikoto gold projects, often cause conflicting interests between stakeholders. This can result in a considerable delay of the project implementation. It has been shown that a transparent hydrogeological management plan involving all parties prior to the start of the projects can reduce these effects. Furthermore, groundwater modeling and reasonable designed modeling scenarios can show whether the demand of freshwater/groundwater can be satisfied without over-abstracting local aquifers. Important modeling results shall be made available to the public as the public shall be involved continuously during the whole process of the mining application. It has been shown that private users in the vicinity of the proposed projects could benefit from groundwater investigations and were able to enhance their water supply system. All in all, less negative effects during the construction phase could be observed. Some original mine plans had to be adopted or modified, but did not cause a delay in the project implementation.

For the Omitiomire copper project, which is located in a farming area relying on groundwater supply, it has been shown that groundwater abstraction for the mine and pit dewatering would not have negative impact on surrounding farm boreholes. The mine should abstract only small volumes from boreholes tapping the local aquifer but should rather make use of recycled groundwater from mine pit dewatering.

The Otjikoto gold project plans to make use of groundwater from a nearby marble aquifer which is already utilized by the main Namibian bulk water supply utility and which is the only source of fresh water for the town of Otjiwarongo and local farmers. The groundwater investigations, including numerical models, showed that mine pit dewatering and sustainable abstraction of groundwater from production wells tapping the marble aquifer would not have negative impact on the water supply to the town and the farming community.

A transparent approach and early stage involvement of stakeholders and the public, combined with thorough scientific but easy to understand groundwater investigations and models can help to implement groundwater dependent mining projects within a reasonable time frame, as well.

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