Communs geol. Surv. Namibia, **13** (2004), 85-91

Report : Assessment of Potential Environmental Impacts and Rehabilitation of Abandoned Mine Sites in Namibia

[1]L. Hahn, [2]F. Solesbury and [3]S. Mwiya
[1]Federal Institute for Geosciences and Natural Resources, Hannover, Germany
[2]Geotec Namibia, P O Box 30989, Windhoek, Namibia
[3]Geological Survey of Namibia, Private Bag 13297, Windhoek, Namibia

The results of the assessment of the environmental hazard potential of the abandoned copper mines Klein Aub, Oamites, Matchless, Khan and Onguati and the lead/zinc mine Namib Lead, located in Central Namibia, are presented. The methodology applied comprised geochemical and geotechnical investigations. Mitigation and rehabilitation options for the mine sites are proposed.

Introduction

The Government of Namibia attaches a high prior- ity to environmental protection. The Environmental Management Bill which has not yet been promulgated, covers pollution control and waste management legislation with respect to all branches of industry including mining (Directorate of Environmental Affaires, 1999).

In order to cope with the existence of approximately 260 mines which were abandoned by their owners without any remediation measures, the Geological Survey of Namibia (GSN) on behalf of the Ministry of Mines and Energy applied for the study "Rehabilitation of Abandoned Mine Sites". Commissioned by the Federal Ministry for Economic Cooperation and Development (BMZ) the Federal Institute for Geosciences and Natural Resources (BGR), supported by a local consultant, carried out a Project of Technical Cooperation with the GSN and the Directorate of Mines in 1999 and 2000. The mine sites

- Klein Aub – copper,
- Oamites – copper,
- Matchless – copper,
- Namib Lead – lead/zinc,
- Khan – copper, and
- Onguati - copper

which are located in Central Namibia, were selected out of 23 visited sites to assess their environmental hazard potential and to propose remedial measures (Fig. 1). In a second project phase the mine sites of Klein Aub, Matchless and Oamites which had the highest hazard potential were investigated in more detail to evaluate their environmental impacts.

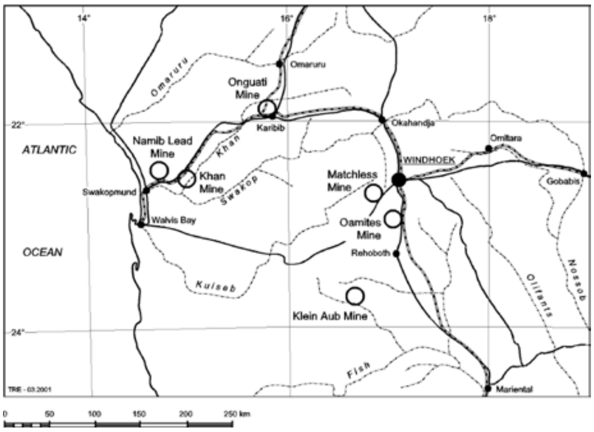

Figure 1: Location of the investigated abandoned mine sites

Methodology and Approach

Before the beginning of the field work, a low level air survey of the mine sites was flown by Professional IT Services (Pty.) Ltd. of Windhoek to document the existing situation of the sites and to create a digital photographic basis for the description and presentation of the environmental hazards.

The field methods applied to assess the hazard potential of the abandoned mine sites comprised a geochemical sampling programme and geotechnical investigations.

Geochemical programme

The geochemical programme included drilling of the tailings dumps, collection of tailings samples, stream sediments, soil and water samples and *in situ* measurements of physico-chemical parameters of water. In addition γ-spectrometric measurements on traverses across tailings dams were conducted.

The drilling of the tailings dumps of the investi-gated mines was carried out by West Coast Drilling of Usakos. A total of 29 boreholes were drilled with a combined length of 243 m (Table 1). A sample of approximately 5 kg was recovered per metre of drilling. From each sample, an aliquot of 300 g was sent to the laboratories of BGR and the GSN, respectively. In ad-dition at each 3rd metre, a sample of 2-3 kg was taken; it is archived at the GSN.

The major element composition of all tailings samples, soils and stream sediments were determined by x-ray fluorescence and trace elements (including rare earth elements) were analysed by inductively coupled plasma – mass spectrometry (ICP-MS) in the laboratories of BGR. The average abundances and ranges of

Table 1: Boreholes drilled on tailings dumps

Mine	Boreholes	Drilled Metres
Klein Aub	1 x 15 m, 4 x 5 m	35 m
Oamites	1 x 15 m, 1x 10 m, 1 x 5 m	30 m
Matchless	1 x 15 m, 4 x 10 m	55 m
Namib Lead	3 x 11 m, 2 x 12 m, 2 x 13 m	83 m
Khan	2 x 2 m, 1 x 3 m, 1 x 4 m, 1 x 6 m, 1 x 8 m	25 m
Onguati	1 x 4 m, 1 x 5 m, 1 x 6 m	15 m

elevated concentrations of the elements are shown in Table 2. In addition, X-ray diffraction studies were performed on tailings samples of all mine sites in order to determine major, minor and trace minerals and to distinguish between primary and secondary minerals.

Stream sediment sampling was done by collecting a composite sample of fine grained sediment perpendicular to the river course. In order to remove the coarse sediment fraction a 1 mm nylon sieve was used at the sample site. A quantity of 200 g was stored in a special craft paper bag and air-dried.

At each mine site the stream sediment survey included the collection of background samples. A test was conducted to determine the best contrast between background element concentrations and contamination. The analysis of several fractions showed that the < 63 µm fraction had the highest concentrations of nearly all minor elements. Yet, in order to guarantee a sufficient sample quantity for analytical purposes the < 150 µm fraction was selected for the routine analysis. Furthermore, the collection and analysis of control samples was carried out.

Table 2: Average abundances and ranges of concentrations of major, minor and trace elements in borehole samples of tailings dumps

Major and minor elements	n	Mean	Minimum	Maximum
Klein Aub Mine				
SiO_2 (%)	19	58.78	55.24	60.96
Al_2O_3 (%)	19	14.14	13.27	16.15
CaO (%)	19	5.22	4.28	6.74
Cu (ppm)	19	2698	1466	4262
Ag (ppm)	19	8.9	4.21	15.2
Oamites Mine				
SiO_2 (%)	18	74.60	68.87	78.78
Cu (ppm)	18	776	433	1458
Pb (ppm)	18	128	87	169
U (ppm)	18	47	27	77
Matchless Mine				
Fe_2O_3 (%)	49	18.90	13.11	22.22
SO_3 (%)	49	3.40	1.04	4.49
CaO (%)	49	3.50	1.35	4.42
Cu (ppm)	49	846	312	1748
Zn (ppm)	49	4635	1605	7731
Pb (ppm)	49	160	80	248
Cd (ppm)	49	9.9	3.1	20.2
Ba (ppm)	49	7535	3952	11195
Onguati Mine				
SiO_2 (%)	14	69.59	45.62	85.07
CaO (%)	14	12.37	5.78	26.84
SO_3 (%)	14	4.25	1.36	8.06
Cu (ppm)	14	1942	747	4133
W (ppm)	14	682	303	1434
Se (ppm)	14	27.8	10.1	57.3
Ag (ppm)	14	3.6	1.6	5.8
Namib Lead Mine				
Fe_2O_3 (%)	36	30.00	21.00	39.85
CaO (%)	36	23.07	13.33	31.50
SO_3 (%)	36	19.31	8.51	25.06
Pb (ppm)	36	2100	497	4504
Zn (ppm)	36	25495	8629	67257
As (ppm)	36	138	58	307
Ag (ppm)	36	7.0	3.3	13.1
Cd (ppm)	36	79.4	22.6	232
In (ppm)	36	7.6	2.1	21
Sn (ppm)	36	890	386	2437
Khan Mine				
CaO (%)	27	11.6	9.53	13.60
Cu (ppm)	27	4791	718	15182
Zn (ppm)	27	284	200	379
Pb (ppm)	27	63	13	207
Ag (ppm)	27	3.6	1.0	11.3
Ba (ppm)	27	1115	829	1636

Soil sampling consisted of the collection of brown, raw soil which had developed as a layer of 2 – 3 cm above the bed rock. A quantity of 200 g was stored in a special craft paper bag and air-dried.

Water sampling comprised the collection of 2 samples at each site:

- 250 ml unfiltered, unacidified sample in a poly-ethylene bottle for anion analysis (Cl^-, Br^-, F^-, NO_3^-, NO_2^-, SO_4^{2-}, BO_2^-).
- 100 ml filtered (0.45 mm filter), acidified sample in a pre-acidified teflon (FEP) bottle for major cation analysis (Na^+, K^+, NH_4^+, Ca_2^+, Mg_2^+) and trace metals (Cu, Pb, Zn, Co, Ni, Fe, Mn, Cr, Cd, As, Hg, U, dissolved constituents).

Acidification was done with 1 vol. % HNO_3 (65%) Suprapur to pH < 2. The following physico-chemical parameters were measured directly at the sample site:

- Temperature (°C)
- pH
- Electric conductivity EC (mS/cm)
- Redox potential EH (mV)
- Dissolved oxygen (mg/l)
- Dissolved oxygen concentration (%).

The measurements were carried out with the portable kit Multi Line F/Set3 of the Wissenschaftlich-Technische Werkstätten, Weilheim (Germany).

Analysis of inorganic trace elements (heavy metals Cu, Pb etc.) was done with ICP-MS. Analysis of inorganic constituents (cations) Na^+, K^+ etc. was done with ICP-OES.

Occasionally dissolved carbon dioxide (CO_2) and bicarbonate (HCO_3^-) were analysed at the sample site by titration applying 0.05 N NaOH and 0.05 N HCl, respectively.

The anions Cl^-, NO_3^-, Br^- and SO_4^{2-} were deter-mined by ion-chromatography, PO_4^{3-}, NO_2^- and the cation NH_4^+ by photometry and F^- by ion sensitive potentiometry.

The analytical results of the geochemical/hydrochemical programme were compared with accepted environmental standards or guideline values. Solubility tests (shake flask tests) on tailings, drainage and soil samples were carried out and the resulting eluate was analysed for the heavy metal concentrations which would be soluble and mobile under natural conditions. In order to assess their environmental impact, these concentrations were compared with the guideline values for drinking-water quality of the Department of Water Affairs (DWA). Furthermore, the inorganic major constituents of the water samples were compared with the above mentioned guideline values of the DWA and an acid-base accounting test was conducted to calculate the acid-producing (AP) and acid-neutralising (NP) potentials of the tailings samples of the Matchless, Namib

Lead, and Onguati Mines. AP and NP were determined with the pyritic sulphur and pH-stat methods, respectively.

Geotechnical investigations

The geotechnical investigations of the project dealt with the safety situation of the mine sites, i.e. open shafts and ramps, collapsed ground, toxic chemicals, calculation of the volume of the tailings dumps, stability of tailings dumps and earth dams, dry density tests with tailings material, removal of scrap metal heaps etc. Dust monitoring systems were established on top of the dumps.

Results of the mine site investigations and proposed remedial measures

Klein Aub Mine

The main environmental aspects identified at this mine site (Fig. 2) are

- wind-borne tailings dust,
- erosion features on the tailings dump,
- collapse structures related to the underground mine, and
- the quality of the shaft water

A wind monitoring programme revealed that the community of Klein Aub is affected by easterly winds which transport dust from the adjacent tailings dump. The construction of a 0.5 m high graded gravel cover on top of the tailings dam is recommended as a sustainable option to impede the wind transport of fine tailings material and stop erosion by rain water. To the east of the tailings dump, in the Maria Shaft area, a waste rock dump containing 15000 m^3 of dark shale is found which could be used as a graded cover with finer material at the bottom and coarser one at the top.

During the operation phase of the mine collapse features occurred close to the Koper River and the West Shaft. They appear to have stabilised. However, should large amounts of mine water be pumped for agricultural or other purposes the status quo might change. It is therefore necessary that the collapse areas be fenced and monitored.

The drinking-water supply of the local community of 1200 inhabitants is insufficient. It is suggested to use the enormous water resources of the abandoned subsurface mine infrastructure. Based on mine plans the subsurface volumes of the Van Zyl Shaft/West Shaft and the Maria Shaft open stopes were calculated as 640 000 m^3 and 1.5 Mm^3, respectively. The analytical results of the Van Zyl Shaft water show that the major inorganic constituents and trace elements fulfil the requirements of the DWA guideline values for drinking-water quality of "Group B" (Good Quality). Microbiological analyses indicate that the water complies to the "Group A" guideline for drinking-water.

A shaft water sample was also analysed for AOX, (absorbable organic halogenated compounds), which are found in defatting and cleaning solvents used for maintenance of mine equipment. The analysis showed 17 µg/l, which is below the guideline value of 50 µg/l for raw water.

However, the consumption of the water causes slight digestive problems probably due to the relatively high sulphate concentrations (444 – 560 mg/l; DWA guide-

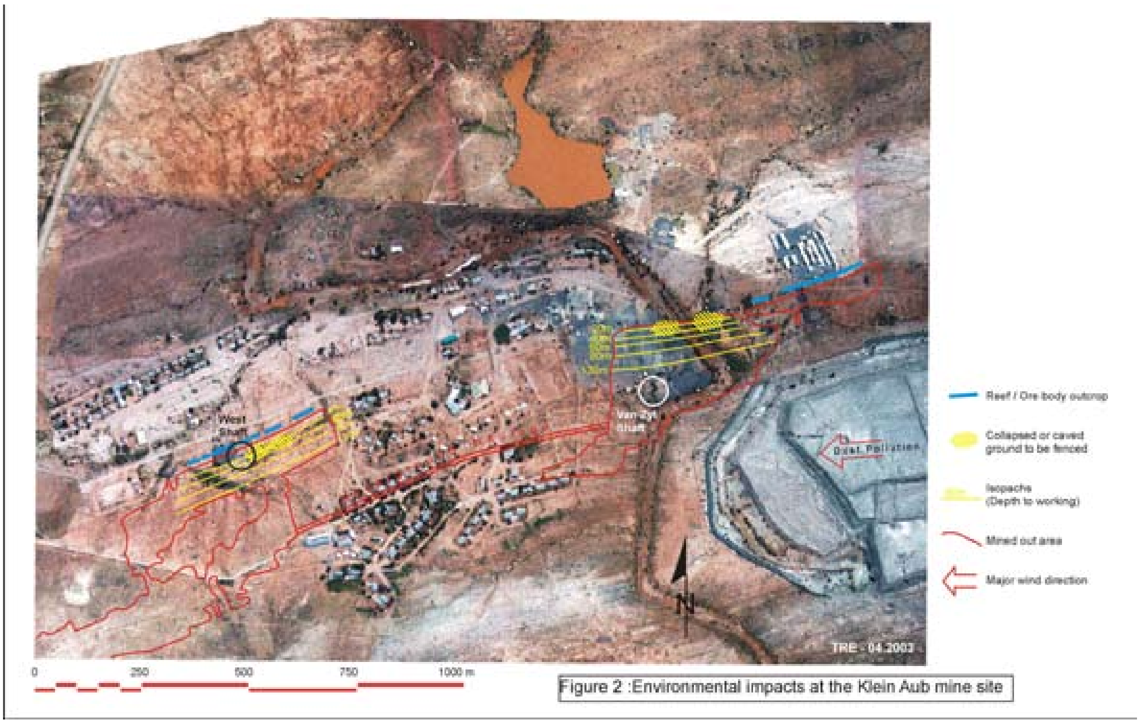

Figure 2 :Environmental impacts at the Klein Aub mine site

Figure 2: Environmental impacts of the Klein Aub mine site

line value 200 mg/l SO_4). Therefore, it is recommended to dilute the shaft water with the water of a dam (SO_4 1.7 mg/l) adjacent to the community. After mixing, water should be filtered and chlorinated. The water quality has to be monitored regularly for both inorganic and organic constituents as well as bacteria.

Matchless Mine

At the mine site and its surroundings major problems of environmental concern are pyrite-rich tailings and waste rock dumps, contamination of water and sediments of a 4 km-long section of the Matchless River (Minen Rivier) between the mine workings and Myburgh's Dam by acid mine drainage (AMD), a deep erosion feature in the downstream face of the main tailings dump, earth dams which are not very effective or are breached and the access to old adits and the main shaft (Fig. 3).

The drilling campaign on the tailings dump comprised 5 boreholes with a total depth of 55 m and the collection of 49 samples. The metal contents of the dump was calculated as follows:

- Zn 2920 t
- Cu 532 t
- Pb 100 t
- As 8 t
- Cd 6 t

An acid-base accounting test (Table 3) with tailings samples of the Matchless, Namib Lead, and Onguati Mines revealed that only the Matchless samples correspond to the categories "acid" and "uncertain" (White *et al.* 1999). All samples of the Namib Lead and Onguati Mines clearly correspond to category "non-acid".

The contaminated stream sediments are characterised by enhanced concentrations of Cu, Zn, Pb and Cd which show seasonal variations. Due to a higher discharge of AMD from the mine site and transport of tail-ings material as a result of higher river flow, the samples taken in the rainy season (April 2000) had considerably higher heavy metal concentrations than those collected during the dry season.

The water surveys showed that acidic, heavy-metal-containing (Cu, Pb, Cd, Co and Ni) sulphate water derived from the oxidation of pyrite-rich tailings and waste rock material contaminates the river system. Due

Table 3: NP, AP and NP/AP ratio of Matchless, Namib Lead and Onguati tailings samples

Sample No.	Neutralisation Potential (NP) kg/t $CaCO_3$eq	Acid-Producing Potential (AP) kg/t $CaCO_3$eq	NP/AP	Category
Matchless Mine				
M1/2	293	107.8	2.71	Uncertain
M1/5	542	243.4	2.22	Uncertain
M1/9	507	307.5	1.64	Uncertain
M1/15	243	256.8	0.94	Acid
Namib Lead Mine				
N3/1	946	24.68	38.33	Non-acid
N3/6	1042	48.75	21.37	Non-acid
Onguati Mine				
ON1/5	950	8.75	108.5	Non-acid
ON1/6	950	3.12	304.4	Non-acid

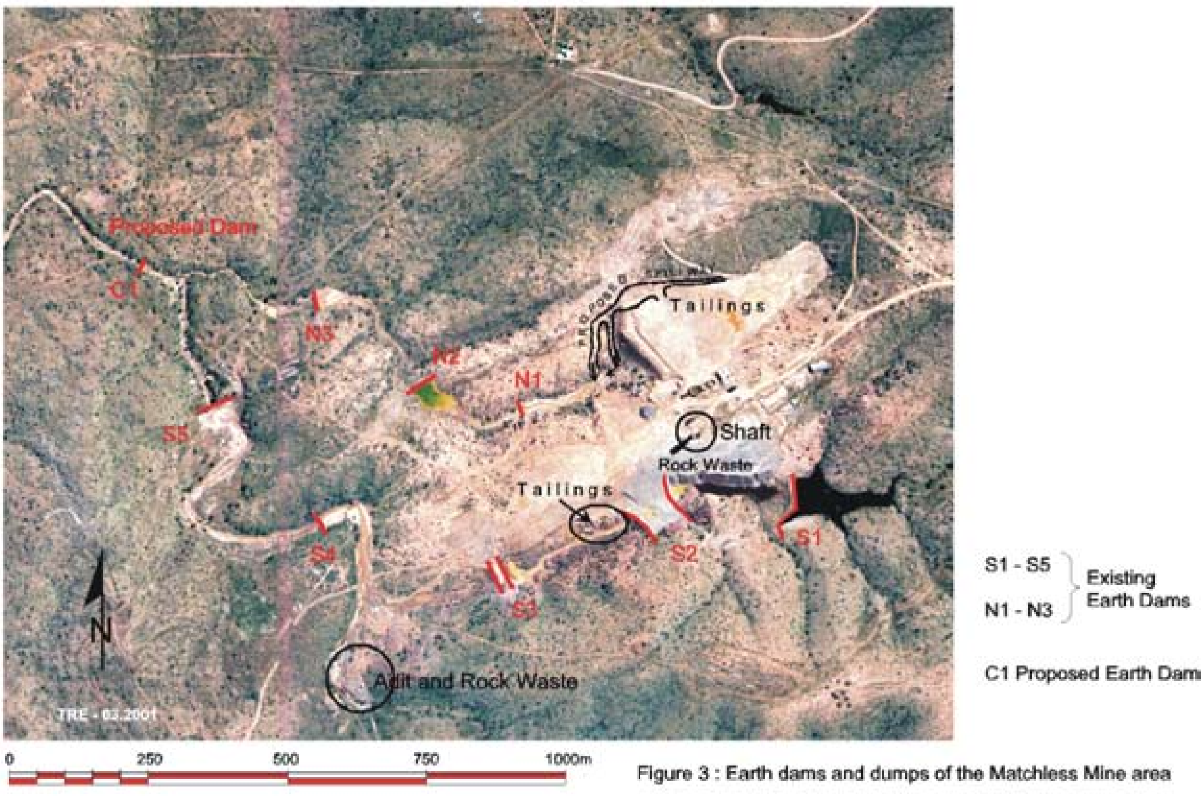

Figure 3: Earth dams and dumps of the Matchless Mine area

to evaporation the total dissolved solids (TDS) of the dry season water were higher than those measured in the rainy season. In the case of one of the earth dams in the mine surroundings breaking due to advancing erosion or a flush flood the contamination could reach the Friedenau Dam which is located 16 km (aerial distance: 10 km) downstream of the mine (Fig. 4).

The construction of a spillway system to by-pass the main tailings dump is the most urgent remedial measure. It will help contain future erosion and reduce the discharge of pollutants downstream. In order to contain or attenuate AMD from the tailings and waste rock dumps it is recommended to reinforce earth dam S3, repair dam S5, raise dam N3 and/or construct a new dam in the river system below the mine workings. To cut off access to the old adits on the Minen Rivier and the ventilation inlet beneath the main shaft will entail the construction of walls to close the openings.

Oamites Mine

At the mine site subjects of environmental concern for the adjacent camp of the Namibia Defence Force are wind-borne tailings dust, the caved area of the old underground workings and the waste water-treatment plant (Fig. 5).

A wind monitoring programme showed a uniform ENE wind direction on the SW tailings dump and ENE and NNE directions on the NE tailings dump. The construction of a 0.5 m high graded gravel cover on top of the NE tailings dam is recommended to reduce the wind transport of fine tailings material. The cover material could be partly derived from a waste rock dump close to the tailings dam.

The caving of the old underground mine workings has created a very dangerous situation, and the hole which was originally fenced by the mine operators should be refenced. Furthermore, it was noted that the waste water-treatment plant located at the southwestern edge of the SW tailings dump is out of order so that untreated sewage with high ammonia and nitrite concentrations discharges directly into the adjacent Oamites River.

Namib Lead Mine

At the mine site a major problem of environmental concern is the safety situation (Fig. 6). In the surroundings of the mine wind-borne tailings dust and contaminated stream sediments cause a negative environmental impact. The attempt to reprocess the old tailings failed.

The mine site is particularly dangerous since all shafts – vertical, inclined and ventilation are still open and badly secured. Dangerous chemicals remain on site and the overhanging oxidized tailings are also hazardous.

Distribution and deposition of tailings material containing elevated Pb, Zn, As and Cd concentrations occurs by wind and river transport. A plume of tailings dust with an extension of 900 m is found to the SW of the main tailings dump and tailings material is transported for 900 m in the drainage system to the S and SW of the tailings dam. All water samples collected from the mine site are highly contaminated with respect to most of the major inorganic constituents and heavy metals.

The original tailings dump of the mine had a volume of around 4.0 Mm^3, of which 1.25 Mm^3 have

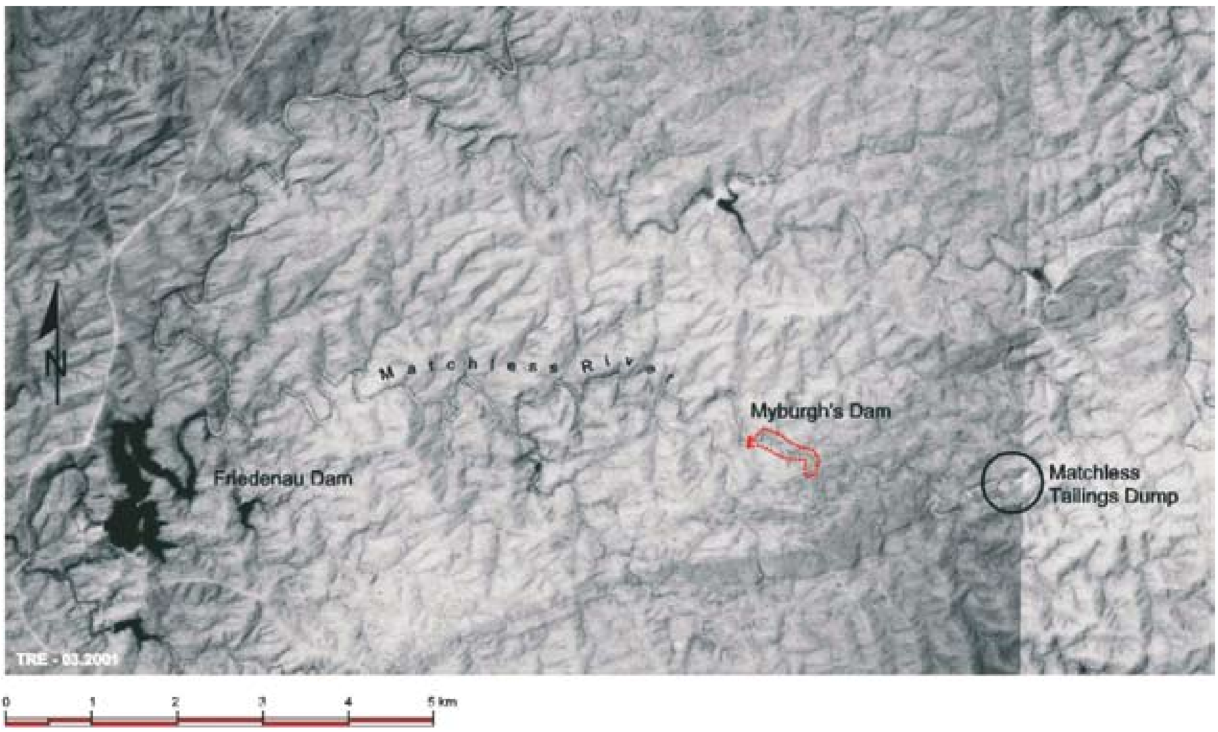

Figure 4 : Location of Matchless Mine, Myburgh's Dam and Friedenau Dam

Figure 5 : Oamites tailings with dust pollution

been reworked for Zn. The old tailings contain average abundances of 2.54% Zn, 0.21% Pb and 7.0 ppm Ag whereas the new ones have an average grade of 2.14% Zn, 0.15% Pb and 7.9 ppm Ag. This indicates that the reprocessing of the old tailings inefficient and uneconomic. A bulk sample of tailings material should be send to MINTEK in the Republic of South Africa to in-vestigate the possibility of an economic reprocessing of the tailings dump.

Khan Mine

At the mine site in the Khan Gorge problems of major environmental concern are the safety situation and the contamination of the gorge by tailings material.

Stream sediments mixed with tailings material collected in the gorge are characterised by elevated concentrations of Cu, Zn, Pb and Ba which can be traced for approximately 5 km down to the junction with the Khan River.

The remedial work which suggested for the mine

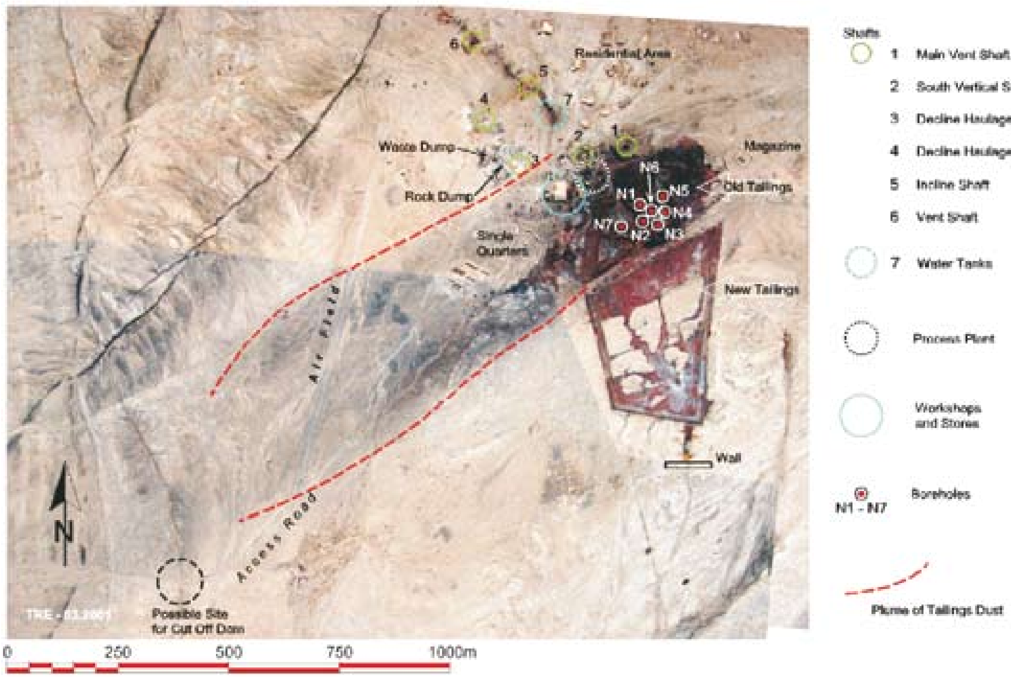

Figure 6: Namib Lead Mine

site comprises the closure of all shafts and adits and a clearing up of the area. The concept of providing camping facilities for tourists, should be taken up with the present mine owner.

Onguati Mine

The hazards of the abandoned workings are open adits and shafts, scrap metal and a contamination of the adjacent creek by tailings material.

In order to render the old mine workings safe it will be necessary to brick up the adits and fill the ventilation shaft with waste rock. It is not recommended that scrap metal, trucks etc. be put in the adits prior to closure, instead they should be consolidated into one yard outside of the mine workings.

The tailings dam which is located directly in the bed of an adjacent creek and blocks its course, shows the effects of erosion and it can be seen that tailings material is transported in the river bed over a distance of 1.5 to 3 km. This is also indicated by Cu and W concentrations, which are several times higher than the local background area.

Conclusions

The environmental impacts of the investigated mine sites depend on the type of mineralisation, its host and country rocks, the geographical situation, and the climatic conditions. All mine tailings have in common that they are affected by wind and/or rain water erosion. The Matchless Mine is the only mine with typical acid mine drainage features. The other mines are marked by an almost neutral or alkaline environment which reduces the dissolution and transport of toxic metals. The recommended mitigation measures took into account the hazard potentials of the mine sites and their surroundings, as well as social aspects. Consequently, adverse impacts on neighbouring human settlements or water reservoirs were dealt with special priority.

References

Directorate of Environmental Affaires. 1999. Environmental Legislation Project: Pollution control and waste management legislation, DEA, Windhoek.

White, W.W., Lapakko, K.A. and Cox, R.L. 1999. Static-test methods most common used to predict acid-mine drainage: practical guidelines for use and interpretation. *Reviews Econ. Geol.*, **6A**, 325-338.