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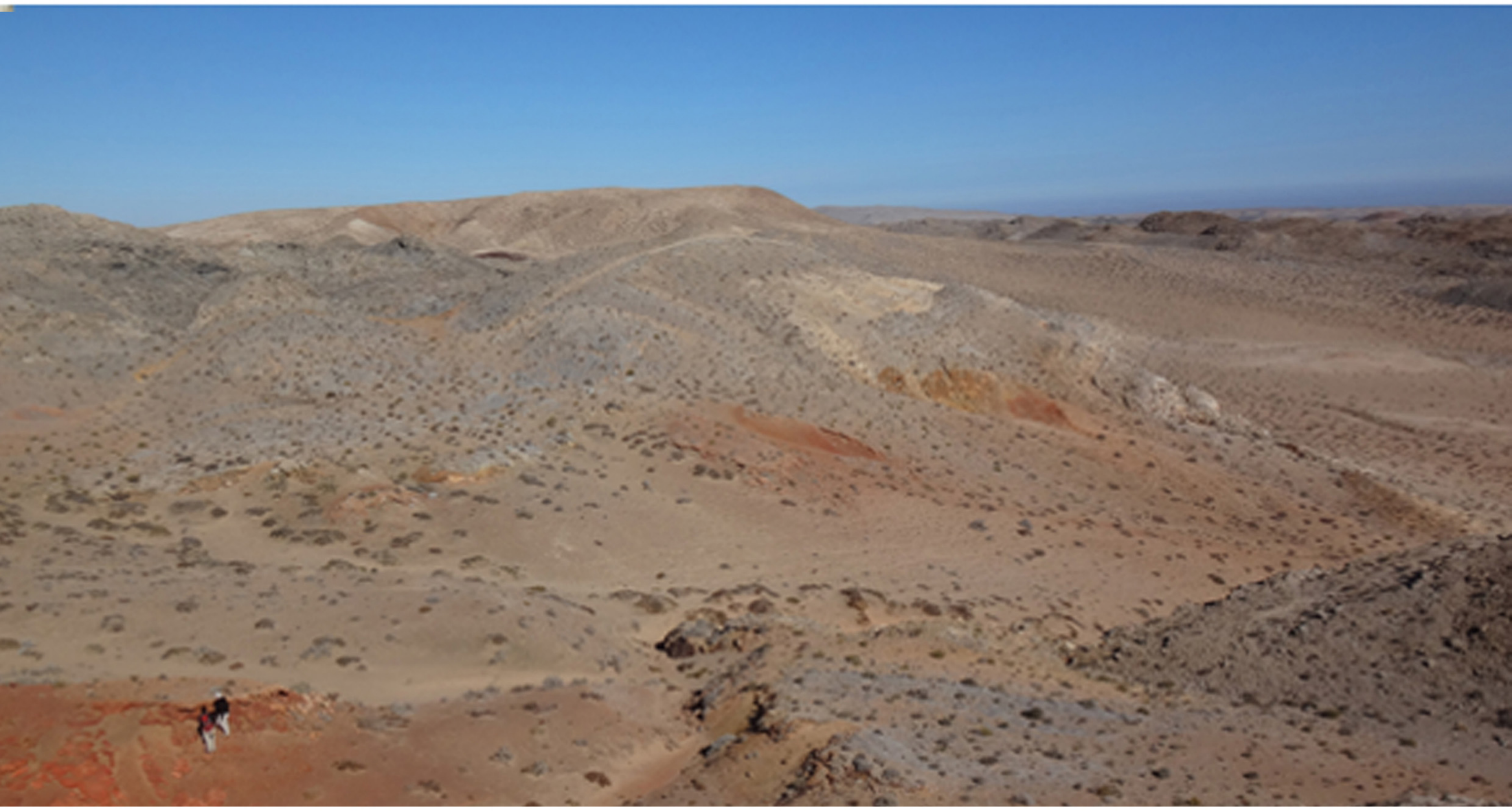

MINISTRY OF MINES AND ENERGY

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PAPERS

Cover Image : Geologists studying the Bo Alterite in the type outcrops 1 km north of Chalcedon Tafelberg (in the background), Sperrgebiet, Namibia

Environmental situation around the Tsumeb Smelter Complex, Namibia

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Abstract: More than 100 years of mining, processing and smelter activities in Tsumeb have left their traces in the soils of the area. Sources of contaminations are solid and gaseous emissions from the smelter complex and particle emissions from processing facilities, tailings dumps as well as slag deposits. Easterly winds are prevailing in the Tsumeb area causing air borne pollution mainly to the west of the smelter complex. Geochemical studies on groundwater and soil, complimented by medical tests and studies on freshwater fish as well as agricultural products were carried out by the Geological Survey of Namibia (GSN) and its partner institutions to assess the environmental situation and to guide urban and regional land use planning.

The analytical results of more than 550 soil samples taken around the smelter complex show critical concentrations of arsenic, cadmium, copper and lead which partly exceed international guideline values for residential and agricultural land uses. The heavy metal concentrations of most of the fruits and vegetables generally correlate with the heavy metal concentrations of the underlying soil. However, root and leaf vegetables showed comparably high concentrations of the heavy metals while stem vegetables and fruits are less affected.

It was recommended to restrict land use in an inner buffer zone adjacent to the smelter complex to industrial activities. A planned major town extension of Tsumeb had to be stopped but alternative future residential areas could be delineated to the south and east of the town based on the soil surveys. In an intermediate zone, agricultural land use has to be limited to growing of fruits and stem vegetables.

The current owner of the Tsumeb Smelter, Weatherly International, is highly supportive in implementing land use recommendations by GSN. An intensive coordination with the smelter management, the Ministry for Regional and Local Government, the town planners and other affected Ministries guarantees the outcome-oriented integration of the recommendations of our studies into future town and regional land use planning.

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Introduction

Tsumeb is one of the largest towns situated in northern Namibia. It is well known for its polymetallic vein and replacement deposits of Mississippi Valley Type hosted by Late Neoproterozoic sedimentary rocks. Industrial copper mining and smelter activities in Tsumeb date back to more than a century and have left their traces in the soils around Tsumeb.

The Geological Survey of Namibia (GSN) monitored the environmental situation in Tsumeb in cooperation with the German Federal Institute for Geosciences and Natural Resources (BGR), the University of Namibia and for specific studies with the Czech Geological

Survey, the Inland Aquaculture Centre (IAC) and Department of Water Affairs and Forestry (DWAF). Research included geochemical studies on groundwater and soil, complimented by studies on freshwater fish and agricultural products. Recommendations and conclusions were based on the analysis of 550 soil samples collected from different areas including the proposed town extensions, as well as alternative development sites in and around Tsumeb for contaminants of concern (arsenic, lead, cadmium, copper, zinc).

The main objectives of these studies were:

- To assess the soil and groundwater contamination in the Tsumeb area,
- Give recommendations for further town planning to the Tsumeb Municipality,
- Investigate the bioaccumulation of heavy metals,
- Determine the specific contaminant uptake by various crops; and
- To advise affected organisations on mitigation measures.

Overview of the Geology of Tsumeb

Tsumeb is located in the northern central part of Namibia on the edge of the Otavi Mountainland. The major part of the current urban area of Tsumeb is developed on deeply weathered arkosic sandstone and shale of the Tschudi Formation (Mulden Group) and carbonate rocks of the Hüttenberg Formation of the Tsumeb Subgroup. The carbonate rocks of the Hüttenberg Formation are part of the Precambrian platform sedimentation close to the Congo Craton in the northern zones of the Damara Sequence (Schneider, 2004). The dolomites and limestones comprise a thickness of several hundred meters and consist of thin bedded dark dolomite rock with some intercalations of phyllite, limestone, and chert (Schneider, 2004). These carbonate rocks are in some places heavily fractured due to major faults stretching north-south to the west of Tsumeb. The slightly disconformably overlying Tschudi Formation consists of up to 1600 m of reddish brown to grey, massive to thinly bedded, well cemented arkose sandstone with minor basal greywacke (Miller, 1983, 2008). Sedimentary rocks of the Tschudi and Hüttenberg formations are the hosts of copper mineralisations in the Tsumeb area. These mineralisations additionally influence the geochemistry of the soils (Goscombe *et al.*, 2004; McDermot & Hawkesworth, 1990; Nex *et al.*, 2001; Tack & Bowden, 1999).

The morphology of the area is dominated by the Tsumeb hills made up of gentle slopes with some steeper rocky parts where carbonate bedrocks are exposed. The annual average rainfall is 580 mm causing intense chemical weathering of the carbonate rocks, which leads to a wide variety of karst features such as karren, sinkholes, pinnacles and small dolinas.

Sources of Heavy Metal Contamination in Tsumeb

Sources of heavy metal contamination in Tsumeb are solid and gaseous emissions from the historic and recent smelter complexes and airborne particles from processing activities, tailings dumps as well as slag deposits. Easterly winds are the prevailing wind direction causing air borne pollution mainly to the west of Tsumeb. Based on a total of 65 sample points, Kribek & Kamona (Eds, 2005) recorded heavy anthropogenic contamination by metals over an area of approximately 20 km^2 stretching west of the smelter. The solid emissions from the current smelter contain high amounts of sulphur dioxide (up to 11.3 % S), copper (5 %), lead (0.5%), and other metals (Zn, As, Cd, Hg) (Kribek & Kamona, Eds, 2005). Dust from the tailing dumps contains 0.7 % Pb, 0.57 % Zn, 0.59 % Cu and elevated amounts of As, Cd and Tl. 14.7 % of the dust are PM_{10} particles. The slag deposits are composed mostly of medium-grained silicate glass particles that contain up to 11 % Cu, 6 % Zn, 4.4 % Pb and high amounts of As, Cd, Co, Ga, Ge and Mo (Kribek & Kamona, Eds, 2005).

Sampling and Analytical Methods

Soil sampling

To quantify the natural and anthropogenic inventory of heavy metals in the soils, analysis included both surface samples (taken from the first three centimetres of the soil profiles) and background soil samples (taken 70-90 cm below the surface in areas with developed soil profiles and at depth between 30 and 60 cm in rocky areas) (Fig. 1). Sampling was done along lines or nets with different spacing depending on the morphology and the proposed land use, and thus, expected variation in soil contamination and significance of the soil-human and soil-plant-human pathways.

The soil samples were sieved into fractions of ≤2 mm and ≤0.18 mm. The ≤0.18 mm fraction samples were analyzed in the field using a portable x-ray fluorescence (XRF) spectrometer XLt 700 Series Environmental Analyzer Version 4.2 of NITON Corporation, USA. The detection limits are at 10 ppm for the elements of concern. The samples were analyzed for 100 to 130 seconds to optimize the results. For quality control, sets of samples were quality controlled by ICP-MS and ICP-OES at Analytical Laboratory Services in Windhoek, Namibia, and the laboratories of BGR in Hannover as well as UFZ in Leipzig, Germany.

Figure 1. Soil sampling campaign of the GSN in June 2006 opposite the Tsumeb smelter complex.

Groundwater Sampling

The sampling points were selected to cover a wide region in the expected downstream direction of the groundwater flow. A total number of 10 boreholes were sampled west and north of Tsumeb. Samples were also taken upstream and downstream of the municipal waste disposal site in order to determine the upstream hydrochemistry and identify an eventual contamination plume downstream. In addition, water samples were collected from three operational fish ponds (earthen but plastic lined) at the Mannheim Fish Farm, 15 km to the North of Tsumeb.

Measurement of physico-chemical parameters (temperature, pH and electrical conductivity) was done onsite with a multi-parameter portable instrument (MultiLine F/Set 3 of

Wissenschaftlich-Technische Werkstätten Weilheim). The following types of water samples were collected:

1. One 250 ml PE bottle, filtered with a 45µm filter, acidified with 5 % HNO_3 to pH<2, for major cations and trace elements analysis.
2. One 250 ml PE bottle, unfiltered, unacidified, for anions analysis.
3. Three 10 ml headspace glass bottles for volatile organic compounds (VOC) analysis.
4. Two 250 ml glass bottles, acidified with 0.5 ml concentrated HNO_3, for analysis of absorbable organic halogenated compounds.
5. One 2000 ml brown glass bottle with ground glass stopper, for polycyclic aromatic hydrocarbons (PAH) analysis.
6. One 2000 ml brown glass bottle with ground glass stopper, for petroleum hydrocarbons (PHC) analysis.

The analyses were carried out by Inductively Coupled Plasma Optic Emission Spectrometer (ICP-OES) at Analytical Laboratories Services, Windhoek and the BGR laboratories, Germany.

Vegetable Material

A total of 43 plant samples comprising of fruit crops (marula – *Sclerocarya birrea*, papaya – *Carica papaya*), vegetables (tomato – *Solanum lycopersicum*, parsley – *Pretroselinum crispum*, carrot – *Daucus carota*, bean – genera Fabaceae, pumpkin – *Cucurbita sp.*, chilli pepper – *Capsicum sp*) and field crops (maize – *Zea mays)* were randomly collected at farms and private gardens in the Tsumeb area.

Two types of samples were collected from each sampling point; one plant sample was cleaned with distilled water and the other was not cleaned in order to investigate the effect of superficial adsorption of dust. All samples were air dried. The vegetal material was analysed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) by the Institute for Soil, Climate and Water in Pretoria, South Africa.

Fish

Three fish (spot tilapia: *Oreochromis andersonii*) from Mannheim Fish Farm weighing between 200 and 500g, were caught from each of the two sampled ponds. Three types of tissues (liver, gill, meat) where separated from the fish for further analysis, packed in plastic containers and stored on ice. The frozen material was sent to the Institute for Soil, Climate and Water (ARC-LNR), Pretoria, South Africa. Zinc and copper were determined by ICP-OES and confirmed by ICP-MS; other elements were determined by ICP-MS.

Results and Discussion

Guideline Values

In the absence of guideline values for soil contamination in Namibia, the GSN uses criteria from Canada (Contaminated Sites clean up Criteria 1999, updated 2006), and Germany (Eikmann-Kloke-Values for Soil Contamination, 1993). The guideline values refer to ecotoxical risks, trigger values and acceptable concentration for the intended use of a particular site. The guideline values of the World Health Organisation (Codex Alimentarius) and European Union were applied for the interpretation of metal concentrations in vegetable materials and fish (USDA-NRCS, 2000).

Soil Samples

The soil analyses show contamination of various heavy metals forming a plume to the west of the Tsumeb smelter and mining area. The closer the area is located to the historic and current smelter complex, the higher are the contaminations (Fig. 2). Additionally, local morphology has been controlling the sedimentation of the dust emissions from the smelter area. The concentrations of arsenic, cadmium, copper and lead exceed international guidelines for residential grounds in some areas. The highest contaminations were found adjacent to the historic smelter area with maximum values of 229 mg/kg arsenic, 38.7 mg/kg cadmium, 483 mg/kg copper, 1080 mg/kg lead exceeding intervention guideline values many fold.

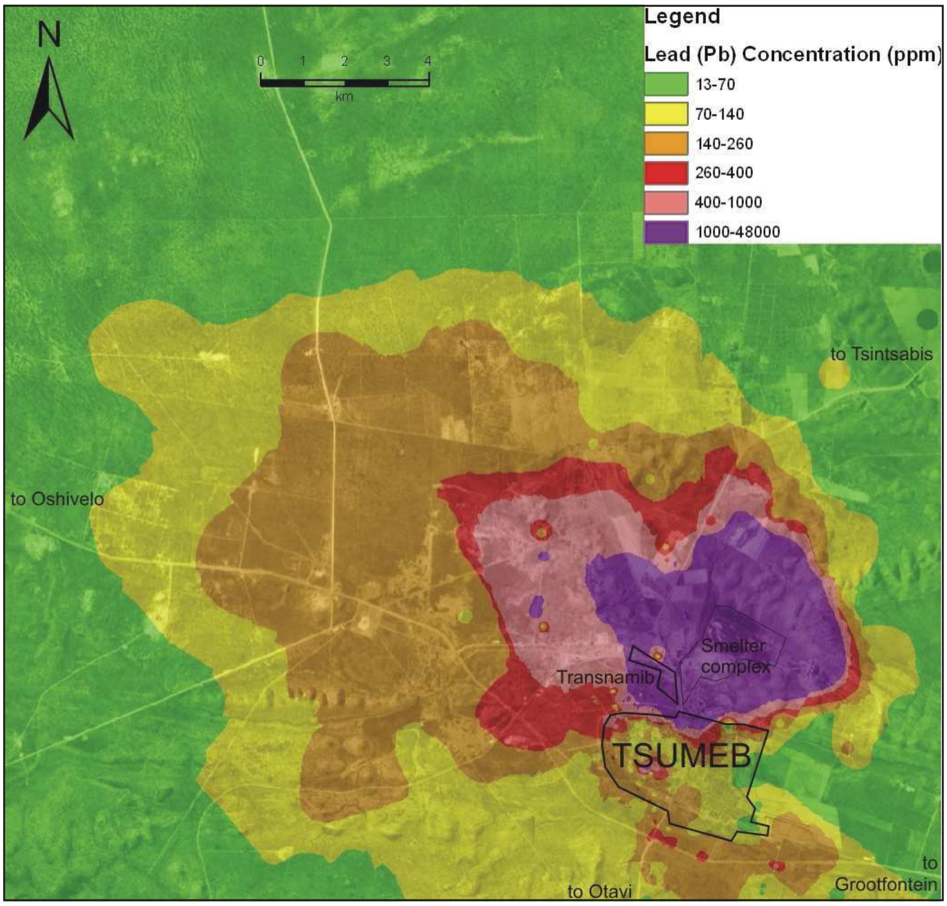

Figure 2. Lead concentration of the 0.18 mm fraction of top soils in the Tsumeb area

Groundwater

All concentrations of major elements in the groundwater samples are well within the limits of drinking water of excellent quality (Group A) according to the Namibian water guidelines. The element spectra are typical for groundwater of karstic aquifers. The concentrations of As, Cd, Co and Pb are below the detection limit of the ICP for all the samples and fall within the limits of drinking water of Group A of the Namibian guideline values. The alkaline soils and the buffering capacity of the carbonate rocks in the Tsumeb area effectively prevent heavy metal infiltration into the groundwater.

In addition, the water samples were analyzed for 30 organic compounds which are typical for contaminations by landfills and industrial sites. All determined parameters, like absorbable organically bound halogens, benzene, toluene, ethylbenzene, xylenes, volatile halogenated organic compounds, polycyclic aromatic hydrocarbons and petroleum hydrocarbons do not occur in concentrations higher than the determination limits of the laboratory equipment of BGR, Hannover. The hydrochemistry of the background samples in the proposed upstream and far downstream directions is comparable to the groundwater samples near the waste disposal site, thus, groundwater of the sampled boreholes is not affected by contamination from the current land fill and industrial activity.

Vegetable Material

The concentrations of arsenic, lead and cadmium of most of the sampled fruits and vegetables (marula fruits, pumpkins, chilli, and tomato) correlate with the heavy metal values of the underlying contaminated top soils. The relative uptake of arsenic, lead and cadmium from the soil into the plant is shown by soil-plant transfer coefficients. The metal distribution, in general, decreases from root to stem and leaf to edible parts (Adriano 2001). In general, all plant samples showed high lead concentrations while cadmium was critically concentrated in some chili, pumpkin and carrot samples. The concentration of arsenic was significantly increased in parsley, carrots and pumpkins. Leaf vegetables such as parsley and root vegetables such as carrots seem to be extremely prone to the accumulation of the investigated toxic elements. None of the analysed plant samples show critical contamination of copper and zinc.

Fish

The fish ponds are lined with plastic, and thus, the aquaculture is not in direct contact with the soil. The magnesium-calcium-bicarbonate water in the fish ponds is of acceptable quality according to the Namibian Guideline Values for Drinking Water. The heavy metals indicative for airborne contamination from the Tsumeb smelter were found in low concentrations dissolved in the water. As a positive effect, the hardness of the water causes a decrease of the solubility (and availability) of most of the metals. In addition, these metals occur in similar concentrations in the groundwater supplying the ponds which points to a negligible effect of smelter derived emissions on the water quality.

The only metals of concern in the pond water are selenium and mercury. As the Tsumeb smelter can be excluded as a source for mercury and selenium, the contamination has most likely a source in connection with fish feed.

Copper is concentrated in the fish liver and exceeds the WHO and EU (2001, 2006) guideline values for food by up to 5 times. In contrast, meat and gills show copper concentrations far below the guideline values. The fish liver has to be excluded from any kind of human or animal consumption.

Conclusions and Recommendations

More than 100 years of industrial processing and smelter activities in Tsumeb caused contaminations of the surface soils with arsenic, cadmium, copper and lead which exceed international guideline values for residential and agricultural land use in areas adjacent to the smelter complex (Fig. 3). Any kind of development proposed in this area needs to be assessed with due respect of the kind of planned businesses (potential pathways of exposure and contamination) and the contaminant concentrations in the surface sediments. Due to the increasing distance from the smelter and favourable morphology in form of the Tsumeb Hills between the smelter and Tsumeb town, contamination in the current Tsumeb urban area is relatively low (Fig. 3).

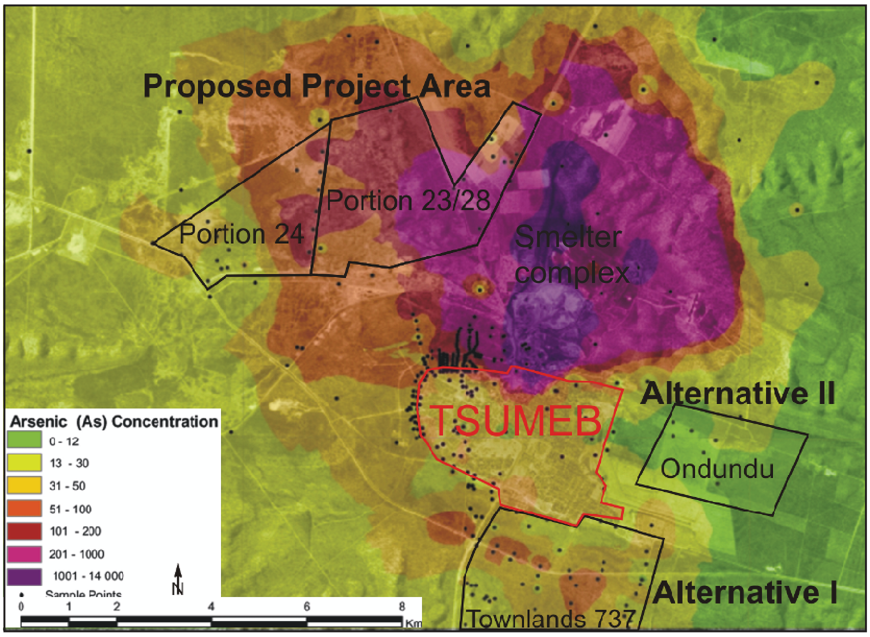

Figure 3. Arsenic concentration in the 0.18 mm fraction of the top soils in the vicinity of Tsumeb showing proposed agricultural projects (Note: yellow and light orange indicate contaminations below the German guideline value)

The groundwater in the aquifers used for the supply of drinking water in Tsumeb is not or not significantly affected by industrial activities and waste dumping. However, regular monitoring of the groundwater quality is obligatory with respect to inorganic and organic contaminants in future. The most important step for future groundwater protection is to restrain municipal waste dumping at the current waste site. The establishment of a safe new waste disposal site has to be enforced according to the Minimum Requirements for Waste Disposal by Landfill (DWAF, 2005).

Bioaccumulation of lead, cadmium and arsenic is evident in all plant samples. It is strictly recommended to cease any agricultural land use activities near the smelter. Especially critical is the area towards the west and north of the smelter, where a buffer zone should be established. Leaf and root vegetables grown in the Tsumeb area have to be intensively washed before consumption. Farmers and supermarkets are advised to clean all root vegetables properly before distribution (ATSDR, 2005).

To guarantee an integration of the results of this study into development projects of various Ministries, the study was presented to Cabinet. In response, an action plan was elaborated by the current owner of the Tsumeb smelter (Namibia Customs Smelter of Weatherly International Inc.), the Municipality of Tsumeb and the project partners GSN and BGR.

Land use in the zone adjacent to the smelter complex will be strictly limited to industrial activities. Further development proposals on moderately contaminated areas are assessed by GSN individually based on the degree of contamination and the intended land use. So far, GSN (2006a, 2006b, 2007a, 2007b, 2007c) advised the Ministry of Regional and Local Government and the Tsumeb Municipality on 9 development proposals of which a few had to be rectified in light of the findings of these studies. Although the contamination of the soil is mainly caused by historic smelter activities, the highly supportive management of Namibia Customs Smelter agreed to exchange contaminated farmland for uncontaminated agricultural land and to signpost clearly the contaminated land. A further decrease of dust fall-out can be expected due to ambitious mitigation measures of the smelter management.

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