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IMPACT OF ORE PROCESSING ON THE ENVIRONMENT IN THE TSUMEB AREA, NAMIBIA

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The environmental degradation in the Tsumeb Area, Namibia, is poorly qualified in spatial terms, since the availability of accurate and up-to-date regional geochemical data for both, unpolluted and polluted areas are limited. To determine an extent of the past industrial pollution, geochemical mapping of soils and grasses was carried out in the Tsumeb Area and the results were compared with those of numerical modeling of solid and gaseous emissions from the Tsumeb smelter, which is still in operation. The area was covered by a semi-regular network of topsoil sampling with a density of at least one composite sample for a 1 x 1 km basic cell using the methodology recommended by Salminen et al. (1998). The mapping in a scale of 1: 25 000 covered a total area of 429 km^2. As the anthropogenic contamination is usually restricted to the surface layer of soil, reference samples were taken from a depth of 80–90 cm of the soil profile. The Tsumeb region agriculture is mostly oriented on the livestock production. Therefore, different grass species collected from pasturelands were analysed for heavy metals contents. Soil, anthropogenic sediments and grass were analysed for As, Cd, Co, Cu, Ga, Ge, Hg, Mo, Pb, Zn, Tl, S_{sulf} and C_{org}. Statistical characteristics of analytical data were obtained using non-parametric statistical programme S-plus (MathSoft, USA). Geochemical data were expressed in the form of spot or isoline maps using SURFER (Golden Software Inc.) program. Numerical modeling was carried out using Symos´97 program (EIONET, 2003), which is based on the Gauss-type distribution of the emissions halo.

Sources of contamination

The following sources of contamination were identified in the studied area:

(1) Solid emissions from the copper and lead smelter contain high amounts of SO_2, high amounts of potentially toxic metals (up to 5.6 wt.% Cu, 0.5 wt. % Pb, 0.3 wt. % Zn) and increased amounts of Cd, As, Hg, Ga, Ge and Tl. Lead is mostly bound to relatively soluble sulfates, anglesite and lanarkite. Dust fall contains more than 85 wt. % of fine-grained particles (PM_{10}) that are hazardous with respect to the human respiratory system.

(2) Dust from the beaches of tailing impoundments contains up to 0.7 wt. % Pb, 0.57 wt.% Zn, 0.59 wt. % Cu and increased amounts of As, Cd and Tl. Approximately 14.7 wt. % of the PM_{10} particles was recorded in the dust fall.

(3) Slag deposits are composed mostly of medium-grained silicate glass particles with up to 11 wt. % Cu, 6 wt. % Zn, 4.4 wt. % Pb and high amounts of As, Cd, Co, Ga, Ge and Mo. Metals are bound partly to silicates, partly to easily soluble sulfide minerals or occur in native form.

Distribution of heavy metals and sulfur in soils

To differentiate geological source, i.e. primary geochemical regional background of metals in soils and anthropogenic contamination, the concept of correlation between metals concentrations in topsoil and in the subsurface soil horizon (70 to 90 cm depth) was accepted. Using this concept, higher concentrations of metals in the surface layer of soil than in deeper

Using this concept, higher concentrations of metals in the surface layer of soil than in deeper soil horizon were considered to represent anthropogenic contamination caused mainly by airborne dust particles. In contrast, higher concentrations of metals in the lower soil horizon compared with topsoil were considered to reflect the natural geochemical contribution from bedrock (primary mineralization). For example, high concentrations of lead in topsoils were found west and north-west of the smelter and tailings impoundment (Fig. 1). The highest lead contents (> 1500 ppm) are interpreted to represent downwind dust contamination. Anomalous values of lead detected in subsurface soil in the area of the Tsumeb mine (Fig. 2) can be, however, related to primary sulfide mineralization.

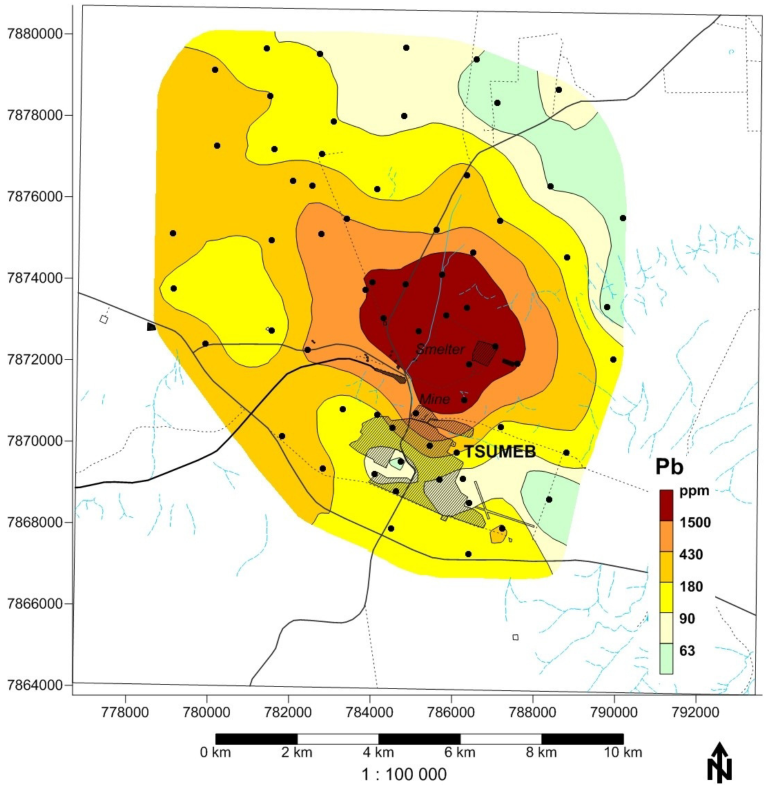

Figure 1: Distribution of lead in topsoils in the Tsumeb area. Black dots represent sampling points.

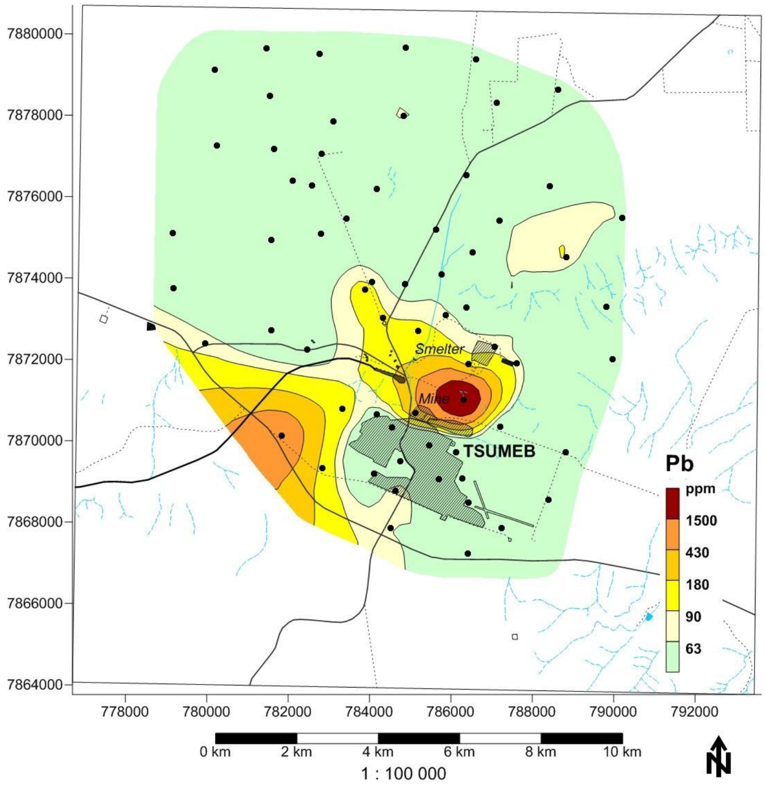

Figure 2: Distribution of lead in the subsurface soil horizon of the Tsumeb Area. Black dots represent sampling points.

The distribution of total sulfur in topsoils (**Fig. 3**) reflects the combined effect of sulfur emissions from the smelter, high content of sulfate around the closed Tsumeb mine (primary mineralization) and contamination of the Jordan River Valley with flotation wastes released during the failure of the of old tailing impoundment. It was established that the degree of industrial contamination may be the best expressed using the Coefficient of Industrial Pollution (CIP), which is a sum of the concentrations of selected metals in topsoil at the individual sampling point, divided by the median values of the same metals in topsoil of the whole region (**Fig. 4**):

$$CIP = \frac{As}{m}+\frac{Cd}{m}+\frac{Cu}{m}+\frac{Hg}{m}+\frac{Pb}{m}+\frac{Zn}{m})/6,$$

where m is a median value of the metal concentration.

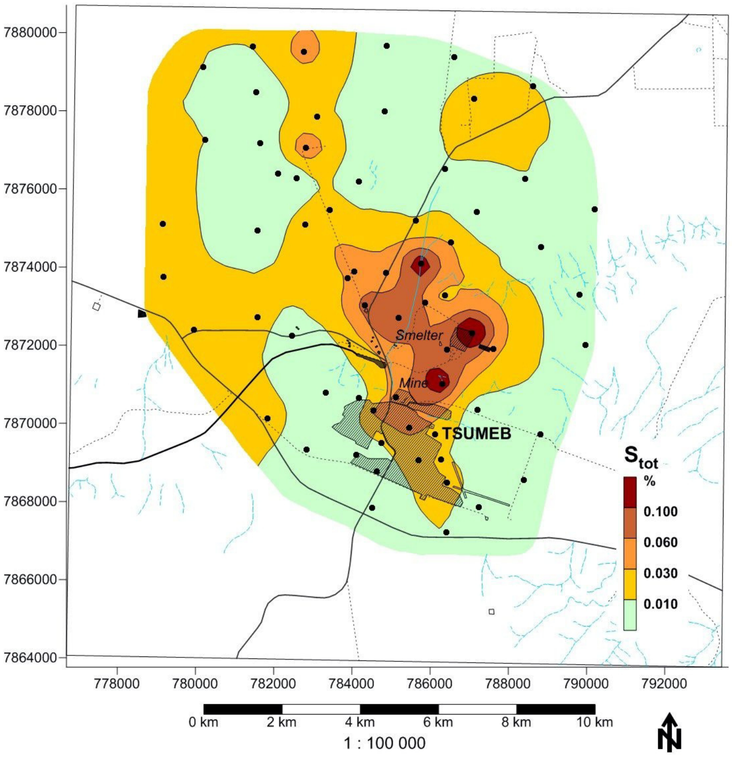

Figure 3: Distribution of total sulfur in topsoils of the Tsumeb Area. Black dots represent sampling points.

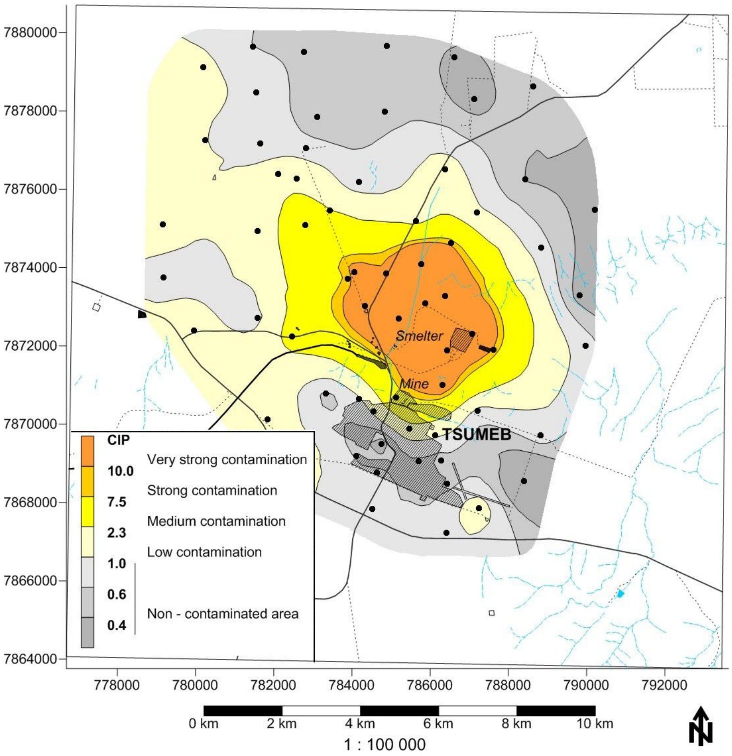

Figure 4: Coefficient of the industrial pollution (CIP) values in the Tsumeb Area. Black dots represent sampling points.

Distribution of heavy metals in plants

The Tsumeb region agriculture is mostly oriented on the livestock production. Therefore, different grass species from pasturelands were analysed for heavy metals/metalloids contents. It was found that 25.8 % of grass samples exceed the threshold of the As concentration in dry feedstock according to the Czech limits (CMR 987), 54.8 % exceed the threshold for Mo and 12.9 % the threshold for Pb (Fig. 5). The highest contents of metals (26.6 ppm As, 52.6 ppm Mo and 104 ppm Zn (on dry weight) were recorded in the grass species *Eargrotis cf. porosa* sampled in the grassland near the Tsumeb Smelter. A large number of grass samples from the Tsumore 761 Farm, 1335 Cadastre and peripheral parts of the Dannenberg 478 Farm is affected by contamination. Very high Pb concentrations in grass are found in the vicinity of the smelter. The contamination with Mo and especially with As is, however, traceable over a distance of 12 km NW from the Tsumeb Smelter.

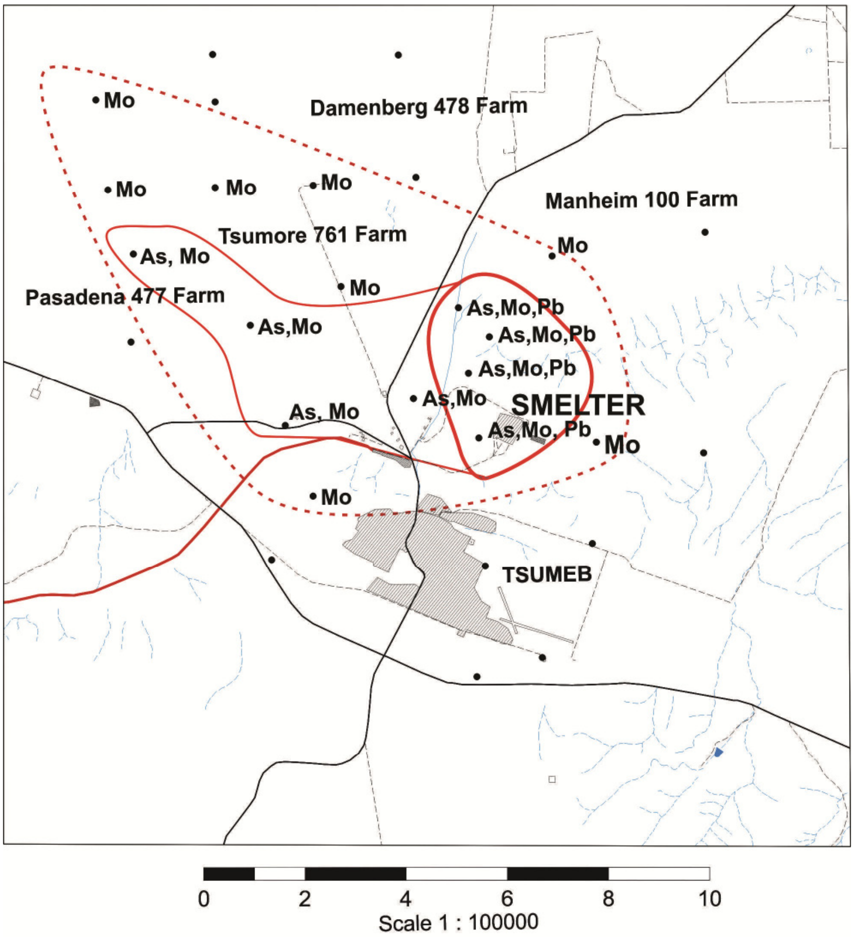

Figure 5: Metals in pasture grass in the Tsumeb Area. The assemblage of metals exceeding Czech limit for dry feedstock at individual sampling points is plotted by their symbols. Heavy red line restricts area contaminated by As, Mo and Pb, light red line restricts area contaminated by As and Mo and broken red line restricts area contaminated by Mo.

Numerical modeling of emissions from the Tsumeb Smelter

The results of the numerical modeling of the SO_2 emissions from the Tsumeb Smelter revealed a contamination of the Tsumeb Town area. However, according to the modeling results, the expected concentration of SO_2 is relatively low (< 0.1 $\mu g.m^{-3}$) and the health risk can be classified as acceptable according to Czech regulations. High SO_2 concentration haloes are expected to be located at the hilltops to the east and south of the smelter (Fig. 6).

The highest dust fall concentrations (> 100 $g.m^{-2}$) are expected to be found around the Tsumeb Smelter (Fig. 7). The Tsumeb residential area is less affected (< 0.X $g.m^{-2}$) due to a favorable landscape morphology between the smelter and town (the Tsumeb Hills). A large area of dust fall contamination is expected to be located downwind, west of the Tsumeb Smelter. The results of numerical modeling of the SO_2 concentration and dust fall generally correspond with the results of environmental-geochemical mapping. Differences can be explained by additional sources of contamination (dust fall from tailing impoundments and slag deposits, mineralized dust from abandoned mines) that were not considered in the numerical model.

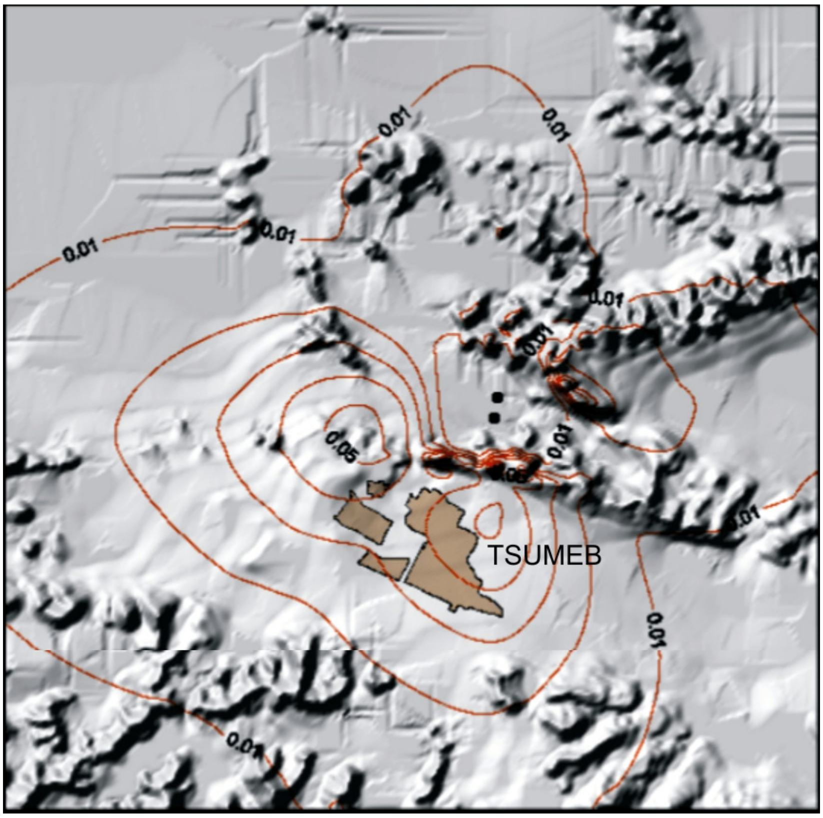

Figure 6: Numerical model of the SO_2 dispersion halo around the Tsumeb Smelter. Isolines represent annual average concentrations of SO_2 (in $\mu g.m^{-3}$). The position of smelter stacks is marked by black dots.

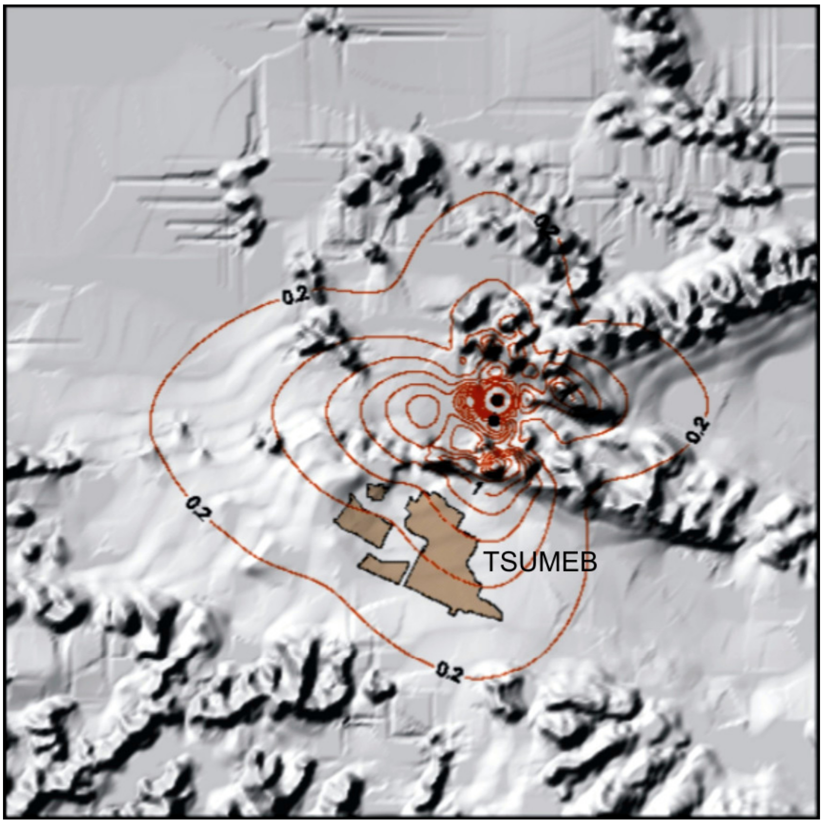

Figure 7: Numerical model of the dust dispersion halo around the Tsumeb Smelter. Isolines represent annual average concentrations of dust fall (in $g.m^{-2}$). The position of smelter stacks is marked by black dots.

Acknowledgments

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