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Contamination of soil and grass in the Tsumeb smelter area, Namibia: Modeling of contaminants dispersion and ground geochemical verification

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ABSTRACT

The area of the city of Tsumeb in northern Namibia is strongly affected by gaseous emissions and by dust fallout from the local smelter. This is also reflected in increased concentrations of lead and arsenic in blood and urine of the residents. Consequently, modeling of the dispersion of dust and SO_2 emissions from the smelter was used in this study to delineate the contaminated area and to assess the health risks. The modeling results were verified by ground-based geochemical survey of soil and grass in the area. The results of modeling revealed that the concentrations of SO_2 in the Tsumeb town were relatively low, whereas the highest dust fallout concentrations were found around the Tsumeb smelter. The Tsumeb town residential area was less affected due to favorable landscape morphology between the smelter and the city (the Tsumeb Hills).

The results of modeling of dust fallout and geochemical survey coincided very well. Since the anthropogenic contamination was bound only to the surface layer of soil, the local soils were sampled at two depth horizons: topsoil and the deeper soil horizon. This enabled us to distinguish between the anthropogenic contamination of soil surface from natural (geogenic) concentrations of studied metals in the deeper part of the soil profile. Concentrations of metals in grass correlated with the concentration of metals in topsoil.

In contrast to a good conformity with the modeling of dust fallout from the smelter and geochemical survey, the results of modeling of SO_2 contents in the air, and total sulfur content in soils were different. Differences can be explained by additional sources of contamination, as for example a sulfate-rich dust fallout from local tailings ponds and slag dumps that were not considered in the SO_2 dispersion model.

The results of the present investigation can be used by the mining companies in the management of air quality, assessment of the efficacy of applied remediation measures, and in reducing the impact of dust fallout on the local ecosystem. The Municipal Administration may use these results to plan further development of the city of Tsumeb, especially in terms of further expansion of housing construction.

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1. Introduction

Non-ferrous metals smelting activities represent one among the most important point sources regarding the metal/metalloid pollution of soils *via* atmospheric deposition of particulates and

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sulfur dioxide emissions from local smelters. Environmental and ecotoxicological research is mainly conducted in developed countries where risks to the population are efficiently reduced by legislation and technical measures (Hutchinson and Whitby, 1974; Rieuwerts et al., 1999; Sterckeman et al., 2000; Courtin-Normade et al., 2002; Burt et al., 2003; Udachin et al., 2003; Martley et al., 2004; Williamson et al., 2004; Beavington et al., 2004; Ettler et al., 2005; Lottermoser, 2005; Douay et al., 2008; Ettler et al., 2010). The studies that deal with mineralogy and chemical composition of dust fallout from mining operations, ore treatment plants, and smelters have shown that the dust composition primarily depends on the chemical composition of the ores, the technology of their processing, the grain size and structure of dust particles, and the distance of dust fallout from the sources of contamination (Beavington et al., 2004; Castellano et al., 2004; Khan et al., 2004; Ettler et al., 2009). The chemical composition of the contaminants in soils depends not only on the chemical composition of extracted ores, but to a large extent, also on the weathering processes during which a range of secondary minerals originate (Courtin-Normade et al., 2002; Kim et al., 2002; Zhang et al., 2004; Liu et al., 2005; Walker et al., 2005; Sracek et al., 2010a,b).

In contrast to developed countries, relatively few studies have focused on ecosystems (soils, air, biota) polluted by mining/smelting industries in developing countries in Africa (e.g., Meter et al., 1999; Banza et al., 2009; Kříbek et al., 2010; Vítková et al., 2010, 2011; Ettler et al., 2011, 2012; Albanese et al., 2014; Konečný et al., 2014; Vaněk et al., 2014).

Another aspect is that a number of models have been developed in recent years to predict plant available concentrations of potentially toxic elements in soils, but these models are based on data for temperate soils and could not be successfully applied to tropical soils (Rieuwerts, 2007). In this context, the binding, mobility, plant accessibility, and toxicity of metals/metalloids in highly contaminated soil/plant systems in the tropics is still not fully understood (Rieuwerts, 2007; Mihaljevič et al., 2011; Ettler et al., 2012, 2014b; Kříbek et al., 2014a,b). In areas contaminated by dust fallout from mines, mineral processing plants, and smelters, much attention was paid to the contamination of vegetation, especially agricultural crops and fodder (Hutchinson and Whitby, 1974; Fonkou et al., 2002; Kachenko and Singh, 2006; Yruela, 2009). It can be generalized that soil conditions play an essential role in the uptake of contaminants by plants. In well-aerated acid soils, several metals (Cd and Zn in particular) are easily mobilized and available to plants, while in poorly aerated neutral or alkaline soils, metals are substantially less available to plant metabolism (Kabata-Pendias, 2004).

The Tsumeb area in Namibia (Fig. 1) is a well-known district of former base metal mining. At present, all mines in the Tsumeb area are decommissioned, but the Tsumeb smelter is still in operation. Based on previous study of the soil contamination (Kříbek and Kamona, 2004) this paper is focused on the (1) modeling of the dust and sulfur dioxide concentration field around the Tsumeb smelter and, (2) on the verification of modeling results by ground-based geochemical sampling of the soil. Special attention was paid to the evaluation of contamination of soil in the adjacent town of Tsumeb. As the Tsumeb region agriculture is livestock-oriented, contamination of grass by potentially harmful elements (PHEs) was studied and the degree of contamination of grass was compared with the contamination of the soil.

2. Study area

2.1. General information

The Tsumeb area forms a part of the Oshikoto Region located in northern Namibia. The total population of the Tsumeb region is estimated at 22 500, of whom some 15 970 live in the town of Tsumeb.

The Tsumeb region forms a part of the northern flanks of the Otavi Mountains, composed of Neoproterozoic limestones and dolomites with schist intercalations (Miller, 1983). Numerous karst phenomena (scrap, sinkholes) are characteristic of the carbonate-dominated landscape. Summit areas attain heights 1300–1400 m above sea level, and the bottoms of intermontane basins are located at an altitude from 1220 to 1230 m.

2.2. Climate

Tsumeb has a semi-arid climate of subtropic latitudes (BSh; Kottek et al., 2006). The annual mean temperature for Tsumeb is 25 °C with the mean monthly temperatures varying from 32 to 16 °C throughout the year. The annual average rainfall is 470 mm. Most of the rainfall in Tsumeb occurs between December and February (summer). May and June are dry winter months with little or none of rain. The average relative humidity for Tsumeb is 30% signifying a region of high saturation deficit. Annual average wind data recorded in the Tsumeb area between 1971 and 1976 are given in Fig. 2. The flow fields are dominated by stable winds from the southeasterly quadrant. These winds have an average wind speed between 3 and 6 m/s and they occur 44% of the time. During the summer (January) and autumn (April), the northeasterly winds are more frequent. Winter months are characterized by the highest frequency of easterly winds.

2.3. Soils

Soil cover in Tsumeb area is formed by a mosaic of different soils. The character of the soils is conditioned by geological and geomorphological settings. The development of Chromic Arenosols and Regosols is typical of areas formed by lowland aeolian sandy sediments. Their soil profile is characterized by a shallow slightly developed humus horizon with underlying parent material. Slight development of luvic properties and presence of clay bridges over the sand grains is not evident enough to classify some of these soils as Luvisols. Haplic Vertisols are present in flat areas with calcareous clays. These soils are characterized by a relatively deep profile with high clay and humus contents. Sloping areas are covered by a variety of Leptosols with varying soil depth and skeleton content, depending on the landscape position. The urbanized and industrial areas are covered by Technosols with a wide range of properties given by the intensity of original profile disturbance and character of material that forms the soils profile.

2.4. Mining and ore processing industry

The exploration works at the Tsumeb deposit began in 1903, and mining operations in 1905. Mining continued intermittently until 1996, when the mine was decommissioned. The ores contained on average around 11 wt.% lead, 5 wt.% copper, and 4.3 wt.% zinc with economic concentrations of silver, cadmium, germanium, and arsenic. It was once the foremost producer of lead in Africa and, over its life, had produced in excess of 2 million tons of lead, some 500 000 tons of zinc, and over 1 million tons of copper (Ongopolo Mining and Processing Limited, 2001).

The old tailings from the Tsumeb mine were deposited in a pond located north of the town of Tsumeb, in the area of the Tsumeb smelter. The new tailings pond is located eastward of smelter.

The Tsumeb smelter was erected to smelt both high grade copper and lead ores in 1907. Two Pb–Cu blast furnaces were built in the Tsumeb area by the Otavi Minen und Eisenbahn-Gesellschaft

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