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Distribution of copper, lead, cadmium and zinc concentrations in soils around Kabwe town in Zambia

Backsion D. Tembo *, Kwenga Sichilongo, Joseph Cernak

Department of Chemistry, The University of Zambia, P.O. Box 32379, Lusaka 10101, Zambia

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Abstract

The extent of pollution of the environment as a result of mining activities in Kabwe, the provincial capital of Central province in Zambia has not yet been evaluated. Mining of lead and zinc were the core activities of Kabwe mine while cadmium and silver were produced as by-products. The smelting processes produced a significant amount of copper. The spatial distribution of four heavy metals in soils in the northern, eastern, southern and western directions of the mine was analyzed using atomic absorption spectrometry (AAS). Samples were collected up to 20 km in each direction from the mine. Results were consistent with the wind flow patterns in the town. Results ranged between 0.08 and 28 $\mathrm{mg\,kg^{-1}}$ (Cd); 0.20 and 0.61 $\mathrm{mg\,kg^{-1}}$ (Cu); 0.10 and 758 $\mathrm{mg\,kg^{-1}}$ (Pb) and 0.40 and 234 $\mathrm{mg\,kg^{-1}}$ (Zn) suggesting high precipitation of metals from the core mining activities. These concentrations were for only the fractions of metals extractable by 0.5 M nitric acid and that could be available for plant uptake in the environment. The distribution of metals indicated a decrease of metal concentrations with distance from the mine, which confirmed that precipitation due to mining activities was the main cause of soil contamination.

Keywords: Kabwe mine; Metals; Atomic absorption spectrophotometer; Soil samples; Mean recovery

1. Introduction

Until 1994, Kabwe the provincial capital of Central Province in Zambia used to be a lead and zinc mining town. Cadmium and silver were also produced as by-products. Kabwe is situated at about 28°26′E and 14°27′S. Lead, zinc and cadmium mining, smelting operations and sulphuric acid production made the environment around Kabwe probably the most polluted in the whole of Central Africa (Kaoma and Salter, 1979). The dense fumes, which came from smelters of mines, were rich in metallic pollutants such as cadmium, copper, lead and zinc. Copper and zinc form volatile carbonyls and were present in these fumes. Lead and cadmium are quite volatile and formed significant compositions of the fumes. These metallic pollutants in the air eventually precipitated on the ground surface depending on wind flow patterns and increased their concentration in adjacent areas. Since these metals are non biodegradable, their pollution is long lasting and would entail pollution remediation strategies in future (Lim et al., 2005; Luo et al., 2005; Meers et al., 2005). Metallic pollutants are significantly toxic (Petänen and Romantschuk, 2003; Zabetoglou et al., 2003) even in very small amounts.

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[*] Corresponding author. Tel.: +260 97855826; fax: +260 1254406.
E-mail address: bdtembo2004@yahoo.com (B.D. Tembo).

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This is because of their non-biodegradability and cumulative nature. Their reactions with proteins in living systems render essential reactions impotent (John, 1973; Friberg et al., 1979; Spiro and Stiglian, 1980; Biddle, 1982). These metals can also cause debilitating diseases in humans and animals as they cause irreversible changes in the body especially in the central nervous system leading to psychotic disorders and other ailments (Lewis et al., 1992; Coen et al., 2001; Järup, 2003; Dolk and Vrijheid, 2003). In the future, the risk assessment studies for the closed Kabwe mine should be done in a similar manner to the US EPA methodologies for human health risk assessment were applied on an abandoned smelter in Poland (Wciso et al., 2002). The aim of this study is to determine four heavy metals that are extractable with 0.5 M nitric acid and available for plant uptake (Cottenie et al., 1982) in soils around the closed mine in Kabwe town.

2. Materials and methods

Soil samples were collected randomly up to a distance of 20 km from four directions around the closed Kabwe mine. Control samples were collected from Tobwe Estate, Bonanza, Moyo and Makombe Farms near Kabwe and Golden Valley, Kyindu farms as well as Chalimbana International Conservation Research for Agro-Forestry(ICRAF)/Southern African Development Community (SADC) station near Lusaka. Samples were collected and analysed over a period of 12 months, from April 1991 to May 1992. At least three composite soil samples were collected from each sampling point. Soil samples were collected into transparent plastic bags using a steel Auger from a depth of 0–15 cm. Samples were air-dried in the laboratory by spreading out on transparent plastic on a bench for several days. They were then passed through a 2 mm sieve and repacked in transparent plastic bags until they were analysed. 20 g of sieved air-dried soil samples were placed in well cleaned 250 cm^3 conical flasks and 100 cm^3 of 0.5 M nitric acid was added. The flasks were mechanically shaken for at least 30 min using a mechanical shaker. The samples were then filtered into 100 cm^3 plastic bottles through ashless Whatman filter paper 40. Some control samples were analysed for background target analytes and then spiked with known amounts of cadmium, copper, lead and zinc and passed through the whole process to determine the recovery rates of extraction procedure. The differences between the background concentrations and the concentrations of the spiked samples accounted for the percent recoveries. General purpose reagent cadmium nitrate of a minimum purity of 99% was used in the preparation of solutions used to spike the samples for cadmium. An analytical grade of a nitrate salt of lead and analytical grade granules of copper and zinc were used in the preparation of solutions used in the spiking of samples for lead, copper and zinc. A reagent blank for each metal was also prepared and passed through the whole process and used in the determination of samples for the chosen metals. Calibration curves were prepared using analytical grade metals and metal salts. Cadmium, copper, lead and zinc were determined using a Varian Techtron AA6 atomic absorption spectrophotometer using corresponding metallic hollow cathode lamps. Acetylene gas was used as the fuel and air as the support. An oxidising flame was used in all cases. Table 1 shows the different parameters at which the instrument was set for each metal.

Table 1
Parameters set on the Varian Techtron AA6 atomic absorption spectrophotometer

Element	Band width (nm)	Wavelength (nm)	Lamp current (mA)
Cadmium	0.5	288.8	3
Copper	0.2	324.8	12
Lead	1	217	6
Zinc	0.2	213.9	5

Calibration curves were used to calculate the concentrations of four metals. A reagent blank was used to zero the instrument. This was followed by aspiration of standard solutions and finally the soil sample extracts were aspirated.

3. Results and discussion

The mean recovery values for the extraction and analysis of 10 spiked samples for zinc and cadmium were 91% and 92% respectively while that for 8 spiked samples for lead was 84%. Copper recovery experiments were done on 6 samples and the mean recovery was 96%. Tables 2–5 show the distribution of the four heavy metals easily available to plants with distance from the Kabwe mine in ($\text{mg}\,\text{kg}^{-1}$) along with their coefficients of variation (COV) values. As seen from the tables, there is a general decline in concentration of the four metals with distance from the mine. The term "general trend" is used to describe this observation.

From Table 2, the concentration of cadmium in the eastern side was negligible compared to the high levels of lead and zinc in the same direction. The copper concentration was also on average and in comparison to lead and zinc, very low in this direction.

From Table 3. the general trend in the distribution of the copper and cadmium in the northern direction was similar to that observed in the eastern direction. However there were differences in the distribution of lead and zinc in the eastern and northern directions and these were significant at distances of 0–5 km from the mine.