Bull. Environm. Contam. Toxicol. 22,625-631 (1979)

Cadmium, Lead and Zinc Concentrations in Soils and in Food Grown Near a Zinc and Lead Smelter in Zambia

J. N. Nwankwo, Ph.D.[1] and C.-G. Elinder, M.D.[2]

[1]*Water Quality Laboratory, Water Resources Research Unit, National Council for Scientific Research, P. O. Box CH 158, Chelston, Lusaka, Zambia, and*
[2]*The Department of Environmental Hygiene, The Karolinska Institute, S-104 01 Stockholm 60, Sweden*

The steady increase in mining and smelting activities during the industrial age has led to large emissions of potentially harmful metals to the environment. Arsenic, cadmium, lead and mercury are the most important ones. Pollution by these metals which has resulted in serious health effects in humans, has alerted scientists the world over.

The present study has focused on the concentrations of cadmium and lead in soil and food grown close to a Zambian lead and zinc smelter, the Broken Hill plant in Kabwe. The plant has been in operation since 1906 and the yearly production has risen steadily from the start. In 1975 the total production was 40,000 tons of zinc, 20,000 tons of lead and about 1 ton of cadmium. The total production during the plant's existence has been estimated at 1 115,000 tons of zinc and 600,000 tons of lead (HOARE 1976).

The city of Kabwe, with about 70,000 inhabitants, has been built in the neighborhood of the plant, mainly to the north (see figure 1). The prevailing winds are from the east and thus transport fumes and dust from the plant to the west.

During the relatively short period 1971 to 1973, 27 cases of severe lead intoxication with encephalopathy occurred among children aged 10 to 30 months living in the township of Kasanda, which in 1972 had a population of 10,000. Kasanda lies about 2 km north-west of the plant area. Between April 1973 and July 1974 lead concentrations in air were measured. Monthly averages ranged from 5 to 145 ug Pb/m^3 and the overall average for all months was 10 ug Pb/m^3 (CLARK 1975). Lead concentrations in soil close to the smelter have been reported to range from 100 to 2,400 ug/g (CLARK 1975). REILLY and REILLY (1972) also reported highly elevated lead concentrations in soil samples taken near the plant.

In conclusion, the studies by CLARK and by REILLY and REILLY show that lead emitted by the Broken Hill plant in Kabwe has heavily contaminated the environment and that serious health effects have occurred.

0007-4861/79/0022-0625 $01.40

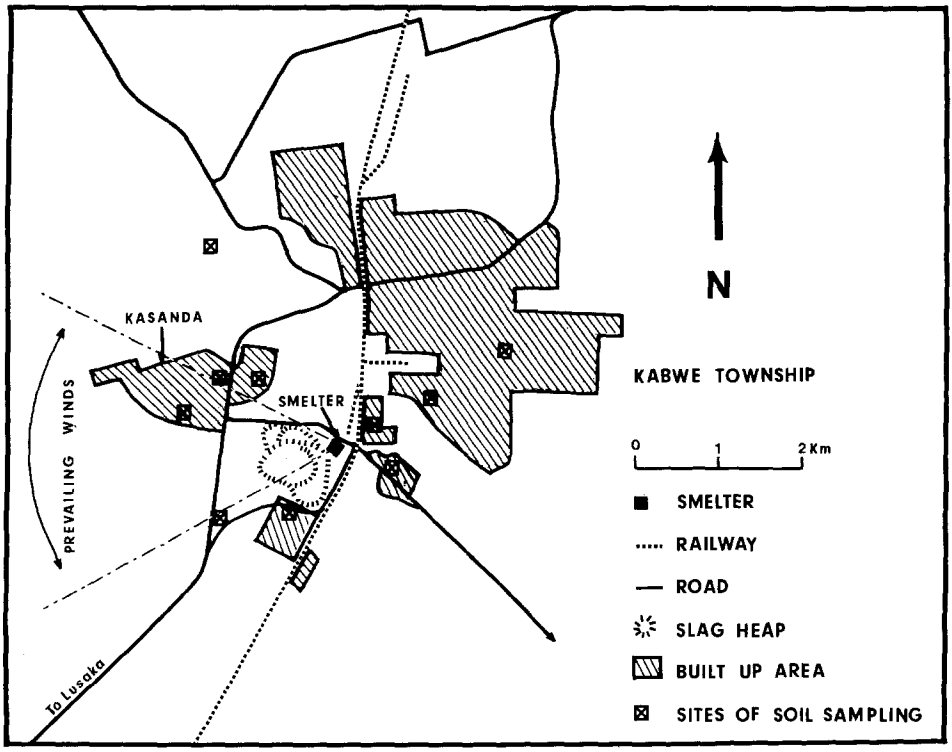

FIGURE 1. Schematic map of the surroundings of the zinc and lead smelter in Kabwe, Zambia.

The objective of the present study was to evaluate whether cadmium might also constitute an environmental problem in the area. The work has been carried out as a collaborative project between the National Council for Scientific Research in Zambia and the Department of Environmental Hygiene of the Karolinska Institute, Sweden.

MATERIALS AND METHODS

A total of 29 soil and 39 food samples have been analyzed for cadmium, zinc and lead concentrations. Samples from Lusaka and suburbs of Lusaka were used as control and reference material. The material was collected between November 1976 and September 1977. Eleven soil samples were taken at a depth of 0-10 cm in different directions within 1 to 5 km radius of the lead smelter, one soil sample was taken 10 km from the plant, and another 17 soil samples were taken in a similar way from an area around Lusaka.

Food samples, 19 from Kabwe region and 20 from the Lusaka region, were also analyzed. Fresh vegetables were collected as closely to the site of soil sampling as possible. Maize, grown during the preceding season, was collected from persons living around the smelter in Kabwe and in different places in urban Lusaka. Six of the food samples were obtained from the local market in Kabwe.

Acid extractable amounts of cadmium, lead and zinc in soil were determined according to the following procedure. Samples were dried in an air-oven at 35-40°C for several hours, handground and sieved to pass a mesh of 30 (0.5 mm). Samples of 10 g were extracted with 200 mL of a 2.5% acetic acid solution for 4 h, using a Gallenkamp reciprocating shaker. Extracts were filtered through Whatman No. 44 filter paper and analyzed for cadmium, zinc and lead with atomic absorption spectrophotometry (AAS).

The soil samples were also analyzed by a digestion technique which yielded the total metal content. A mixture of nitric acid and hydrogen peroxide was utilized according to the method described by KRISHNAMURTY et al. (1976).

The food materials were oven-dried at 105°C prior to grinding in an aluminium cast blender. Samples of 4 g were then dry-ashed twice at 450°C and analyzed according to the method of KJELLSTRÖM et al. (1974), except that flame AAS was used. Background correction for non-atomic absorption was made with a hydrogen continum hollow cathode lamp.

RESULTS

Metals in soil

Cadmium, lead and zinc concentrations in soil around Kabwe were strikingly high (Table 1). Soils from the township of Kasanda, west of the plant, had especially high metal concentrations. The average concentrations of acid extractable cadmium, lead and zinc of 4 samples taken within 2 km west of the plant were 4.1, 350 and 1,120 ug/g dry weight, respectively. In the reference material from urban Lusaka, acid extractable cadmium, lead and zinc concentrations were about 100 times lower than the soil concentrations around the plant. One soil sample, not included in Table 1, taken 10 km south-west of the plant, had acid extractable metal concentrations of cadmium, lead and zinc in the same range as the concentrations in the Lusaka soil. The tocal cadmium and lead concentrations, measured by digestion with nitric acid and hydrogen peroxide, were on an average 5 times higher than acid extractable cadmium and lead. Within 1 to 5 km of the plant total metal concentrations were magnitudes higher compared with soils from Lusaka. Total metal content in one soil sample collected 10 km south-west of the plant was 0.37 ug Cd/g, 40 ug Pb/g and 67 ug Zn/g.

TABLE 1

Cadmium, Lead and Zinc Concentrations (ug/g dry weight) in Soils Taken From Within 5 km of the Kabwe Plant, and From Lusaka and Its Vicinity.

	Number of samples	Range	Average
Kabwe			
Total cadmium	11	0.55-46.4	9.0
Total lead	11	92-2580	862
Total zinc	11	180-3500	1050
Acid extractable cadmium	11	0.16-8.4	1.9
Acid extractable lead	11	2.9-492	153
Acid extractable zinc	11	61-2150	529
Lusaka			
Total cadmium	17	0.08-0.81	0.16
Total lead	17	1.1-40	16.1
Total zinc	17	10.0-97.5	35.0
Acid extractable cadmium	17	0.007-0.24	0.025
Acid extractable lead	17	0.01-3.18	1.14
Acid extractable zinc	17	1.2-43.4	10.3

A significant correlation, $r = 0.75$, $n = 26$, was found between the cadmium and zinc concentrations in soil samples. This is not surprising since cadmium and zinc usually occur together in nature and in ores, and these metals most probably have been emitted together from the plant as well.

Metals in food materials

Seven maize samples grown in private gardens within a 3 km radius of the smelter had cadmium concentrations ranging from 0.028 to 0.116 ug Cd/g dry weight and lead concentrations ranging from 0.57 to 1.36 ug/g dry weight. The average cadmium concentra-

tion was 0.064 ug/g and the average lead concentrations was 0.90 ug/g dry weight. The highest metal concentrations were recorded in samples collected on the west side of the plant. In 16 reference maize samples grown in private gardens around urban Lusaka cadmium ranged from 0.002 to 0.088 ug/g, with an average of 0.025 ug Cd/g dry weight (lead was not measured). The observed difference between cadmium concentration in maize grown in Kabwe and in maize grown in Lusaka is statistically significant ($p < 0.05$).

Three samples of fresh, washed vegetables (1 of spinach and 2 of cabbage) collected on the west side of the plant had excessive metal concentrations, cadmium ranging from 2.1 to 6.4 ug Cd/g dry weight and lead ranging from 47.5 to 322 ug Pb/g dry weight. Another 3 samples, cabbage, rape and spinach collected on the north side of the plant, had considerably lower values, cadmium ranging from 0.08 to 0.12 and lead from 20.5 to 29.4 ug/g dry weight.

In 4 samples of vegetables obtained around urban Lusaka; 1 rape, 1 cabbage, 1 spinach and 1 lettuce, cadmium concentration ranged from 0.003 to 0.053 ug Cd/g dry weight. Six samples of food obtained at the Kabwe market, 1 cabbage, 1 maize, 1 kaffix corn, 1 rape, 1 rice and 1 spinach, had metal concentrations ranging from 0.02 to 1.5 ug Cd/g and 0.4 to 66.4 ug Pb/g dry weight respectively. The spinach and the rape samples had the highest metal concentrations in the same range as in the food materials taken from urban Lusaka.

DISCUSSION

In non-polluted areas total cadmium concentrations in soil are generally well below 1 ug Cd/g dry weight (FRIBERG et al. 1974). In the present study, the total cadmium concentrations in 17 soil samples from Lusaka ranged from 0.08 to 0.81. These figures agree well with the results of a Swedish study of soils regarded as not contaminated with cadmium, where 90% of 361 analyzed soils had concentrations from 0.12 to 0.49 ug Cd/g dry weight (ANDERSSON 1977). Higher values, from around 1 to 69 ug Cd/g dry weight, have been recorded in soils near cadmium emitting industries and in areas irrigated with cadmium contaminated water (FRIBERG et al. 1974). No specific threshold limit of cadmium in soil has been set, but in Japan rice fields having more than 1 ug (total) Cd/g in soil are suspected to be contaminated by cadmium (YAMAMOTO 1972, cited by FRIBERG et al. 1974).

In this study, soil samples taken within 5 km of the Broken Hill plant in Kabwe had total cadmium concentrations ranging from 0.6 to 46.4 ug Cd/g dry weight, i.e. within the range of cadmium found in polluted rice fields in Japan. About 20% of the total cadmium and lead content was found to be acid extractable.

A limited number of food samples were also analyzed. In the Lusaka region, values were in good accordance with other reports on cadmium in food materials from non-polluted areas in the USA and Sweden (CORNELIUSSEN 1970, FUCHS et al. 1976). Maize grown close to the plant had significantly higher cadmium concentrations than maize grown in Lusaka. Cadmium concentrations in 3 samples of fresh vegetables obtained close to the west side of the plant were excessively high, i.e. above 1 ug Cd/g dry weight.

Two of the food samples obtained from the Kabwe market had high cadmium and lead concentrations, whereas the other 5 samples had low concentrations, i.e. in the non-contaminated range. The low level samples most probably have been grown in areas outside Kabwe, not so heavily contaminated by cadmium. Generally the highest cadmium concentrations were recorded in spinach, cabbage and rape, which agrees with experimental studies where it has been shown that these plant species take up cadmium much more efficiently than other plant species, such as wheat, beans and maize (PETTERSSON 1977).

In the near future, it is of great importance to make further analyses of cadmium in food and to find out to what extent different types of foodstuffs constitute the staple diet of the local population. Such information would make it possible to estimate the daily intake of cadmium in the area and to compare these data with the tolerable weekly intkae of 400 to 500 ug Cd/week, which has been set by the FAO/WHO Expert Committee on Food Additives (WHO 1972).

Another way to estimate the daily intake of cadmium would be to sample total fecal excretion from a selected number of the exposed inhabitants. Total fecal output of cadmium gives a good approximation of intake due to the fact that only about 6% of ingested cadmium is absorbed (RAHOLA et al. 1972). The feces method has the advatange that only one biological medium has to be analyzed. Furthermore, the fecal concentration of cadmium is higher than in most of the foodstuffs, which is an advantage with regard to analytical validity. The average fecal elimination of cadmium among Europeans not exposed to cadmium from any specific sources of contamination is on the order of 10 to 40 ug Cd/day (KJELLSTRÖM et al. 1978). Median fecal amounts of about 200 ug Cd/day have been reported for people living in cadmium contaminated areas in Japan, where health effects have been observed (KOJIMA et al. 1977).

Finally, it should be of great value to collect liver and kidney cortex samples during autopsies of people who have lived in the area, and to compare the metal concentrations in these samples with autopsy results from other areas in Zambia and from Europe and USA (SCHROEDER and BALASSA, 1967, ELINDER et al. 1976).

REFERENCES

ANDERSSON, A.: Swedish J. Agric. Res. 7, 7 (1977).

CLARK, A.P.L.: The sources of lead pollution and its effects on children living in the mining community of Kabwe, Zambia. London School of Hygiene and Tropical Medicine, University of London (1975).

CORNELIUSSEN, P.E.: Pestic. Monit. J. 3, 89 (1970).

ELINDER, C.-G., T. KJELLSTRÖM, B. LIND, L. LINNMAN and L. FRIBERG: Arch. Environ. Hlth. 6, 292 (1974).

FRIBERG, L., M. PISCATOR, G.F. NORDBERG and T. KJELLSTRÖM: Cadmium in the Environment. 2 ed. Chemical Rubber Co. Press, Cleveland, Ohio (1974).

FUCHS, G.: Vår Föda 6-7, 160 (1976).

HOARE, R.: Personal communication. Metallurgical Superintendent, NCCM, Broken Hill, Kabwe (1976).

KJELLSTRÖM, T., B. LIND, L. LINNMAN and G.F. NORDBERG: Environ. Res. 8, 92 (1974).

KJELLSTRÖM, T., K. BORG and B. LIND: Environ. Res. 15, 242 (1978).

KOJIMA, S., Y. HAGA, T. KURIHARU, T. TAMAWAKI and T. KJELLSTRÖM: Environ. Res. 14, 436 (1978).

KRISHNAMURTY, K.V., E. SHPIRT and M.M. REDDY: Atom. Absorp. Newsl. 15, 68 (1976).

PETTERSSON, O.: Swedish J. Agric. Res. 7, 21 (1977).

RAHOLA, T., R.-K. AARON and J.K. MIETTINEN: Symposium on Assessment of Radioactive Contamination in Man. IAEA, Vienna, p. 553 (1972).

REILLY, A. and C. REILLY: Med. J. Zambia 6, 125 (1972).

SCHROEDER, H.A. and J.J. BALASSA: J. Chron. Dis. 14, 236 (1967).

WHO: World Health Organization Techn. Rep. Ser. No. 505, Geneva (1972).