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Effects of flooding in southern Poland on heavy metal concentrations in soils

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Abstract. Total concentrations of heavy metals in soils were measured before and after the catastrophic floods of 1997, which devastated most districts within the commune of Racibórz in southern Poland. The assays covered lead, zinc, cadmium, chromium, nickel and copper. Analyses on soil samples taken in 2002, after the floods, were compared with those of 1992, taken as part of regular monitoring. There was an increase in the mean concentrations of heavy metals as a consequence of the flooding. Only a small part of this increase may be due to changes in the method of analysis between the two dates. The mean concentrations of heavy metals after flooding did not exceed the permissible levels for Polish soils. Permission was therefore granted to continue using much of the flooded land for farming. However, the investigations located a number of places where heavy metals were above permissible levels. Some of these were a consequence of the floods, but others were considered to be due to contamination from previous industry. Where high concentrations were found, land was excluded from agricultural use.

INTRODUCTION

Severe flooding occurred in eastern Europe in August 1997. Low-lying land alongside rivers was affected between Austria and the North Sea, including the Czech Republic, Poland and Germany. Many livestock were killed and large areas of crops were destroyed; in some areas the depth of water over the land exceeded four metres. In Poland, about 50 people died and a number of cities were badly damaged including Racibórz, Klodzko and Opole in the south of the country. When the waters subsided, a layer of silty mud covered the land. There was concern that heavy metals, derived from former industrial activities, may have been carried on to agricultural land by the floods.

Research into environmental protection and engineering has been carried out for many years in Poland, as in many other countries. State monitoring of soils is part of this research, which includes measurement of concentrations and forms of macro- and microelements and establishing permissible levels of each in different types of soil. Researchers also examine the impact of anthropological factors on the condition and quality of soil (Kabata-Pendias and Pendias 1999; Brazauskiene *et al.* 2000; Mielke *et al.* 2000; Yin and Lin 2001; Abollino *et al.* 2002; Becquer *et al.* 2003). This work has enabled researchers to establish baseline concentrations (Manta *et al.* 2002). There is little information available on concentrations of heavy metals in soils after serious flooding. Cabrera *et al.* (1999) and Diaz-Barrientos *et al.* (1999) showed that the level of the heavy metals decreased with soil depth after contamination by flooding.

We compared the results of analyses made on soil samples taken in 1992 (before the floods) with samples taken in the same area in 2002 (after the floods).

GEOGRAPHY AND METHODS

Location

Some of the land at Racibórz was used by a variety of industries in the 19th and 20th centuries, including carbon electrode works, boiler manufacturers, food processing factories and companies producing household chemicals. Many of these closed in the 1990s. Contamination of soils from earlier sources, such as home tanneries, was also likely.

The commune of Racibórz lies in the region of Silesia close to the River Odra and the Ulga canal (Figure 1). One legacy is the presence of illegal waste dumps, regarded as environmental hazards. Most of the land is managed in small farm units. There are nine districts (Figure 2), of which Ostróg, Plonia, Studzienna and Sudól were completely flooded, whereas the others were only partially flooded.

Soils

The Markowice district lies northeast of the Ulga canal, alongside which the soils are alluvial and Histosols; in the eastern part the soils are mainly Podzoluvisols and Cambisols. The Ostróg and Plonia districts lie between the Odra river and the canal and alluvial soils dominate; here, the flood water peaked at 4 m and some flood water remained on the land for two weeks. Sudól, Studzienna and Ocice are districts in the south of the commune, where

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Figure 1. Map of Poland showing location of principal cities.

the soils are alluvial and Podzoluvisols. Brzezie, on the eastern side of the commune, is furthest from the Odra river. The soils in Stara Wieś and Miedonia are more varied.

Sampling and analysis

In 1992, 116 samples of soil were taken, between 4 and 20 from each of the nine districts. In 2002, after the floods had receded, 1400 samples (0–20 cm depth) were taken from 2800 ha on a regular grid across each district. After air drying and sieving (2 mm), and digestion with a mixture of nitric and hydrofluoric acids, metal concentrations were measured using atomic absorption spectrophotmetry (Perkin Elmer) in 1992 and flame atomic absorption spectrophotometry (Varian Spectr AA 880) in 2002. The first set of analyses were undertaken by the Environment Research and Monitoring Institute in Katowice (Poland) and the second set by the Silesian University of Technology in Gliwice (Poland).

RESULTS

Table 1 shows that the mean levels of all metals increased following the floods. Although the mean values were less than the maxima permissible for agricultural soils, several samples exceeded these limits for one or more metals (two in 1992 and 88 in 2002). Table 2 shows the variation in metal content for each district.

Table 1. Concentration of heavy metals (mg kg^{-1}) in soils (0–20 cm depth) of Racibórz commune before (1992) and after the floods (2002).

	Permissible levels	1992		2002	
		Mean	No. samples exceeding permissible levels	Mean	No. samples exceeding permissible levels
Pb	100	30	0	412	18
Cd	3	0.5	0	0.6	3
Zn	300	72	≥1	105	48
Cu	100	16	0	23	2
Ni	100	11	0	25	1
Cr	100	11	≥1	30	16

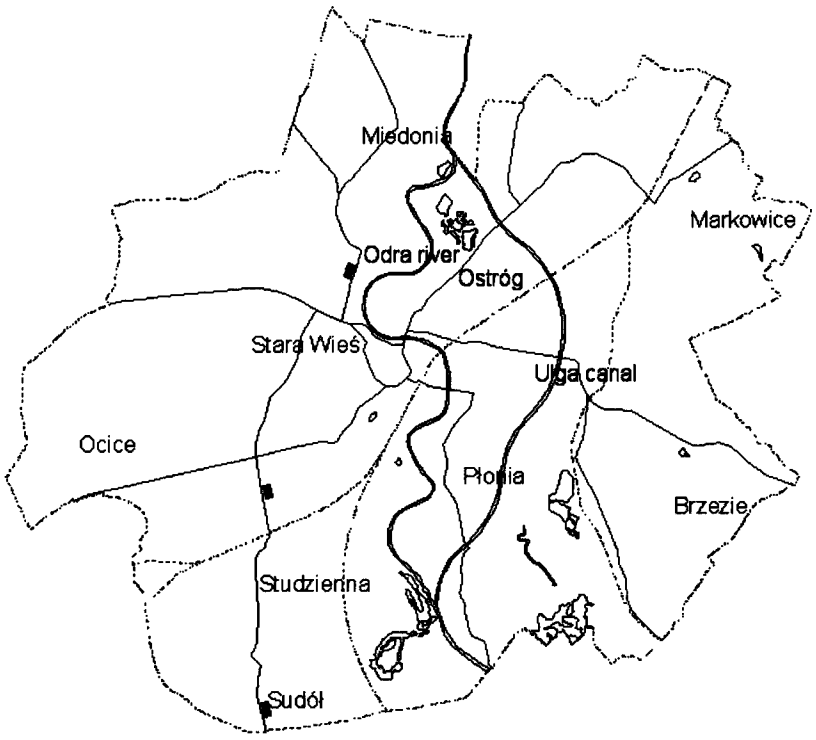

Figure 2. Map of Racibórz commune showing the different districts and main waterways.

Table 2. Concentration ($mg\,kg^{-1}$) of heavy metals in soils in each district before and after the flood.

District	Metal	1992			2002		
		Mean	Highest value	No. exceeding permissible levels	Mean	Highest value	No. exceeding permissible levels
Markowice	Pb	18	48	0	31	11	1
	Cd	0.1	1	0	0.6	3.1	1
	Zn	48	122	0	93	646	3
	Cu	12	22	0	24	85	0
	Ni	10	23	0	26	51	0
	Cr	8	14	0	28	295	1
Ostróg	Pb	53	69	0	134	10915	10
	Cd	0.7	1	0	1	6.2	2
	Zn	114	191	0	231	1650	27
	Cu	31	47	0	41	459	2
	Ni	9	12	0	41	102	1
	Cr	7	10	0	44	931	1
Plonia	Pb	38	60	0	40	101	2
	Cd	0.8	1	0	0.8	1.7	0
	Zn	128	248	0	146	426	7
	Cu	25	38	0	33	69	0
	Ni	20	25	0	44	71	0
	Cr	15	18	0	37	81	0
Brzezie	Pb	29	75	0	31	214	1
	Cd	0.6	1	0	0.6	1.7	0
	Zn	57	116	0	81	432	1
	Cu	12	27	0	16	39	0
	Ni	10	22	0	20	50	0
	Cr	18	113	1	41	1335	14
Sudól	Pb	16	24	0	26	146	2
	Cd	<0.5	1	0	0.6	1.2	0
	Zn	44	60	0	71	427	6
	Cu	11	53	0	15	43	0
	Ni	9	17	0	13	42	0
	Cr	9	16	0	20	43	0
Studzienna	Pb	24	70	0	33	177	2
	Cd	0.1	0.5	0	0.5	1.1	0
	Zn	88	410	1	68	320	1
	Cu	15	24	0	19	89	0
	Ni	10	16	0	19	42	0
	Cr	8.4	13	0	23	44	0
Ocice	Pb	32	61	0	27	70	0
	Cd	0.5	0.5	0	0.5	1.5	0
	Zn	60	105	0	69	255	0
	Cu	9	15	0	16	33	0
	Ni	7	11	0	18	26	0
	Cr	16	22	0	20	31	0
Stara Wieś	Pb	34	46	0	39	99	0
	Cd	0.8	1	0	0.5	1.3	0
	Zn	53	98	0	85	326	1
	Cu	19	29	0	22	43	0
	Ni	13	22	0	20	43	0
	Cr	8	10	0	17	29	0
Miedonia	Pb	22	25	0	27	97	0
	Cd	0.6	1	0	0.5	2	0
	Zn	54	89	0	98	459	2
	Cu	13	21	0	19	48	0
	Ni	11	18	0	21	43	0
	Cr	8	10	0	21	42	0

In Markowice, most samples in 2002 did not exceed the permissible concentrations of heavy metals. However, high concentrations of Zn, Pb and Cd were found in five samples along the Ulga canal. These areas should not be used for farming. In Ostrog, very high maximum levels of Pb ($10915\,mg\,kg^{-1}$), Cd ($6.2\,mg\,kg^{-1}$) and Zn ($1650\,mg\,kg^{-1}$) were found after flooding. The source of contamination appears to have come from an old illegal

dump; this area has been excluded as farmland by the local authorities. In Plonia, the concentrations after flooding were slightly higher than background values before flooding, particularly for Pb and Zn, but were considered to be similar to alluvial soils found in other parts of Poland. In Brzezie, Sudól and Studzienna flooding and human impacts increased levels of Pb and Zn (and especially Cr in Brzezie); the affected areas are not used for farming.

Heavy metals concentrations in Ocice soils did not exceed permissible levels. In Stara Wieś and Miedonia, three samples exceeded maximum permissible levels ($326\,mg\,kg^{-1}$ Zn in Stara Wieś and $459\,mg\,kg^{-1}$ Zn in Miedonia); these locations are not used for farming. The rest of the districts was not contaminated by the floods. The results obtained in 2002 are considered to be more precise, because of the progress in analytical techniques and precision of the surveys.

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