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IMPACT OF CERTAIN INDUSTRIAL DUSTS ON THE ACCUMULATION PROCESS OF HEAVY METALS IN THE FOREST SOIL

The concentrations of lead or zinc in the upper layer of soil of anthropogenic origin is correlated not only with the concentration of industrial dust deposited but also with the kind of dust. A factor analysis carried out on a set of variables (representing the impact of several industrial dusts on the forest environment) allows establishing a model with a small number of factors that are responsible for the accumulation process. Directions of further research are proposed, aiming at elucidation of the enrichment or enpoverishment of the soil with heavy metals.

1. INTRODUCTION

The impact of industrial dusts on the forest environment was the subject of long-term study conducted on experimental plots in the Niepołomice Forest. The experiment and its results were first described in the Scientific Bulletin of Agricultural Academy of Kraków [1]. Due to various relationships between the parameters, additional statistical analysis has been performed. This statistical analysis is the subject of this paper.

2. DESIGN OF THE EXPERIMENT

Experimental plots, each of 240 m^2, were established in the Niepołomice Forest, 25 km north-east from Kraków. Plots were randomly arranged in the pine stands, 10 m from each other (10 m buffer zone). Sample plots were treated with dusts from electrofilters from six different industrial plants: aggregating plant, aluminium plant, zinc plant, cadmium plant, power plant, cement plant.

Dust was applied in the following quantities: 100, 500, 1000, 2000 and 5000 $t/km^2 \cdot y$. Dust was sown by hand four times a year at 3 month intervals.

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In a five-year experiment, each kind and concentration of dust were investigated separately. In the course of experiment and later, the determination included among others: the effect of dust on soil, plant associations, epigenous fauna and increases in stand volume.

In experimental area there were also control plots. Samples from several control plots were mixed to obtain one sample.

3. CHARACTERISTICS OF DUSTS APPLIED

The chemical composition of particular dust and chemical composition of the water extract of dusts are presented in tables 1 and 2.

It should be taken into account, however [2], that in the dust there might have occurred trace amounts of other elements. Although they have not been determined, they may affect the pattern of the experiment.

Table 1

Chemical composition of dusts (in %)

	Component concentration					
	Agglomerating plant	Aluminium smelter	Zinc smelter	Cadmium smelter	Power plant	Cement plant
Na_2O	0.32	4.56	0.48	0.04	0.27	0.21
K_2O	0.78	0.08	0.71	0.42	0.40	1.28
MgO	1.85	0.35	0.72	0.02	1.29	1.04
CaO	12.44	5.30	7.94	5.67	10.75	47.04
MnO	0.30	0.01	0.12	0.01	0.04	0.05
ZnO	0.02	0.01	22.06	1.75	0.02	0.05
CuO	0.01	0.04	0.08	0.01	0.01	0.0
PbO	0.04	0.02	3.08	4.07	0.01	0.07
CdO	–	–	0.63	3.02	–	–
CoO	0.01	0.01	0.01	0.01	0.02	0.02
NiO	0.01	0.04	0.02	–	0.03	0.01
Fe_2O_3	40.94	1.90	4.58	0.20	3.76	0.89
SiO_2	20.92	43.18	43.74	45.34	68.21	16.26
S	0.19	0.08	1.66	0.42	0.20	0.60
Al_2O_3	8.69	21.42	8.13	21.83	4.71	28.43

Table 2

Chemical composition of water extracts of dusts (in mg/dm^3)

	Agglomerating plant	Aluminium smelter	Zinc smelter	Cadmium smelter	Power plant	Cement plant
pH	8.7	7.4	6.5	5.7	11.5	9.5
Na^+	192	55	172	33.1	21.7	133.3
K^+	610	8.8	101.5	306.2	15.7	945.8
Mg^{2+}	37.7	0.5	28.3	1.6	sl	2.6
Ca^{2+}	104.2	sl	223.0	14.9	88.1	68.7
Mn^{2+}	sl	sl	0.5	0.3	sl	sl
Fe^{3+}	0.04	0.04	0.04	0.04	0.04	0.04
Zn^{2+}	sl	sl	24.1	657.1	sl	sl
Cu^{2+}	0.02	sl	0.01	0.02	sl	0.01
Pb^{2+}	0.16	0.06	4.48	59.4	0.11	sl
Cd^{2+}	0.1	sl	53.3	606.9	sl	0.01
HCO_3^-	31.1	61.0	12.8	12.2	632.1	30.5
Cl^-	790.0	69.1	251.1	1460.0	15.0	255.3
SO_4^{2-}	570.8	584.4	863.9	27.0	560.4	1641
PO_4^{3-}	0.03	0.03	0.05	0.04	0.03	0.13

4. METHODS

The plots were established in a coniferous forest site. Before the experiment was started, analyses of plants from 6 random plots were carried out using the Braun–Blanquet method. The results of phytosociological records showed an insignificant differentiation of the species composition on particular plots, and hence their good comparability.

The soil of the plots tested has been classified under podzols with the fairly intense mineralization of organic matter. The thickness of the humic-mineral black stratum was 10 cm.

The soil tested showed high biological activity confirmed by fairly large number of bacteria.

The upper soil horizon was analysed according to the methods used conventionally in the analytical studies. The following parameters were determined:

1. pH was measured potentiometrically using a glass electrode.

2. Concentrations of metals were determined according to the ASA method. Soil samples were treated with hot 60% $HClO_4$.

3. Concentration of HCO_3^- ions was determined acidometrically.

4. Concentration of SO_4^{2-} ions was determined nephelometrically.
5. Concentration of PO_4^{3-} ions was determined colorimetrically.
6. Concentration of Cl^- ions was determined argentometrically.

5. RESULTS

The experiment lasted five years. During this time, particular components of dust either were accumulated in the surface layer of soil or were leaked and penetrated into the deeper layer. The behaviour of heavy metals is of special interest because of their toxic effects [3], [4], [6], [7]. Table 3 shows the concentrations of some heavy metals in the soil after the 5 year experiment.

Table 3

Content of lead, cadmium and zinc in the upper layer of soil (in ppm)

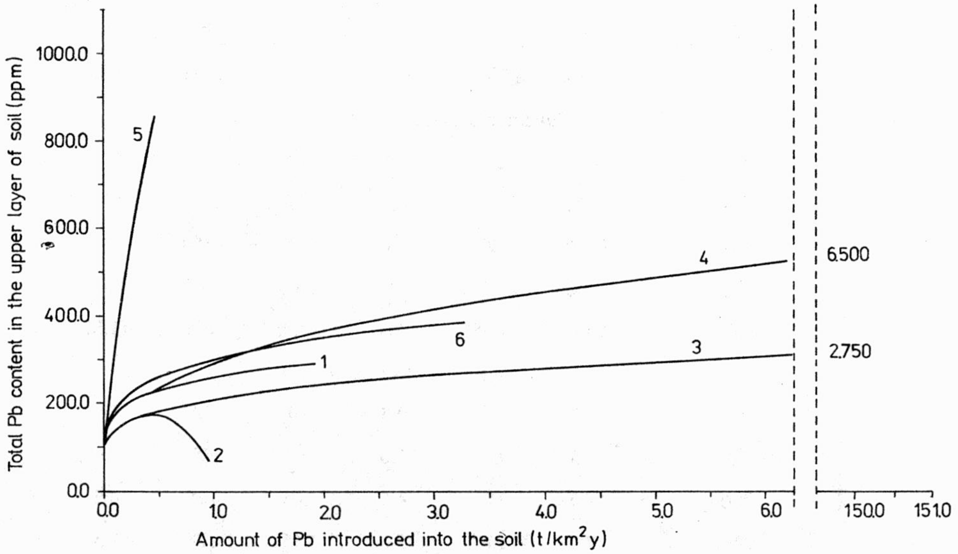
Quantity of dust ($t/km^2 \cdot y$)	ALH level (0–3 cm)			A_1 level (3–5 cm)		
	Pb	Zn	Cd	Pb	Zn	Cd
1	2	3	4	5	6	7
1. Dust from agglomerating plant						
100	140	85	2.4	58	28	0.7
500	206	120	2.5	98	65	0.5
1000	175	154	11.5	70	53	2.4
2000	199	165	9.4	116	104	3.1
5000	404	311	14.8	152	69	9.2
0	128	120	1.5	82	70	0.5
2. Dust from aluminium smelter						
100	116	95	2.8	93	104	1.1
500	152	138	3.6	46	57	2.9
1000	140	109	4.8	70	69	2.1
2000	175	128	5.7	58	32	3.9
5000	69	57	1.3	58	61	1.5
3. Dust from zinc smelter						
100	350	820	10.00	140	270	8.0
500	480	2200	55.00	210	480	15.0
1000	860	3650	140.0	490	820	38.0
2000	1350	7900	225.0	580	1600	135.0

1	2	3	3	5	6	7
5000	2750	15 400	500.0	975	2100	200
		4. Dust from cadmium smelter				
100	450	1250	120	280	150	25
500	1100	2700	210	375	200	140
1000	1800	4200	600	525	1350	150
2000	3400	10 700	1100	1800	3500	500
5000	6500	24 050	1620	2700	8050	1150
		5. Dust from power plant				
100	155	105	2.5	90	70	0.5
500	145	100	1.0	80	45	0
1000	220	150	4.5	165	125	0.5
2000	505	310	5.0	145	125	1.5
5000	845	690	4.5	190	110	1.0
		6. Dust from cement plant				
100	185	270	1.0	130	145	0
500	137	151	1.0	100	100	5.0
1000	295	225	2.0	200	140	1.0
2000	375	400	2.0	180	140	0.5
5000	440	300	1.5	145	120	0.0

5. ACCUMULATION OF LEAD IN THE UPPER LAYER OF SOIL

Data from tables 1–3 allows us to establish the relationship between the amount of lead introduced into the soil and the concentration of this metal in the upper layer after the the experiment with dust deposits from industrial plants. The relationships are presented in figure. X-axis represents the amount of lead introduced into the soil with industrial dust. The scale of the diagram (6t/km^2) represents the entire amount of the lead in dusts from the aggregating plant, aluminium smelter, power and cement plants. In dusts from the cadmium or zinc smelter, however, the quantity of lead introduced with the annual dose exceeds the scale by 25 and ca 35 times, respectively. Such a simplification in presentation of results allows better comparison of 6 curves.

Y-axis represents the total concentration of lead in the upper layer of soil (ALH level) (similarly, in soils treated with the dusts from cadmium and zinc smelter their real amounts exceed the scale). In our considerations, the total lead content is taken into account, although according to the chemical analysis, of the 128 ppm of lead found in



Relationship between concentration of lead introduced into soil and its content in the upper layer after the experiment

the upper layer of soil in the control plot, only 3.5 ppm were in the form available for plants. It is assumed that for a different pH and different soil composition the above ratio can vary.

Behaviour of lead in dust from aluminium smelter is different. Initially, at increasing quantities of dust, concentration of lead in the surface layer of soil increases. For an amount of 2000 t of dust/km^2·y, the function decreases and a further increase in quantity of lead gives significant decrease in its content in the upper layer of soil. 2000 t of dust from aluminium smelter (0.4 t of lead) is the threshold value.

Slopes of other curves are differentiated, which can be expressed by regression coefficients. They are as follows:

for dust from power plant the slope is 1664,
for dust from aggregating plant the slope is 138,
for dust from cement plant the slope is 94,
for dust from cadmium plant the sloper is 33,
for dust from zinc plant the slope is 17.

Lead in the dust from the power plant is accumulated in considerably higher concentrations in the surface layer than that in the dusts from other plants, even if its concentrations are equal.

Factor analysis seems to be appropriate to determine which properties and componets of dusts account for the mobility of lead in soil.

The figure shows the upper layer of soil. At a depth of 7 cm and below (below A_1/A_2 level), the increased lead concentrations are not observed. The regression coefficients (slopes) for this depth were, respectively:

for dust from power plant 3.0,
for dust from aggregating plant 1.3,
for dust from cement plant –0.2,

for dust from cadmium plant 0.5,
for dust from zinc plant 1.9.

6. ACCUMULATION OF ZINC IN THE UPPER LAYER OF SOIL

Due to the mutual interactions of elements, it is interesting to state whether behaviour of other heavy metals in dust is similar.

In the case of cadmium such a consideration was not possible, because its content in the dust was below the detection limit (with the exception of dusts from cadmium and zinc smelter). Nevertheless, when considering the amount of dust introduced, the shapes of the curves are similar to those of lead.

Curves showing concentration of zinc in soil in relation to the amount of zinc introduced with dust were similar in shape to these representing lead, although the differences between them were slight. The curve relating to aluminium smelter reached its maximum and then decreased at the dose of 5000 t/km^2.

Simple regression coefficients for the remaining industrial plants are listed below:
for dust from power plant 754,
for dust from aggregating plant 257,
for dust from cement plant 73,
for dust from cadmium plant 341,
for dust from zinc plant 17.

7. FACTOR ANALYSIS (PRINCIPAL COMPONENT)

Factor analysis has been performed using SPSS/PC+. Such an analysis allows us to establish which variables are most responsible for different dust behaviour.

Independent variables used were presented in tables 1 and 2.

Table 4

Numbers of bacteria (in million/g of soil) on experimental plots treated with dusts from different industrial plants

Dose of dust (t/km^2·y)	Agglomerating plant	Aluminium smelter	Zinc smelter	Cadmium smelter	Power plant	Cement plant
0 (control)	1.52	1.52	1.52	1.52	1.52	1.52
100	1.68	1.62	1.31	1.42	1.48	1.51
500	1.69	1.55	0.91	1.38	1.60	1.84
1000	1.29	1.70	0.95	0.84	1.77	1.48
2000	2.66	1.76	0.75	0.80	1.84	3.13
5000	2.22	1.38	0.65	0.82	1.54	2.17

For a description of accumulation of lead and zinc in the upper layer of soil as well as in the layer A_1 (3–5 cm in depth), regression coefficients were used as dependent variables.

The accumulation of lead in the A_1/A_2 layer of soil (7–15 cm in depth) was also intended to be considered, but the concentrations of that element and zinc in plot no. 9 were increased considerably, which might have resulted from the local deposit of litter or from another reason. Therefore, this level was not considered.

The variables were named, respectively: RPb, RPb2, RZn, RZn2. Two additional dependent variables, displaying the effect of dust on living organisms, were introduced. The first was the coefficient of simple regression for the number of bacteria in the soil treated with dusts of different origin and amount. The second was the coefficient of simple regression for the number of higher plants found in plots treated with dusts. The respective data is presented in tables 4 and 5.

Table 5

Numbers of higher plants on experimental plots treated with dusts from different industrial plants

Dose of dust ($t/km^2 \cdot y$)	Agglomerating plant	Aluminium smelter	Zinc smelter	Cadmium smelter	Power plant	Cement plant
0 (control)	32	32	32	32	32	32
100	36	22	14	23	30	40
500	32	17	16	15	36	34
1000	38	19	11	9	33	28
2000	26	27	11	11	33	36
5000	31	21	9	7	38	34

Simple regression gives a good approximation of change in the number of bacteria if the quantity of dust is increased. In the case of dusts from the aluminium smelter, the threshold value has been observed at the dust dose of 2000 $t/km^2 \cdot y$. Therefore, it has been decided to exclude the last data from the analysis, showing only the positive influence of the dust on the number of bacteria. The same was done for dust from the power plant.

Coefficients of regression for the number of bacteria and various amounts of dusts:

	Rbct
aggregating plant	0.00015
aluminium smelter	0.00011
zinc smelter	–0.00014
cadmium smelter	–0.00013
power plant	0.00018
cement plant	0.00027

Data describing the number of higher plants was scattered. Only in the case of dusts from the zinc and cadmium smelters their negative influence on plants was stated. In such a case, the coefficients of regression provide a rough approximation only. Nevertheless, they do reflect the general trend. These were:

	Rpl
aggregating plant	−0.00083
aluminium plant	0.00041
zinc smelter	−0.00256
cadmium smelter	−0.00353
power plant	0.00114
cement plant	0.00008

Pearson's correlation coefficients were computed for all independent variables and 6 dependent variables. There were 4 coefficients significant at the level of 0.01 and one at the level of 0.001:

1. r = 0.9894, sign. 0.001 – correlation coefficient for the accumulation of lead in soil and the amount of HCO_3^- anions in the water extract of dust.

2. r = −0.9324, sign. 0.01 – correlation coefficient for the number of bacteria in soil and the content of PbO in dust.

3. r = −0.9164, sign. 0.01 – correlation coefficient for the number of bacteria in soil and the content of Mn^{2+} cations in the water extract of dust.

4. r = −0.9219, sign. 0.01 – correlation coefficient for the number of higher plants and the content of PbO in dust.

5. r = 0.9349, sign. 0.01 – correlation coefficient for the number of higher plants and the pH of the water extract of dust.

Factor analysis is expected to explain the relationship between sets of variables with a relatively small number of interpretable factors [5]. As a result of analysis of the set of variables, estimates of 5 factors were obtained. Final statistics and a factor matrics are presented below.

Final statistics:

Variable	Communality	Factor	Eigenvalue	Pct of Var	Cum Pct
RPb	1.00000	1	11.49820	31.9	31.9
RZn	1.00000	2	8.04765	22.4	54.3
RBKT	1.00000	3	6.81584	18.9	73.2
RROSL	1.00000	4	5.44459	15.1	88.4
Na_2O	1.00000	5	4.19371	11.6	100.0
K_2O	1.00000				
MgO	1.00000				
CaO	1.00000				
MnO	1.00000				
ZnO	1.00000				
CuO	1.00000				
PbO	1.00000				
CdO	1.00000				

CoO	1.00000
NiO	1.00000
Fe^{3+}	1.00000
SiO_2	1.00000
S	1.00000
Al_2O_3	1.00000
pH	1.00000
COND	1.00000
Na^+	1.00000
K^+	1.00000
Mg^{2+}	1.00000
Ca^{2+}	1.00000
Mn^{2+}	1.00000
Zn^{2+}	1.00000
Pb^{2+}	1.00000
Cd^{2+}	1.00000
HCO_3^-	1.00000
Cl^-	1.00000
SO_4^{2-}	1.00000
PO_4^{3-}	1.00000
SAL	1.00000
RPb2	1.00000
RZn2	1.00000

Factor matrix:

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
RPb	–0.41757	–0.75067	0.10525	0.42413	0.26678
RZn	–0.07470	–0.62337	0.19691	0.74159	0.13074
RPb2	–0.39491	–0.70395	0.19471	0.50892	0.22715
RZn2	0.56302	–0.21117	0.14871	0.77099	0.14791
RBCT	–0.82416	0.00485	–0.42787	0.26589	–0.25880
RPL	–0.90068	–0.31984	–0.26037	0.12906	–0.04500
Na_2O	–0.12905	–0.22198	–0.24211	–0.83473	–0.42270

K_2O	–0.28242	0.74993	–0.16884	0.46733	0.33306
MgO	–0.76776	0.18226	0.39609	0.44948	–0.13566
CaO	–0.41186	0.52229	–0.61810	0.34183	0.24226
MnO	–0.32335	0.49028	0.69292	0.25272	–0.33326
ZnO	0.20631	0.28638	0.52337	–0.40120	0.66374
PbO	0.90902	0.9257	0.22088	–0.00684	0.34100
CdO	0.97158	–0.06726	–0.03582	0.22319	0.02042
Fe_2O_3	–0.31419	0.33706	0.60810	0.29679	–0.57428
SiO_2	0.14191	–0.91295	0.20361	–0.10434	0.30666
S	0.19911	0.43842	0.33632	–0.24796	0.77042
Al_2O_3	0.27575	0.36138	–0.87012	–0.10653	–0.15785
pH	–0.82350	–0.34189	–0.13026	0.42410	0.09017
Na^+	–0.29296	0.84618	0.44389	–0.01879	0.02756
K^+	–0.17915	0.74112	–0.36794	0.51925	–0.11685
Mg^{2+}	–0.14297	0.55936	0.80795	0.02863	–0.11434
Ca^{2+}	–0.20768	0.33721	0.66620	–0.04090	0.63061
Zn^{2+}	0.93560	–0.11690	–0.12696	0.29305	–09487
Pb^{2+}	0.94587	–0.10668	–0.10535	0.27878	–0.07160
Cd^{2+}	0.94920	–0.10251	–0.10028	0.27335	–0.06114
HCO_3^-	–0.42605	–0.81533	0.06102	0.30541	0.23816
Cl^-	0.79243	0.20342	0.10702	0.45016	–0.34145
SO_4^{2-}	–0.60541	0.54693	–0.41256	–0.03307	0.40379
PO_4^{3-}	–0.19510	0.58527	–0.65136	0.19844	0.39464

On the basis of the matrix it is possible to explain the change in the number of bacteria and plots represented by the variables Rbct and Rpl. The variables are strongly correlated with factor 1 and only weakly with the rest of the factors. Factor 1 in the above matrix can be interpreted as the effect of dust from cadmium smelter. It is closely correlated with such variables as the concentrations of Zn^{2+}, Pb^{2+}, Cd^{2+} and Cl^- ions, as well as of ZnO, CdO and PbO. Factor 1 is also characterized by high negative correlation with pH reaction (a high acid reaction is particularly characteristic of dust from the cadmium smelter).

Transformation of the factor matrix makes the next four dependent variables more easy to interpret. They quantify accumulation of lead and zinc in the surface layer of soil

(ALH) and in the adjacent layer (A_1). After orthogonal rotation, the variables RPb, RPb2, RZn and RZn2 can be correlated with only one or two factors. Factor matrix, sorted after rotation, is shown below. The matrix contains only loadings greater than 0.5 in absolute value.

Rotated factor matrix:

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Cd^{2+}	0.96187				
Pb^{2+}	0.96169				
Zn^{2+}	0.95945				
CdO	0.95727				
Cl^-	0.93379				
RZn2	0.84787		0.52020		
PbO	0.79181				0.55340
NiO	−0.78264	−0.50312			
RPL	−0.74867				
PO_4^{3-}		0.96015			
CaO		0.95895			
K_2O		0.92905			
K^+		0.85850			
SO_4^{2-}	−0.56229	0.80736			
SAL	0.64089	0.65582			
SiO_2		−0.61900	0.59742		
RPb2			0.97512		
RPb			0.95423		
RZn			0.94137		
HCO			0.90353		
pH	−0.54597		0.71513		
CoO		0.59745	0.63766		
Al_2O_3			−0.59601		
Na_2O		−0.50531	−0.54293		
MnO				0.99075	
Fe^{3+}				0.96612	
Mg^{2+}				0.89762	
Na^+				0.74935	

MgO				0.74459	
COND	0.60963			0.71795	
ZnO					0.98715
S^-					0.96391
Mn^{2+}					0.86199
Ca^{2+}					0.86032
CuO					0.82579
RBKT	−0.60224				−0.63322

Factor 1 represents acidic reaction and high concentrations of cadmium, lead, zinc and chloride ions, while factor 2 describes such components of dust as sulphate and phosphate ions, calcium and potassium oxides and deficiency of silica.

Factor 3 can be identified as components of dust from the power plant, characterized by the alcaline reaction, high content of bicarbonate ion and silica, deficiency of aluminium and sodium oxides.

Factor 4 strongly correlated with the concentrations of magnesium, iron and sodium cations, which are characteristic of the iron industry.

Factor 5 represents high loadings of sulphates, calcium and manganese ions, cadmium, lead and zinc oxides.

RPb, RPb1 and RZn are highly correlated only with factor 3, and are not correlated at all with the rest of the factors (coefficients less than 0.25 in absolute value).

Accumulation of zinc in the A_1 level of soil (3–5 cm in depth) dependent on variable RZn2 follows a different pattern. This variable can be expressed as a function of factor 1 (coefficient of 0.8478) and of factor 3 (coefficient of 0.52), which implies strong correlation between accumulation of Zn in the soil and the contents of Pb^{2+}, Cd^{2+}, Zn^{2+} and Cl^- ions in dust.

8. CONCLUSIONS

The dust from power plant causes a much greater accumulation of lead and zinc in soil than dust from any other industrial plant with the same heavy metal content.

Dust dose from the aluminium smelter appears to show a threshold value. After exceeding this value, the concentrations of lead, zinc and cadmium in soil decrease. Greszta [8] explains this phenomenon by the function of anions whose action calls forth a release of heavy metals from the dusts and from the organic substances of soils and their transport outside the soil profile. The experiment did not explain what anions or components of dust are responsible for this effect. Further research should be undertaken to clarify the mechanism of the ions action.

Of the Pearson's correlation coefficients computed, four were significant at the level of 0.01 and one at the level of 0.001. They expressed the influence of HCO_3^- ion concentra-

Factor analysis allows establishing an appropriate model on the basis of principal components. Factor responsible for impact of industrial dusts on living organisms was identified as dust from cadmium smelter where the significant role is played by cadmium, lead and zinc chlorides and oxides and strong acid reaction of dusts.

In order to explain an accumulation of zinc and lead in soil, the best model was obtained as a result of matrix transformation. The only factor responsible for lead accumulation in soil represented the alcaline reaction of dust and the high content of hydrocarbonate ion and silica. In the case of zinc accumulation in the surface layer (organic matter), the situation was the same. In the deeper layer, however, the influence of the factor representing dust from the cadmium smelter with lead, zinc and cadmium chlorides was stronger.

Factor analysis failed to explain the behaviour of dust from the aluminium plant because of insufficient data and complex effects enhancing the behaviour of that dust.

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ODDZIAŁYWANIE PYŁÓW PRZEMYSŁOWYCH NA ŚRODOWISKA LEŚNE

Stężenia ołowiu i cynku, pochodzące z emisji przemysłowych, nagromadzone w wierzchnich warstwach gleby są skorelowane nie tylko z ilością deponowanych pyłów, lecz także z ich rodzajem. Na zbiorze zmiennych obrazujących szkodliwe oddziaływanie pyłów przemysłowych na środowisko leśne przeprowadzono analizę czynnikową. Otrzymano model o niewielkiej liczbie czynników odpowiedzialnych za proces akumulacji zanieczyszczeń. Zaproponowano kierunki dalszych badań, aby wyjaśnić ubożenie lub wzbogacanie wierzchnich warstw gleby w metale ciężkie.

ВОЗДЕЙСТВИЕ ПРОМЫШЛЕННЫХ ПЫЛЕЙ НА ЛЕСНЫЕ СРЕДЫ

Концентрации свинца и цинка, происходящие из промышленных эмиссий, накопленные в верхних слоях почвы, связаны не только с количеством депонируемых пылей, но также с их видом. На совокупности переменных, образующих вредное воздействие промышленных пылей на лесную среду проведен факторный анализ. Получена модель с небольшим количеством факторов, отвечающих за процесс аккумуляции загрязнений. Предложены направления дальнейших исследований для выяснения обогащения или обеднения верхних слоев почвы тяжелыми металлами.