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Potential ecological risk due to acidification of heavy industrialized areas - the Upper Silesia case

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Abstract

Currently the critical loads concept applies to natural aquatic and terrestrial ecosystems. Critical loads calculation and mapping carried out to support the second Sulfur Protocol negotiations have shown that there are some areas in Poland where the commonly used ecosystems sensitivity criteria for acidification do not reflect the real level of risk. In the Upper Silesia region, the most heavily industrialized in Poland, a number of specific phenomena occur. The energy production is mainly based on hard coal burning what results in intensive emission of acidic gases and solid particles. These particles, alkaline in nature, neutralize substantially the acidification effect of the emitted gases. Excessive reduction of solid particles can lead to excessive acidification of precipitation. On the other hand this area is heavily polluted with heavy metals of natural and anthropogenic origin. Leaving this system out of control can result in spontaneous release of heavy metals and their migration into soil, surface and ground waters. This may lead to unforeseen consequences the more dangerous that addressed to one of the most populated areas in Europe. Preliminary study done in the Institute for Ecology of Industrial Areas in Katowice revealed some evident symptoms of the above mentioned hazards. From this it should be concluded that a comprehensive research program should be undertaken aimed at a thorough identification of the problem and development of an effective environmental policy for heavy industrialized areas.

1. INTRODUCTION

Progressing acidification of atmospheric precipitation belongs to the phenomena more and more often observed in the world. The effects of acidification have impact on a broader and broader territory and their forms are constantly becoming more and more drastic like destruction of forests in Central Europe or biological degradation of Scandinavian lakes.

The problem of acid precipitation impact on the areas loaded with heavy metals accumulated as a result of industrial activity is a phenomenon remaining still not fully recognized. Generally, at present heavy metals exist in soil in the form of insoluble compounds, however excessive acidification of natural environment in which they are deposited may lead to their mobility in the forms that may be absorbed by living organisms. Plants turn out to be quite resistant to heavy metals contamination but animals, and humans are prone to the toxic impact of those metals. The situation is particularly serious in the case of industrial agglomeration inhabitants in that for children first of all.

Insufficient recognition of the problem on one hand and wide range of possible hazardous effects on the other, impose a prompt necessity to undertake adequate investigations. As study area the Upper Silesian Industrial Region has been selected, in which the problem of impact caused by heavy metals seems to be of particular importance and the risk of quick progress in the acidification of natural environment most real. It should be stressed here that the obtained research results can find application in risk assessment in other industrial

agglomerations.

2. GENERAL DESCRIPTION OF THE STUDY AREA.

The Katowice province is situated in south-western Poland. The province is a typical industrial area, with high level of urbanization and serious environmental problems, which place it on the list of most polluted regions in Europe. The province covers the area of 6650 km^2, which makes 2.1% of the total area of Poland, and it is inhabited by about 4 million people (10.5% of total population in the country).

The average population density amounts to 602 people per one km^2. About 87% of the population lives in towns where the average density amounts to 2051 people per one km^2. High level of urbanization is the result of intensive industrialization based on local mineral resources. The main branches of industry developed in the Katowice District include: coal mining, coal-fired electricity and heat generation, non-ferrous metal processing and mining (including zinc and lead ores), chemical industry, production of building materials.
The extraction and raw materials processing, machinery and chemical industries developed in an uncontrolled manner. They have not been modernized, causing many ecological problems, proper living and working conditions cannot be secured for Silesia inhabitants.

According to the reports of the Regional Sanitary-Epidemiological Station in Katowice the air pollution in the Katowice province belongs to the highest in Poland. In 1991 24% of gaseous pollutants and 20.2% dust pollutants in Poland came from the emission sources located within the Katowice province. The annual permissible concentrations of most of the monitored pollutants are exceeded many times, particularly within industrial-urban areas (Chorzów, Świętochłowice, Bytom, Ruda Śląska, Zabrze), and also in peripheral areas of the province. Particularly high concentrations are found for such pollutants as carbon monoxide, nitrogen dioxide and of suspended dust - within which high concentrations of lead and benzo-a-pyrene occur (Table 1).

Atmospheric precipitation causes contamination of surface waters and soil. In the vicinity of plants processing non-ferrous metals (zinc smelters), the lead fallout in dust has resulted in contamination of the topsoil, reaching drastically high levels of several grams of lead per kilogram of soil (Miasteczko Śląskie, Bytom, Bukowno).

The Upper Silesia region suffers a severe water resources shortage. The deficit of water is estimated at about 250000 m^3/day for municipal use and about 300000 m^3 for industrial use. In 1991 the total use of water was of about 1081.4 hm^3. Of this, about 753.5 hm^3 was discharged as effluent, and 517.6 hm^3 was treated, but only 26-27% of total effluent were treated properly. The remaining 235.9 hm^3 was dumped into the surface water system without any treatment. Industrial effluent discharged into rivers contain excessive amounts of heavy metals, phenols, cyanide, ammonia nitrogen and salt. Discharge of municipal waste water and saline mine waters has resulted in catastrophic degree of river pollution. Water quality monitoring indicates that 62.8% of the overall length of the rivers of Katowice province carry excessively polluted water, unsuitable for any use (in Poland - 35%).

Table 1
Pollution levels in Katowice province in 1991.

Substance	Units	Annual concentrations (observed) from	to	Permissible mean annual conc. D_a
ammonia	$\mu g/m^3$	18	79	51
phenol	$\mu g/m^3$	5.2	27	2.5
fluorine	$\mu g/m^3$	0.8	1.9	1.6
formaldehyde	$\mu g/m^3$	2.6	44	3.8
carbon dioxide	g/m^3	0.76	0.94	-
carbon monoxide	mg/m^3	4.4	7	0.12
sulphur dioxide	$\mu g/m^3$	21	87	32
nitrogen dioxide	$\mu g/m^3$	25	134	50
volatile hydrocarbons	mg/m^3	3.4	4.8	-
suspended dust	$\mu g/m^3$	66	253	50
tar substances	$\mu g/m^3$	7	32	-
benzo-a-pyrene	ng/m^3	15	125	1
perylene	ng/m^3	3	37	-
lead	$\mu g/m^3$	0.11	1.51	0.2
zinc	$\mu g/m^3$	0.19	7.6	-
manganese	$\mu g/m^3$	0.03	0.21	1
iron(Fe_2O_2)	μ/m^3	2	24	-
copper	μ/m^3	0.3	4.4	0.6
cadmium	ng/m^3	2.1	72	10
chromium	ng/m^3	2.1	44	400
nickel	ng/m^3	2.3	59	25
dust deposition	g/m^2y	35	466	200
lead deposition	mg/m^2y	2	2822	100
cadmium deposition	mg/m^2y	0	87	10

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Annually, the Katowice province industry generates 60-70 mln tons of wastes (1991), from which:

- coal mining 53.0 mln tons
- power generation industry 5.0
- iron and steel metallurgy 4.5
- non-ferrous metallurgy 3.5
- chemical industry 1.0

It makes about 50% of wastes generated in Poland (128 mln tons).

- 42.0 mln tons of wastes generated annually are utilized (for production purposes, filling excavation, reclamation, land levelling, soil fertilizing)
- 0.005 mln tons are neutralized
- 23.0 mln tons are dumped

Annually 30 mln tons of wastes (mainly from coal mining) are used for non-industry purposes, such as: filling excavations, levelling and building roads. Only 10 mln tons of wastes are used as row material for building materials production.

The degradation of the natural environment is closely related to lower values of many health indices for children and young people, and also with the all-revealing infant mortality rate. With the average value for the province at 16.2 in 1991, it is much higher in most of the cites within Upper Silesia (in 1990 in Katowice province - 17.8, in Zabrze and Sosnowiec - 22.7, in Piekary Śląskie - 24.8, in Tychy - 26.7, in Czeladź - 27.7 and in Świętochłowice - 31.3). In Poland: 1990 year - 15.9, 1991 year - 15.0. Among the diseases resulting from environmental pollution the predominant ones are pulmonary diseases (around the coke plant at Dąbrowa Górnicza), heart conditions, allergies, deficient cellular immunity and chromosomal disorders (in areas affected by lead, cadmium and zinc pollution).

3. EMISSION SOURCES OF HEAVY METALS

It has been assessed that since the beginning of industrial activities in the Upper Silesian Region up to present times about 2 mln mln tons of industrial wastes have been generated. It makes approx. 300 thousand ton of wastes per km^2 i.e. the concentration highest in the world in such a densely populated areas as the Upper Silesian Region. About 78% of wastes is accumulated on the earth surface which in a significant way enhance their impact on natural environment causing harm to soil, water and air quality in the area of the Katowice Province.

The dispersion of landfill sites makes the situation even more difficult; only about 680 landfill sites are inventoried and the number of 'wild' landfill sites is assessed to be 280 - 300. Those landfill sites are not adopted to hazardous wastes disposal, neither are there suitable technologies, equipment and selected disposal areas [1].

From the point of view of heavy metals impact on environment the wastes generated in energy production as well as those from non-ferrous metals industrial plants, especially in the processes of cadmium, lead and zinc production create special risk to environment. These metals along with Hg, Cu, Tl, Sn, Cr, Sb, Ag and Au are classified into the group of elements of especially high probability of potential risk for living organisms [2]. Annual increase of solid wastes mass connected with energy production (i.e. slag and ashes) is assessed as approx. 6 mln tons whereas the total mass of the already disposed wastes, according to the same assessments, is assumed as 68 mln tons. Emission of volatile ashes

into the atmosphere is currently on the level of 200 thousand tons. It includes about several tens of tons of zinc in the form of oxygen compounds, several tens of tons of lead and 1-2 tons of cadmium. The impact of non-ferrous metals industry (Zn, Cu, Cd) located in the Upper Silesia Region is observable already in the phase of ores exploitation, their enrichment and during processing. The solid wastes disposed on landfill sites are assessed as approx. 80 mln tons and the annual increase is assessed on the level of 4 mln tons [3,4]. In 1992 the discharges into the atmosphere in the form of dusts included 90 tons of ZN and 20 tons of Pb [5]. One should also not forget about the role that the 800 year history of zinc and lead ore mining not fully registered in documents played in the development of the present state of natural environment in the Upper Silesian Region. Transport is another source of lead in the discussed region. Annual emission from that source is assessed on the level of 150 tons.

Summarizing it should be said that the major sources of heavy metals pollution in the Katowice Province are: energy production industry and non-ferrous metals like zinc, lead and cadmium industry and in the case of lead also transport. The disposal sites of slag and ashes as well as flotation wastes store at present approx. 150 mln tons of wastes. Their impact on environment is of regional character.

Emission of dusts into the atmosphere has impact on a much more extensive area. Annually, about 100 tons of Zn, 160 tons of Pb and 1-2 tons of Cd are transported mainly in the form of oxygen compounds. Power plants and their disposal sites are situated uniformly in the central and at the same time most densely populated part of the province, whereas the non-ferrous metals industry is located in the northern and eastern parts of the province i.e. the area of Bytom, Tarnowskie Góry, Chrzanów and Bukowno.

4. TRENDS IN ACIDIFICATION OF ATMOSPHERIC DEPOSITION

Generally hazardous situation concerning acid deposition in the Katowice Province is well known. It can be illustrated by the results of the investigations carried out by IEIA within the international research program for Convention on Long-Range Transboundary Air Pollution Transport [6]. That research proved considerable exceedances of the critical loads of acidity, especially for sulphur compounds in the South-Western part of Poland, in that in the Katowice Province (Fig. 1 and 2) [7].

The research on atmospheric pollution is carried out among others in the Institute for Ecology of Industrial Areas in Katowice - Załęże. In order to obtain information on the time variability of rains pH the data collected from monitoring were processed. The results of the calculations are presented in Fig. 3 and 4. On their basis it is possible to state that the pH of rains measured at IEIA station has been showing a significant tendency to decrease in the recent four years (Fig.3). Also the presented in Fig.4 correlation between the concentration of particulates in the air and precipitation pH is statistically significant. The decrease of precipitation acidity together with the increase of dusts concentration proves its basic character. An independent confirmation of the observed in IEIA tendency of precipitation acidity increase is the research performed in recent years at the Silesian University in Katowice.

INSTITUTE
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NATIONAL FOCAL
CENTER
KATOWICE

CRITICAL LOADS
of SULPHUR

[eq ha^{-1} yr^{-1}]

0-200
200-500
500-1000
1000-2000
> 2000

Figure 1.

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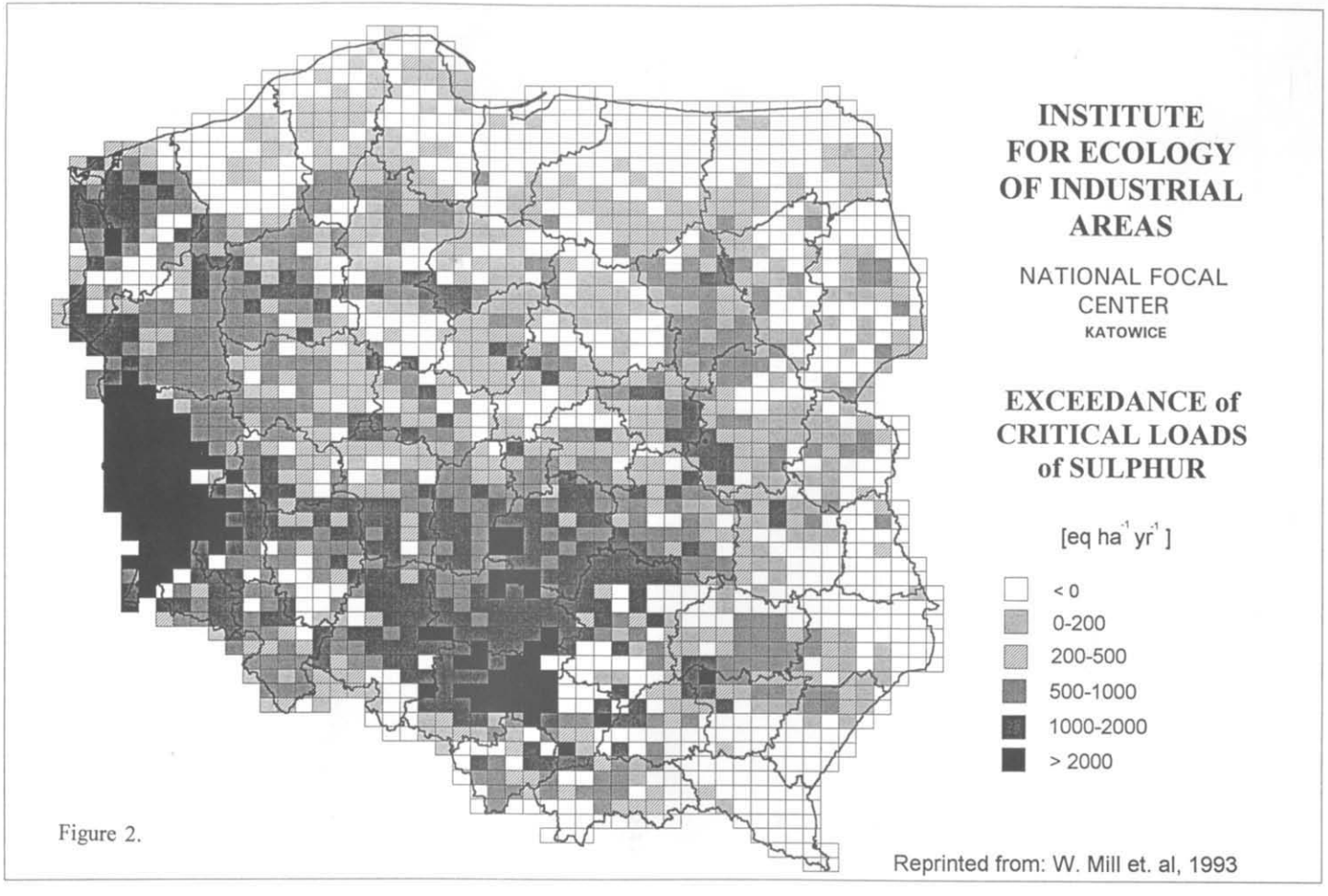

Figure 2.

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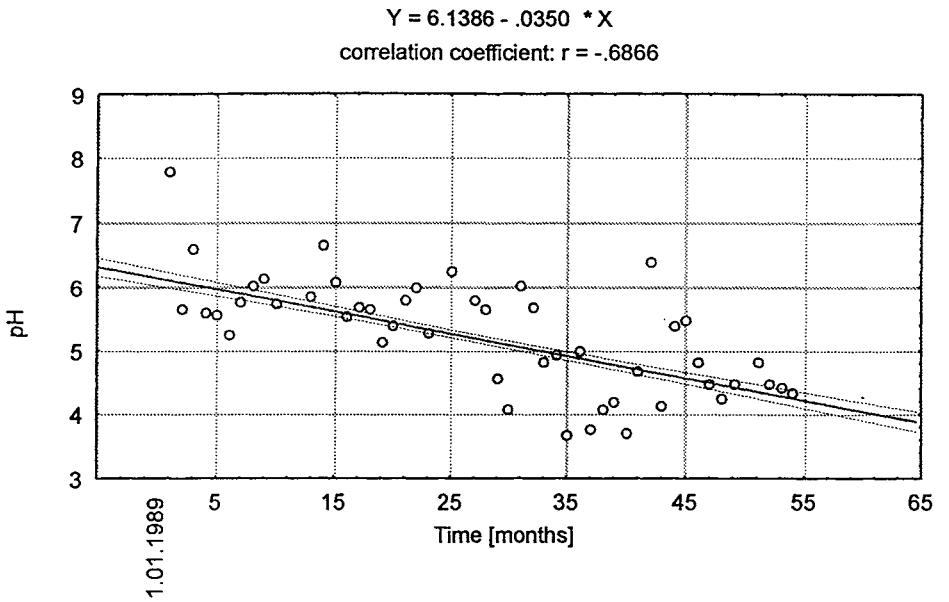

Fig.3. Changes of precipitation pH in time

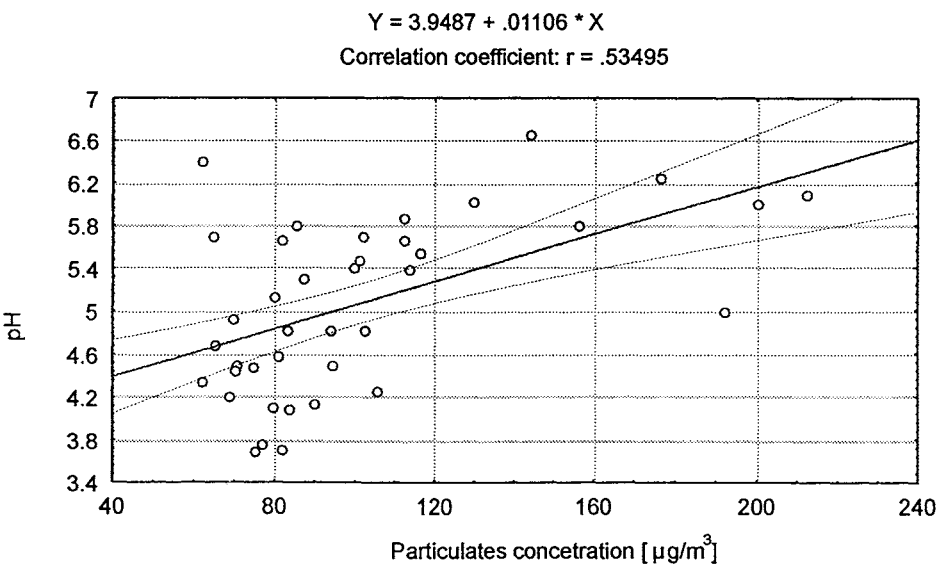

Fig 4. Correlation between parcitulates concentration in air and precipitation pH

5. POTENTIAL RISK TO ECOSYSTEMS DUE TO INCREASING ACIDIFICATION

Practically speaking, all components of environment in the Upper Silesian Region are exposed to the effects of the increasing acidity of precipitation and in consequence to the enhanced migration of heavy metals. The presence of heavy metals especially of Pb, Zn, and Cd in soil water and air creates a real risk of penetration of those toxic elements into human organism. Acid rains even rise that phenomenon in power.

5.1. Soils

A considerable amount of heavy metals migrating into soil is immobilized as a result of complexing process taking place in humus or unmeasurable sorption by clay materials or finally in sparingly soluble compounds etc.

The main factor influencing the concentration of heavy metals in soil solution (and at the same time the possibility of toxic impact on plants) is soil pH. As a rule the concentration of heavy metals in soil solution increases parallel with the decrease of soil pH. When the area under the emission of heavy metals covers with the area of acid rains appearance the situation turns out to be especially dangerous [8].

R.Kucharski, M.Marchiwńska et al [9,10] carried out research on the concentration of heavy metals in soils used for agricultural purposes and plants cultivated on them. Their developed an agricultural land assessment method, which allows to classify the area, considering environmental pollution [11]. The classification is performed using the method of simple indices, easy to operate, and showing which species of plants could be safely grown regarding consumer's exposure. With the application of this method and on the basis of environmental quality data, more than half of total arable land area has been evaluated in the district. Up till now, about 140000 hectares of arable soils have been assessed, out of which 55% were classified as A category (safe zone), 38% - as B category (limited agricultural activity) and 7% - as C category (unsafe zone). It seems also important to pay attention to the fact that the majority of research was carried out in the time when the problem of acid rains was not so glaring as today.

The fate of heavy metals accumulation in arable soils is different than in forest areas. Due to ploughing a process of "dilution" of the immited elements in big mass of soil is observable. In the case of forest soils very high concentrations appear in the surface layers, mainly in the humus, whereas in the deeper levels they are usually low with the values often comparable to those observable in unpolluted soils [8][12].

In the case of forest a more serious problem is the mobility of the active Al^{+3} ions resulting from the excessive acidification. Those ions have toxic impact on the root systems of trees. It is assumed that the presence of heavy metals in soil solution strengthens that effect. Research on the identification and inventory of forest damages in the area of the Upper Silesia is carried out by the Research Institute of Forestry. The documentation of those damages is published in annual statistic reports and for the year 1990 forest area endangered by air pollution in Katowice district amounts to 99.2 %, within the third class of trees injury relates to nearly 15 % of the total forest area in district [13].

5.2 Surface waters

Heavy metals exist in surface waters in the form of soluble compounds (ionic and complex), colloids and suspended matters. Soluble forms easily accessible to organisms are only a negligible percentage of the metals total mass. The predominant amounts of metals are deposited in the form of sediments.

Sediments are that part of water ecosystem in which the accumulation of metals takes place and they may at the same time be the terminal stage of metals migration in environment. However, in some conditions, heavy metals accumulated in sediments can be released and migrate into water causing its degradation. That is the reason why the heavy metals accumulated in sediments are often called "chemical time bomb". The processes of metals release from sediments are the effect of the activity of various mechanisms conditioned both by interior and outerior factors of a given ecosystem. The mechanisms of those processes are still not well recognized, and it especially concerns water ecosystems loaded with heavy metals.

Preliminary research consisted in the determination of contamination with heavy metals and their distribution in river between the water phase, suspended matter and sediments as well as the determination of the form in which those metals are bounded in sediments on the example of the Biała Przemsza River [14]. The Biała Przemsza River and its tributaries remaining under strong impact of zinc-lead ore exploitation and processing industry, showed very high level of contamination with zinc, lead and cadmium (Table 2).

Table 2
Concentrations of heavy metals in the Biała Przemsza River Basin

	Range of concentration in the cross sections:	
	Below the point sources	Above the point sources
1. Water phase		
Zn, mg/l	0.03 - 3.7	u.d.* - 1.2
Pb, mg/l	0.02 - 1.3	u.d.* - 0.2
Cd, mg/l	u.d.* - 0.01	u.d.* - 0.002
2. Suspended matter		
Zn, mg/kg .d.w.**	4,513 - 68,000	840 - 9,900
Pb, mg/kg	588 - 42,700	866 - 12,000
Cd, mg/kg	28 - 1,200	39 - 840
3. Sediment		
Zn, mg/kg d.w.**	166 - 16,545	31 - 164
Pb, mg/kg	167 - 4,100	13 - 183
Cd, mg/kg	0.9 - 73	0.1 - 2.1

*u.d.- under determination level **d.w.- dry weight

Metals in soluble form were only an insignificant quota in comparison to their contents in suspended matter and sediments. Maximal concentrations of metals in soluble form reached in the cross sections loaded by emission from point sources the following values (mg/dm^3): Zn - 3.7; Pb - 1.3; Cd - 0.01; whereas in suspended matter they reached the values respectively (mg/kg of dry weight): Zn - 68,000; Pb - 42,700 and Cd - 1,200. Sediments showed also high level of contamination with heavy metals yet still lower than in suspended matter. The highest measured values were (mg/kg of dry weight): Zn - 16,500; Pb - 4,100 and Cd - 73.

The natural contents of those metals in sandstones padding the Biała Przemsza Valley is rather low and amounts (mg/kg): Zn - 16; Pb - 7 and Cd - 0.02. In that context the contents of metals in sediments in the control cross section - above the point sources of emission was also many times lower and proves the impact of non-point emission sources.

The presented results of sediment contamination with heavy metals, limited due to insufficient measurements number only to the Biała Przemsza River Basin, show that the risk that metals accumulated in sediments has already been real.

5.3. Groundwater

The groundwater resources of the Katowice Province are 5 main underground water reservoirs of the total surface 3350 km_2. Those reservoirs create a slit - karst water bearing supply complex of the carbonate series of Trias. They are the main source of groundwater supply in the urbanized and industrialized agglomeration of Upper Silesia.

Observations show that groundwater is especially exposed to pollution from earth surface in the catchment areas [15]. In water in the vicinity of zinc and lead ore mines decreased pH as well as considerable concentration of Zn up to 21 mg/dm^3 and Pb up to 7 mg/dm^3, exceeding the permissible values (respectively 5 and 0.5 mg/dm^3) were stated.

Also exceedance of Cd concentration permissible value is noted.

6. SUMMARY AND CONCLUSIONS

The above presented overview enables to draw the following conclusions:

1. The results of the precipitation pH measurements in the area of the Katowice Province prove the progressing process of its acidification.

2. In the territory of the Katowice Province there are areas considerably loaded with heavy metals as a result of industrial activity connected with exploitation and enrichment of non-ferrous metals ores and production of those metals, mainly cadmium, zinc and lead. That situation concerns first of all such cities and communes like Bukowno, Bytom, Chorzów, Chrzanów, Katowice, Świętochłowice and Tarnowskie Góry. They cover approx. 10% of the province area and are inhabited by about 20% of the province population.

3. In the Katowice Province the effects of heavy metals mobilization have already been tangible in the form of excessive contamination of agricultural products as well as surface and underground water. Progressing acidification may only enhance the processes of heavy metals mobilization.

4. The assessment of heavy metals mobilization processes in time is rather difficult due to nearly complete lack of data on the macrokinetics of those processes.

Generally, it can be stated that the negative effects of the excessive pollution with heavy metals in the area of the Katowice Province are tangible. The impact of the increased precipitation acidity may progress only in one direction i.e. towards the increase of heavy metals mobility making at the same time the situation very dangerous.

The time scale of the discussed phenomena is difficult to determine. While the data on the steady-state thermodynamics in soils are relatively rich, the questions addressing the rate of soil processes connected with heavy metals mobilization have not found satisfactory answers so far. The reason for this are considerable experimental difficulties connected with the collection of kinetic data for soil systems.

Currently the critical loads concept applies to natural aquatic and terrestrial ecosystems. Critical loads calculation and mapping have shown that there are some areas in Poland where the commonly used ecosystems sensitivity criteria for acidification do not reflect the real level of risk. Especially in the Upper Silesia region a number of specific phenomena occur. In this connection a comprehensive research program should be undertaken aimed at a thorough identification of the problem and development of an effective environmental policy for Upper Silesia region.

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