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Impact of mining and metallurgical industries on the environment in Poland

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Abstract—Mining and metallurgical industries cause great devastation of both terrestrial and aquatic environments on a local and regional scale. Mines and smelters produce large quantities of wastes, which must be deposited on land or in aquatic systems. The major effects are due to pollution of air, soil, river water, and groundwater with heavy metals. The most endangered surficial flows are the upper courses of both the Vistula and Odra Rivers, whose increase in concentrations of contaminants — mainly heavy metals + chloride ions — must be regarded as alarming. About 50% of surficial flows do not even meet the standards for quality class III. In 1990 the volume of wastes produced by the mining and processing industries was more than 660 million tonnes of spoil and over 490 million tonnes of tailings. It is estimated that in the period 1984–2000 about 900 million m^3 of spoil will be dumped in the area of the Upper Silesian Coal Basin alone. Taking into account emission of dusts and gases and the volume of dumped wastes including sewage per km^2, 27 ecologically endangered regions have been distinguished. Mining and smelting districts make up almost half of these regions. Copyright © 1996 Elsevier Science Ltd

INTRODUCTION

Mining and smelting activities impose harmful, usually irreversible, effects on the terrestrial and aquatic environments. The most serious are: (1) changes in hydrogeological systems; (2) hydrological transformations of soils and surficial flows; (3) contamination of soils and surficial water reservoirs; (4) pollution of the atmosphere. In most cases impact of mining on the environment is both regional and local. The metallurgical industries are commonly situated near the metal ore mines, while the thermal power and heating plants are located in the vicinity of coal mines.

Among the approximately 700 million tonnes/a of mineral commodities have been exploited recently in Poland (Fig. 1) the most important are: bituminous and brown coals, Cu, Zn and Pb ores, native S, and rock-salt (Table 1).

The metallurgical industries in Poland have become some of the largest in Europe. The huge plants, which are located in already heavily industrialized areas, have generally caused large scale deterioration of the environment.

UPPER SILESIAN DISTRICT

Hard coal has recently been mined in Poland in 3 districts: the Upper Silesian Coal Basin (USCB) (Katowice, Rybnik areas), Lower Silesian Coal Basin (LSCB) (Wałbrzych and Nowa Ruda areas), and Lublin Coal Basin (LCB) (east of Lublin) (Fig. 1). Negative effects of mining activity are especially recognizable in the Upper Silesian Coal Basin, as coal has been intensively exploited there for about 150 a. In the 1980s, 62 coal mines in the Upper Silesia Region extracted 190–200 million tonnes of coal per year (Nowicki, 1993).

A substantial amount of the coal extracted is burned in several power stations and in the heating-power plants of the Silesia agglomeration, which has almost 4 million residents. Coal is also converted into coke. In 1991 Katowice province produced 34% of the coke, and was the major producer of coal, Zn and steel in Poland (Table 2).

The hydrological system of the USCB is strongly influenced by naturally mineralized and polluted waters which originate from dewatering of mines and are discharged to the surficial flows. In 1989 the

Table 1. Size of mining activities in Poland (in 1991)

Commodity	No. of mines	Production (10^6 t/a)	Wastes produced (10^6 t/a)
Hard coal	68	170	80
Brown coal	11	70	300 (mln m^3 of overburden material)
Zn–Pb ores	4	5.3	4
Cu ores	4	31	30

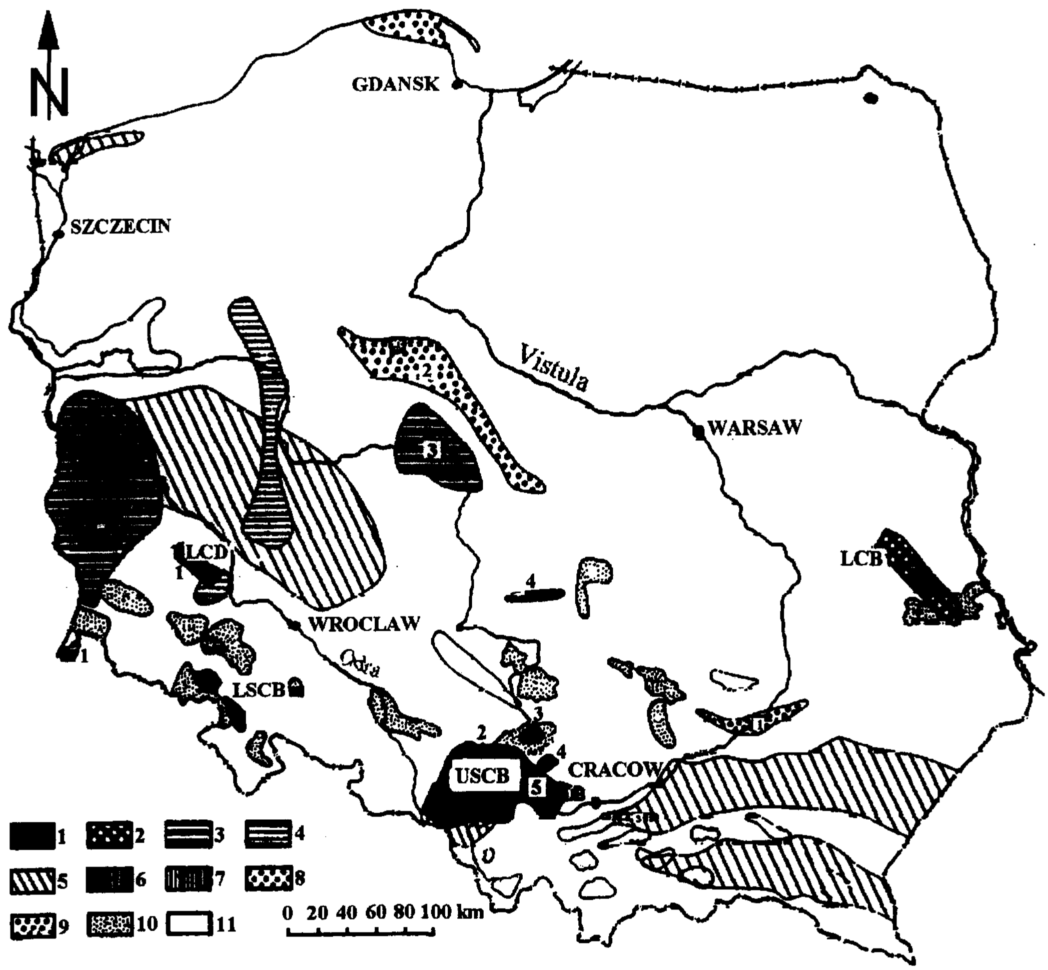

Fig. 1. Occurrence of principal mineral raw-materials in Poland (Kozłowski, 1983). Hard coal districts: 1, operating; 2, designed. Brown coal districts: 3, operating; 4, designed (1, Turoszów; 3, Konin; 4, Bełchatów); 5, petroleum and gas districts. Metallic ore districts: 6, operating; 7, designed (1, copper; 2, 3, 4, 5, Pb–Zn). Chemical raw material districts: 8, operating; 9, designed (1, sulphur; 2, 3, rock-salt). Industrial stones: 10, operating; 11, designed.

Table 2. Main industrial activities of the Upper Silesia Region (area, 6650 km^2; population, 4 million) in 1991 (Przybylski, 1991)

Activity	No. of mines/plants	% of national output
Coal mining	55	98 (170 mln t/a)
Pb–Zn mining	4	100 (5.3 mln t/a)
Smelting	16	50 (steel), 34 (coke)
Power plants	23	-

operating coal mines in the USCB supplied about 720,000 m^3 of water per day from 83 discharge points. These waters are rich in Cl^- and SO_4^{2-} and contain high amount of heavy metals (Guziel, 1988; Wilk *et al.*, 1990). In 1990 the total amount of Cl^- and SO_4^{2-} ions released to the USCB surficial flows reached 8000 tonnes per day, of which 5000 tonnes were eventually transported to the Vistula River and 3000 tonnes to the Odra River. Concentrations of Cl^- and SO_4^{2-} ions in excess of 300 g/m^3 (max. 1600 g Cl^-/m^3) over a distance of about 200 km have been recorded in the Upper Odra and Vistula River sections (Wilk *et al.*, 1990).

Mineralized waters in the USCB coal mines show high concentrations of natural radioactive isotopes (Lebecka and Skowronek, 1993) owing to the reducing environment that prevails in the coal formations. In such conditions some elements (e.g. Ra) are selectively leached from the wall-rocks, resulting in anomalously high concentrations of Ra with respect to U and Th in the mine waters. The concentrations of ^{226}Ra in waters discharged mainly to the Vistula and Odra Rivers vary from < 0.1 to 28.1 kBq/m^3.

In the Upper Silesian Zn–Pb district the principal environmental problem is the formation of depression cones due to the dewatering of mines. In the Bytom subdistrict, where ores have been worked since the 12th century, the static waters have been almost completely drained from the mining fields and adjacent areas. Although the Bytom mines have been inactive since 1989, the water is still pumped and discharged into the surficial flows (mainly to the Brynica stream). This discharge supplies 100 tonnes of TDS (total dissolved solids) per day (90% of SO_4^{2-}) and appreciable amounts of base metals (up to 2 g/m^3, mostly Zn and Pb). Mine waters commonly contain phenols (1–2 g/m^3) which originate from infiltration of surficial contaminants.

The industrial waters are commonly discharged to the surficial flows after clarification in the tailing ponds. Such waters may contain up to 300 g/m^3 SO_4^{2-} and up to 3 g/m^3 Zn^{2+} and Pb^{2+}. One example is the severely degraded Luszówka River (a tributary of the Vistula River), which receives 2.2 tonnes SO_4^{2-}, and 22 kg of Zn and Pb per day.

An important problem is the pollution of both the bottom and flood-plain sediments of the Vistula and Odra Rivers with heavy metals derived from mine waters and released by ore processing and smelting plants (the principal ores being those of Zn, Pb and Cu). Recent investigations (Macklin and Klimek, 1992) have shown very high concentrations of Zn (up to 11,000 mg/kg), Pb (over 1700 mg/kg), and Cd (up to 150 mg/kg) in the overbank alluvial sediments of the Upper Vistula and Przemsza Rivers.

Industrial waters discharged from Zn–Pb ore processing plants as well as mine waters and meteoric waters infiltrating the waste dumps are the principal pollutants of the Przemsza River (a tributary of the Vistula River). The concentrations of heavy metals in the bottom sediments of these 2 rivers are very high, and reach a maximum of 7000 mg/kg Zn, above 900 mg/kg Pb and 200 mg/kg Cd in the Przemsza River, and up to 6000 mg/kg Zn, 800 mg/kg Pb and about 140 mg/kg Cd in the Vistula River (Helios Rybicka, 1992, 1993). The maximum concentrations of Cd are particularly high, approaching some of the highest levels (up to 200 mg/kg) recorded in river sediments anywhere in Europe. The concentration of heavy metals in the Odra River is also high with values of up to 6700 mg/kg Zn, 4000 mg/kg Pb, 1800 mg/kg Cu, 350 mg/kg Ni and 12 mg/kg Cd having been recorded.

The other serious hazards to the environment are posed by industrial sewage, which reached about 9 × 10^{11} m^3 in 1991 (Nowicki, 1993). Hence a number of chemicals, large quantities of heavy metals, etc., go directly into rivers.

Soils in the neighbourhood of metal mines and smelters show metal concentrations exceeding background up to 100 times (Table 3) (Kucharski *et al.*, 1992).

Table 3. Soil contamination in the Upper Silesia Region (mg/kg)

Site	Pb	Cd	Zn
Bytom	129–2290	2–85	193–12,592
Bukowno	46–1520	1–42	90–9200
Tarnowskie Góry	26–8200	1–143	103–13,250
Katowice	20–1050	X–20	61–2110
Chrzanów	24–1100	1–35	62–5660

One of the serious environmental problems in Poland appears to be contamination with Cd and Pb. The ranges of metal concentrations in soils from metal-processing areas are as follows: 1665–13,800 mg/kg Zn; 72–2480 mg/kg Pb; 6–270 mg/kg Cd (Kabata-Pendias and Pendias, 1992).

The recent investigations of the heavy metal contents in the soils in the vicinity of a Zn–Pb mining and smelting complex in Bukowno have shown high concentrations of Zn, Pb and Cd: 234–12,400; 42–3570; 25–133 mg/kg, respectively (Verner *et al.*, 1994).

Mining activity yields several tens of millions of tonnes of wastes every year (Fig. 2). Two types of waste can be identified: spoils and cleaning wastes. It is estimated that production of 1 tonne of hard coal is accompanied by an additional 0.4 tonnes of various wastes, of which 46% remains underground and the remaining 54% (cleaning wastes) is dumped on the surface. Petrographically, the wastes are Carboniferous sediments containing variable amounts of heavy metal sulphides. Ashes and slags from power stations constitute a relatively small percentage of wastes (2–3%).

In the USCB about 140 waste dumps have been located, some of them outside the mining areas. Although land rehabilitation has been completed for most of the dumps, pollution of ground waters due to the leaching of soluble components by percolating meteoric waters still continues. Thus, despite their age, the dumps are classified as potential pollution sources for surface and groundwater.

In 1989 industrial plants generated about 170 million tonnes of waste, of which 43% — including 2–3 million tonnes of hazardous waste — was dumped at waste disposal sites. Almost half of the total industrial wastes at waste disposal sites in Poland (i.e. 1500–2500 million tonnes) is accumulated in the small area of Katowice province (Fig. 2).

One of the most dangerous environmental hazards caused by waste dumps is the pollution of surface water and groundwater by soluble substances leached from the wastes (Fig. 3). This is supported by studies of pore solutions derived from the Carboniferous spoils and of waters seeping from the dumps (Twardowska *et al.*, 1988). The results proved the presence of solutions highly contaminated with the products of sulphide weathering/decomposition throughout typical spoil dumps of various ages. In solutions collected from beneath 7–15-a-old spoils concentrations of SO_4^{2-} exceeded 10–80 times the standards for potable waters. Formation of especially dangerous, highly acidic waters (pH < 4) appears to be a common effect. The leaching time of sulphides from fine-grained, oxygenated spoils is estimated to be about 11 a, on average. In mine stone dumps this process is much slower owing to the coarse grain size fraction of the

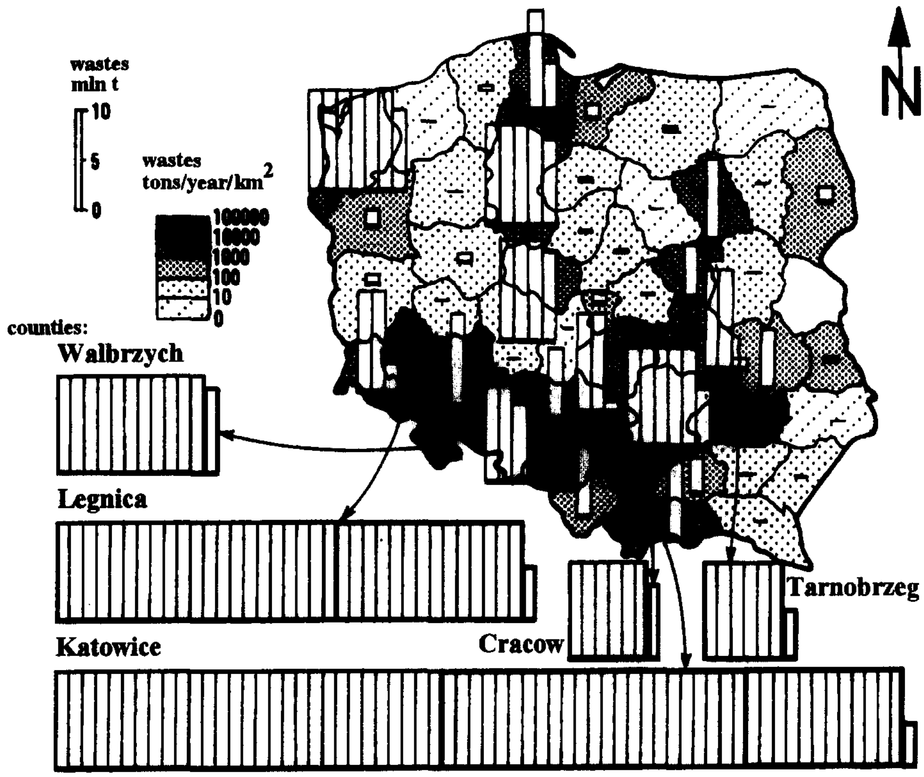

Fig. 2. Accumulated industrial wastes by counties in Poland (GUS, 1991).

spoils and limited volumes of meteoric waters available. However, some spoil dumps can be persistent sources of contamination with products of sulphide oxidation, which may affect the environment for decades.

The metals industry also releases noxious gases: S and N oxides, F and others (Table 4). In the neighbourhood of the Miasteczko Śląskie Zn–Pb smelter, forest and other vegetation have been almost completely destroyed.

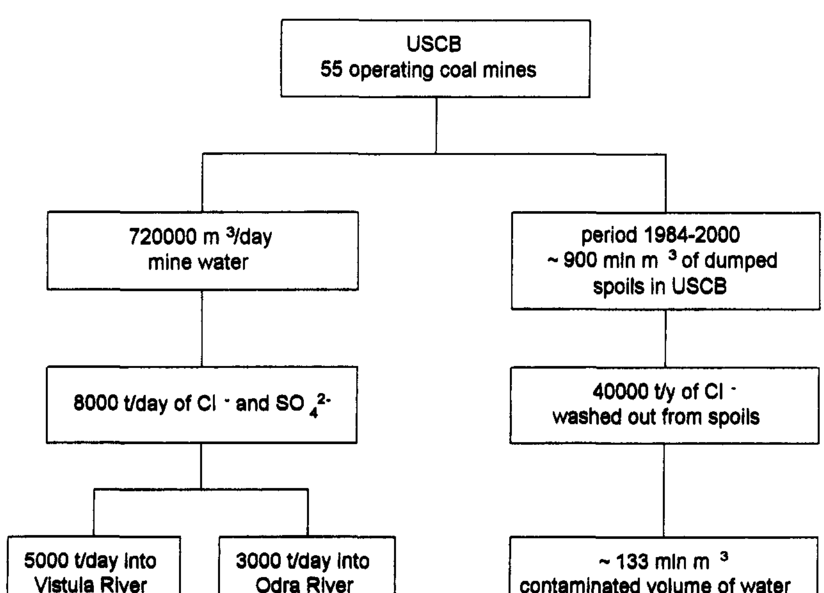

Fig. 3. Water pollution in the Upper Silesia Region (USCB).

Table 4. Atmosphere emissions in the Upper Silesia Region in 1990

Type of pollutant	Amount (thousand tonnes)
SO_2	900
NO_X	250
Particulates	500

LOWER SILESIAN REGION

Of the mineral commodities that have been exploited for long periods of time in the Lower Silesia Region (LSR), the most important are: (1) hard coal in the Wałbrzych and Nowa Ruda areas (Lower Silesian Coal Basin, LSCB, 4 hard coal mines); (2) brown coal in the Turoszów area; (3) Cu ores (Lubin Copper District, LCD).

In the LSCB the total quantity of dissolved solids released into the surficial flows from the mine waters reached 180 tonnes per day in 1989. The mine waters are of the polyionic, SO_4^{2-}–HCO_3–Mg–Ca–Na type with local admixture of Cl^-. The high concentrations of SO_4^{2-} in ground waters result from infiltration of meteoric waters containing pollutants leached from numerous spoil dumps and also result from prolonged residence of groundwater in abandoned workings. Potential pollution sources of waters infiltrating the LSCB mines are 17 dumps collecting various types of spoils of different ages (Wilk *et al.*, 1990).

The total area affected by damage from brown-coal open-pit exploitation is about 60,000 ha and is the largest area affected by open-pit mining in Poland. Besides the Turoszów brown-coal mining and power station industry district, 2 others are presently in operation in Poland: Belchatów and Mid-Poland (Konin, Turek). Deleterious environmental effects caused by brown-coal open-pit mining are irreversible and affect waste areas (Guziel, 1988).

Apart from geomechanical processes (subsidence, slamps, landslides, erosion) which lead to the complete destruction of soils and irreversible changes in the landscape, the drainage of open pits influences hydrological systems. Both surficial flows and underground (shallow and deep) reservoirs are affected by (1) formation of depression cones which results in lowering of shallow and deep water tables, and (2) changes in watersheds and divides. Dewatering of open pits results in a deficiency of water in farm lands and forests districts. Mine waters from brown-coal pits are generally uncontaminated and commonly meet the standards for potable waters.

Environmental problems caused by the brown-coal mining industry are linked to those created by adjacent power stations, which utilize most of the output. Combustion of brown-coal results in mass emission of gases (CO_2, SO_2, N oxides) and dusts (composed mostly of Al_2O_3 and Fe_2O_3) with admixture of heavy metals (Zn, Pb, Cd). Brown coals mined in Poland show S concentrations of 0.5–1.1%. As this S is bonded to organic matter its removal before combustion is impossible. Huge amounts of SO_2 are thus released to the atmosphere, giving rise to "acid rain" and, consequently, to the degradation of soils by acidification.

In a small area at the Polish–German–Czech border is the largest basin for brown-coal extraction, with annual production of about 200 million tonnes (of which about 20 million tonnes are extracted within the Polish part). This represents about 25% of total brown-coal extraction in Europe. It is used within the same area in 12 big power stations (including one in Poland at Turów). The SO_2 emission in this area, called "the Black Triangle", is very high accounting for 20% of the total European emission of this compound. This area has the largest S deposition rate in Central Europe (>5000 mg/m^2/a), and the resulting formation of H_2SO_4 in the atmosphere causes rain water to have a pH < 3. This has resulted in the complete destruction of forests in the Izerskie Mountains (EMEP, 1992; Nowicki, 1993).

In the Lubin Copper District (LCD) mine and industrial waters are purified before being discharged to the Odra River which prevents deterioration of the quality class. Periodically, during high river flows waters of increased TDS (14.5 g/dm^3) are released at rates less than 70 m^3/min. The load supplied to the Odra River in 1984 included 66,000 tonnes of Cl^-, 21,000 tonnes of SO_4^{2-}, 3.6 tonnes Cu, 3.0 tonnes Pb and 3.2 tonnes Zn (Wilk *et al.*, 1990).

In the LCD the 4 metal ore mines produced 400,000 tonnes/a of metals, and created about 30 million tonnes/a of wastes, they are accompanied by processing plants and 4 smelters which contribute significantly to the overall pollution (about 200,000 m^3 accumulated wastes, and 2650 ha sedimentation reservoirs).

The soils in the vicinity of Cu smelters are rich in heavy metals. The concentration of Cu in the surface soil may exceed 7000 mg/kg, and the Pb content is almost 2000 mg/kg (Helios Rybicka *et al.*, 1994).

The Polish base metal ores are relatively low-grade. Hence, wastes (mostly tailings) constitute 90–98% of the total output. The volume of wastes produced by the base metal industry is second only to the coal (and power) industry. The wastes are deposited in dumps and tailing ponds. The latter in particular pose environmental hazards owing to the rise of the ground water table in adjacent areas (in some cases up to several meters). This results in excessive moisture in soils and the formation of marshes and ponds.

It must be emphasized that waters percolating from tailing ponds are highly polluted and, depending on the contaminants, that they contain, they may severely degrade the ground water and soils. In the LCD waters in tailing ponds contain large amounts of Cu, Zn, Pb and SO_4^{2-}, Cl^- as well as organic compounds. Groundwater contaminated with those pollutants is unfit to drink and may be harmful for vegetation as well. The spread of contaminants around huge tailing ponds in the LCD (Gilów and Zelazny Most) has become a serious problem as pollution has affected an area of about 12 km^2.

CRACOW URBAN–INDUSTRIAL AREA

Cracow is a large metropolitan area with a number of polluting industrial plants, of which the most dangerous are: a metallurgical factory; an Al plant; coal power and heating stations. These sources of gases and dusts are principally responsible for the occurrence of smog in Cracow city. More than 47% of the area of Cracow province is subject to threatened degradation (Michna, 1991).

Beside the steelworks (HTS) and power and heating stations in Cracow, the major sources of air pollution are individual coal-fired stoves and local boiler houses. The annual mean concentrations of suspended particulates, SO_2 and F in the air in the years 1981–1991 were very high (55–95, 60–105 and 1–4 $\mu g/m^3$, respectively), although they have been decreasing since 1988. The highest emission of particulates (> 140 thousand tonnes/a), of which the steelworks contribution makes up about 50% (Rymont, 1992), was observed in 1985 (Table 5),

Significant contamination with Cd, Cr, Ni and Pb has been detected in allotment gardens in the Cracow agglomeration: 18, 86, 64 and 226 mg/kg, respectively (Grodzińska *et al.*, 1987).

In the Cracow region approximately 3,100,000 tonnes of industrial wastes were generated in 1991; only about 2,200,000 tonnes were utilized. The rest were disposed of in dumps, which take up a total area of about 438 ha. The major wastes were metallurgical wastes, about 1,400,000 tonnes from the steelworks (i.e. slags and ash), and about 800,000 tonnes from thermal power stations (Rymont, 1992).

The main river of the Cracow region is the Vistula. The river water, which makes up 80% of the region's water resources, does not conform to any of the quality classes. Owing to the high salinity of the Vistula River caused by the Silesian mines, water which reaches Cracow province is already too contaminated to be used as drinking water or for industrial and agricultural purposes. Because of the local industrial activities the Vistula River tributaries in the Cracow area are also heavily polluted (Helios Rybicka, 1993).

Table 5. Emission and the concentration of metals in dusts in Cracow region

Metal	Max. conc. (%) of metal in dust	Emission (t/a)
Pb	1	130
Zn	15	470
Cd	0.5	3
Fe	70	14,000

SUMMARY

The mining and metallurgical industry has caused a great deal of devastation of the natural environment in Poland. The most endangered surficial waters are the upper courses of both the Vistula (and its Upper Silesian tributaries) and the Odra Rivers, where the increase of contaminants (especially in recent years) must be regarded as alarming. Most of the polluting substances originate from highly mineralized waters raised from the Upper Silesian coal mines.

Both the Vistula and Odra Rivers are important sources of waters for domestic and industrial purposes. The Vistula River supplies about 0.5 billion m^3/a of water along the 550-km upper and middle courses, which account for nearly 35% of the total water consumption in Poland. The Odra River yields an additional 300 million m^3/a downstream to the mouth of the Nysa Luzycka River (i.e. about 2% of total consumption). Progressive pollution of both rivers (and their tributaries) is a real peril and may lead to an ecological catastrophe.

About 50% of the river waters included in the Polish water quality classification do not even meet the standards for quality class III. The total load of domestic and industrial sewage transported to the Baltic Sea by rivers from Polish drainage basin includes, among others, the substances listed in Table 6.

Other important sources of pollution are wastes produced by industry. Of the approximately 128 million tonnes of industrial wastes generated in 1991, more than 50% were generated by the fuel and energy industry, which, together with the non-ferrous and metallurgical industry wastes, yielded about 83% of the total amount of wastes in Poland. This material consisted of mine wastes (43%), postflotation wastes and washing wastes from coal, barite, S, Cu and Zn–Pb industries (29%), and fly ash and slags from heating and electro-power stations and mineral dusts (11%). About 50% of the wastes have been generated in the Katowice district and about 16% in the Legnica district (Piotrowska, 1993).

Hard-coal mining yields the largest volume of wastes. It is estimated that in the period 1984–2000 about 900 million m^3 of spoils will have been dumped

Table 6. Average total quantities (t/a) of main pollutants transported to the Baltic Sea by rivers from Polish drainage basins estimated for 1988–1989 (data from Main Statistical Office, GUS, 1991)

P	N	Zn	Pb	Cu	Cd	Hg	Cr	Ni
15,584	207,326	3331	448	515	40	90	443	284

in the USCB alone (Witczak and Szczepańska, 1987). The annual load of chlorides in these spoils is as high as 40,000 tonnes. Such a volume is sufficient to contaminate 133 million m^3 of water at concentrations exceeding the quality standards.

Most of the pollutants originate from the weathering of sulphides contained in spoils, specifically from their oxidation to sulphates and/or sulphuric acid. Under oxidising conditions the decomposition of sulphides may yield 450,000 tonnes of sulphates per year (Twardowska *et al.*, 1988) — a volume large enough to pollute 2300 million m^3 of water (i.e. twice the annual consumption of the whole Katowice province) at levels exceeding quality standards. Many dumps may produce highly acidic waters (pH < 4).

A combination of hydrological, chemical and/or geochemical investigations can provide much additional valuable information on concentrations of pollutants, e.g. trace metals, for the estimation of the environmental impact of mining and processing activities on rivers, groundwater and soils.

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