Impact of Mine Waters on River Water Quality in the Upper Silesian Coal Basin

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ABSTRACT

The Upper Silesian Coal Basin (USCB) is located within the Vistula and Oder basins in the southern part of Poland. The coal seams in the USCB are exploited by the underground mining of average depth of 650 m, up to 1200 m. Studies on hydrogeochemical environment showed a normal vertical and horizontal hydrogeochemical zonation in the whole of USCB. As a general trend the level of groundwater mineralization increases with depth and is independent of the age of the strata. Thus the coal mines pump groundwaters of different mineralization which varies from 0.2 to 372.0 g/dm^3. The natural inflow of groundwaters into the mines equals 630 m^3/min. There is a high degree of diversification of mine waters total dissolved solids (TDS), pumped out from the mines into the rivers. Mean mineralization of these waters is about 11 g/dm^3. The discharge of the saline mine waters with the content of 7069 Mg/d of Cl^- and SO_4^{2-} has resulted in degradation of the river water quality. About 66% of the overall length of the rivers in USCB carry excessively polluted water which is unsuitable for any use and 91% of the surface water resources belong to the out-of-class purity class.

INTRODUCTION

The development of coal mining within the USCB is limited by (among many others) the fines paid for discharging the saline waters to the rivers. Such discharging causes degradation of waters' quality and makes them impossible to use.

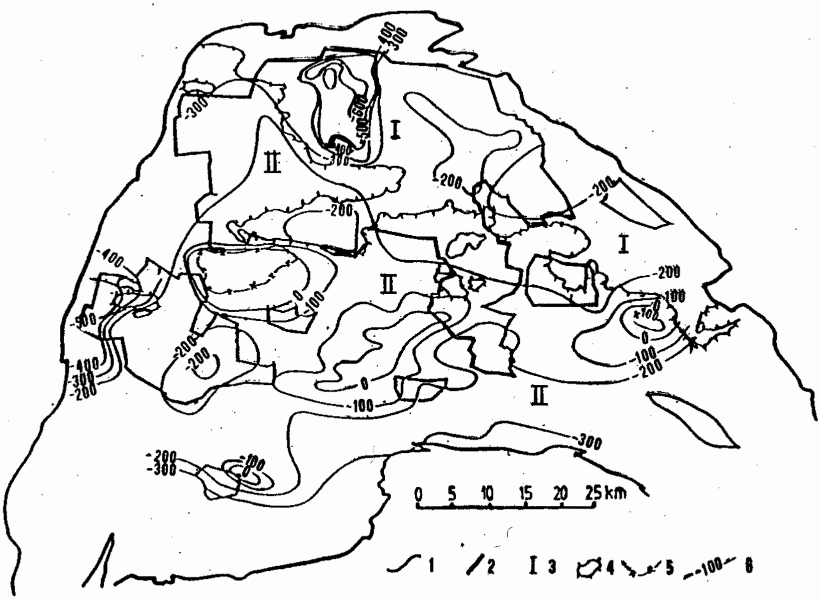
In the present paper the chemical composition of mine waters, explanation of its differentiation and evaluation of quantity of mine waters discharged to the rivers as well as salinity of these waters and their influence on changes of rivers water purity classes will be presented.

THE OUTLINE OF GEOLOGICAL STRUCTURE AND HYDROGEOLOGY

The USCB, 7500 sq. km. in area (including 5500 sq. km. in Poland) is situated in the Upper Silesian Variscean intermontana depression.

The thickness of the molasse sediments of the productive Upper Carboniferous approximates 8200 m in depression.

Coal-bearing Carboniferous rocks occur beneath the Quaternary and Mesozoic formations in the NE part of the basin and clayly Tertiary series in the southern and north-western parts of it (Figure 1). In the Tertiary formation the salt deposits occur locally. The Tertiary strata reach up to 1000 m. in thickness in the Alpine depressiary structures.



1 - extension of the Upper Silesian Coal Basin (USCB); 2 - extension of the coal fields; 3 - hydrogeological regions; 4 - extension of the isolating series of the Tertiary; 5 - extension of the Tertiary salt deposits; 6 - isolines of absolute height of groundwaters surface with TDS 35 g/dm^3.

Figure 1. Sketch map of the surface of brines (USCB)

Taking into consideration the recharge conditions of the Carboniferous water bearing sandstones two hydrogeological regions (I, II) can be distinguished in the USCB. Their boundaries are delineated by the extend of the isolating series of the Tertiary clayly formations (Figure 1).

Pumping by the coal mines in the USCB of about 1 x 10^6 m^3/day caused drainage of Carboniferous water bearing rocks. Triassic and Quaternary rocks are drained too, but only in the first hydrogeological region.

At present the mean drainage depth due to mining amounts to about 650 m while the maximum is 1200 m.

CHEMISTRY OF GROUNDWATERS

Groundwaters occurring within the USCB appear differentiated in chemical composition and total mineralization [1,2]. Fresh waters occur in covering Quaternary, Jurassic and Triassic formations as well as in the outcrop areas of the Carboniferous formation.

Groundwaters in the Tertiary formation are characterized by mineralization ranging from 0.5 to 220 g/dm^3 and primarily they represent the Cl-Na type.

In the coal bearing Carboniferous formation the total mineralization of ground waters ranges from 0.5 to 372 g/dm^3.

It has been found that the mineralization of the groundwaters increases with depth independently of the age of the rocks. This general trend is disturbed by the phenomenon of hydrochemical anomalies. These phenomena have been observed among others in the uppermost links of the Carboniferous strata within the Carpathian Fordeep, in the vicinity of the Tertiary salt deposits in the Zawada Graben, as well as along some regional fault zones. The anthropogenetic anomalies have been caused by mining activity. [2,8].

Fresh waters (TDS < 1) are mainly of hydrochemical types: HCO_3 - Ca, HCO_3 - SO_4 - Ca, SO_4 - HCO_3 - Ca - Mg. Their hydrochemical coefficients have the following values: r(Na/Cl) > 1, r(Ca/Mg) > 1, r(100 x SO_4/Cl) > 1. Nitrogen predominates in gaseous composition of these waters. The waters described occur in the oxidation zone.

Saline waters with TDS < 35 g/dm^3, belong to multi ions and Cl-Na hydrochemical types. The following values of coefficients are typical for them: r(Na/Cl) = 1.3-0.87 and r(100 x SO_4/Cl) from 0.07 to 9.1. In the upper part of occurrence of these groundwaters in gaseous composition nitrogen is predominant, while the lower one is dominated by methane. This evidence allows one to assume that saline waters may occur in the oxidation zone as well as in the reduction zones.

Brackish mine waters from the oxidation zone are enriched with sulphate ions in the mining excavations, due to the oxidation processes of pyrites and sulphur from the coal seams.

Brines of TDS above 35 g/dm^3 belong to the hydrochemical Cl-Na and Cl-Na-Ca types of waters. There are the following values of hydrochemical coefficients in these waters: r(Na/Cl)= 0.72-0.96, and r(100 x SO_4/Cl) < 1. They occur only in the reduction zone.

Highly mineralized waters of isolated structures represent the buried brines of the Cl-Na-Ca types. Methane from degasation of coal seams predominates in gaseous composition of those brines.

The studies on the hydrogeochemical environment demonstrate a vertical succession of hydrochemical zones in the Carboniferous formation in the area of the USCB.

Three hydrochemical zones have been distinguished: the zone of infiltration waters, the intermediate zone of mixed waters and the lower zone of the buried brines which have been discussed in the papers of some other authors [1 - 6].

Occurrence of these zones can be defined on the basis of the values of the hydrochemical coefficients and groundwater mineralization [7].

The thickness of the zone of infiltration waters approximates the depth up to c. 300 m. in the first hydrogeological region and up to 80 m. in the second one.

An intermediate flow system is developed within the zone of the hindered replacement and mixing of the infiltrating waters, of the Quarternary and Tertiary age, during the last infiltration period, with buried brines. It occurs within the Tertiary and Carboniferous formations occupied by brackish saline waters and brines. Mixing processes are increased in this zone due to mining activity.

The lower boundary of the intermediate zone of mixed waters in the first hydrogeological region occurs at the depth of 450 - 600 m, maximum at 800 m. The thickness of the zone is about 200 - 300 m. In the second hydrogeological region the lower boundary of this zone lies at the depth of about 400 m, while its thickness reaches about 320 m.

The general trend of deepening and enlargement of the infiltration and intermediate zones has been observed in the last 40 years due to deeper exploitation and intensive mining drainage [2,5,8,9].

The zone of buried brines underlies the intermediate zone. Hydrochemical investigations have shown that the roof of this zone is at a depth of 450 to 850 m (Figure 1). This fact is connected with variability of geological conditions and mining activity within the separate geological structures of the USCB.

MINE WATERS

Considering the resources and the output of the hard coal (c. 150 mln tons/year) the USCB is now one of the biggest coal basins in the world. Mining activities have been run here since the second half of the 18th century.

The coal fields cover the area of c.2000 sq. km. The depth of mining varies from 400 to 1200 m. (Figure 1). The majority of coal mines are disposed in the area of shallow occurring productive Carboniferous in the north-eastern part of the USCB. The area of coal deposits occurring deeper and overlaid by clayly Tertiary rocks is now under intensive mining development.

It should be stressed that the mean depth of mining as well as mean mineralization of mine waters is increasing distinctly in connection with construction of new deeper exploitation levels in the old mines and building of new deep mines in the southern part of the USCB. For example in 1957 the mean depth of mining amounted to 200 to 400 m [10] while in 1989 it was - 650 m [5].

The increase in the mine water mineralization with depth independently of the age of the strata has been noted [1].

Geological structure, recharge conditions of the Carboniferous water bearing sandstones and the mining activities influenced the hydrochemical differentiation of the mine waters between the 1st and the 2nd hydrogeological region. Therefore the coal mines groundwaters have different mineralization which varies from 0.2 to 372.0 g/dm^3. The natural inflow of groundwater into the mines equals 630 m^3/min (1992). There is a high degree of diversification of mine waters pumped out from the mines.

It should be stressed that mean mineralization of mine waters increases distinctly due to construction of the new levels in the old mines and building new mines in the southern part of the USCB. It has increased from 4.9 g/dm^3 in 1970 [11] to 10.9 g/dm^3 in 1984 [5], while the volume of the water pumped by the coal mines increased only by 10%. This shows the growing inflow of highly mineralized ground water into the mines in the last period.

The maximal inflow of the groundwaters into the particular mines situated in the first hydrogeological region that is in the north eastern part of the USCB varies from 0.9 to 73 m^3/min. The mean mineralization of the pumped waters is low and does not exceed several g/dm^3.

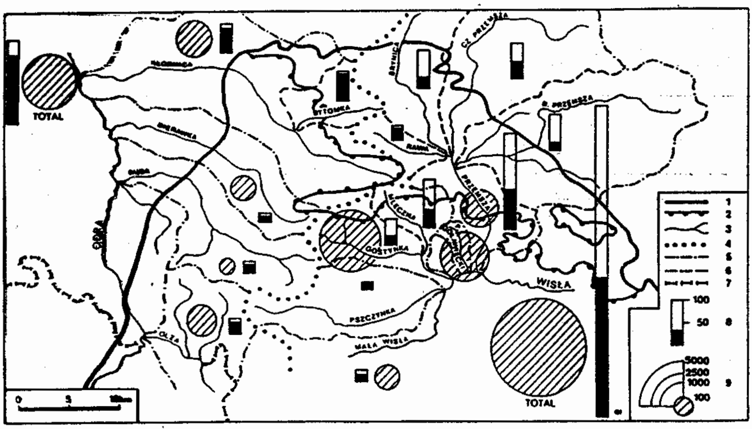
The mines which carry out the exploitation in the second hydrogeological region usually have inflows of about 6.3 to 10.4 m^3/min. They pump ground waters mainly from the static resources. The mean mineralization of these waters varies from 12.0 to 102.0 g/dm^3. The most mineralized waters are pumped by the following mines: "Piast", "Ziemowit", "Czeczot". The total amount of ground waters discharged by these mines amounts to 67.0 m^3/min and their $Cl+SO_4$ ions load in waters equals about 2870 Mg/d.(Figure 2).

IMPACT OF THE MINE WATERS ON THE RIVER WATERS QUALITY

The USCB is located within the Vistula and Oder basins (Figure 2). The Silesian Upland, on which most of Katowice province is situated, contains most of the source areas of rivers which mouth into the Vistula and Oder rivers. These tributaries are short and have small flows. The total length of streams and rivers within the Vistula river basin equals 1226.5 km., and within the Oder river basin 916.7 km. An average outflow of water from the province is estimated between 5.4 and 5.6 x 10^6 m^3/d.

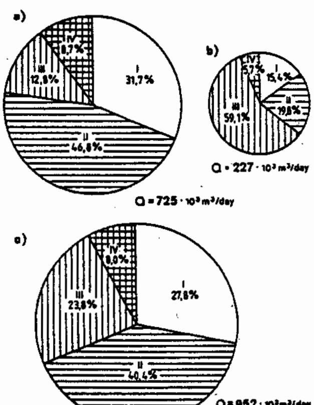
In recent years, communal and industrial use of water has reached about 3.0 x 10^6 m^3/d. About 2.3 x 10^6 m^3 of this was discharged into the rivers as effluents from which 1.5 x 10^6 m^3 was treated. The remaining 0.8 x 10^6 m^3/d was dumped into the surface water system without any treatment. Industrial effluents are dominating here - 1.3 x 10^6 m^3/d, from which 0.6 x 10^6 are mine waters that is 26% of the total waste waters dumped into the rivers.

Almost half of the rivers in the province have excessive salt content resulting from discharging saline mine waters into the surface waters [5, 12].



1 - extension of the USCB; 2 - extent of isolating series of Tertiary strata; 3 - rivers and streams; 4 - watershed between the Odra and Vistula rivers; 5 - boundaries of the second range river drainage basin; 6 - boundaries of the third range river drainage basin; 7 - state boundaries; 8 - natural inflow of groundwaters to the mines in thousands m^3/d: a - fresh waters (TDS < 1 g/dm^3), b - saline water and brines; 9 - amount of $Cl^- + SO_4^{2-}$ load discharged from mines to the rivers in t/d.

Figure 2. Amount of mine waters pumped out and their influence on water-course salinity (USCB, 1991)



a - mines within the Vistula drainage basin; b - mines within the Odra drainage basin; c - in general within the USCB.

Figure 3. Contribution of groundwaters of particular groups of mineralization in total inflow to the coal mines, USCB (after Rogoz (17))

Discharge of municipal waste waters and saline mine waters has caused degradation of the quality of the river waters. About 66% of the overall length of the rivers of the Katowice province carry excessively polluted water unsuitable for any use [13]. In the Upper Silesia industrial region about 90% of the river courses are extremely polluted. The percentage breakdown of various classes of water purity is shown on Table 1 together with the corresponding amounts of the surface resources.

Table 1. Purity classes in river waters of Katowice province.
(after Czaja & Jankowski [12]).

Purity class	River length studied		Resources	
	km	%	m^3	%
1st	35	2.5	67,391	1.24
2nd	208	14.8	290,529	5.33
3rd	201	14.3	121,230	2.22
out of class	961	68.4	4,873,533	91.27
TOTAL	1,405	100.0	5,325,683	100.0

Mine waters are discharged to the water courses by 66 coal mines. In 1992 the total amount of waters pumped out from the mines amounted to 905,000 m^3/d, 682,000 came from mines localized in the Vistula river basin and 223,000 from the mines in the Oder` river basin (Figures 2 and 3). Direct discharge of the mine waters into the rivers equaled 575,000 m^3/d. Mean mineralization of the mine waters inflows to the particular water courses ranges from 1.7 to 31.5 g/dm^3.

Mine waters pumped from the mines in the USCB belong mainly to the groups I and II (70%). Mine waters pumped within the Vistula catchment area belong mainly to the groups I and II (80%) while those in the Oder catchment area - to the groups III and IV (80%) (Figure 1). Mine groundwaters classification is given below.

The mine waters discharged into the rivers contain 7069 Mg/d. of chlorides (92%) and sulphates [13]. The main load of the $Cl+SO_4$ ions, equals 5115.9 Mg/d and comes from the mines within the Vistula basin.

According to the mining classification the mine waters are divided into four groups:

I. Waters with a TDS below 1.0 g/dm^3 and Cl^- and SO_4^{2-} concentration smaller than 0.6 g/dm^3; these waters are good for drinking mainly after utilization;

II. Waters with a TDS from 1 to 3 g/dm^3 and Cl^- and SO_4^{2-} concentration from 0.6 to 1.8 g/dm^3; these waters can be used for industrial purposes;

III. Saline waters with a TDS from 3 to 70 g/dm^3 and Cl^- and SO_4^{2-} concentration from 1.8 to 42.0 g/dm^3; they are usually discharged to the rivers;

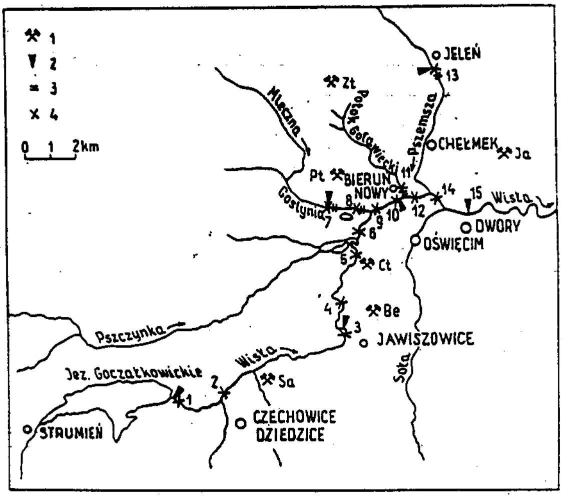
IV. Brines with a TDS above 70 g/dm^3 and Cl-SO_4 ions concentration above 42.0 g/dm^3; such waters constitute a grave danger to the surface waters because of their high mineralization but they can be used for the salt production and industrially useful waters.

Concentration of Cl+SO_4 ions in the river stream waters within the USCB are shown on the Table 2.

Table 2. Concentration of the Cl and SO_4 ions in the river waters. (after Nalecki [16])

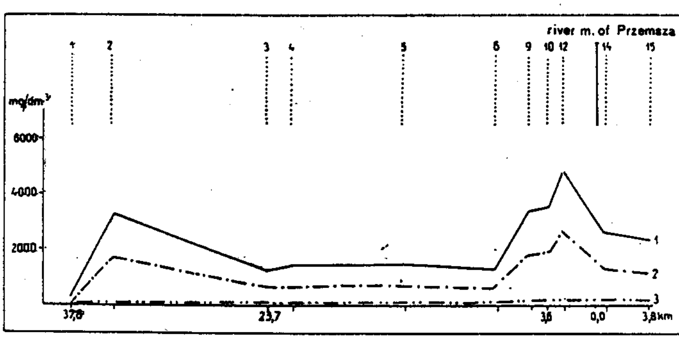
Name of the river	Cl^+ SO_4 ions load g/dm^3
The Vistula River Basin	
Gostynia	10.4
Mleczna	9.4
Szarlejka	2.0
Czarna Przemsza	1.7
Brynica	0.9
Przemsza	0.6
Rawa	0.7
Bobrek	0.4
The Oder River Basin	
Klodnica	2.1
Bytomka	1.4
Olza	1.0
Bierawka	1.0
Ruda	0.7

The authors of this paper have done field investigations of the Upper Vistula River basin in order to determine the influence of the discharging of the mine waters on the surface waters regime. The investigations were carried out in the section between Goczalkowice reservoir and the Przemsza river (Figure 4). These rivers are the main collectors of the discharged mine waters. The investigations dealt with seasonal measurements of the stream flows and chemical analysis of the stream and river waters [14,15].



1 - underground coal mines: Be-Brzeszcze, Ct-Czeczot, Ja-Janina, Pt-Piast, Sa-Silesia, Zt-Ziemowit; 2 - water level gauge cross sections; 3 - flow rate measurement sites; 4 - sampling sites of waters.

Figure 4. Location map - drainage basin of Upper Vistula river.



1 - TDS of waters mg/dm^3; 2 - content of Cl ions in mg/md^3; 3 - content of SO_4 ions in mg/dm^3

Figure 5. Hydrochemical cross section of the Upper Vistula river

The total volume of the waters being pumped from the coal mines in the Upper Vistula basin amounts to about 682000 m^3/day. These waters show a high degree of diversification of mineralization. About 41% of them have TDS below 1.5 g/dm^3, while 58% have the content of TDS equalling 1.5 to 70.0 g/dm^3 and about 1.8% have TDS above 70 g/dm^3.

The authors have stated that the hydrogeological regime of the Upper Vistula river and its investigated tributaries has been co-created mainly by the discharged mine waters. This fact has contributed to the disturbance of the natural regime of the streams and rivers.

The contribution of the mine waters discharged into the Upper Vistula river has been changed from 14 to 35% of the total winter and spring flow at the Dwory water-level gauge (Figures 4 and 5).

The mine waters discharged to the Upper Vistula River have influenced vitally the change of mineralization and chemistry of the river waters (Figures 4 and 5). The Vistula river waters near Goczalkowice water-level gauge, i.e. before collecting the mine outflows, are characteristed by mineralization of about 0.3 g/dm^3 and by the hydrochemical type of HCO_3 -SO_4-Ca. The Vistula river waters at the Bierun Nowy and Dwory water-level gauges, i.e. after inflow of the mine waters, have the following mineralizations: 3.3 - 3.5 g/dm^3 and 2.4 - 3.1 g/dm^3 respectively. These waters are of the Cl-Na type. TDS of the river waters depends in 80% on the mine waters inflows.

The pollution of the Vistula river waters between Goczalkowice and the Dwory water-level gauge has eliminated the possibility of utilizing them as drinking waters and even as industrial waters. The investigations have shown that the mine waters discharge into the rivers has caused multiple - overnormative increase of salt load changes in the rivers. Because of the high level of water pollution only slight dynamics of the salt load changes can be observed. It concerns mainly the Przemsza and the Gostynia rivers where the seasonal differentiation of the salt loads does not exceed 5 - 8%.

CONCLUSIONS

The groundwater occuring in the USCB appears differentiated in chemical composition and total mineralization. A general tendency of groundwater TDS increasing with depth independently of the age of formations has been found. Therefore, the coal mines groundwater has different chemistry with TDS from 0.2 to 372 g/dm^3. There occurs a high degree of diversification of TDS content in the mine waters pumped from the mines into the rivers (2 - 102 g/dm^3). It depends on geological structure of the coal fields and depth of mining.

Direct discharge of the saline mine waters in amount of 575,000 m^3/d. has brought about the degradation of the river water quality in the USCB. About 91% of the river water resources show the out-of-class purity.

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