Groundwater Quality Degradation in the Area of Abandoned Zn-Pb Ore Mines (Bytom Syncline - Southern Poland)

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ABSTRACT

The Bytom Triassic fissured-karstic groundwater basin is situated in the central part of the Upper Silesian agglomeration. This is an exceptional area, where the natural environment undergoes the long-lasting intensive and multi-level degradation associated with the devastated surface of the ground (the surface falls, numerous wastes dumps), the Zn-Pb ore mining (in the Triassic formations), as well as the hard coal mining (in the situated lower Carboniferous formations).

Special attention has been paid to the negative influence of the Zn-Pb ore exploitation on the groundwaters. The exploitation in question has lasted for over 450 years and has led to the unparalleled extreme perforation of the massif and the creation of the vast (over 100 sqkm), regional cone of depression in the reach of which the lowering of the groundwater table ranges from 30 to 100m.

Degradation of the groundwater quality has been discovered on the entire area of the basin, although the highest intensity can be observed in the reach of the old workings of the Zn Pb ore mines, where the groundwaters contain exceptional concentrations of SO_4^{2-} (up to 1508 mg/dm^3), Cl^- (up to 510 mg/dm^3), Na^+ (up to 316 mg/dm^3), Zn^{2+} (up to 15 mg/dm^3). This regional hydrochemical anomaly has been stimulated hydrodynamically. As a result of the long-drawn intensive drainage and the extention of the thickness of the unsaturated zone the processes of the oxidation of the sulphide ores have been intensified and large amounts of sulphates, easily soluble in the infiltraiting rain waters, have formed.

The more mineralized waters occur in the western part of the area, which is connected with the more sulphide character of the Zn-Pb deposits and the greater load of pollution migrating from the surface of the ground.

Taking into consideration the fact that the pumping of waters from the Triassic formations must not be suspended (due to the exploitation of hard coal conducted below) the authors maintain that the alleviation of the environmental threat of the pumped out contaminated groundwaters requires:

a) creating an effective, economic method of their utilization after their having been pumped out to the surface,

b) undertaking activities in the formation itself (eg. reduction of the thickness of the unsaturated zone by means of partial flooding of the old workings) and reduction, and consequently, elimination of the pollution infiltrating from the surface of the ground.

INTRODUCTION

The Upper Silesian agglomeration, being the area of the most intensive concentration of mining and other heavy industries, faces a major problem of the supply of high-quality drinking water for its inhabitants (c. 4 million people). The scarce surface water resources in this region are highly degraded. An important source of water are Triassic groundwater basins localized in the reach of the Cracow - Silesian monocline. Although they are resourceful, the quality of the water they contain undergoes gradual degradation due to the intensive anthropogenic activity mainly associated with the direct and indirect influence of both the working and abandoned Zn-Pb ores mines.

One of the most endangered and degraded areas of this kind is the Bytom groundwater basin where all the negative effects of excessive concentration of industry as well as the results of neglected environmental care are focused. Despite of the closing down of the Zn-Pb ores mines the direct influence on the groundwaters has not ceased.

GENERAL HYDROGEOLOGICAL CHARACTERISTICS OF THE BYTOM GROUNDWATER BASIN

The Bytom groundwater basin (Figure 1) is situated in the centre of the Upper Silesian agglomeration, the area of the greatest concentration of mining and heavy industries.

It is a narrow elongated tectonical depression of the approximately latitudinal run of 30 km. The groundwater basin in question has an area of 214 sq. km. and constitutes a closed hydrodynamic structure with tectonic-erosive and hydrodynamic borders. The groundwater basin is formed by limestones and dolomites of Lower and Middle Trias underlaid with sand-loam formations of Lower Trias. The Triassic formations lie discordantly on those of the Carboniferous period which build an analogous syncline structure (Figure 2).

In the profile of the Triasic carbonate formations two water-bearing horizons can be differentiated: the Muschelkalk horizon and the Rhoetian one. In the natural conditions they formed a single fissured-karstic groundwater complex called the Triassic carbonate series.

The thickness of the Triassic carbonate aquifer ranges from 20 to 100 m and its average transmissivity amounts to 24 m^2/h (1). The Bytom groundwater basin is generally open and supplied as a result of rainwater infiltration directly on the outcrops of the carbonate series or indirectly through the Quaternary overburden. The surface streams (river Brynica), the mine water sedimentation basins and the untight sewage system play the minor part.

The water-bearing horizon of the Muschelkalk has been drained by the Zn-Pb ore mines for the last hundred years. The lower water-bearing horizon of Rhoetian is exploited by the well and mining intakes as well as drained by the still lower excavations of the coalmines.

In the natural conditions, before starting the intensive drainage of the massif the groundwater table in the Triassic formations existed c.270 m above sea level. The contemporary groundwater table is situated c.170 m above sea level in the centre of the area, and c.240 m above sea level in its SE part. The regional cone of depression, with the centre

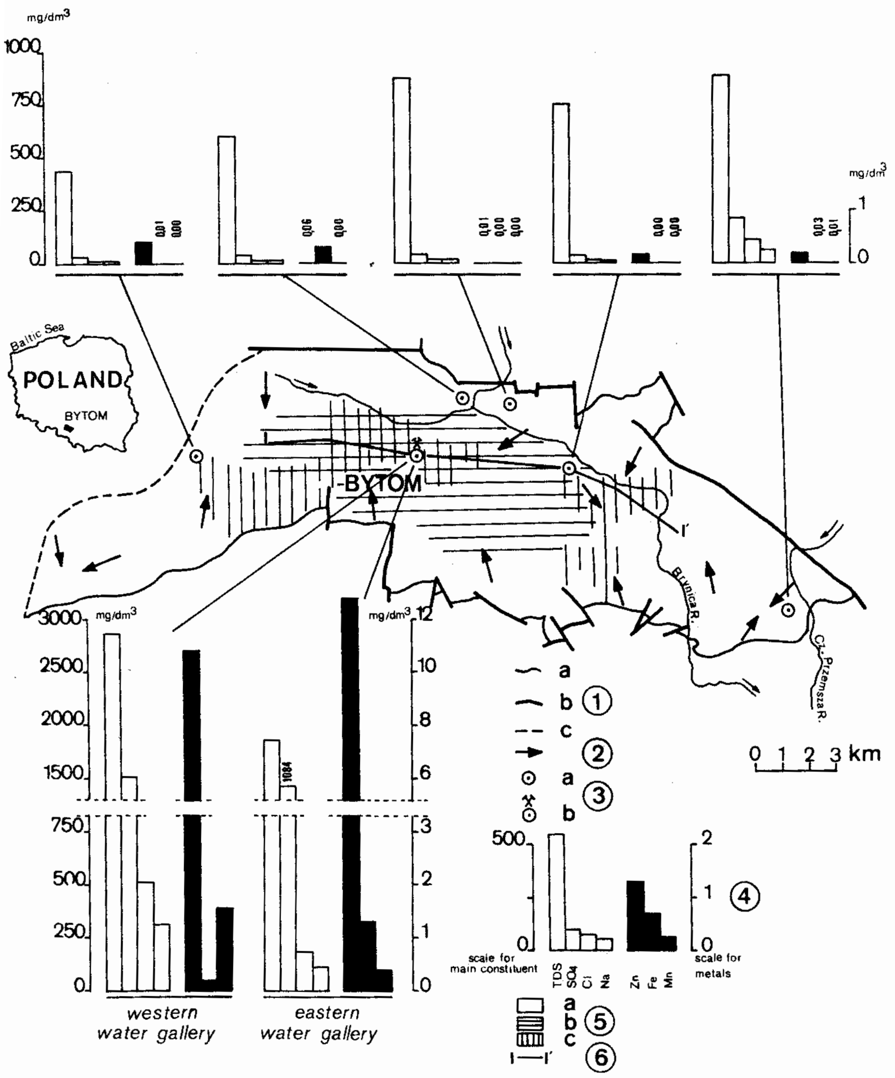

Figure 1. Hydrogeological sketch of the Bytom Basin.
1-boundaries of the basin: a-erosional, b-tectonic, c-hydrodynamic, 2-direction of the groundwater flow in the Triassic carbonate series, 3-water sampling site: a-wells, b-water galleries, 4-selected chemical parameters, 5-chemical types of water: a-HCO_3-SO_4, b-SO_4-HCO_3, SO_4, c-SO_4-Cl, Cl-SO_4, SO_4-HCO_3-Cl, Cl, 6-line of the hydrogeological section.

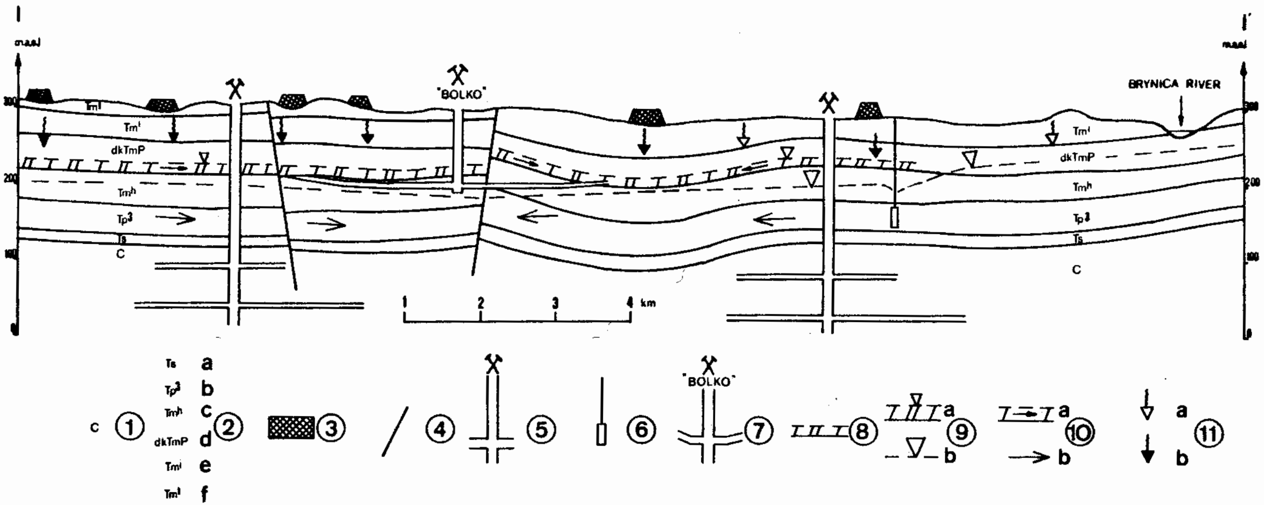

Figure 2. Hydrogeological cross-section I - I'.
1-Carboniferous, 2-Triassic: a-Bunter Sandstein, b-Roethian, c-Gogolińskie Beds, d-ore-bearing dolomite, e-Jemielnickie Beds (diplopore dolomite), f-Tarnowickie Beds, 3-coal mining disposal, 4-faults, 5-coal mining excavations: shafts, galleries, 6-wells, 7-water galleries near the "Bolko" ore shaft, 8-ore-mine workings (inactive), 9-groundwater pumping level in the Triassic carbonate series, present: a-Muschelkalk aquifer (ore-mine working), b-Roethian aquifer, 10-direction of the groundwater flow in the: a-ore-mine workings (Muschelkalk aquifer), b-Roethian aquifer, 11-water seepage: a-ordinary waters, b-polluted waters.

in the vicinity of the town Bytom, extends over c.50% of the area of the groundwater basin (Figure 1).

The total consumption of the water from the groundwater basin is estimated at the level of c. 3900 m^3/h. The sum of the estimated capacities of the wells situated on its area amounts to 2136m^3/h (2).The aquifer is resourceful; the modulus of its disposable resourses amounts to 7.64l/s/sq km (1).

POTENTIAL AND ACTUAL ANTHROPOGENIC ENDANGERING OF THE GROUNDWATERS

The area of the Bytom groundwater basin is exceptional; here the natural environment is subject to the sustained intensive multi-level degradation associated with the pollution of the air and of the surface waters, with the devastated surface of the ground, the Zn-Pb ore mining (in the Triassic formation) and the coal mining (in the formations of the Carboniferous period). This multi-level system of anthropogenic threat is shown in the simplified version on Figure 2.

The lack of isolation, the fissured-karstic type of the groundwater basin as well as its intensive perforation caused by the mining exploitation in association with extremely concentrated anthropogenic threat endanger the groundwater basin.

The pollution migrating from the surface of the ground is a considerable danger. It is connected with the extremely polluted atmosphere, contaminated surface waters, numerous wastes dumps as well as other local sources of contamination (eg. a filling station, fattening farms). The disasterous condition of the environment can be evidenced by the following data:

- the average year concentration of N_2O_5, phenol or cancerogenic benze-a-pyren in the air exceed the standards four times. Average year cadmium precipitation amounts to 12 $mg/m^2/year$ (1987) exceeding the standard four times as well;

- over 95 percent of the total length of river network is constituted by water beyond any recognised standards; actually they are industrial waste waters;

- on the area of the Bytom groundwater basin there are 125 operating and inactive wastes dumps ie. 82 industrial wastes dumps (half of which come from the coal mines and 21 from the Zn-Pb ore mines), there are 32 operating waste dumps presently.

The abandoned Zn-Pb ore mines are a very important factor that has its influence on the groundwaters. Exploitation of the Zn-Pb ores in the Bytom region was being carried out for over 450 years in the Muschelkalk formations, mostly in so called ore-bearing dolomites to the depth of c. 100 m. below ground level. The sulphide minerals are dominated by sphalerite (ZnS), marcasite and pyrite (FeS_2) as well as galena (PbS); among the oxygenic minerals smithsonite ($ZnCO_3$) is predominant (3) The deposit in question was rendered accessible by 19 vertical shafts and 2 drifts.

Depletion of the industrial resources of Zn-Pb deposits resulted in the gradual closing of the mines operating in this area in the period 1979-90. Since that time mining excavations, especially water galleries have acted as adrainage system for the discussed area. In the period 1945-89 the ore deposits were drained by 5 shafts with the amount of water pumped ranging from 22.0 - 56.3 m^3 per minute. Since 1991 after previous closing down of all the vertical workings "Bolko Shaft" has become the central and the only drainage shaft. Water from other workings is directed towards this shaft at a rate of 19-25 m^3 per minute.

The intensive long-drawn mining exploitation has left a number of excavations and resulted in lowering of the groundwater level from 30 m. in the SE part and 60-70 m, in the W part to 100 m, in the centre. As a consequence of this, a considerable extention of thickness of the unsaturated zone occured and the ore zones situated lower have shifted to the oxydation zone. The process of oxydation of the sulphides occuring in the entire zone, with the free oxygene intake, having caused the conversion to soluble sulphates.

The reaction of weathering of pyrite or marcasite can be an example of oxidation very common in the groundwater medium.(4)

$$4FeS_2 + 14H_2O + 15O_2 \dashrightarrow 4Fe(OH)_3 + 8H_2SO_4$$

Reactions of this kind enrich the groundwaters with a large amount of sulphates.

Under the discussed Triassic formation, in the Carboniferous period formation, the intensive exploitation of coal is conducted by 12 mines to the depth of 1100 m. below ground level. These mines posses a number of shafts traversing the Triassic formations. Some of them used to have or still posses direct connections with the excavations of the Zn-Pb ore mines.

The result of this intensive exploitation is the draining of the Carboniferous formation. Additional effects of this activity are the following: great quantity of wastes, salination of the surface streams and formation of surface falls (max.20 m). The deformation of the massif result in frequent damage to the water networks and sewage systems causing infiltration of the untreated sewage into the Triassic carbonate series.

This overlapping negative influence of various kinds is anything but neutral to the chemistry of the groundwaters and their quality.

THE CHEMISTRY OF THE GROUNDWATERS AND ITS MODELLING FACTORS

The waters of the Triassic carbonate complex are characterised by varied chemical composition.

Generally two definite areas of chemical quality of the groundwaters can be differentiated i.e.:

a) peripheral areas of the groundwater basin situated out of the reach of exploitation of Zn-Pb ores

Tab.1. The chemical characteristics of groundwaters from the Triassic Carbonate Aquifers.

	Groundwaters from:			Waters pumped out by "Bolko"Shaft (1993)	
	The Triassic Main Groundwater Basins (Silesian-Cracow Monocline)	The Bytom Basin (out of range of Zn-Pb ore mining)	Bytom Basin in the area of Zn-Pb ore mines 1989-1990	Western water gallery	Eastern water gallery
The general hardness, (mval/dm^3)	2.0 - <15.0	6.29 - 16.96	19.5 - 39.0	32.8 - 38.4	29.5 - 29.6
Total dissolved solids (TDS) (mg/dm^3)	104.0 - <1000.0	360.0 - 1448.0	1895.8 - 3392.8	2953 - 3509	2320 - 2413
Concentration of: (mg/dm^3) Na^+	2.1 - 79.5	2.4 - 372.2	132.6 - 344.6	244.8 - 316.0	110.4 - 120.0
K^+	0 - 29.9	0 - 42.3	3.5 - 78.3	18.4 - 21.1	11.2 - 18.0
Cl^-	<1.0 - 110.0	6.1 - 150.0	171.3 - 429.6	372.0 - 510.0	182.0 - 188.0
SO_4^{2-}	3.7 - 394.0	24.2 - 374.8	646.7 - 1494.1	1235 - 1508	1084 - 1098
The chemical type of water according to Szczukariew-Prikłoński - mainly	HCO_3-Ca-Mg HCO_3-Ca	HCO_3-SO_4-Ca-Mg	SO_4-Ca-Mg SO_4-HCO_3-Ca-Mg	SO_4-Cl-Ca-Mg-Na	SO_4-HCO_3-Ca-Mg
- sometimes	HCO_3-SO_4-Ca-Mg	SO_4-HCO_3-Ca-Mg	SO_4-Cl-Ca-Na-Mg SO_4-Cl-Ca-Mg-Na		

b) The central part in the reach of excavations of the closed-down Zn-Pb ore mines where the anthropogenic influence is the greatest.

On the eastern, northern and western edges of the groundwater basin (Figure 1.) there occur utility waters mostly of the types: HCO_3 - SO_4 - Ca - Mg and SO_4 - HCO_3 - Ca - Mg, with TDS varying from 360 to c. 1450 mg/dm^3 (Table 1.). These are anthropogenically altered waters, especially due to the negative influence of the pollution migrating from the surface of the ground. It can be evidenced by the high local and periodical concentrations of NO_3^- up to 20 mg/dm^3, NH_4^+ up to 1.68 mg/dm^3 as well as increased SO_4^{2-}, Cl^-, K^+ contents (Table 1.). The quality of these waters is on the bad side, locally they are undrinkable. However, on the average, they are comparable with the ones occuring in the Triassic carbonate series formations in the other parts of the Cracow-Silesia monocline influenced by the similar anthropogenic factors (Table 1.).

In the central part of the groundwater basin subject to the mining activity carried out by five Zn-Pb ore mines, the quality of waters pumped by five operating main pump stations varied, by and large they were more degraded than in the surrounding areas. Selected chemical components of these waters obtained in the analyses conducted in 1989-90 are presented in Table 1. The wide range of the values is remarkable. Waters of the best relative quality were pumped from "Dabrówka" mine situated in the E part of the deposit .

After closing down of the Zn-Pb ore mines the central part of the groundwater basin (Figure 1.) is still being drained by the numerous inactive excavations. The base of the whole drainage system is constituted by two water galleries (the eastern and western ones) by which the water reaches "Bolko" shaft in the "Orzel Bialy" mine from where it is pumped up to the surface and, after preliminary utilization, dumped into Brynica river.

Presently, in both galleries there is a measuring point of the regional network of groundwater quality monitoring.

The chemical composition of the waters drained from the western part is different from that from the eastern one. It is caused both by natural geogenic factors (lability of the mineral composition of the Zn-Pb deposits) and by anthropogenic ones (differences in the spacial management of the surface of the ground and various degrees of the anthropogenic threat).

In the eastern part there occured waters of the SO_4 - HCO_3 - Ca - Mg type with SO_4^{2-} content up to c. 1100 mg/dm^3 and Cl^- up to c. 190 mg/dm^3 (tab. 1.). The waters are also characterised by high Zn and Fe ions content (up to 15 mg/dm^3 and 2.74 mg/dm^3 respectively). The TDS of these waters amounts to 2400 mg/dm^3 while pH = 7.0 - 7.3.

The waters occurring in the western part are considerably enriched with the Cl ions whose content approximates 510 mg/dm^3. These are waters of the multi-ionic SO_4 - Cl - Ca - Mg - Na type with TDS approximating 3500 mg/dm^3 and pH = 7.6 - 7.9.

The SO_4^{2-} content is higher than that in the eastern part and intermittently exceedes 1500 mg/dm^3 (Table 1.). The waters are highly degraded and contain not only SO_4^{2-} and Cl^-

but Na^+ (up to 316 mg/dm³), Mn^{2+} (up to 1.54 mg/dm³) and NH_4^+(up to 10.2 mg/dm³) - all values surpassing the standard.

Analysing the chemical composition of the groundwaters in the centre of the Bytom groundwater basin we deal with the regional hydrochemical anomaly caused by the overlapping multi-level anthropogenic influences. The anomaly in its general form has been stimulated hydrodynamically. As a result of exploitation of Zn-Pb ores and the drainage associated with it, combined with the extention of thickness of the unsaturated zone considerable disturbance of geochemical conditions took place leading to the occurance of abnormally high concentration of SO_4^{2-} in the groundwaters.

Dealing with the causes of variations in the SO_4^{2-} content in the reach of the above mentioned anomaly it is necessary to take into consideration the character of the Zn-Pb deposits. In the western and central part of the area in question the sulphide minerals are predominant while the farther east the more oxygenic minerals can be found (3). In connection with this the processes of oxidation of the sulphides taking place in the deposit are more intensive compared with the western part. This creates. potentially greater content of soluble sulphates which, in the shallow and intensely fissured deposits, can be easily dissolved in the infiltrating rain water rich with O_2 and CO_2.

The inflow of pollution from the surface of the ground is an additional factor considerably affecting the chemical composition of the groundwaters occuring here. As it has already been mentioned, in the reach of the Bytom groundwater basin, especially in its central and western parts, a number of coalmine wastes dumps are situated. Large amounts of chlorides and sulphates are leached from them. Examination of the groundwaters in the vicinity of these dumps proved their extreme pollution. The concentration of Cl^- approximated 3000 mg/dm³, SO_4^{2-} - 1050 mg/dm³ and Na^+ 2150 mg/dm³ with TDS reaching 7000 mg/dm³. As a result of the local infiltration of the contaminated waters percolating through the dumps the groundwaters occuring in the Triassic groundwater basin have become enriched with the Cl ions, which is clearly visible in the western part of the area.

THE PROPOSED SPHERE OF ACTIVITIES DIRECTED TOWARDS AMELIORATION OF THE QUALITY OF THE GROUNDWATERS

Presently, the waters pumped from the "Bolko" shaft undergo preliminary purification by means of addition of lime in order to precipitate the excesive number of Zn ions. As a result of this operation the content of the Zn ions in the waters carried away into the river Brynica becomes reduced to c.1,0-1,5 mg/dm³ (before the purification Zn ions content amounts to c.10,0 - 15,0 mg/dm³). This operation does not lead to a decrease of the SO_4 ions content.

The most important problem connected with the waters in question is deminishing the quantity of the sulphates dissolved in them. Now the entire amount of the waters pumped (c. 22m³ per minute on the average) supplies the river Brynica with a load of 14,000 tons of sulphates per year. It seems that the activities leading to amelioration of the quality of these waters should be directed to:

a) creating an effective, economically justified method for their utilization,

b) undertaking activities, in the formation as well as on its surface leading to direct or indirect gradual reduction of the extra amounts of pollution , mostly sulphates.

Ad. a. Application of a proper method of utilization of the waters resulting in a reduction of the sulphates content to a level acceptable for drinking waters, that is 200 mg/dm^3, is an urgent and still open problem. It is undoubtedly a difficult task, which can be seen by the fact that during utilization of the above mentioned waters within 24 hours over 30 tons of sulphates must be removed from them.

Ad. b. Decrease in the thickness of the unsaturated zone by means of raising the groundwater table and partial flooding of the old excavations as well as of the weathering remnants of the ore deposits could be another solution to the problem. In this way the range of the unsaturated zone can be diminished and the quantity of the sulphates soluble in infiltrating rainwaters can be reduced. This activity should lead to gradual yet long lasting decrease of the sulphates content in these waters. However this solution may be counteracted by the threat which for situated below coal mines will be created by the flooded old working in a karstic - fissured carbonate massif.

Another direction of activities is connected with reduction of the negative influence of a number of potential sources of pollution localized on the surface of the ground eg.: industrial and municipal wastes dumps, and the coal mines water sedimentation basins. The special danger is created by intensive exploitation of coal which results in numerous rock bursts and deformations of the surface of the ground. This activity causes high perforation of the massif, breaking the natural local isolation of the water bearing horizons.

All the mentioned negative effects of the mining influence and stimulate the infiltration of the contaminated surface waters and sewage into the Triassic formation. An example of this can be the overflow of 210,000 m^3 of water from the newly built and unsealed sedimentation basin of "Jowisz" coal mine in 1975 and a similar escape of c. 400,000 m^3 from the two sedimentation basins of "Andaluzja" mine in 1977 (5). The entire amount of these contaminated waters found its way into the Triassic formation.

To limit the inflow of the wastes and to protect the resourceful Triassic groundwater basin in this area it is indispensable to regulate the sewage - water economy (building a water purification plant, suitable for this complicated conditions of sewage system, the maintenance of the proper technical condition of the surface stream beds, constructing the open collectors and the mine water sedimentation basins). It is also important to address restrictions on the creation of new industrial and municipal wastes dumps and liquidation or proper utilization of the old ones.

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