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# IMPACT OF LEAD/ZINC ORE MINING ON GROUNDWATER QUALITY IN TRZEBIONKA MINE (SOUTHERN POLAND)

Bogumil Gajowiec
State Geological Institute, Uppe Silesian Branch
Sosnowiec ul.Bialego 1, Poland

Andrzej Witkowski
Silesian University, Department of Hydrogeology and Engineering Geology,
Sosnowiec ul.Mielczarskiego 60 Poland

## ABSTRACT

The intensive mining activity carried out by "Trzebionka" zinc-lead mine causes chafiges in the hydrodynamic regime of the triassic aquifer as well as essential changes in the chemical composition of the groundwater.The mine water, in comparison with groundwaters collected directly from fractures and Karstic channels and with groundwaters pumped out from wells situated in Chrzanow region, is characterized by higher contents of almost all major dissolved constituents as, well as, many trace elements. Hydrogeochemical background of triassic carbonate series aquifer has been elaborated. Largest anomalies in extent of almost all elements have occurred in area of the "Trzebionka" mine. In this water general trend of increase of pH, total dissolved solids and $SO_4^{2-}$ concentration with simultaneous trends of decrease of $Zn^{2+}$ and $Pb^{2+}$ concentrations have been noticed. Water pumped out from the mine in spite of its low quality, is utilized in about 80% as potable water after undergoing complicated treatment.

## INTRODUCTION

Fissured - Karstic basin of the Triassic carbonate series in Chrzanow region (southern Poland), is a very important source of potable water for this part of a great urban and industrial agglomeration of the Upper Silesian Coal Basin. It is subjected to a strong anthropogenic pressure which leads to the degradation of water quality and depletion of water reserves. This influence is exesperated at "Trzebionka" zinc-lead mine where the impact of mining on groundwater regime and quality is particularly important in consideration of fact that more than 50% of all water pumped out from the coal basin is mine water.

## GENERAL HYDROGEOLOGICAL CHARACTERISTICS

The area under investigation is located in the eastern part of Silesian Upland where Triassic deposits lie unconformably to carboniferous formations and are covered by Jurassic, Tertiary and Quaternary formations. There are three water levels in the Triassic profile: shell limestone (Muschelkalk), Roethian, and lower mottled sandstone. The first two levels play the basic role and due to hydraulic inter-connection, they are treated as one dolomite-limestone water bearing complex of Triassic carbonate series. In the Chrzanow area, the series forms the main aquifer of karstic-fissured water. The aquifer is mostly covered by isolating Keuper and Tertiary formations (Figures. 1, 2). The permeability coefficient determined for shell limestone and Roethian are $1.4 \times 10^{-6}$ - $3.3 \times 10^{-4}$m/s and $3.1 \times 10^{-7}$ - $1.5 \times 10^{-4}$m/s respectively (2); and the average value for the whole complex of water bearing carbonate Triassic series is $5.16 \times 10^{-5}$m/s.

The basin under consoderation is a closed one and covers the area of 310 sq.km. It is mainly charged directly form the outcrops of series and by infiltration of precipitation water (Figure 1), but also by water from the creeks Chechlo and Luznik or indirectly from the Quaternary and Jurassic aquifers. The Triassic aquifer is drained trough excavations of the Zn-Pb ores mine "Trzebionka", excavations of old mines "Galmany" and "Matylda" - adapted at present as underground intakes of water, and the Przemsza valley (Figure 1). The western part of the area is probably also drained by excavations of the coal mine "Janina", which is proved by vanishing of several springs. The described area is also partly discharged by the coal mine "Jaworzno" in the northern part (5).

In the discussed area, water is taken through concentrated intakes of WPWiK Katowice and thorough individual wells. Most of the water amount is pumped through excavations of the "Trzebionka" mine. Total amount of the pumped water is 3714.0 -3914.5 $m^3$/h, including about 216 $m^3$/h from the "Trzebionka" mine.

Due to intensive drainage of the rockmass a large cone of depression has been formed (Figures 1and 2) with the maximum depth of the water level 240 m below the ground water level. It has caused significant increase of hydraulic gradients and formation of underground water streams directed towards excavations. Due to block tectonics of Triassic formations and isolating character of faults, the range of draining activity of the mine is irregular.

Mean flow velocity of water for the given open porosity and hydraulic conductivity k sr.=4.46 m /d vary from 0.2 m/d in the zones of intensive drainage to about 7 m/d in the groundwater divide zones. Knowledge of extreme velocities connected with flow through micro-hydraulic karstic-fissured systems is very important due to possible endanger of water intakes. At the given fissility coefficient 0.03 (9) and maximum, hydraulic conductivity obtained by pumping tests $3.33 \times 10^{-4}$ m/s possible flow velocities has been calculated: in the zones of low hydraulic gradients 1.5 km/year, in the zones of high gradients 20 km/year. In comparison, flow velocities in a porous system within the mine, at the mean hydraulic conductivity $k=8.19 \times 10^{-9}$ and porosity 0.119 are of several centimetres per year.

Isotopic investigations have been also carried out in the "Trzebionka" mine to determine the age of water inflow from the recharge area to mining excavations (11). According to tritium determination total time of flow has been found as approximately 95 years. The maximum time of flow in the karstic-fissured system is several years.

According to the above data it may be assumed that possible pollution may be transported, due to high speed and low filtering ability on fissures surfaces, at large distance in relatively short time. It may endanger water intakes located in theoretically safe areas covered by aquiclude formations of Rhaetic-Keuper and Miocene.

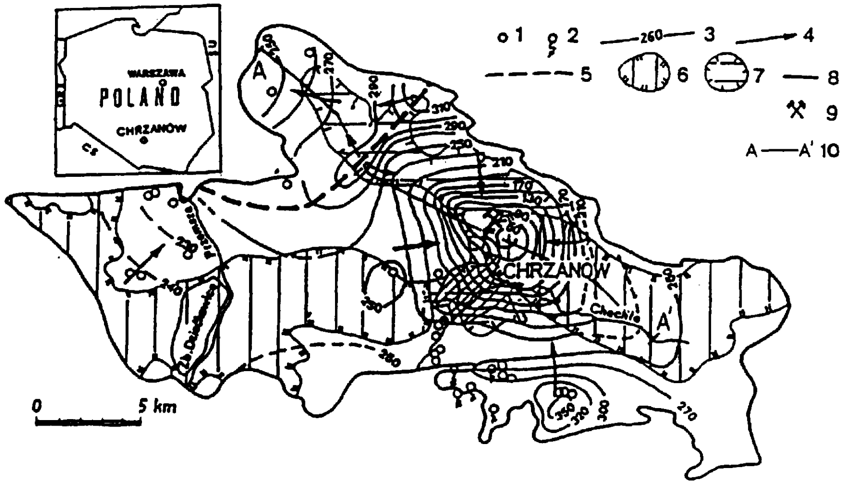



Figure 1. Hydrogeological map of the Chrzanow Basin.

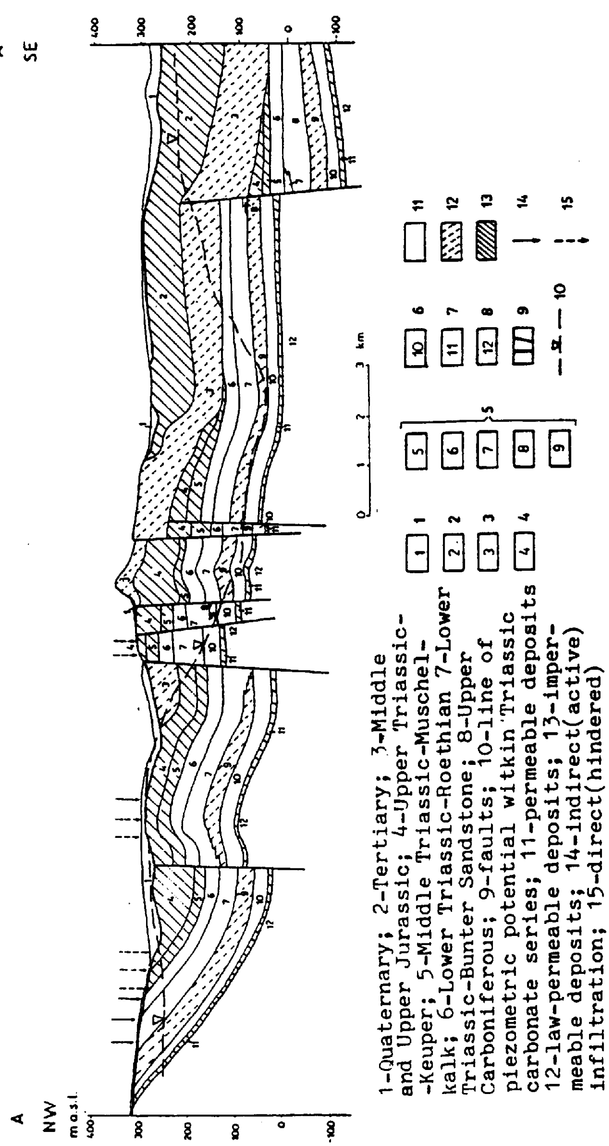
1- wells, 2 - springs, 3 - groundwater contours of the Triassic carbonate series (in metres above sea level), 4 - direction of groundwater flow, 5 - groundwater divide, 6 - extent of impermeable Tertiary deposits, 7 - extent of impermeable Keuper deposits, 8- extent of the Chrzanow basin, 9 - Zn-Pb mine, 10 - hydrogeological cross-section line.

## CHEMICAL COMPOSITION OF GROUNDWATER AND ITS QUALITY

Chemistry of groundwater occurring in the Triassic carbonate series of the Chrzanow basin is variable. Most frequently the water is of $HCO_3$-Ca and $HCO_3$-Ca-Mg types, or rarely, $HCO_3$-$SO_4$-Mg-Ca type. Mineralization of the water ranges from 226 to 940 $mg/dm^3$, 437 $mg/dm^3$ in average.

Anions concentrations are as follows: HCO3 - 141.0 - 488.2 $mg/dm^3$; $SO_4^{2-}$ - 36.0 - 533.0 $mg/dm^3$; $Cl^-$ - 7.5 - 68.0 $mg/dm^3$; N-$NO_3$ - 0.1 - 18.0 $mg/dm^3$; N-$NO_2$ - 0.00 - 0.26 $mg/dm^3$; $PO_4^{3-}$-0.00-0.20 $mg/dm^3$; $F^-$-0.00-0.10 $mg/dm^3$.

Cations concentrations are as follows:




1-Quaternary; 2-Tertiary; 3-Middle and Upper Jurassic; 4-Upper Triassic-Keuper; 5-Middle Triassic-Muschelkalk; 6-Lower Triassic-Roethian 7-Lower Triassic-Bunter Sandstone; 8-Upper Carboniferous; 9-faults; 10-line of piezometric potential witkin Triassic carbonate series; 11-permeable deposits; 12-law-permeable deposits; 13-impermeable deposits; 14-indirect(active) infiltration; 15-direct(hindered) infiltration.

$Ca^{2+}$ - 65.0 - 128.5 mg/dm$^3$; $Mg^{2+}$ - 6.8 - 60.0 mg/dm$^3$; $Na^+$ - 0.44 - 52.40 mg/dm3; $K^+$ - 0.0 - 3.9 mg/dm$^3$; N-$NH_4$ - 0.00 - 0.70 mg/dm$^3$.

Values of pH these water are contained within limits 6.60 to 8.65. General hardness ranges from 4.8 to 21.4 mval/dm$^3$.

The majority of groundwater intakes have been sampled to ensure if their bacteriological contents meet the requirements of the Polish hygienic-sanitary standards. Only the samples of water taken from springs show the bacteriological content exceeding the standard. Determinations of content of some trace elements is very significant for estimation of groundwater quality in the basin under consideration. High content of Pb in water from "Trzebionka" mine (2) is regarded as particularly dangerous for water users and the natural environment. Highest concentration periodically reaches 8.0 mg/dm$^3$ i.e. many times above the limit admitted by the Polish standard for potable water (0.05 mg/dm$^3$) being the result of technological works undertaken at this mine. Lower Pb concentrations occur in almost all of the other intakes situated in this region.

Increased contents of Zn, Cd and Sb ions in mine water is also noteworthy. It has been stated that $Zn_2$ concentrations are as high as 6.0 mg/dm$^3$ also above limit accepted by the Polish standard for potable and river water. Similar instance has been recognized for very toxic Cd ions that content reaches 0.3025 mg/dm$^3$ (Table 1). In addition to the

Table 1. Extreme and average values of selected hydrochemical elements in mining water of the "Trzebionka" mine

| Hydrochemical elements | Contents (mg/dm$^3$) Minimum | Maximum | Average |
|---|---|---|---|
| Cu | 0.0000 | 0.0500 | 0.0080 |
| Zn | 0.0214 | 2.6637 | 0.7407 |
| Co | 0.0000 | 0.0410 | 0.0061 |
| Ni | 0.0000 | 0.4100 | 0.0216 |
| Cd | 0.0000 | 0.0325 | 0.0027 |
| Fe | 0.0048 | 9.5745 | 0.9736 |
| Mn | 0.0000 | 2.9813 | 0.0987 |
| Pb | 0.0100 | 8.0434 | 0.2184 |
| Sb | 0.0000 | 0.1138 | 0.0163 |
| Cr | 0.0038 | 0.0086 | 0.0057 |
| Se | 0.0000 | 0.0809 | 0.0232 |

above mentioned trace elements, in groundwater as a result of anthropogenic pollution increased concentrations of N-$NO_3$ (up to 18.0 mg/dm$^3$) N-$NO_2$ (up to 0.26 mg/dm$^3$), N-$NH_4$ (up to 0.7 mg/dm$^3$), $Mn^{2+}$ (up to 1 mg/dm$^3$) $PO_4^{2-}$ (up to 0.2 mg/dm$^3$), $SO_2$ (up to 533 mg/dm$^3$) and high turbidity (up to 250 mg/dm$^3$) are observed. High concentrations of $SO_4^{2-}$ may be created by the mentioned anthropogenic factors as well as by seepage of water from overlying Keuper layers which are rich in sulphate ions. Raised content of freons and halogen derivatives of alkanes (11) has been reported recently in the water from "Trzebionka" mine.

Appreciation of changes of groundwater quality in Chrzanow region in respect of time has been analysed also by comparative examination of two series of chemical analysis that had been carried out in 1956 -1959 and 1986 -1989 (10). Hydrogeochemical background of the aquifer studied has been elaborated for comparison in each of the periods. Confrontation of the average concentrations of five main ions and total dissolved solids, as well as general hardness reveals their increase in the recent period in comparison with the fiftieth's. Background ranges except $SO_4$ ions show a shift in direction of higher concentrations in limits chaining from 13.2% ($HCO_3$) up to 125.9% ($Cl^-$), mean 52.2% (10). The obtained data clearly point that largest anomalies in extent of almost all elements of the hydrogeochemical background have occurred in area of the "Trzebionka" mine and in the southern part of this region.

In summary it should be stated that water with very low parameters and out of standard quality. Chiefly originating from the "Trzebionka" mine comprise ca. 65% of all the amount of waters pumped out from the basin.

## CHANGES OF MINE WATER CHEMISTRY DUE TO MINING PROCESSES

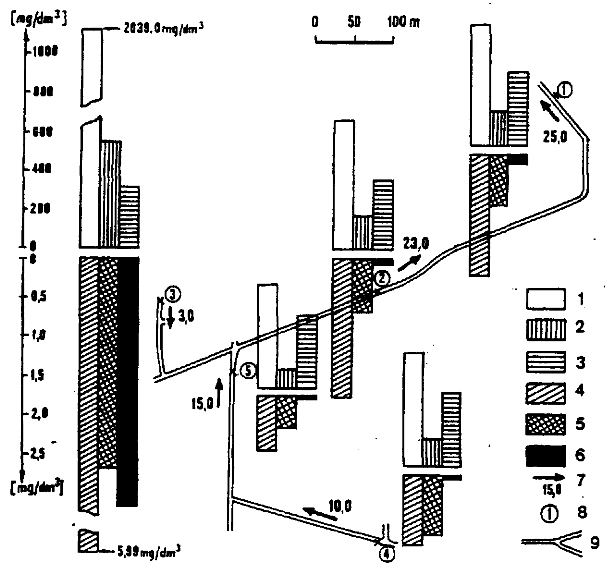
Waters from mines contain higher amounts of toxic and environmentally polluting heavy metals, which is caused by contacts with ore outcrops and pollution originating from mining and extaction processes. Underground water, being in contact with sulphides, oxidize them rather easily and dissolve. At the later stage, precipitation of heavy metals occurs when waters with leached metals in sulphides get in contact with carbonate rocks (7,12,13). Part of these metals are adsorbed by clay minerals.

Natural processes of heavy metals migration as solution or colloidal suspension are interfered by processes connected with ore exploitation in the "Trzebionka" mine, Control series of water sampling in the mine prove higher concentration and significant variations of heavy metals contents in water. This phenomenon is directly influenced by technological processes connected with drilling of blast-holes and bore-holes, blasting, output loading and transport by wheel loaders, backfilling, cleaning of settling tanks of mine waters and cutting through new parts of deposits which are isolated hydrogeological structures (2, 8). Due to the above mentioned mining processes, water flowing in the vicinity of mining excavations abruptly increases its concentration of metals.

A series of water sampling program in the selected part of the mine has been carried out to prove influence of technological processes on quality of mining water (Figure 3).

Five water samples have been taken, of which two were from natural water outflows from the rock mass (measuring points No.4 and 5), the others have been from water drifts. Control point No.3 (Figure 3) is located closely to the place are carried on.

An effect of polluting natural waters flowing out of the massif (measuring points No. 4 and 5) by technological waters (point No. 3) is distinctly visible in the sampled area of the mine. It is very important to emphasise that this negative influence of technological works significantly decreases in the distance of several hundred meters from the source. This phenomenon occurs due to the above mentioned processes of precipitation and sorption as well as dilution of polluted water with that flowing from unexploited regions of the mine (point No. 5 - Figure 3). These processes play different role due to various levels of decrease of the investigated components concentration. The process of dilution plays similar role to all of the components. The processes of precipitation ana sorption significantly decrease contents of such ions as: Fe, Al, Pb, Mn, and are also important for such ions as: Co, Cu, Ni. Decrease of concentration of such well migration ions as Zn and Pd is caused mainly by diluting polluted waters.

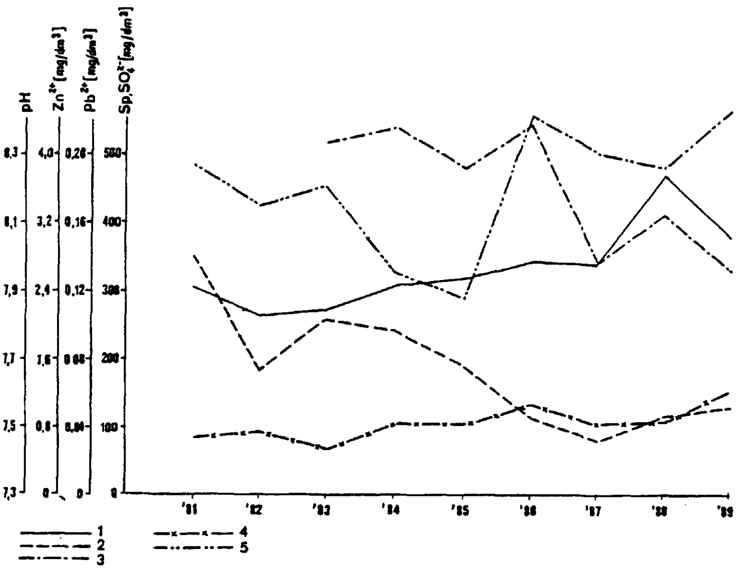


1 - total dissolved solids; ions concentration of: 2 - $SO_4^{2-}$ 3 - $HCO_3^-$, 4 - $NO_3^-$, 5 - $Zn^{2+}$, 6 - $Pb^{2+}$ ; 7 - directions and intensity of flow; 8 - sampling sites; 9 - drainage excavations.

Figure 3. Water chemistry variation of the inflows into "Trzebionka" mine excavations.

The structure of heavy metals load in waters flowing through excavations of the "Trzebionka" mine has been characterized according to 40 analyses from the years 1986-1990 (Table 1). Water pumped out to the surface show again increase of heavy metals contents. It is caused by disturbance of suspension containing large amount of heavy metals, deposited in underground settling tanks (1).

Chemical composition of collected underground water pumped up from the mine often varies and their quality is generally low. Analysis of mean annual values of selected chemical parameters of waters, prepared according to 1317 analyses from the years 1981-1989, show increasing tendency of mean values of pH, total dissolved solids and concentration of $SO_4$ ions [3]. There is also a significant trend to lower concentration of Zn and Pb ions (Figure 4).




1 - pH; 2 - $Zn^{2+}$ ; 3 - $Pb^{2+}$ ; 4 - $SO_4^{2-}$, 5 - total dissolved solids.

Figure. 4. Long-term, variations of pH, total dissolved solids (sp) and concentrations of: $Zn^{2+}$, $Pb^{2+}$, $SO_4^{2-}$ in "Trzebionka" mine water.

However explanation of the reasons of the observed trends, due to irregular course, is impossible without additional, through hydrogeochemical investigations.

It must be emphasized that concentration of Pb ions, despite the fact it is showing decreasing tendency is relatively high and often exceeds allowable limits for potable waters. Average concentration of these ions presented on diagram (Figure 4) significantly exceeds this limit which is 0.05 mg/l.

As most of water is for municipal needs their treatment is necessary. Therefore after pumping up to the surface they are sent to a water treatment plant where Pb is coagulated by $Al_2(SO_4)$, however this process does not give satisfactory results.

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