Groundwater contamination in the area of Zn-Pb ore mines situated in the southern part of the Olkusz-Zawiercie Triassic aquifer (Poland)

Jacek Motyka[1], Andrzej J. Witkowski[2]

[1] Faculty of Mining, University of Mining and Metallurgy, Mickiewicza Av. 30, 30-059 Cracow, Poland, e-mail: motyka@uci.agh.edu.pl
[2] Department of Hydrogeology and Engineering Geology, University of Silesia, Bedzinska Str. 60, 41-200 Sosnowiec, Poland, e-mail: awitkows@us.edu.pl

Abstract. In areas of Zn-Pb ores mines significant contamination of groundwater have been noticed. The analysis of the spatial distribution of such pollution indicators as SO_4, Cl, NO_3, Fe and Zn indicates different exogenic and endogenic origin. Processes of oxidation of sulphide minerals taking place in the rocks are the most significant factors influencing concentrations of SO_4, Fe and Zn in mine water in Olkusz area. The inflow of pollution from the surface of the ground is an additional factor considerably affecting the chemical composition of groundwater (concentration of NO_3 and Cl and locally SO_4 and Fe).

Introduction

The Olkusz-Zawiercie karst-fissured Triassic aquifer (Fig.1) is one of the major sources of potable water for the Upper Silesian agglomeration. Unfortunately this generally very vulnerable aquifer is subjected to high negative human impact related to mining, industry, urbanisation and agriculture. Particularly bad situation is observed in southern part of this aquifer in area of Zn-Pb ore mines where a progressive deterioration of groundwater quality has been noticed. Before intensive mining activity TDS of groundwater in carbonate Triassic rocks in Olkusz region varied between 250 and 500 mg/dm^3 and average concentrations of SO_4 was 37 mg/dm^3, Zn - 0,52 mg/dm^3, Pb - 0,06 mg/dm^3 (Adamczyk and Wilk 1976). Unfortunately currently groundwater quality has been significantly changed in this area. High concentrations of SO_4 (over 5 000 mg/dm^3), Cl (locally up to 600 mg/dm^3), Fe (up to 400 mg/dm^3), Zn (up to 50 mg/dm^3) and also NO_3 (up to 60 mg/dm^3) in areas of Zn-Pb ores mines have been noticed. Based on the analysis of the spatial distribution of such pollution indicators as SO_4, Cl, NO_3, Fe and Zn major sources of groundwater contamination have been defined in this paper.

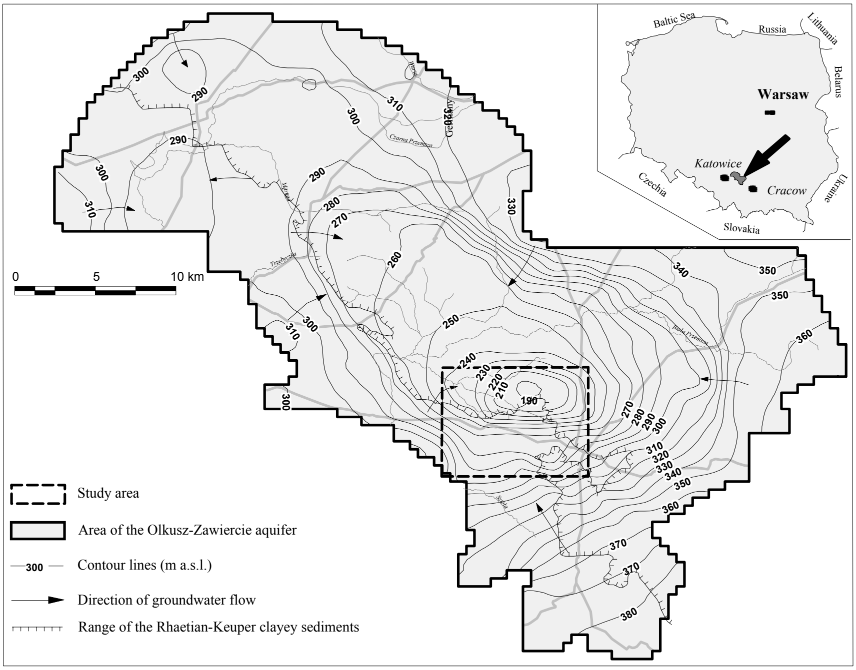

Fig. 1. Hydrogeological sketch of the Olkusz-Zawiercie Triassic aquifer (according to Witkowski at al. 2001)

Groundwater system

The Olkusz region belongs to the Silesian-Cracow Monocline built up of the Triassic and Jurassic formations discordantly overlying folded and faulted Palaeozoic basement. There are Quaternary, Jurassic, Triassic and Palaeozoic aquifers in the hydrogeological profile of the Olkusz area.

Most important and resourceful is the Triassic karst-fissured carbonate aquifer (dolomites and limestones with marl interbeddings). Generally two water-bearing horizons can be differentiated within this aquifer: the Muschelkalk horizon and the Roethian one. These two horizons are often considered jointly as one aquifer (Różkowski ed. 1990). Considered Triassic aquifer is partly covered by clayey Rhaetian-Keuper sediments (Fig.1). Hydraulic structure of fissured and karstified Triassic rocks consists of three types of spaces: pores, fissures and caverns. Limestones represent fissured-cavernous type of the aquifer while dolomites represent porous-fissured-cavernous type (Motyka 1998). Fissures and karstic channels are favourable pathways of groundwater flow while the pore space is the main water reservoir. It resulted in a vertical and horizontal differentiation of rock permeability. The thickness of this aquifer ranges from a several to about 150m.

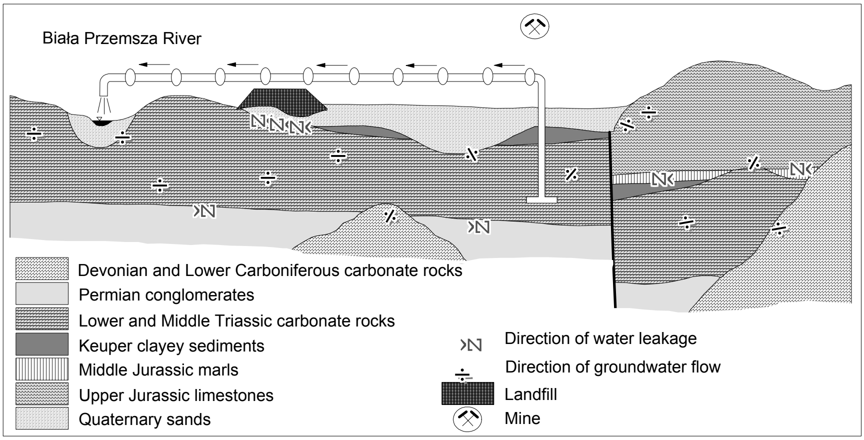

Fig. 2. Groundwater circulation scheme

Triassic aquifer is recharged directly in outcrop areas or indirectly through permeable Quaternary, Jurassic or Palaeozoic sediments. Other sources of recharge include water downward leakage from the shallow aquifers through poorly permeable Upper Triassic, Lower and Middle Jurassic sediments as well as water seepage from rivers, mainly from The Biala Przemsza river (Fig.2). Important, from the point of view of amount and quality of recharged water, hydraulic contacts in Triassic aquifer are of the erosive, sedimentation-transgressive and tectonic types (Fig.2) (Motyka 1988).

In natural conditions, Triassic aquifer in the Olkusz region was drained by springs and rivers. Currently this aquifer is intensively drained by three Zn-Pb ores mines (“Bolesław” – abandoned at the end of 1996, “Olkusz” and “Pomorzany”) and numerous groundwater intakes.

Mining drainage in this region has lasted for more than 400 years. Significant increase of this drainage has been observed from 1975 after starting of exploitation by the “Pomorzany” mine – the third and biggest mine in this region. Average total amount of water pumped out by three mines is about 330 m^3 per minute. This intensive long lasting drainage has caused significant changes in hydrodynamic conditions in the whole region. Lowering of groundwater table up to over 120 m resulted in changes of flow directions, increase of hydraulic gradients and creation of the extensive regional cone of depression covering an area of about 470 km^2 (Fig.1). In this way a new extended unsaturated zone has been originated. Thickness of this zone exceeds 80 m in the area of the “Olkusz” and “Pomorzany” mines.

Potential sources of groundwater contamination

In the study area a negative impact of exogenic and endogenic factors on groundwater quality is observed. Mentioned extended unsaturated zone is an important endogenic (Motyka and Witkowski 1999; Adamczyk et al. 2000).

Quantity of the potential and real load of contaminants originated in this zone mainly depends on the amount and type of sulphides, intensity and length of time of oxidation processes occurring there. Because of very irregular occurrence of sulphides reliable estimation of the amount and nature of the potential load of contaminants originated in this zone is difficult.

A lot of real and potential sources of groundwater contamination situated on the surface of the considered area are an important exogenic factor affecting groundwater quality. There are 9 industrial and 7 municipal landfills (4 unauthorised), 2 tailing dams, areas without sewerage network, leaky septic tanks, 14 petrol stations, 4 treatment plants, 2 animal husbandry.

The most important sources of pollution deteriorating quality of groundwater in the Triassic carbonate formations in the area of Olkusz are:

- previous discharge area of lignosulfonates from the Paper and Cellulose Mill in Klucze which were deposited in the sands of Desert of Błędów. Approximately about 450 000 ton of lignosulfonates were deposited in that period from 1930 till 1979.
- tailing dams from which leachates are enriched in sulphates and heavy metals.
- industrial landfill where rich in metals waste from the rolldown furnaces and acid waste from the sulphuric acid plant were deposited until quite recently
- municipal landfill (without any protective measures) located in the abandoned quarry in the area of the “Bolesław” mine
- uncontrolled leaks of sewers from a leaky septic tanks

Spatial distribution of the major groundwater pollution indicators

Groundwater quality assessment in the area of considered mines have been based mainly on results of sampling of natural inflows to Zn-Pb ores mines done in the period 1996-2001. Moreover, data from existing observation wells situated in the area of “Boleslaw” mine have been taken into account. Because of the peculiarity of the examined area and overlapping of different factors causing water contamination there was performed an analysis on spatial variability of chosen pollution indicators only. The following components were taken into account: sulphates, iron and zinc – as indicators of both anthropogenic and geogenic contamination, and nitrates and chlorides as indicators of anthropogenic contamination.

Analysis of sulphates concentrations in groundwater in the Olkusz area have been already presented by authors (Motyka and Witkowski 1999). Highest sulphates concentrations exceeding 5000 mg/dm^3 have been noticed in the central

part of "Pomorzany" mine. Concentrations of sulphates in analysed groundwater are a result of overlapping impact of a few factors:
- weathering of metal sulphides and simultaneous buffering processes of acid solution originated as a result of this weathering,
- effluents from landfills, concentrated in the area of "Bolesław" mine,
- ascension of groundwater from the bedrock through the Permian conglomerates, where gypsum has been noticed (in some parts of "Pomorzany" mine).

It can be deducted from the spatial distribution of sulphate concentrations (Motyka and Witkowski 1999) that the processes of oxidation of sulphide minerals taking place in the rocks are the most significant factors influencing these concentrations.

The distribution of iron and zinc concentrations in waters of Triassic aquifer in the region of the analysed Zn-Pb ore mines is conditioned by the influence of exogenic and endogenic factors. Pure waters with unchanged chemical composition or changed insignificantly by anthropogenic factors (agriculture, municipal waste, urban sewage) flow from north-west, east and south-east. This is why iron concentration in water inflows to workings in "Olkusz" mine and eastern part of "Pomorzany" mine generally does not exceed the detection limit, i.e. 0,01 mg/dm^3. (Fig.3). This part of Triassic aquifer is also characterised by zinc concentration below 1 mg/dm^3 (Fig. 4).

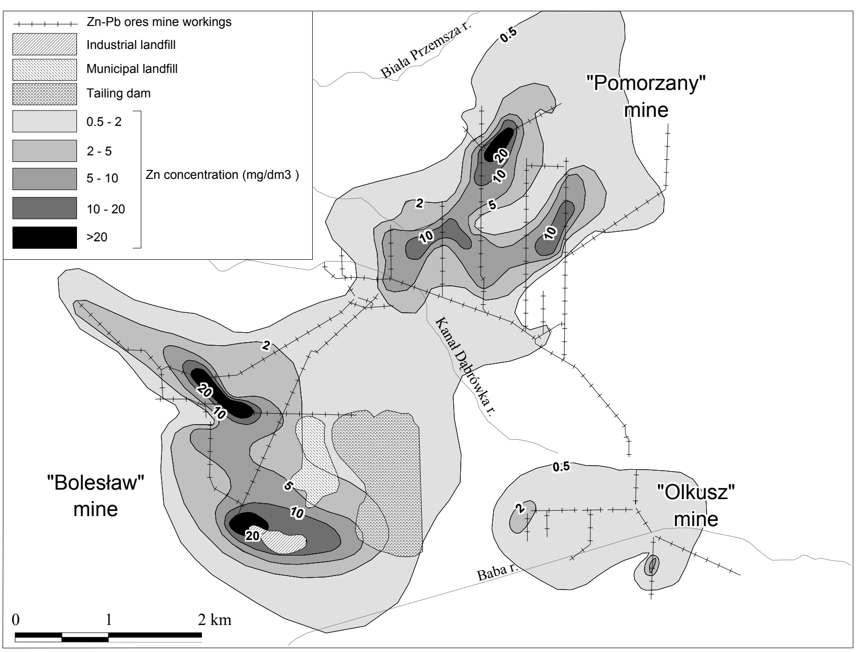

Fig. 3. Spatial distribution of iron in groundwater of the Triassic aquifer

Due to lowering of the primary groundwater table and deepening of the unsaturated zone, and oxidation processes of metal sulphides (mainly pyrite and marcasite) in mine water increasing concentrations of SO_4 as well as Fe and Zn have been observed.

Oxidation processes of sulphate metals are most responsible for high iron and zinc concentrations, exceeding 1 mg/dm^3 Fe (locally 40 mg/dm^3) (Fig.3) and 2 mg/dm^3 Zn (locally 90 mg/dm^3) (Fig.4), in the central part of "Pomorzany" mine.

Increased iron concentrations in water inflows in the north-western part of "Pomorzany" mine are caused by the influence of lignosulfonates, which flow from a place several kilometres away, where they were poured.

The reasons for increased iron and zinc concentrations in water inflows in "Bolesław" mine and in surrounding groundwater are more complicated. This is caused not only by weathering processes of sulphate metals but various contamination sources as well. The most important are industrial and municipal landfills and tailing dam. Effluents from this waste disposals have an affect on a chemical composition of mine water inflows in southern and south-eastern parts of "Bolesław" mine. The highest concentrations of Fe and Zn exceeding 20 mg/dm^3 have been observed there. (Fig.3 ,4).

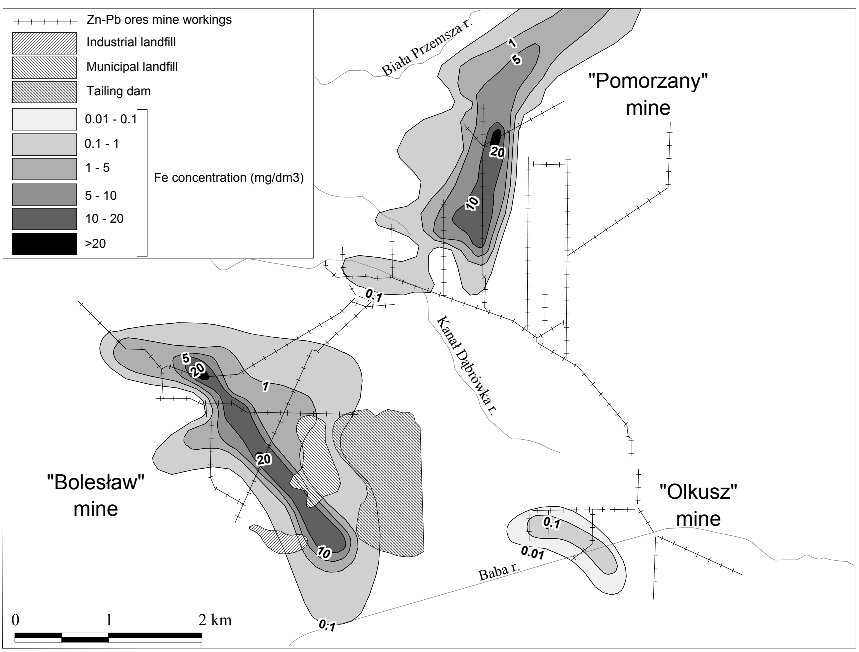

Fig. 4. Spatial distribution of zinc in groundwater of the Triassic aquifer

Nitrates in examined groundwater occur in south-western, south-eastern and north-eastern parts of the analysed area (Fig.5). The distribution of increased concentrations is of mosaic type and is connected with two major factors, i.e. occurrence on the surface such contamination sources as communal landfills, animal farms, built-up areas with no sewage network and natural vulnerability of Triassic aquifer to contamination. The highest concentrations (about 60 mg/dm^3) are reported in the southern part of “Bolesław” mine. They are connected with the uncovered character of the aquifer and obvious influence of the mentioned municipal landfill, as well as flowing, mainly from the west and south, groundwater contaminated with municipal sewage. Negative impact of this landfill can be also proved by high chloride concentrations observed in its neighbourhood, up to 600 mg/l in examined groundwater (Adamczyk et al. 2000).

Visibly increased concentrations of nitrates were reported also in the region of “Olkusz” mine (Fig.5). This contamination results from both negative impact of built-up areas with no sewage network and contaminated water flowing from the east, from Jurassic deposits.

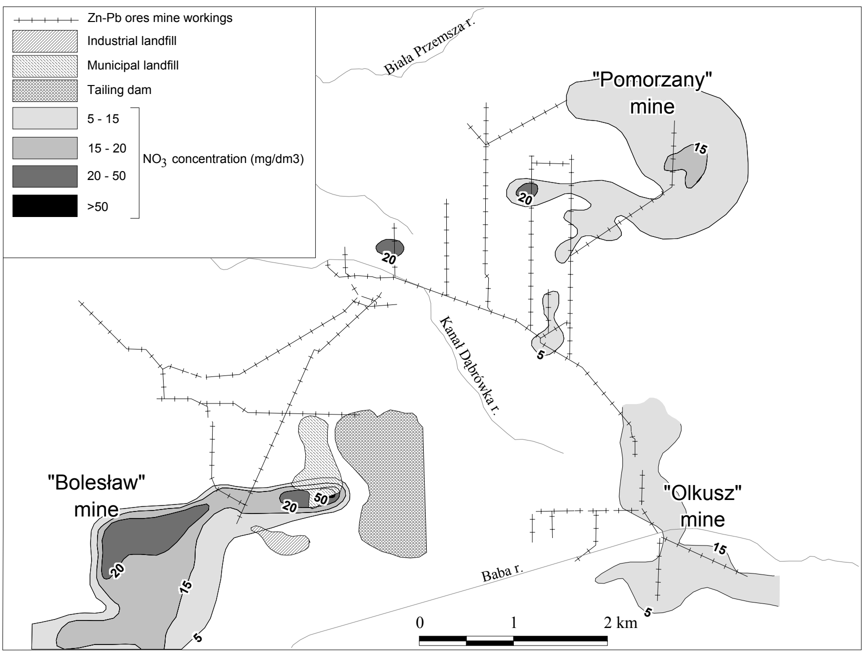

Fig. 5 Spatial distribution of nitrates in groundwater of the Triassic aquifer

Observed increased concentrations of nitrates in the eastern part of “Pomorzany” mine, because of insulating Keuper deposits occurrence, are connected with the flow of contaminated water through hydrogeological windows from Jurassic deposits. Increased nitrates concentrations in the remaining parts of the mine are due to the water flow from Quaternary and Jurassic deposits in the zones of local erosive or anthropogenic (cavings, boreholes) contacts.

Conclusions

Observed deterioration of groundwater quality in considered area is a result of overlapping negative impact of endogenic and exogenic factors. Analysis of the spatial distribution of SO_4, Fe, Zn concentrations in mine water shows that the processes of oxidation of sulphides minerals taking place in the rocks are the most significant factors influencing these concentrations. Comparison of mentioned constituent concentrations to concentrations of NO_3 points on additional significant impact of local human sources of pollution (tailings dams, municipal and industrial landfill, injected lignosulfonates) on groundwater quality. Negative impact of the exogenic factors on groundwater is visible not only in very vulnerable, uncovered parts of the Triassic aquifer in the area of “Bolesław”mine but also in area of “Pomorzany” mine in parts of local hydraulic contacts between Quaternary, Jurassic and Triassic aquifers.

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