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The Effect of Hard Coal Mine Drainage Water on the Quality of Surface and Ground Waters

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1. Introduction

The working and exploitation of most beds with usable minerals requires rock mass dewatering. In turn, the exploitation of such chemical materials as sulphur and salts involves forcing in water. These processes lead to significant transformations of the water relation in the geological environment. The lowering of the natural drainage base to dewatering levels, the formation of voids in rock mass, the fracture of rock strata above the bed, the unsealing of fault planes, the deformation of rock strata and the depression of surface area – all these give rise to hydrodynamically and hydrochemically complex systems of groundwater and surface water circulation. From the point of view of regulations, any water from dewatering is treated as wastewater. The range and scale of influence of mining on the changes in the water relation following intensive exploitation of mineral resources are illustrated on the map of hydrogeological transformation (Wilk ed. 1990, Wilk 1999).

The area of supply of water-bearing levels under mine drainage in Poland is approximately 5000 km^2 – 1.5% of the country's area. 3 mln $m^3 \cdot day^{-1}$ water was pumped from underground and surface mines per year (Witkowski 2005). The chemical composition and quality classes of mine waters discharged into water depend on the location of exploited and drained beds in the groundwater circulation system. These waters have different quality classes, from fresh to salt water. The latter were

15.6% of the total amount of pumped mine waters containing 2.5 million tons of chlorides and sulphates per year, and nearly all of them (94%) were discharged into water waste. Most mine waters were and still are discharged into surface watercourses either directly or following their use for technological purposes. As a result, nearly half of the rivers in Silesia are characterized by waters with abnormal composition and higher mineralization (Różkowski 1995, Macioszczyk & Dobrzyński 2002, Szczepański 2004).

The Bogdanka mine pumps $14\cdot10^3$ $m^3\cdot day^{-1}$ of waters classified according to mining classification as normal and industrial waters. $13.5\cdot10^3$ $m^3\cdot day^{-1}$ of these waters is drained to wastewater, while $0.5\cdot10^3$ $m^3\cdot day^{-1}$ is used by the mine. In the Lublin Coal Basin the degree of nuisance caused by draining waters from the Bogdanka mine to the watercourse is not significant (Wilk & Bocheńska ed. 2003, Michalczyk et al. 2007). The mine dumps industrial waters classified as fourth class quality into the river Świnka, its waters being classified also as second class quality. The waters drained to the watercourse are multi-ionic with higher concentrations of chlorides and sulphates.

2. Methods and material

The study was performed from 2014 to 2015 by analysing the physical and chemical indicators of water samples. The samples were taken from the following sources: piezometers a depth to 120 m; points groundwater; drainage ditch; water feed, the river Świnka (eight samples for each site). The analyses were performed at a chemical laboratory of the Central Mining Institute in Lublin. A number of physical and chemical indicators were determined using a multispectral analyser. The following parameters were examined: pH, electrolytic conductivity, dissolved substances, total hardness, calcium, magnesium, sodium, nitrates, sulphates and chlorides. The examined indicators were subjected to Friedman's nonparametric univariate analysis (ANOVA) for measurements repeated using the Statistica software. The aim of this work is to investigate the effect of the Bogdanka mine's activity on the drainage of ground water as well as the physical and chemical indicators of both ground and surface waters.

3. Hydrogeological conditions

The study was conducted in the Lublin Coal Basin in the area of mining activity of the "Bogdanka" mine. The mining area is 57 km^2. It comprises three mining regions: Bogdanka, Nadrybie and Stefanów. Aside from the mining activity, the area is marked by increased tourism (Chmielewski ed. 2009, Sawicki & Łyszczarz 2009).

One can distinguish four main aquifers in the Lublin Coal Basin: I – Quaternary and Upper Cretaceous; II – Lower Cretaceous; III – the Upper and Middle Jurassic; IV – Carboniferous complexes. It has been found that there is no hydraulic communication between the waters at use level and the waters located below. The upper hydrodynamic zone comprises the Quaternary and Upper Cretaceous aquifers down to a depth of approximately 170 m. Quaternary aquifers are bound with sand and gravels forming free water table levels. Quaternary waters are therefore exposed to anthropopressure, which can lead to changes in their chemical composition and physical properties as well as variations in water quantity. Ground waters at lower water levels are separated at a depth of 320-563 m from the first aquifer waters by an over layer of impermeable Cretaceous formations with a mining floor of approximately 250 m (Wilk ed. 2003, Porzycki & Zdanowski 1995).

The central hydrodynamic zone with a mining floor of about 830 m comprises formations from Jurassic. The aquifer forming a huge water reservoir in the roof of productive Carboniferous formation has a direct effect on flooding of mining excavations. Carbonate, fractured-porous, locally fractured karst rock formations are characterized by hindered water exchange in the hydrogeological profile and different water-bearing properties. Starting at a depth of about 1000 m, the lower hydrodynamic zone comprising water levels of older Paleozoic elements is contained in the range of the hydrodynamic stagnant zone. In the section of the productive Carboniferous aquifer Westphalian and Namurian formations occurred. The aquifers are beds of porous fractured sandstone. The hydrodynamic zonation of the Lublin Coal Basin is confirmed by hydrochemical zonation, which means that the total mineralization of waters increases with increasing depth. The higher mineralization and changes in ionic composition reflect the dip layers and regional water flow (Różkowski & Rudzińska-Zapaśnik 1987, Szczepański et al. 2007).

Due to safety reasons, waters from all aquifers, particularly the first and third ones, must be taken and drained from the excavation area. The water from water intakes around the mine is used for living and farming purposes. As a result, the safety requirements for mining works and coal production partly meet the demand for water of both the mine and nearby communities. More deeply located Jurassic formation waters are also a huge reservoir of very high quality waters which can be used for municipal purposes. The results of examination of the concentration of Jurassic waters demonstrate that these waters have the properties of curative mineral waters (Ciosmak 2002).

4. Results

The impact of the ”Bogdanka” mine on hydrosphere is connected with the drainage of deep-seated waters for correct operation of the mine. The mean annual inflow of water to the excavations in the Bogdanka mine is 14 000 $m^3 \cdot day^{-1}$ and the average total mineralization is 2100 $mg \cdot dm^{-3}$. Given the concentration of chloride and sulfuric ions, mine waters are classified as second class industrial waters. The hydrogeological study of the groundwater condition revealed that there exists insulation between individual aquifers located at different depths underground and the lack of water drainage from Jurassic Carboniferous rocks in the zone of coal seams exploitation to the Quaternary and Upper Cretaceous level. The results of regular analyses of radioactive substances in the inflowing mine waters also reveal that the concentration of Rad226 ranges to 0.174 $KBq \cdot m^{-3}$. The results of water radioactivity are stable and significantly below the tolerable limits (Ciosmak 2012).

Figure 1 shows the box plots illustrating the variations and scatter in the values of the selected physical and chemical parameters depending on 4 categories of waters: ground waters (piezometres), drinking waters (well), surface waters in the ditches and rivers.

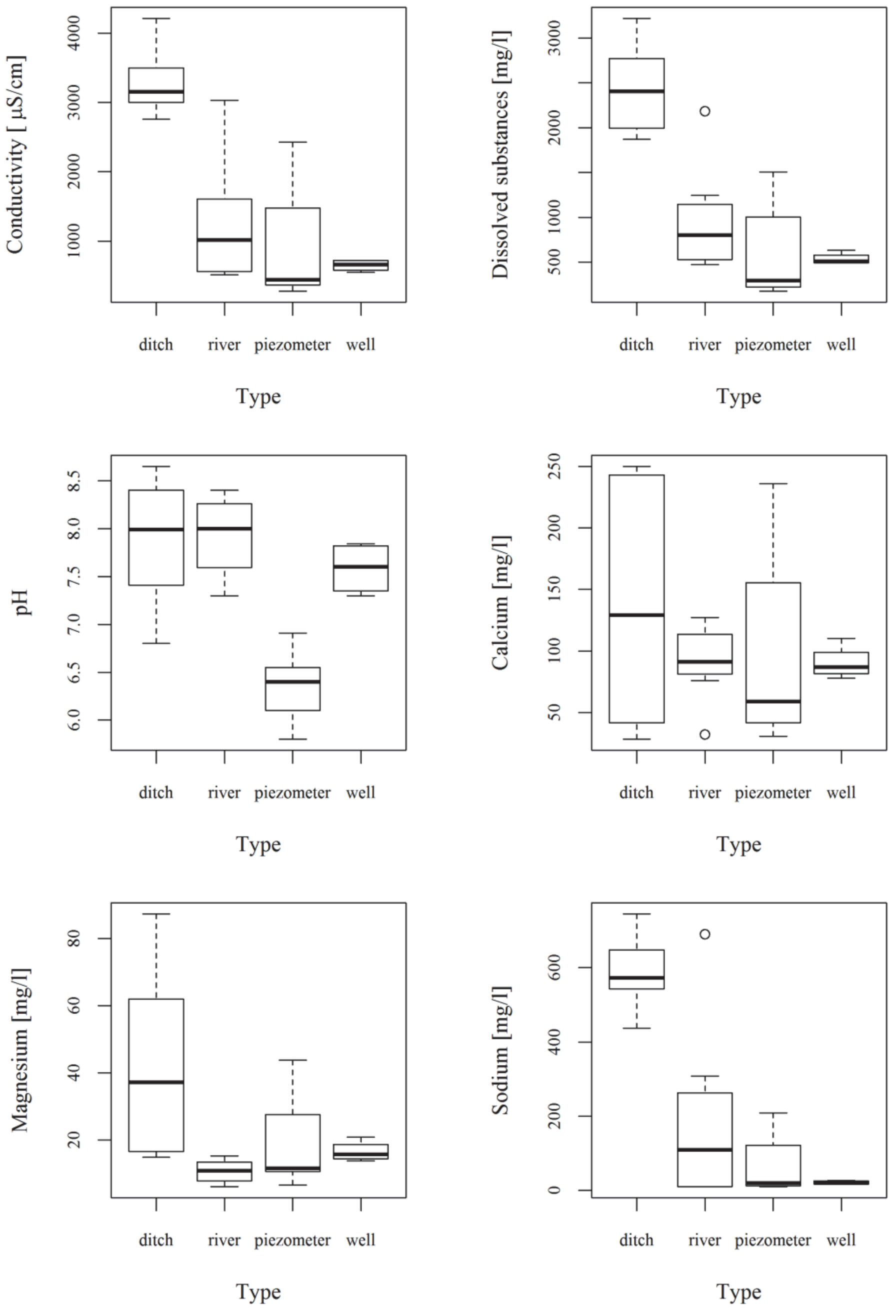
The highest conductivity was measured in a drainage ditch where it amounted average 3200 $\mu S \cdot cm^{-1}$. In turn, the lowest conductivity was measured in ground water where it amounted to 383 $\mu S \cdot cm^{-1}$. With regard to conductivity, ground water was included in quality class I and quality class II [Dz. U. 2016.85]. For surface water, the limit values are not determined [Dz. U. 2016.1187]. A similar situation can be observed for dissolved substances. The highest value dissolved substances was measured in drainage ditch where it amounted average 2400 mg·dm^{-3}. The lowest value measured in river, average 300 mg·dm^{-3}. For surface water, the limit values are not determined.

The highest average value pH was measured in a water feed. The lowest average electrolytic conductivity was measured in coal water. Ground water is characterized by neutral pH, whereas surface water is slightly alkaline. With regard to value pH alls water was included in quality class I. The highest average total hardness was measured in drainage ditch. The lowest average total hardness in ground water (Fig. 1). In terms of total hardness, all waters were classified as hard water.

The highest average value calcium was measured in drainage ditch, where it amounted 233 mg Ca^+·dm^{-3}. The lowest average value calcium was measured in ground water, where it amounted 57 mg Ca^+·dm^{-3} was included in quality class II. Surface water was included in quality class I. The highest value magnesium was measured in drainage ditch, where it amounted 68 mg Mg^+·dm^{-3}. The lowest value was measured in ground water, where it amounted 10 mg Mg^+·dm^{-3}. With regard to Mg^+ ground water was included in quality class I and II. Surface water was included in quality class I (river) or II (ditch). The highest value sodium was measured in drainage ditch, where it amounted 608 mg Na^+·dm^{-3}. The lowest value was in ground water, where it amounted average 17 mg Na^+·dm^{-3}. With regard to value Na^+ ground water was included in quality class I. For surface water, the limit values are not determined.

The highest value sulfates was measured in drainage ditch, where it amounted 1200 mg SO_4^-·dm^{-3}. The lowest value was measured in river, where it amounted 77 mg SO_4^-·dm^{-3}. With regard to SO_4^- ground water was included in quality class II [Dz. U. 2016 poz. 85]. Surface water was included in quality class I [Dz. U. 2016 poz. 1187]. The highest value chlorides was measured in water feed. The lowest value was in ground water (Fig. 1). With regard to Cl^- ground water was included in quality class III. Surface water was included in quality class I (river).

The highest value nitrates was measured in ditch, where it amounted 100 mg NO_3^-·dm^{-3}. The lowest value was in ground water (well). With regard value NO_3^- ground water was included in quality class I. For surface water, the limit values are not determined.


Conductivity [µS/cm]
1000
2000
3000
4000
Dissolved substances [mg/l]
500
1000
2000
3000
pH
6.0
6.5
7.0
7.5
8.0
8.5
Calcium [mg/l]
50
100
150
200
250
Magnesium [mg/l]
20
40
60
80
Sodium [mg/l]
0
200
400
600
ditch
river
piezometer
well
Type

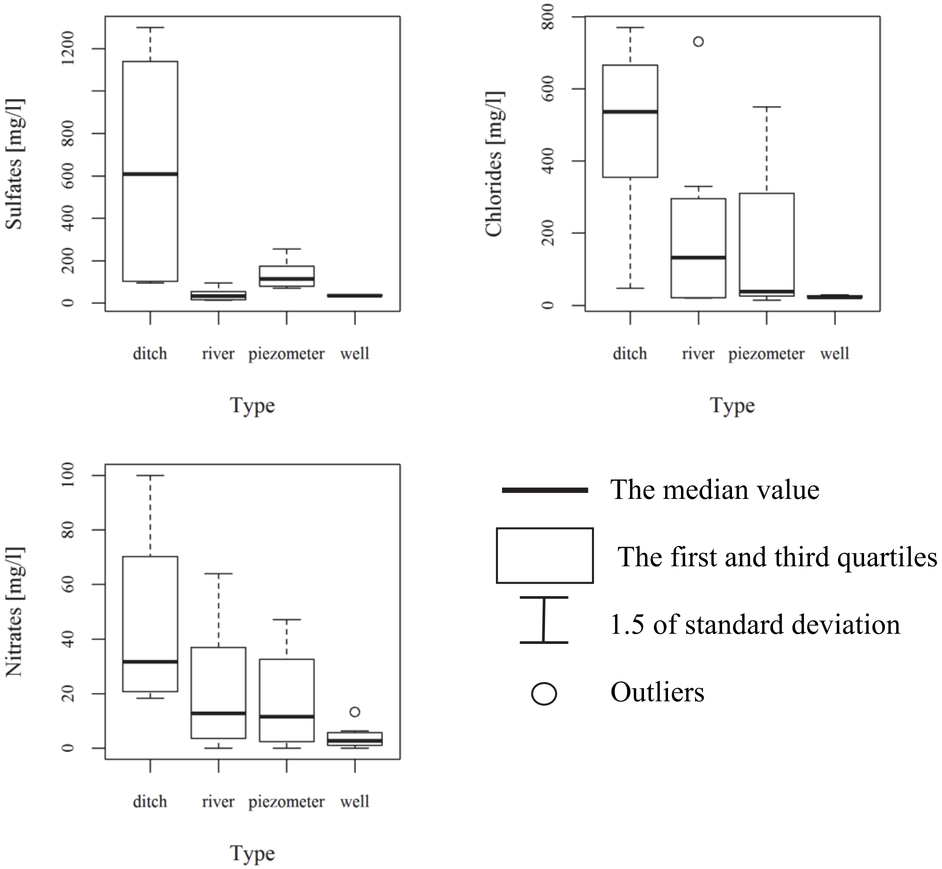


Fig. 1. Box plots comparing the selected parameters for types of water
Rys. 1. Wykresy pudełkowe wybranych parametrów dla rodzajów wód

The results of statistical analysis point to significant differences between both the types of water (except of calcium) and no differences in the measurements (except pH value) (Tab. 1). The highest concentrations of analysed pollutants were recorded most frequently in the drainage ditch, and the lowest in ground water. The situation was different for pH value and nitrates. In the case of pH the highest values were recorded in water feed. In the case of nitrates the highest values were recorded in river and the lowest in water feed. The highest pH value and the lowest concentration of nitrates in water feed is a result of the fact that the water was drained from protected areas with a very low level of use. The high quality of the water from the ditches may be due to the small quantity and weak flow of water.

Table 1. p-values of chemical parameters obtained from the Freidman test by water type and measurements
Tabela 1. Wartości testu Friedmana dla parametrów chemicznych wg rodzaju wód i pomiarów

Parameter	Type	Value
Conductivity	0,0074 *	0,8254
pH	0,0129 *	0,0336 *
Total hardness	0,0256 *	0,3080
Calcium	0,0576	0,9600
Magnesium	0,0256 *	0,4402
Sodium	0,0074 *	0,5519
Nitrates	0,0440 *	0,0503
Sulfates	0,0112 *	0,6149
Chlorides	0,0129 *	0,2725
Dissolved substances	0,0112 *	0,3916

* statistically significant differences

5. Conclusions

The results of this study together with the examination of water and sewage management enable assessment of physical and chemical indicators describing waters in the mining area in the Lublin Coal Basin. The rate of changes in these indicators is best illustrated by the way in which surface waters react in contact with mine waters (Michalczyk et al. 2007, Staniszewski & Jusik 2013).

Although one can observe changes in the examined parameters describing the quality of the river Świnka waters, it must be stressed that the significant increase in mining activity had no effect whatsoever on its water quality. The increase in chemical concentrations in mine waters drained to the river are not so high as to cause irreversible changes in this ecosystem. This is shown by a rapid (after a distance of 1 km) return of water quality in the river to the pre-drainage condition. Comparing their current state to the beginning of mining activity in the Lublin Coal Basin, the majority of mine water indicators show stability (Ciosmak 2012). The observed single increases in concentrations do not remain fixed. The actions applied for environment protection are effective.

Waters taken from the piezometers, the well and the river were classified as second class water quality, while the waters from the land improvement ditches did not meet these criteria (there are no standards for lower classes). The highest quality was observed for groundwater, which is often classified as second class quality. This means that the aquifers provide good insulation and are not affected by the Bogdanka mine's activity.

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Wpływ wód z odwodnienia kopalni węgla kamiennego na jakość wód powierzchniowych i gruntowych

Streszczenie

Ocenę wpływu wód kopalnianych na właściwości fizyczne i chemiczne wód powierzchniowych i gruntowych prowadzono w 2014 i 2015 roku na terenie Lubelskiego Zagłębia Węglowego. Pobierano 2 razy co roku próbki wody do analiz właściwości fizykochemicznych. Próbki wody pobierano z piezometrów, studni, rowów melioracyjnych oraz rzeki Świnki. Analizie poddano następujące parametry: pH, przewodność, substancje rozpuszczone, twardość ogólna, wapń, magnes, sód, azotany, siarczany i chlorki. Badane wskaźniki poddano nieparametrycznej analizie Friedmana (ANOVA) dla powtarzanych pomiarów przy użyciu oprogramowania Statistica.

Przeprowadzane badania oraz analiza gospodarki wodno-ściekowej, pozwalają na ocenę parametrów fizykochemicznych wód w obszarze prowadzonej eksploatacji w Lubelskim Zagłębiu Węglowym. Najlepszą oceną intensywności

zmian parametrów może być to, w jaki sposób środowisko wód powierzchniowych, odpowiada na kontakt z wodami kopalnianymi.

Wody podziemne charakteryzowały się niskimi wartościami wskaźników chemicznych. Wody pitne ze studni we wszystkich przypadkach zaliczane były do I klasy jakości. Wody gruntowe z piezometrów były najczęściej zaliczane do II klasy jakości. Maksymalne wartości przewodności nie przekraczały 2500 $\mu S \cdot cm^{-1}$, zaś substancji rozpuszczonych 1500 $mg \cdot dm^{-3}$. Jedynie w przypadku wapnia i chlorków zdarzały się przypadki zaliczenia wody do III klasy jakości. Maksymalne wartości wapnia wynosiły 2500 mg $Ca^{+} \cdot dm^{-3}$, zaś chlorków 300 mg $Cl \cdot dm^{-3}$. Woda w rzece charakteryzowała się wartościami parametrów zbliżonymi do wody podziemnej. Pozwalało to zaliczyć ją do II klasy jakości (wartość graniczna przewodności wynosi 2000 $\mu S \cdot cm^{-1}$, zaś substancji rozpuszczonych 1000 $mg \cdot dm^{-3}$. Odmiennie sytuacja wyglądała w przypadku wody z rowów. Wartości wskaźników jakości wody były tu nawet trzykrotnie wyższe niż w rzece. W tym przypadku zostały przekroczone wartości graniczne dla II klasy jakości, a dla pozostałych klas ich się nie wyznacza.

Dają się zaobserwować zmiany w analizowanych głównych parametrach jakościowych wód rzeki Świnki, jednak znaczne zwiększenie intensywności wydobycia nie wpłynęło na jakość. Podwyższone stężenia składników wód kopalnianych, jakie spływają do rzeki, nie są jednak o tak dużych wartościach, aby doszło do nieodwracalnych zmian w tym ekosystemie. Świadczy o tym szybki powrót jakości wód w tej rzece do stanu sprzed miejsca zrzutu. Większość parametrów wód kopalnianych, porównywanych od początku istnienia kopalni ze stanem obecnym, wykazuje stabilność. Obserwowane pojedyncze wzrosty stężeń nie ulegają utrwaleniu. Wodę pochodzącą z piezometrów, studni i rzeki zakwalifikowano do drugiej klasy jakości, zaś woda z rowów nie spełnia tych parametrów. Najwyższą jakości charakteryzują się wody gruntowe zaliczane najczęściej do pierwszej klasy czystości. To wskazuje na dobrą izolację warstw wodonośnych i brak wpływu na nie działalności kopalni.

Abstract

The effect of mining waters on the physical and chemical properties of surface and ground waters was evaluated in 2014 and 2015 within the Lublin Coal Basin. Samples of water for physicochemical analyses were taken twice a year. Water was sampled from piezometers, wells, drainage ditches and from the river Świnka. The following parameters were analyzed: pH, conductivity, dissolved substances, general hardness, calcium, magnesium, sodium, nitrates, sulphates and chlorides. The examined indicators were subjected to Friedman's nonparametric univariate analysis (ANOVA) for measurements repeated using the Statistica software.

The tests and analysis of water and sewage management make it possible to evaluate the physicochemical parameters of waters within the mining area in the Lublin Coal Basin. The best measure of the intensity of parameter changes can be the response of the surface water environment to contact with mining waters.

Underground waters featured low values of chemical indicators. Drinking water drawn from wells in all cases was classified as quality class I. Ground waters sampled from piezometers were most often classified as quality class II. The value of maximum conductivity did not exceed 2500 $\mu S \cdot cm^{-1}$, while that of dissolved substances, 1500 $mg \cdot dm^{-3}$. Only with regard to the content of calcium and chlorides were some cases of water quality class III recorded. The maximum value for calcium was 2500 mg $Ca^{+} \cdot dm^{-3}$, while for chlorides this was 300 mg $Cl \cdot dm^{-3}$. Water in the river featured parameter values similar to those recorded for underground water. Therefore, it could be included in quality class II (the limit value for conductivity is 2000 $\mu S \cdot cm^{-1}$, for dissolved substances 1000 $mg \cdot dm^{-3}$). The situation was different for water sampled from ditches. Here, water quality indicators were even three times higher than in the river. In this case the limit values for quality class II were exceeded. Such limit values are not determined for other classes.

Can observe changes in the examined parameters describing the quality of river Świnka waters, it must be stressed that the significant increase in mining activity had no effect whatsoever on its water quality. The increase in chemical concentrations in mine waters drained to the river are not that high so as to cause irreversible changes in this ecosystem. This is proved by a fast return of water quality in the river to the pre-drainage condition. Comparing their current state to the beginning of mining activity, the majority of mine water indicators show stability. The observed single increases in concentrations do not remain fixed. Waters taken from the piezometers, the well and the river were classified as second water quality, while the waters from the land improvement ditches did not meet these criteria. The highest quality was observed for groundwater which is often classified as Type I water quality. This means that the aquifers provide good insulation and are not affected by the Bogdanka mine's activity.

Keywords:
chemical indicators, water inflows, Lublin Coal Mine

Słowa kluczowe:
wskaźniki chemiczne, dopływ wody, Lubelskie Zagłębie Węglowe