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ESTIMATING THE WATER POLLUTION IN POTOK GOŁAWIECKI, POLAND, BASED ON SELECTED WATER QUALITY INDICATORS

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Abstract: Potok Goławiecki (a river in the province of Silesia) is polluted in a way typical for the Upper Silesian industrial zone. It is the river into which the Ziemowit coal mine discharges its salt waters and it also receives municipal sewage. Changes in the values of selected indicators of water quality for Potok Goławiecki along its course were determined in the paper. It was found that the hydrochemical character of the water in Potok Goławiecki depended strongly on salt water discharges from mines, which were the main factor disturbing the river's natural environment. The pollution of the river makes its water non-potable, and excludes its use even in industry.

INTRODUCTION

Human economic activity affects on water ecosystems by changing a wide range of physical and chemical indicators of water quality. It also changes species composition and the populations of plant and animal organisms. Additionally, heavy pollution of rivers makes the intensity of natural self-purification processes weaker. Mines have a significant impact on water quality in Polish rivers as they discharge salt waters into them. Different chemical substances occurring in mine waters pollute the natural environment and act negatively on Polish economy. The discharged waters carry large amounts of chlorides, sulphates and suspended matter. The waters are strongly mineralized, and, in addition, they contain other substances (e.g. lubricants, phenols) that pollute the waters during the coal mining process [3, 5, 7, 16]. In recent years, coal mining has declined, and many initiatives have been introduced in order to lower the volume of waters pumped out as well as to increase their usability and reduce their toxicity, e.g. by water desalination [10], or pumping waters containing dust and other mining wastes into exploitation pits. However, the volume of mine waters discharged into rivers is still considerable.

The problem of pollution made by mine waters is encountered in many countries (e.g. [9, 12, 17]), but the specific feature of Polish coal mines is their geographical location, due to which the main Polish rivers are already being polluted at their upper courses. It is worth emphasizing that Poland is relatively poor in terms of fresh water resources per capita – approximately 1/3 of the overall European average. According to [1], about 35% of all water used in Poland is taken directly from the Vistula River, and if one includes its basin – about 60%. Much less water is taken from the Oder River. The coal mines located in the Vistula basin discharge their mine waters either directly into the Vistula or through the catchments of the following three left tributaries of the Vistula: the Gostynka, Potok Goławiecki and the Przemsza. The Ziemowit coal mine discharges its mine waters into Potok Goławiecki (PG). The disposal of contaminated water in this way, which is typical for Upper Silesia, induces characteristic changes in the PG's water quality.

This paper presents the results of hydrochemical investigation performed on the PG's water in 2005. The aim of the investigation was to determine linear changes in selected water quality indicators, and thus show the current state of the PG's water environment.

STUDY AREA

The PG's basin, which is located in the southeast of the Upper Silesian industrial zone and belongs to the Vistula catchment, has an area of 37.7 km^2. The PG rises at sources located near the Ziemowit coal mine (in the area of the Lędziny Mining Region), from where it flows towards the south (Fig. 1). The source area is situated 260 m above s.l. The land is slightly folded and hilly with the PG valley clearly visible. At the level of Kopciowice,

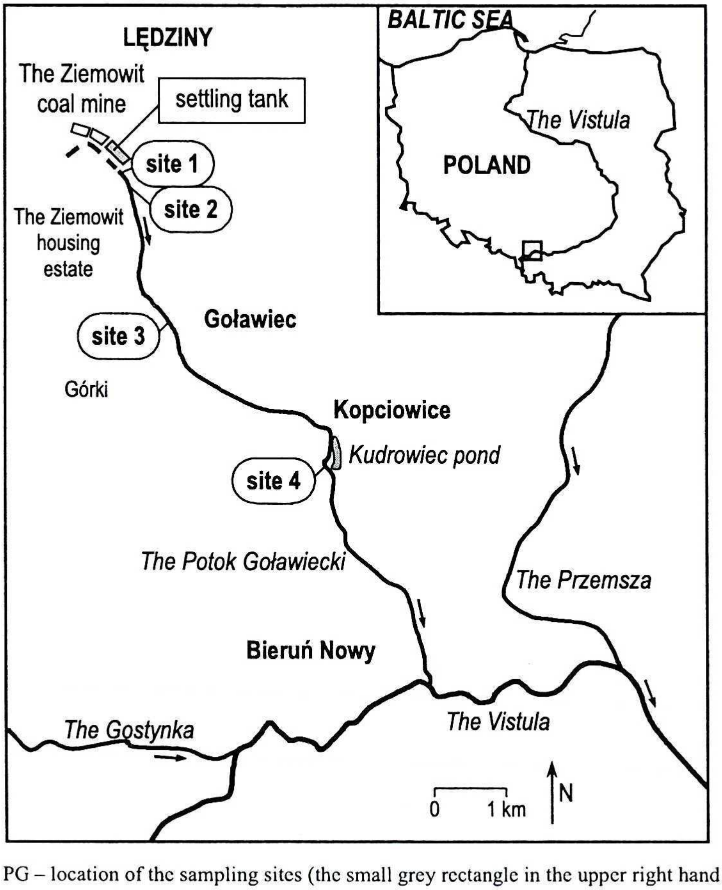

Fig. 1. The PG – location of the sampling sites (the small grey rectangle in the upper right hand corner shows the location of the PG in Poland)

the PG valley joins the Potok Mąkołowski valley, from which it is separated by a ground elevation at the upper course. To the east, the PG basin is bounded by a range of heights: the Chełmskie Height 286 m above s.l., which links through a wide valley with the Imielińskie Height 284 m above s.l in the south. The valleys, which run mainly southwards, have a varying gradient: about 0.5 m per 1 km at the headstreams, and lower the closer one gets to the river-confluence with the Vistula. According to the hydrographic division, the PG's length is 9.5 km and its width ranges from 3 to 5 m. The PG flows into the Vistula at Bieruń Nowy. The PG's riverbed is controlled by a man-made stone bed in its upper course, but it becomes natural below the 4th kilometer. The coal mine discharges its mine waters from exploitation pits into the headstreams, which also collect rain waters and domestic sewage. The characteristic flows of the PG's water at the cross-section ending its catchment, including water intake and sewage discharge, are as follows [14]:

– mean annual flow (MAF) – 0.264 $m^3\ s^{-1}$,
– mean low-water flow (MLF) – 0.105 $m^3\ s^{-1}$.

METHODOLOGY

The investigation lasted from June until December 2005. During the investigation seven series of water samples were taken (once a month) from four sites (Fig. 1), which were located along the upper (site 1), middle (sites 2 and 3) and lower (site 4) course of the PG. The sites were located in accordance with Council Directive 79/869/EEC [2]. The sampling sites were as follows:

– Site 1 was located about 5 m below the runoff from the Ziemowit's salt water settling tank, from which water is discharged directly into the PG. In fact, the PG begins its apparent course at the level of the runoff (so far it flows under ground), and therefore it was not possible to take samples above the runoff. The mine pumps all the salt water from mining levels II (500 m) and III (650 m) into the tank. The waters occurring at the two levels are classified mainly as meanly salted (containing 1.8–42 g dm^{-3} of Cl^- and SO_4^{2-} ions). The waters are discharged into the settling tank at a rate of 17 $m^3\ min^{-1}$ in order to remove suspended matter from them.
– Site 2 was situated near Ziemowit Street. The Ziemowit treatment plant discharges sewage between sites 1 and 2, and in addition waters from the pumping station located in Ziemowit Street are discharged there.
– Site 3 was situated near Folwarczna Street, where the river flows through meadows and pastures.
– Site 4 was chosen near Kudrowiec pond in Leśna Street. Sewage from Chełmno and Kopciowice is discharged into the river between sites 3 and 4.

The water samples were taken using a Patalas sampler in synchronization with the river flow time. The speed of water flow was measured by a HEGA-1 hydrometric current meter. The speed measurement was performed before every sampling series. The values of water flow speed varied from 0.25 to 0.52 $m\ s^{-1}$. The volume of flowing water was also determined in the most important tributaries of the investigated river stretch: from the Ziemowit treatment plant, from Kudrowiec pond, and form the pumping station in Górki. Water samples were taken from each site in order to determine water temperature, dissolved oxygen, pH and turbidity – the measurement of the above mentioned indicators was done immediately on site using a HORIBA U-22.23 probe. Other chemical determinations were completed in the laboratory, using generally applied methods and in accordance with obligatory standards [8]. The concentrations of suspended matter, sulphate(VI) ions and dissolved substances were determined using a gravimetric method in compliance with PN-74/C-04541, the concentration chloride ions was determined using an argentometric method in accordance with PN-74/C-04566/09. Biochemical oxygen demand (BOD) was determined using an oxygen probe after 5 days of incubation at a temperature of 20°C, and chemical oxygen demand (COD) was detected using a dichromatic method in accordance with PN-74/C-04578/03. The results presented in the paper are the arithmetic mean from five measurements. The figures show the mean values of an indicator for the four sampling sites described above.

RESULTS AND DISCUSSION

Changes in the PG's water temperature during the investigation time are presented in Figure 2. The highest temperature (25.4°C) was observed in July, but in Septe mber the temperature fell to 11°C. However, in October it rose to 18°C. Over the next months it decreased, falling to 7°C in December. The changes in water temperature are caused by atmospheric conditions as well as the water inflow from Kudrowiec pond.

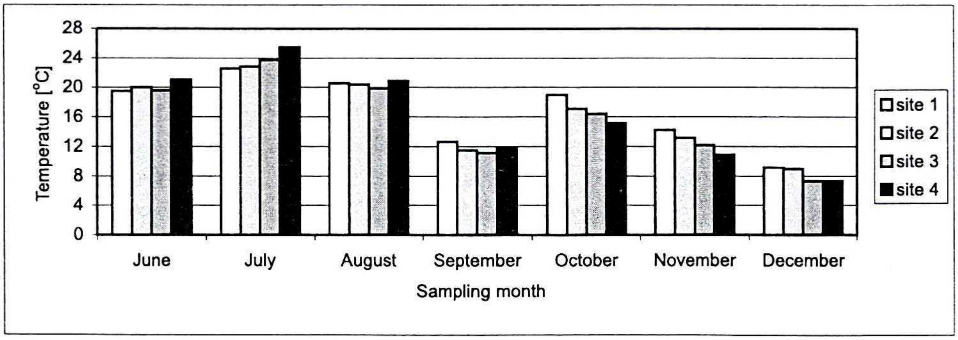

Fig. 2. Changes in the PG's water temperature

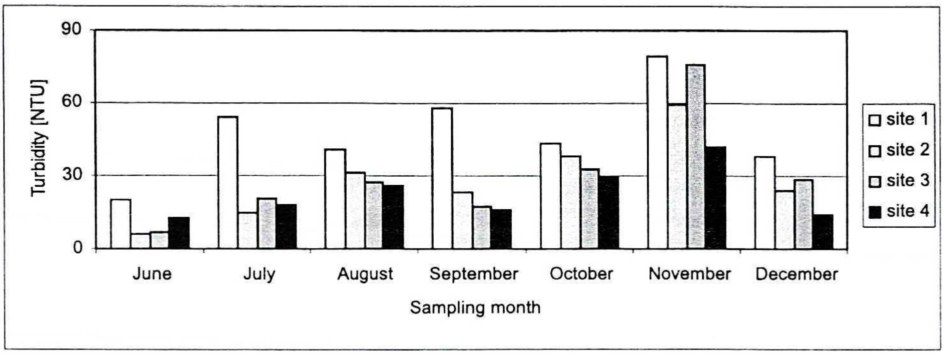

Fig. 3. Changes in turbidity in the PG's water

Changes in the PG's water turbidity are shown in Figure 3. The turbidity values varied from 5.9 NTU in June to 79.4 NTU in November. The highest value was observed in late autumn, and the lowest (5.8–6.4 NTU) was detected in June at sites 2 and 3. Throughout the investigation the highest turbidity values were found at site 1, where the waters from the settling tank were discharged into the river. Water turbidity determines the concentration of small suspended or colloidal particles, which can come from clay, silts and aluminosilicates, occurring in the mine waters. Owing to the small sizes of the particles, they hardly settle, remaining in the water discharged into the PG.

It can be observed that the turbidity values tend to decrease further down the river course. This implies that some suspended particles in the PG's water are deposited. Increases in turbidity (in relation to the values from a higher site) which are observed in some cases (e.g. June – site 4, November – site 3) may be caused by surface down flows from ploughed fields as well as by rainfalls.

There was minor variation in pH values, with results falling into a range between water cleanliness classes I–III (from pH = 6.7 to pH = 7.6). The pH values did not change rapidly – this can be explained by the big buffering capacity caused by a high concentration of dissolved oxygen and also by high water hardness.

Changes in dissolved oxygen concentrations in the PG's water are presented in Figure 4. Dissolved oxygen concentration in the river's water varied from 3.5 to 11.9 mg O_2 dm^{-3}. The highest values were observed in late autumn (6.7–11.9 mg O_2 dm^{-3}), but in July and August the concentration fell to 3.6 mg O_2 dm^{-3}. The lower concentration of dissolved oxygen determined in summer is connected with higher water temperature, at which oxygen solubility in water is lower. The dissolved oxygen concentration is much lower than its solubility in water (at a given temperature). This results from the high salinity of the PG's water caused by mine waters. They contain about 30 g dm^{-3} of Cl^- and SO_4^{2-} ions (Tab. 1), which makes oxygen solubility about 1–2 mg O_2 dm^{-3} lower. It is noticeable that the dissolved oxygen concentration is lower at site 1, where the PG's waters have direct contact with those from the mine. The investigation results show that dissolved oxygen concentration rises along the river course, with a few exceptions. Particularly, a considerable growth in the concentration can be seen at site 4 in relation to site 3. The oxygenation occurring between sites 3 and 4 probably results from the mixing the PG's waters with those flowing from Kudrowiec pond.

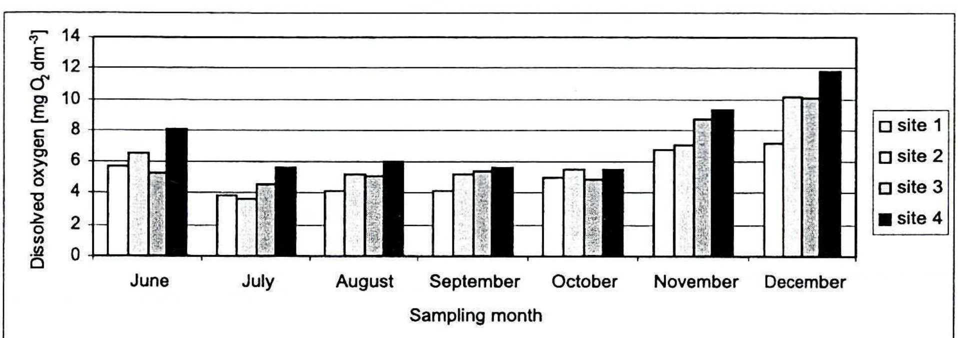

Fig. 4. Changes in dissolved oxygen concentrations in the PG's water

Changes in suspended matter concentrations are shown in Figure 5. The values of the concentration varied from 28 to 119 mg dm^{-3}. The highest values were found in the upper course (site 1), especially during the period from August till November. The investigations performed at the other sites showed that the concentration tended to fall with the river course, except for August and October, when a growth in the concentration is visible at site 4. This growth is probably the result of heavy rain. Generally, higher concentrations of suspended matter were observed in autumn and winter along the river's stretch between sites 2 and 4, while in summer the concentration values at site 4 were about 50% less than at site 1.

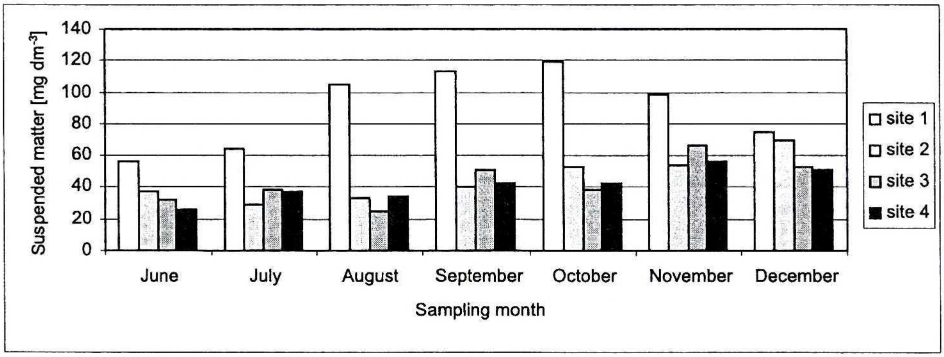

Fig. 5. Changes in suspended matter concentrations in the PG's water

Changes in the concentration of organic compounds susceptible to aerobic biodegradation on an example of BOD_5 are shown in Figure 6. The values of BOD_5 varied from 4.2 mg O_2 dm^{-3} in June to 18.3 mg O_2 dm^{-3} in November. Over the whole investigation period the BOD_5 values varied considerably. From August till December relatively high values of BOD_5 were observed, especially at sites 3 and 4 (7.1–18.3 mg O_2 dm^{-3} and 8.3–15.5 mg O_2 dm^{-3}, respectively). Discharges of mine water did not increase the BOD_5 values in the river's water, since at site 1 the BOD_5 values were much lower (4.2–9.7 mg O_2 dm^{-3}) than the values found at the other sites. It is noticeable that the BOD_5 values rise with the river course.

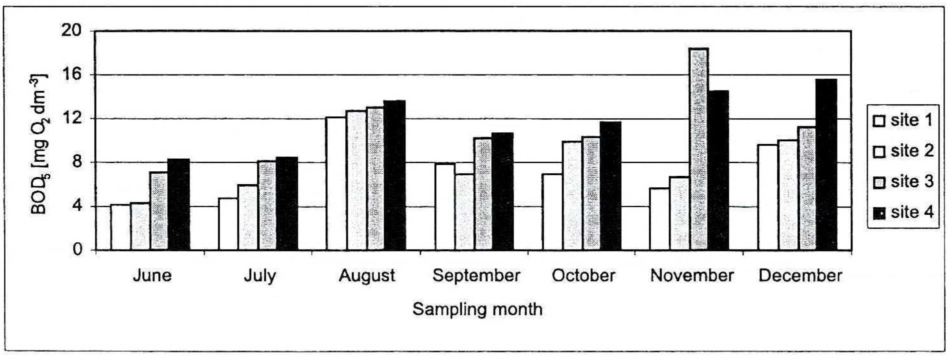

Fig. 6. Changes in BOD_5 values in the PG's water

Changes in the concentration of organic compounds expressed by COD are presented in Figure 7. Over the whole investigation period the highest values of COD were detected at site 1 (40–128 mg O_2 dm^{-3}). From September till December an increase in the indicator value is visible at the site. In November, the COD value rose to 128 mg O_2 dm^{-3}. At the other sites the COD values, like the BOD ones, oscillated irregularly. However, it is noticeable that the COD values tended to fall with the river course. At site 2 the COD values varied from 28 to 68 mg O_2 dm^{-3}, and at site 3 – from 24 to 60 mg O_2 dm^{-3}. At the last sampling site the oscillation range of COD values was the smallest – from 25 to 52 mg O_2 dm^{-3}.

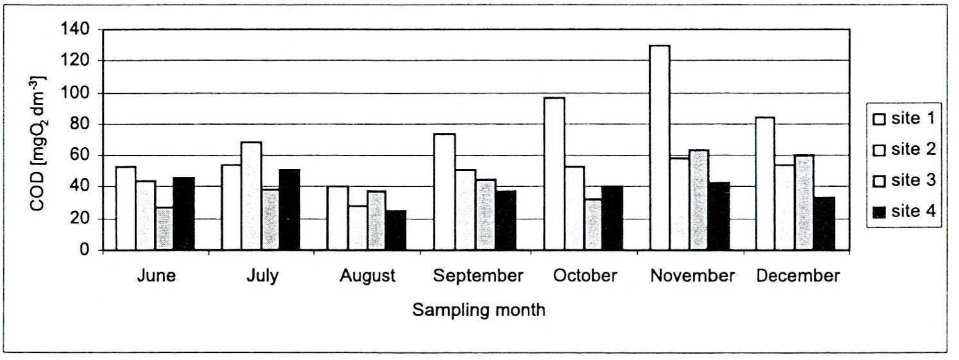

Fig. 7. Changes in COD values in the PG's water

Changes in concentrations of chloride ions, sulphate(VI) ions and dissolved substances are shown in Table 1. Values of the concentrations varied from 15 to 35 g Cl^- dm^{-3} for chlorides, from 0.59 to 1.88 g SO_4^{2-} dm^{-3} for sulphates(VI), and from 26 to 57 g dm^{-3} for dissolved substances. Such high concentrations of the compounds are typical for sea-water. They exceed the concentration limits permitted for fresh waters many times. At site 1 the PG's water mineralization is high, but it falls slightly at next sites because of the PG's tributaries, in which the water is less mineralized. During the investigation period the lowest concentrations of chloride ions, sulphate(VI) ions and dissolved substances were observed in autumn, when the most intensive rainfalls occurred. Such high values of the concentrations show how strongly the mine waters affect the PG.

Table 1. Values of the PG's water flow and the concentrations of chloride ions, sulphate(VI) ions and dissolved substances in the PG's water

Site	Flow min – max, m^3 s^{-1}	Concentration min – max / average [g dm^{-3}]		
		chlorides	sulphates(VI)	dissolved substances
1	0.274 – 0.343	27.8 – 35.1 32.3	0.96 – 1.88 1.64	49.3 – 56.7 53.3
2	0.373 – 0.498	19.9 – 26.5 24.0	1.20 – 1.53 1.35	34.2 – 45.9 41.3
3	0.413 – 0.565	18.1 – 24.5 21.3	1.05 – 1.38 1.22	31.2 – 42.1 36.7
4	0.485 – 0.770	14.9 – 21.6 18.0	0.59 – 1.28 0.99	25.6 – 37.3 30.9

The hydrochemical investigation results showed that the PG's water is polluted by industrial sewage all along its course. The concentrations of dissolved substances, chloride ions, sulphate(VI) ions and suspended matter in the PG's water is determined by the salt waters discharged from the Ziemowit coal mine. This conclusion is confirmed by changes in the concentrations along the river course during the investigation period. The highest values of the indicators mentioned above were observed at site 1, just below the point where the most salted mine waters flow into the PG. Near Chełmno and Kopciowice (sites 3 and 4) the concentrations of chlorides, sulphates(VI) and dissolved substances fell because of dilution by the PG's tributaries. The measured values of these three indicators put the river's water in cleanliness class V as defined by Ministry of the Environment [4]. The large volume of the discharged waters in relation to the PG's MLF means that it is impossible not to exceed the permitted concentrations of chlorides and sulphates(VI) in the PG's water. Assuming the PG's MAF equals 0.298 $m^3 s^{-1}$ it follows that 2.5 Mg d^{-1} of suspended matter enter the PG, which gives 912.5 Mg y^{-1}. As for chloride and sulphate(VI) ions, about 850 Mg d^{-1} (310 250 Mg y^{-1}) on average is fed into the river. The concentration of mineral salts is reflected in the euhalic salinity degree of the PG's water [11, 13].

Suspended matter concentrations and turbidity at site 1, which is directly influenced by the discharged mine waters, was evidently higher than at the other sites. The turbidity of the PG's water is caused mainly by the mineral particles occurring in the mine waters discharged into the river [6]. This is caused by the intensive surface flow in the settling tank induced by temperature differences between the water in the tank and the mine water flowing into it. The mine water just delivered into the tank has a higher temperature and a lower density than the water already in the tank, so it remains in the upper layers, and then after a relatively short time it flows out of the tank. In effect, the water is retained for too short a time for suspended matter sedimentation to occur efficiently. The measured concentrations of suspended matter matched water cleanliness classes III and IV, except for the river stretch 1–2, where the observed concentrations placed the PG's water in cleanliness class V.

Despite the high salinity and high values of COD, all the performed analyses showed the presence of relatively large amounts of dissolved oxygen. The lowest values of this indicator were found in summer. Dissolved oxygen concentration is a function of water temperature, any increase in which limits the solubility of oxygen in water. Currently, no phenomena that lead to oxygen supersaturation or depletion have been detected in the investigated ecosystem. The oxygen concentrations varied across the range of limits suitable for water cleanliness classes II, III and sometimes IV.

Analysis of the water samples taken also showed the presence of organic pollutants. Average COD value was equal to 75 mg O_2 dm^{-3} at site 1 and about 42 mg O_2 dm^{-3} at the other sites. The values of COD put the river's water in cleanliness class IV, except for the stretch 1–2 (cleanliness class V). The BOD_5 values increased along the river course as a result of municipal sewage inflow. The average value of BOD_5 was equal to 5.8 mg O_2 dm^{-3} at site 1 and about 9.5 mg O_2 dm^{-3} at the other sites. The indicator values put the river's water in cleanliness class V, and on the river's stretch 1–2 only – in cleanliness class III. However, the concentration of organic compounds susceptible to biodegradation is low, so the autopurification processes are insufficient to purify the PG's water.

The detected concentrations of chlorides and sulphates, which exceed the values of acute toxicity for some organisms, allow very few species of flora and fauna to exist in the PG. Environmental conditions in the polluted PG have to be estimated as very unfavorable for the formation of living organism assemblages [15].

CONCLUSIONS

1. The values of the investigated indicators of water quality confirm the anthropogenic impact of Ziemowit mine waters on the PG's waters.
2. Hydrochemical character of the PG's water is co-formed by mine water discharges that contribute to disturbing the PG's natural water environment. The pollution of PG's water makes the water unpotable, and even excludes its use in industry.
3. The PG is also polluted by municipal sewage discharged from nearby housing estates, which is confirmed by higher concentrations of BOD_5 and COD at sites 3 and 4.
4. To improve the river's water quality it is necessary to decrease the amount of pollutants brought into the river by the mine waters. This can be achieved by improving the water management and sewage disposal of the Ziemowit coal mine, and specifically, by removing mineral and carbonic suspended matter in the process of mine water purification. As for the removal of mineral compounds, this requires special methods and is connected with constructing a mine water desalination station.

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kosztów i zysków dla wytypowanych możliwości alternatywnych rozwiązań problemu zasolonych wód kopalnianych z Nadwiślańskiej Spółki Węglowej, Instytut Ekologii Terenów Uprzemysłowionych, Katowice 2000.
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OCENA ZANIECZYSZCZEŃ WODY POTOKU GOŁAWIECKIEGO NA PODSTAWIE WYBRANYCH WSKAŹNIKÓW JAKOŚCI WODY

Potok Gołowiecki (województwo śląskie) jest zanieczyszczony w sposób typowy dla Górnośląskiego Okręgu Przemysłowego. Jest on odbiornikiem rzutowych wód dołowych kopalni „Ziemowit" oraz ścieków komunalnych. W pracy określono zmiany wybranych wskaźników jakości wody Potoku Goławieckiego wzdłuż jego biegu. Stwierdzono, że charakter hydrochemiczny wody rzeki jest współkształtowany przez zrzuty wód kopalnianych, które przyczyniają się do zakłócenia jej naturalnego reżimu wodnego. Zanieczyszczenie wody tego odbiornika eliminuje możliwość jej wykorzystania do celów pitnych, a nawet przemysłowych.