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IMPACT OF LIGNITE MINE WATERS FROM DEEP SEATED DRAINAGE ON WATER QUALITY OF THE NOTEĆ RIVER

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Abstract

Open-pit lignite mines affect many compartments of the environment. Surface mines cause changes in the catchment basin, re-shaping the land relief, modifying soil properties and depressing lake water levels as well as the groundwater table. Although the environmental concerns raised by this type of mines have been widely surveyed, we lack sufficient information provided by research reports on regarding the influence of lignite mines there on surface water bodies. In general, there are two types of mine waters from brown coal mining: runoff from the surface and water percolating from deep seated drainage. This paper discusses the impact of lignite mine waters from a deep seated drainage system in the Lubstów Mine on the quality of water in a lowland river. Lignite had been excavated in Lubstów until 2009, and untreated mine waters had been discharged to the Noteć River. The aim of the study was to assess possible changes of the river water quality after the long-term contamination with mine waters. For the assessment, three sites were selected (one above and two below the mine water inflow) for water sampling in order to perform chemical analyses according to standard methods (spectrophotometry, atomic absorption spectroscopy). Properties of mine waters, such as pH, conductivity, phosphorus, nitrates, sulphates, alkalinity and heavy metals, were analysed in samples taken directly from the canal which carried discharged mine waters to the Noteć River.

The results showed that lignite mine waters from deep seated drainage generally caused minor changes in river water quality, except alkalinity, in which the water quality below the discharge point (site B) was significantly worse than at the upper site (A). Chemically, site C was similar to site A.

Key words: Noteć River, mine waters, lignite, Kujawskie Lakeland, freshwater quality.

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WPŁYW WÓD KOPALNIANYCH Z ODWODNIENIA GŁĘBINOWEGO ODKRYWKI WĘGLA BRUNATNEGO NA JAKOŚĆ WÓD NOTECI

Abstrakt

Odkrywki węgla brunatnego oddziałują na wiele aspektów środowiska. Kopalnie odkrywkowe wpływają na zmiany zachodzące w zlewni, w tym na strukturę krajobrazu, zmiany w otaczających odkrywkę glebach, obniżanie lustra wód jeziornych oraz gruntowych. Zagadnienia te były wielokrotnie badane, jednak w przypadku oceny wpływu wód kopalnianych na jakość wód rzecznych zakres tych prac nie był szeroki i trudno znaleźć większą liczbę znaczących pozycji literaturowych. Zasadniczo wyróżniane są 2 typy wód kopalnianych z odkrywek węgla brunatnego: wody z odwodnienia powierzchniowego oraz wgłębnego. W pracy zaprezentowano wyniki badań nad wpływem wód kopalnianych z odwodnienia wgłębnego odkrywki węgla brunatnego Lubstów na wartości wskaźników jakości wód rzeki Noteci. Pozyskiwanie węgla z odkrywki Lubstów trwało do 2009 r., a badane wody kopalniane zgodnie z wymogami środowiskowymi odprowadzano do rzeki bez oczyszczania. Celem badań było określenie możliwych zmian jakości wody po kilku latach zrzutu. Wskaźniki jakości wody analizowano na 3 stanowiskach (1 powyżej zrzutu – stanowisko A, 2 poniżej zrzutu – B i C), stosując standardowe metody (spektrofotmetrię, absorpcyjną spektrometrię atomową). Wody kopalniane oceniano na podstawie prób pobranych bezpośrednio z kanału zrzutowego. Określono większość istotnych wskaźników jakości wody, takich jak odczyn pH, przewodność elektrolityczna, stężenia fosforu, azotu azotanowego, siarczanów, metali ciężkich, alkaliczność itp.

Wykazano nieznaczny wpływ wód kopalnianych z odwodnienia wgłębnego na jakość wód Noteci. Jedynie w przypadku alkaliczności zaobserwowano istotną zmianę bezpośrednio poniżej zrzutu z odkrywki (stanowisko B). W punkcie oddalonym o 1 km od zrzutu wód kopalnianych (stanowisko C) jakość wód była zbliżona do jakości wody w punkcie badawczym powyżej zrzutu (stanowisko A).

Słowa kluczowe: Noteć, wody kopalniane, węgiel brunatny, Pojezierze Kujawskie, jakość wód powierzchniowych.

INTRODUCTION

Open-pit lignite mines affect all compartments of the environment. Surface mines cause changes in the catchment basin, reshaping the land relief, modifying soil characteristics, and depressing lake water levels as well as groundwater tables (ILNICKI 1996). The environmental concerns raised by surface mine exploitation have been widely studied, although there is a shortage of research reports concerning the impact lignite mines on surface water quality (YOUNGER, WOLKERSDORFER 2004). At the same time, other environmental issues such as the impact on groundwater and mine wastewater treatment have been described in detail (JANIAK 1992, HILDMANN, WONSCHE 1996, GRÜNEWALD 2001, DOMSKA, RACZKOWSKI 2008, KAVOURIDIS 2008, HANCOCK, WOLKENSDROFER 2012, and others).

The removal of mine waters from a deep seated drainage system at the Lubstów Surface Lignite Mine to the Noteć River (Kujawskie Lakeland, central Poland) began in 2003, affecting the river water discharge and in some cases the water quality parameters. Studies were undertaken to evaluate the impact of the mine waters on the Noteć, a small lowland river, and this paper contains results from the surveys carried out in 2008 and 2009. The total volume of mine water discharged at the surveyed site (MW) was 6,939,433 m^3 in 2008 (0.13 m^3 s^{-1}), while the average river water discharge (1961-2005) at the nearest river monitoring site in Łysek was about 0.89 m^3 s^{-1}, meaning that the contribution of mine waters to the total river discharge was about 17% (WACHOWIAK 2010). This is a considerably large volume of water, considering a relatively low annual precipitation in this region (about 538 mm), which results in low water levels in lakes and watercourses (STANISZEWSKI, SZOSZKIEWICZ 2010).

The sites selected for the evaluation of Noteć River water quality were situated below Brdowskie Lake and above Gopło Lake, a secondary recipient of mine waters. The lakes Brdowskie, Modzerowskie and Przedeckie affect the quality of water in the Noteć River above the surveyed sites, and are similar in terms of water quality and aquatic plant structure (STANISZEWSKI, SZOSZKIEWICZ 2002, 2004, 2005, 2010). The Noteć River had been analysed previously in its upper sections, where both eutrophic and mesotrophic conditions were identified (STANISZEWSKI 2001).

MATERIAL AND METHODS

Water from the Noteć was sampled at three sites in 2008 – 2009. In 2008 and 2009, it was submitted to analyses of the content of dissolved forms of metals, while in 2009 other water quality parameters were assessed. The selected sites were: Dziadoch (A) – above the mine waters discharge site, Nykiel (B) and Ignacewo (C) – both below the mine waters discharge site. The Ignacewo site is situated in the Goplańsko-Kujawski Area of Protected Landscape. There were no other significant sources of potential contamination of water around the selected experimental sites and this part of the catchment was dominated by a rural landscape with patches of woodland or grassland and a few scattered houses. Mine waters were sampled from the canal which carries mine waters to the Noteć (Dziadoch MW – Nykiel). Additional chemical data were obtained from the Konin Coal Mine (personal communication, M. MODELSKA-BABIAK, KWB Konin). All samples were collected to 0.5 l polyethylene bottles and the following analyses of water were performed:

- pH reaction and conductivity – electrometrically;
- soluble reactive phosphates – samples passed through 0.45 µm pore size membrane filters, ascorbic acid method;
- nitrates – samples passed through 0.45 µm pore size filters, cadmium reaction method;
- sulphates – samples passed through 0.45 µm pore size filters, spectrophotometry;

- total phosphorus – the acid persulfate digestion method;
- total concentrations of dissolved metals (Fe, Cd, Zn, Mg, Ca, K, Na) – atomic absorption spectroscopy (AAS) in averaged samples analyzed according to standard methods after passing through 0.45 µm pore size filters.

The bottom sediment in the canal five years after it had been opened (May 2009) underwent chemical analyses, including pH reaction, sediment conductivity, concentrations of total nitrogen (the Kjeldahl method), phosphorus and potassium (the Egner method).

The location of each site was selected so as to obtain a reliable picture of the potential impact of mine waters on the river, assuming that river and mine waters mixed completely. Site A (Dziadoch) lies 50 metres above the mine water discharge and presents the following characteristics: mineral and organic bottom sediments, a very small river slope and tree (mostly black alder) canopy shading on both river banks. Mine waters (site MW) were collected directly from a 40-meter canal, partly made of concrete, and near the canal, from the river, where the bed was composed of stones, pebbles and gravel. Mine waters were discharged through this canal from April 2003 to May 2009. According to the data from the Konin Coal Mina Company (MODELSKA-BABIAK 2011 – personal communication), as much as 58% of surface mine waters flew to the river through that outflow site in 2003, decreasing to about 40% in the subsequent years. Sites Nykiel (site B, 100 m below discharge) and Ignacewo (C, about 1 km below discharge) were similar in terms of their landscape relief and land use (mostly rough pastures and scattered houses).

RESULTS AND DISCUSSION

The levels of phosphorus, nitrates and other parameters in the mine waters were acceptable from the view of sustaining the functions of a river ecosystem. In fact, they did not cause changes to the river water quality (Table 1, Figure 1). Mine waters should meet standards set for wastewater (the Journal of Law no 137, item 984), and the measured values were much below these thresholds, i.e. 30 mg N_{NO3} dm^{-3}, 500 mg SO_4 dm^{-3}, etc. In comparison to the river water quality standards, some parameters such as total phosphorus and alkalinity were above the thresholds in class II, meaning that in the long term they could affect the river ecosystem.

The results show that the concentrations of dissolved metals at the sites below the discharge canal were either lower (zinc) or the same (cadmium, iron) as in the site above. The mine water concentrations of zinc were lower than in the Noteć River and lower than the average values reported by GRABIŃSKA et al. (2006) for Polish rivers flowing through agricultural landscapes (the Narew, Biebrza, Rozoga and the Pisa), ranging from 0.034 to 0.044 mg Zn dm^{-3}.

Table 1

Average and maximum values of main water quality parameters in the Noteć River (sites A, B, C) and in mine waters (site MW) in 2009

Parameters	Site A		Site MW *		Site B		Site C	
	average	max	average	max	average	max	average	max
pH reaction **	7.83	7.91	7.58	7.63	7.75	7.89	7.73	7.86
Conductivity (mS cm^{-1})	0.662	0.720	0.720	0.758	0.685	0.725	0.568	0.634
Total phosphorus (mg P l^{-1})	0.15	0.17	**0.82*** **	**2.86**	0.20	0.38	0.16	0.22
Soluble reactive phosphates (mg PO_4 l^{-1})	0.25	0.31	0.22	0.27	0.29	0.39	0.40	0.66
Nitrates (mg N-NO_3 l^{-1})	0.73	1.40	0.06	0.10	0.63	1.30	0.45	1.30
Alkalinity (mg $CaCO_3$ l^{-1})	202.5	230	**257.5**	**260**	216.3	240	245.0	**260**

* results for mine waters were compared to river standards to facilitate comparisons with the Noteć River water quality; ** median for pH reaction; *** bolded numbers – above water quality class II (Journal of Law No 257, item 1545).

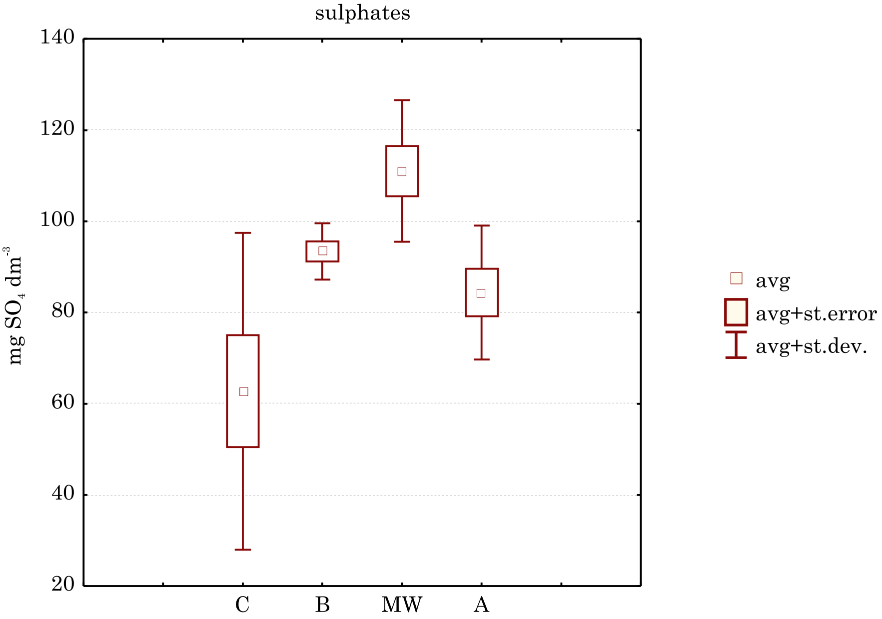

Fig. 1. Comparison of average concentrations of sulphates in the Noteć River and in mine waters in 2009: A – site above mine water discharge, B, C – sites below mine water discharge, MW – mine waters

The analyses carried out in 2008-2009 demonstrated the content of dissolved Fe in the river water was below detectability limits (Table 2). In samples collected in 2004 (M. Modelska-Babiak – personal communication), an average total iron concentration was 1.145 mg Fe dm^{-3} (the threshold for waste waters is 10 mg Fe dm^{-3}), which could explain the presence of iron in sediments from the mine waters canal (Table 3).

Concentrations of magnesium in the Noteć River were similar to those in other rivers in the Polish Lowlands but higher than in lowland water bodies situated in rural areas (Koc et al. 2008). A range of potassium in Polish rivers is wide: from 1.4 to 10.3 (Koc et al. 2004) with an average of about 4.67 mg K dm^{-3}, although the Weser River, for example, it reached 42 mg K dm^{-3} (Grzebisz et al. 2004). The low level of K in mine waters (3.9-5.9 mg K dm^{-3}) did not worsen the quality of the river water (Table. 4).

Changes in the water chemistry below the mine water discharge point were not significant; however, even small changes in water quality can influ-

Table 2

Average and maximum total concentrations of dissolved heavy metals at sampling sites based on analyses carried out in 2008-2009

Parameters (mg dm^{-3})	Site A		Site MW		Site B		Site C	
	average	max	average	max	average	max	average	max
Zn	0.03	0.08	0.01	0.04	0.02	0.05	0.02	0.04
Cd	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.008
Fe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3

Chemical characteristics of sediments in the mine water canal from the Lubstów Surface Mine versus selected Polish data for river sediments

Parameter	Unit	Sediments from mine waters canal	River sediments (Odra R., Wilga R., Kwisa R. Wigierski National Park rivers*)
pH	-	7.49	4.5 - 8.8
EC	mS cm^{-1}	0.50	
C_{org}	%	28.1	
$N_{tot.}$		0.44	
P (as P_2O_5)	mg kg^{-1}	0.17	
K (as K_2O)		3.86	
Fe	mg kg^{-1}	218 542.6	2900 - 45 908
Mn		5353.9	272.1 - 2101
Pb		47.1	5 - 153
Zn		28.2	28 - 1226

* data from publications: Helios-Rybicka (2005), Korabiewski (2005) and others

Table 4
Average total concentrations of dissolved light metals at sampling sites based on analyses carried out in 2008-2009

Parameters (mg dm^{-3})	A	MW	B	C
Mg	14.9	18.2	15.1	13.8
Ca	90.9	88.8	89.4	84.3
K	5.9	3.0	5.7	3.9
Na	19.6	11.0	19.0	14.4

ence the species structure of aquatic organisms such as benthic algae or invertebrates. For instance, a small increase of the Cd contamination can affect the river biota (IWASAKI, ORMEROD 2012). Macro-invertebrates are very susceptible to environmental stressors, and therefore are included in several biological indices broadly used in environmental surveys (BIRK, HERING 2006, BUFFAGNI et al. 2006).

The results of the Wilcoxon test showed that differences found between the river sites were significant only for alkalinity, conductivity and pH (Table 5). There were significant differences in the chemistry of mine waters and the Noteć River water with respect to such quality parameters as sulphates, alkalinity, pH, conductivity and zinc concentration. The levels of phosphorus, nitrates, dissolved metals and the other parameters in the mine waters were acceptable from the point of view of sustaining the river ecosystem.

If concentration of metals in mine waters were higher, Gopło Lake, lying below the sampling sites, and especially its southern end receiving water from the Noteć, would be endangered. The morphological characteristics of lakes make them similar to settling tanks, which is why they collect most of mineral and organic material transported by watercourses.

Another objective of the study was to analyse parameters of the sediment in the canal. Studies on heavy metal concentrations in sediments have been conducted by many authors in recent years, as this is an important

Table 5
Significant differences between pairs of sites using the Wilcoxon test at different *p*

Pairs of sites	Zn	Conductivity	Sulphates	Alkalinity	pH
	p				
MW - A	0.027	0.017	0.011	0.011	0.011
MW - B			0.017	0.017	0.011
MW - C			0.049		
A - B		0.017		0.025	
A - C				0.011	0.049
B - C				0.029	

issue for the environmental quality, research and analytical problems (Boszke et al. 2002, Soylak et al. 2002, Helios-Rybicka 2005, Korabiewski 2005, Szyczewski et al. 2009, and others).

The deposit formed after 5 years of discharging mine waters built up a 2-cm thick layer, consisting mostly of iron (218 542.6 mg kg^{-1}; i.e., 21.9%) and manganese (5353.9 mg kg^{-1}; i.e., 0.54%), which gave it the red colour (Table 3). The determined Fe and Mg levels are significantly different than those reported by Helios-Rybicka (2005) and Korabiewski (2005). Besides, alkaline pH (7.49) and the high content of organic substance (C_{org} = 28.1%) are the chemical features antagonistic to the high levels of Fe, particularly under anoxic conditions.

The acidification capacity, which could be produced by Fe compounds, is generally created by hydratation processes, yielding considerable concentrations of protons and in some cases hydroxyl compounds, as illustrated by these formulas:

$Fe^{2+} + 6H_2O \leftrightarrow Fe(OH)_3 + 3HO_3^+$,

$Fe^{2+} + H_2S + 2\ H_2O \rightarrow FeS + 2H_3O^+$; but

$Fe_2O_3 + 3\ H_2O \leftrightarrow 2Fe(OH)_3$

The third reaction may be considered as intrinsically responsible for alkaline pH, which could be harmful to the environment. In the investigated ecosystem, the direct manifestation is the brownish colour of the wastewater due to high concentrations of dissolved organic matter (mostly fulvic). The geochemical background values of metals in lake or river sediments or deposits, defined by the Polish Geological Institute, are Pb = 15 and Zn = 73 mg kg^{-1} (Bojakowska, Sokołowska 1998). On the other hand, the threshold values for class I (uncontaminated sediments) are 30 mg kg^{-1} Pb and 125 mg kg^{-1} Zn (Bojakowska 2001). The data contained in Table 5 show that the Zn content need not give rise to concern, since its content is below the geochemical background and the class I threshold. This might not be true about lead. It appears that the investigated sediment is slightly contaminated by Pb, moderately by Mn and polluted by the Fe compounds.

CONCLUSIONS

The concentrations of sulphates, phosphates, nitrates and the conductivity in the Noteć River below the mine water discharge point were not high, did not affect the water quality and should not pose a threat to aquatic plants.

The concentrations of dissolved metals in mine and river waters were low, but the total levels of metals were higher due to the elements contained in the layer of sediments in the canal carrying mine waters to the river. Levels of heavy metals should be strictly controlled and technical measures might have to be taken to reduce their level in mine waters because of possible harmful pressure on the river biota.

The analyses of the sediment showed a high concentration of iron, which resulted from the chemical composition of mine waters discharged in 2004-2008.

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