Environmental risk caused by high salinity mine water discharges from active and closed mines located in the Upper Silesian Coal Basin (Poland)

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Abstract

Mine waters, due to the wide spectrum of pollutants, represent a serious problem from an environmental point of view. Therefore, the main goal of the research was to assess the environmental risk posed by highly saline discharges of mine water. In this study the impact of mine water discharged from active and abandoned Polish coal mines located in Upper Silesian Coal Basin region (USCB) on Przemsza river ecosystems has been assessed. The impact of increasing river salinity on inhabiting them aquatic organisms was performed according to Environmental Risk Assessment (ERA) methodology specified by European Commission in Technical Guidance Document on Risk Assessment (TGD 2003). Based on the ERA results for all section of analyzed Przemsza river basin a map of hazards resulting from exceeding the acceptable environmental salinity levels was performed. The studies confirm that discharge of mine water cause the increase in the concentration of pollutants in river waters which in turn may lead to an imbalance in the ecosystem of Przemsza river basin and its tributaries and caused irreversible environmental damage. The study results confirm also that the assessment of surface water quality based on both, ecotoxicological and physicochemical indicators is more favorable than the mandatory classification of pollution.

Key words: mine water discharges, environmental risk, salinity, USCB

Introduction

Water Framework Directive (WFD) is one of the most important document in the field of water protection and water resources management. The main purpose of this document was to establish a framework for the protection of inland surface water and groundwater (Directive 2000/60/EC). The WFD consists of different steps and monitoring procedures which ensure that "good chemical" and "good ecological" status of all European water bodies will be met in 2027. The water quality issue is especially important in Poland, which compared with other European countries has comparatively poor water resources (Mankiewicz-Boczek et. al 2008). The high level of industrialization and urbanization directly affects the quantity and quality of pollutants discharged into the environment (Absalon et al. 2007). Due to the large load of pollutants in discharged mine waters (heavy metals, high salinity, presence of radioactive nuclides, etc.) serious threat to ecosystems is increasing. Taking into consideration the nature of water from Polish coal mines the particular attention in this study was paid to high salinity. The problem of increasing salinity in the surface waters and its impact on ecosystems was already described in the literature. For example, Cañedo-Argűelles described the negative effects of repeated salt pulses resulting from cyclical discharge of mine waters on river and stream ecosystem (Cañedo-Argűelles et al. 2014). Wright et. al described the effect caused by salinity on shellfish populations (Wright et al. 2011), and Bellmer in his work showed a negative effect of salinity and heavy metals on diversity and abundance of organisms inhabiting ecosystem affected by mine water discharges (Belmer et al. 2014). Literature data clearly shows, that excessive exposure caused by increasing salinity load, can lead to death of organisms living in contaminated ecosystems, which in turn, may contribute to the total biological degradation of water reservoir (Kroll et al. 2002). If water monitoring is based mainly on physicochemical analysis it is difficult to predict the full response of living structures on increasing pollution level. Therefore, it is necessary to use a procedures and methods which allow to

assess the potential environmental risks caused by anthropogenic pollution. The need for conducted this type of analysis was documented by Swart and Jarvis. (Jarvis et al. 2000; Swart et al. 1998).
One of the methods for environmental risk assessment (ERA) is the procedure recommended by European Commission, described in Technical Guidance Document on Risk Assessment (TGD 2003). In this study ERA procedure was used to assess the environmental risk posed by discharges of mine waters into the rivers located in Przemsza river basin. Obtained results allowed to develop a map of hazards posed by rising salinity loads in the rivers. Due to the fact, that ERA procedure includes the species sensitivity to pollution, applied methodology allowed to estimate a scale of exposure and predict potential of the environmental damage. Results of the analyses are particularly important, because real scale of environmental problems posed by mine water discharges in the USCB region has not been thoroughly investigated.

Methods

Study Area – Przemsza river basin

The Przemsza river basin belongs to the upper Vistula river catchment. The area of the Przemsza river basin covers about 2121 km^2, and the length of the river is 87.6 km. The basin is situated in the area of the Upper Silesian Coal Basin (USCB). Przemsza river basin consists of 41 bodies of surface water, of which 10 were classified as artificial and 13 were defined as heavily modified. More than 30% of all river channels situated in study area is regulated. Regarding to water management Przemsza river basin can be divided into 2 different subregions: the lower and the upper part of the river. The lower part of Przemsza basin is significantly exposed to the impact of mining activities, including land deformations and surface water pollution related to the discharge of mine water. Due to the location in highly industrialized part of the Silesian Region, this area is exposed to numerous anthropogenic impacts. Cities located within the basin are: Katowice, Bytom, Sosnowiec, Bedzin, Jaworzno, and Mysłowice. This area covers just 27% of the total Przemsza basin but it is a place of living more than 85% of its population. The area is comprised by the Brynica sub-basin situated below the Kozłowa Góra reservoir, the Biała Przemsza sub-basin situated below the confluence with Kozi Bród, lower part of the Czarna Przemsza sub-basin situated below the Przeczyce reservoir and the whole basin below the cofluence of rivers Biała Przemsza and Czarna Przemsza. Almost all from among 20 surface water bodies in this region do not meet the objectives of WFD. Unlike to lower part, the upper part of Przemsza basin is not seriously impacted by mine water. In the area of Biała Przemsza sub-basin there occur a large depression sink which arose in result of mine water pumping. The indirect adverse effect of mining activities to surface water resources is being partially compensated by freshwater discharge from mine draining into rivers. Water quality as well as ecological status of water bodies in upper part of Przemsza basin are in better quality and quantity than in the lower one.

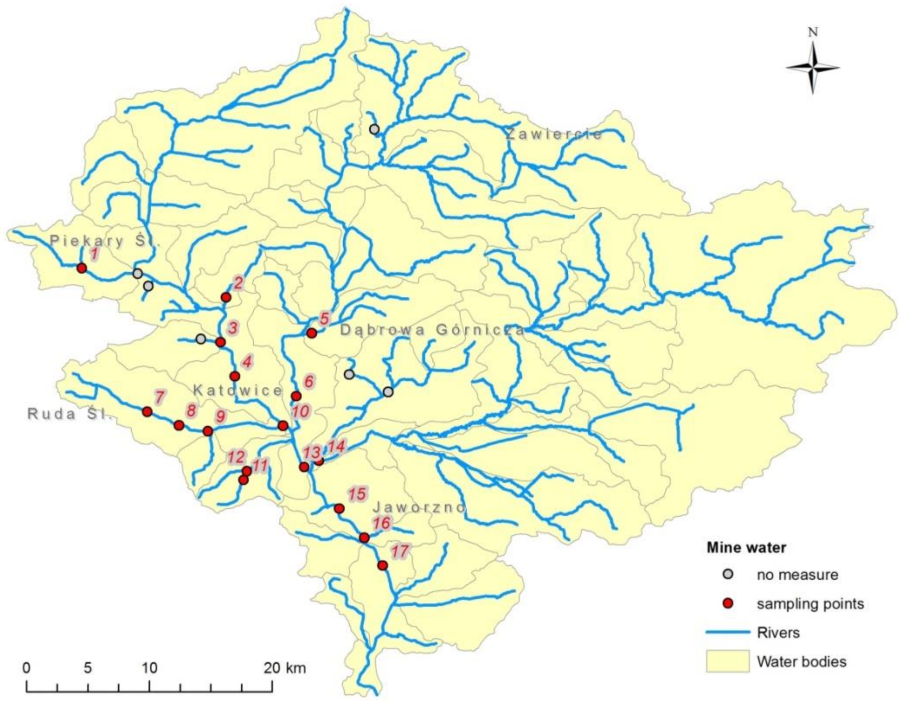

Figure 1 *Przemsza river basin – location of sampling points.*

(1-Szarlejka river above the discharge from CZOK from the Powstańców Śląskich region; 2-Wielonka river above the discharge from CZOK from the Grodziec region; 3-Brynica river above the estuary of Rów Michałkowicki; 4-Brynica river above the discharge from CZOK from the region Saturn; 5-Pogoria river above the discharge from CZOK from the Paryż region; 6-Przemsza river above the discharge from CZOK from the Sosnowiec region; 7-Rawa river above the discharge from CZOK from the Kleofas region; 8-Rawa river above the mine water discharge from KWK Ruch Wujek; 9-Rawa river above the discharge from CZOK from the Katowice region; 10-Rawa river above the discharge from KWK Mysłowice-Wesoła; 11-Bolina Południowa river above the discharge from KWK Wieczorek; 12-Bolina Południowa river above the discharge from KWK Murcki Staszic; 13-Biała Przemsza river above the Bobrek river estuary; 14-Przemsza river above the discharge from CZOK from the Jan Kanty region; 15-Przemsza river above the discharge from ZG Sobieski; 16-Przemsza river water gauge "Jeleń")

Samples collection

In order to estimate the actual salinity level of Przemsza river basin, nineteen sampling points located directly on the Przemsza river and its tributaries were selected. Sampling points were selected in order to capture the main sources of highly saline water inflows from active and abandoned coal mines. Locations of sampling points in comparison with other discharge of mine water is shown in Figure 1.Water samples were collected from March to October 2015. For all river samples a comprehensive analysis of physicochemical properties were performed. Due to the fact that the aim of research was to assess the environmental risk caused by highly saline mine water, only selected water quality indicators were used (chlorides, sulphates, and hardness) (Table 1). During the analyses data from a national monitoring of quality of the surface waters, conducted by the Regional Inspectorate of Environmental Protection in Katowice were also used (Table 2).

Ecological Risk Assessment (ERA) procedure

The Environmental Risk Assessment (ERA) was performed according to methodology described in Technical Guidance Document on Risk Assessment (TGD 2003). Simplified ERA procedure is based on determining two values: PEC (*Predicted Environmental Concentration*) and PNEC (*Predicted No-Effect Environmental Concentration*), which are finally compared in order to estimate the RL ratio (*Risk Level*). The PEC is defined as an expected concentration of a substances in the environment. PEC value reflect the level of pollution (scale of exposure) on which the organisms inhabiting an ecosystem are exposed to. The levels of threat to aquatic species caused by high salinity for all sampling points were expressed as a PEC values. During the ERA analysis as a PEC values both, results of physicochemical analyses (Table 1) and the monitoring data of surface water quality conducted by Regional Inspectorate for Environmental Protection were used (Table 2). In a next step, the PNEC values was estimated. PNEC values is defined as concentration below which exposure to a substance is not expected to cause adverse effects to species in the environment. Therefore, the PNEC is the threshold value of the negative effects caused by exposure to the contaminant are observed. Accordance with the ERA methodology described in the TGD guidelines there are at least two approaches for the determination of the PNEC (deterministic and probabilistic approach). Within the study the probabilistic approach was applied. Probabilistic approach is based on the assumption, that well-characterized population is represent by inherent heterogeneity and biodiversity. The approach assumes that PNEC value is expressed as a HC_5 ratio (*Hazardous Concentration)* estimated within the SSD analyses (*Species Sensitivity Distributions*). HC_5 value is defined as a concentration of substance, dangerous for 5% of all exposed species, while the SSD determined a cumulative probability distributions of toxicity values for multiple species. All available ecotoxicological data gathered in database were used to determine PNEC threshold values (PNEC-chlorides; PNEC-sulphates). During the database formation the following data sources were used: ECOTOX database (U.S.EPA), EU Risk Assessment Reports, research centre publications, recommendation of the EU member states, etc. The finally PNEC values (expressed as HC_5) were determined using the ETX2.0 software made available on the websites of the Dutch Environmental Protection Agency. Estimated PNEC values amounted respectively: PNEC chloride:139,06 [mg/l]; PNEC sulphate: 299,90 [mg/l]. The estimated PNEC values represent safe concentration for 95% of species living in affected ecosystem, beyond which the negative effects caused by exposure will be observed. Additionally the PNEC value for chlorides was determined by the use of existing algorithm. Added value of the algorithm is that the estimated PNEC depend on local and background conditions (*Chronic criteria value [mg/l] = 177,87(Hardness [mg/l])*^{0,205797}*(Sulfate [mg/l])*$^{-0,07452}$*)*. Environmental risk posed by high concentrations of chlorides and sulphates according to aquatic ecosystems was expressed by the RL (Risk Level). RL was determined as the ratio of PEC to PNEC (HC_5). The general rule for interpretation of the obtained results assumed that if the RL is less than 1 it means that there is no risk of negative impact from the stressors in relation to the aquatic ecosystem and there is no need to take action to reduce the environmental risk. Contrary, if RL value is higher than 1, it means there is a high risk of negative impact from the stressors to the aquatic ecosystem. In such situations, action to reduce the present environmental risk is needed.

Results and Discussion

The results of physicochemical analyses confirm that Przemsza river basin is highly affected by mining activities. Discharges of mine water into Przemsza river and its tributaries caused an increase of chlorides and sulphates concentrations in surface waters (Table 1). Results of the analyses showed that water salinity expressed as individual concentrations of chloride and sulphate ions, remains respectively in the range: from 40,32 [mg/l] (№ 2, 11) to 729,91 [mg/l] (№12) for chlorides and from 98,97 [mg/l] (№ 11) to 680,77 [mg/l] (№12) for sulphates (Table 1). Data provided by Regional Inspectorate for Environmental Protection in Katowice indicated that the average concentration of chloride ions in the water of Przemsza river basin maintained in the range from 9,79 [mg/l] (Centuria river) to 7.809,21 [mg/l] (Bolina river). Similarly, the concentration of sulfate ions was maintained in the range from 41,98 [mg/l] (Strumień Błedowski river) to 812,79 [mg/l] (Rów Michałkowicki river). The highest salinity was recorded in the rivers most affected by the impact of mine water discharges, which include: Szarlejka river (chlorides concentration 1.042,25 [mg/l]; sulphates concentration 302,90 [mg/l]); Rów Michałkowicki river (chlorides concentration 1.042,25 [mg/l]; sulphates concentration 812,72 [mg/l]), Rawa river (chlorides concentration 1.747,35 [mg/l]; sulphates concentration 476,0 [mg/l]), and Bolina river (chlorides concentration 7.809,0 [mg/l]; sulphates concentration 461,84 [mg/l]). The results shown that location along the river successive emission sources, closely related with increasing pollution load discharge into the river, directly affect the growth of water samples salinity. The estimated contaminant concentrations are similar to the values obtained by other researchers, whose study concern the source and the scale of water pollution in the area of USCB (Absalon et al. 2007; Lewin et al. 2006; Olkowska et al. 2014).

Table 1 *ERA - based on PEC expressed as physicochemical analysis results of surface waters of Przemsza river basin.*

River	№	Physicochemical parameters			ERA RL		
		Cl	SO_4	hardness	Probabilistic approach		Cl algorithm
		[mg/l]	[mg/l]	[mgCaCO$_3$/l]	Cl	SO_4	
Szarlejka	1	109,83	170,94	214,75	0,79	0,57	0,30
Wielonka	2	40,32	110,96	184,67	0,29	0,37	0,11
Brynica *(form Kozłowa Góra river to estuary)*	3	510,24	3208,93	512,22	3,67	10,7	1,45
	4	469,92	380,87	250,50	3,38	1,27	1,32
Pogoria	5	76,47	128,96	239,38	0,55	0,43	0,20
Przemsza (*from Przerzyce reservoir to Biała Przemsza estuary)*	6	48,66	98,97	196,21	0,35	0,33	0,13
	13	539,44	308,90	243,92	3,88	1,03	1,50
Rawa	7	100,10	185,94	120,27	0,72	0,62	0,31
	8	169,62	269,91	144,57	1,22	0,90	0,52
	9	519,97	770,74	220,71	3,74	2,57	1,58
	10	250,25	338,89	164,36	1,80	1,13	0,76
Bolina Południowa	11	40,32	62,98	66,80	0,29	0,21	0,13
	12	729,91	680,77	425,31	5,25	2,27	1,92
Biała Przemsza (*from Kozi Bród river to estuary)*	14	65,34	200,93	218,32	0,47	0,67	0,18
Przemsza (*form Biała Przemsza river to estuary)*	15	350,36	230,92	213,32	2,52	0,77	0,98
	16	329,50	230,92	215,20	2,37	0,77	0,92
	17	379,55	239,92	217,95	2,73	0,80	1,06

***Table 2** ERA based on the monitoring data of surface water quality conducted by Regional Inspectorate for Environmental Protection.*

River	ERA – RL ratio			River water quality - National Monitoring data		Mine water impact
	Probabilistic approach		Cl algorithm	Physico-chemical status	Ecological status/ potential	
	Cl	SO_4				
Przemsza (*from river spring to Przerzyce reservoir)*	0,22	0,21	0,07	good	moderate	-
Brynica (*from river spring to Kozłowa Góra reservoir)*	0,14	0,21	0,05	good	good	-
Szarlejka	7,45	1,01	2,44	bad	poor	D
Jaworznik	0,23	0,32	0,08	bad	moderate	-
Wielonka	0,25	0,36	0,09	bad	moderate	D
Rów Michałkowicki	7,45	2,71	2,44	bad	good	D
Potok Leśny	1,06	0,48	0,37	good	poor	D
Rawa	12,49	1,59	3,79	bad	moderate	D
Brynica *(from Kozłowa Góra river estuary)*	4,91	1,29	1,58	bad	moderate	D/I
Bolina	55,82	1,54	14,64	bad	bad	D/I
Przemsza (*from Przeczyce reservoir to Biała Przemsza river estuary)*	4,28	0,74	1,4	bad	moderate	D/I
Centuria	0,07	0,15	0,03	high	bad	-
Strumień Błędowski	0,15	0,14	0,05	good	poor	-
Biała	0,10	0,91	0,04	bad	bad	D
Biała Przemsza (*from Biała to Kozi Bród river estuary)*	0,21	0,65	0,07	bad	moderate	I
Kozi Bród	0,61	0,78	0,22	bad	good	-
Rakówka	2,68	0,49	0,88	bad	moderate	-
Bobrek	3,73	0,97	1,23	bad	moderate	D/I
Biała Przemsza (*from Kozi Bród estuary to the confluence with Czarna Przemsza river)*	0,08	0,69	0,09	bad	moderate	D
Wąwolnica	2,11	1,08	0,7	bad	poor	D
Byczyna	0,58	0,26	0,20	good	bad	D

Matylda	0,18	0,19	0,07	bad	poor	-
Przemsza *(from Biała Przemsza to Przemsza river estuary)*	2,81	0,76	0,93	bad	poor	D/I

D- direct impact of mine water discharges; I – indirect impact of mine water discharges

Research results clearly indicate that discharge of waters from coal mines located in study area is associated with pollution-related changes to the water quality properties, particularly with respect to its physicochemical parameters. Mine waters discharges into the Przemsza river basin caused a significant modification to water chemistry. The study results confirm the poor chemical and ecological status of Przemsza river basin. Most of analyzed samples do not meet the requirements for the surface water set by Regulation of the Minister of the Environment, on the classification status of surface waters and environmental quality standards for priority substances (Dz.U.2014.1482). For majority of sampling points the existing environmental standards set by the national regulation were exceeded. Determined within ERA analyses acceptable environmental levels of chlorides and sulphates, amounts respectively: 139,06 [mg/l] (PNEC-Cl) and 299,9 [mg/l] (PNEC – SO_4). Obtained values are similar to the environmental standards applicable in other countries. For example, according to Canadian Water Quality Guidelines (CWQG) acceptable chlorides concentration in surface waters is 120 [mg/l], while according to the EPA acceptable chlorides level for surface water is 230 [mg/l]. In relation to the suphates, the obtained value can be only compared with existing standards for drinking water which reach respectively: 500 [mg/l] (CWQG) and 250 [mg/l] (Drinking Water Directive 98/83/EC). Obtained PNEC values were compared with actual concentrations of chlorides and sulfates in the rivers. Based on the results the areas of Przemsza river basin for which the acceptable environmental level has been exceeded (RL> 1) were identified. Exceeding the acceptable risk levels in appointed areas may lead to the occurrence of adverse environmental effects. Summary results of ERA analyses are shown in tables above. The results in form of maps illustrating the environmental hazard posed by high concentration of chlorides and sulphates are shown respectively at Figure 1 and Figure 2. The attached figure illustrating the areas of Przemsza river basin for which the acceptable environmental limits were exceeded (RL >1). Exceeding the acceptable level for chlorides was recorded for 21 of 40 analysed samples. Adequately acceptable level for sulphates was exceed in 12 of 40 analyzed samples. Comparison of the ERA results shown that with algorithm approaches, which requires input a data concerning background condition, environmental risks are identified less frequently than in the case of probabilistic approaches based only on ecotoxicological data (RL>1 for chlorides were reported for 13 from 40 analyzed samples).

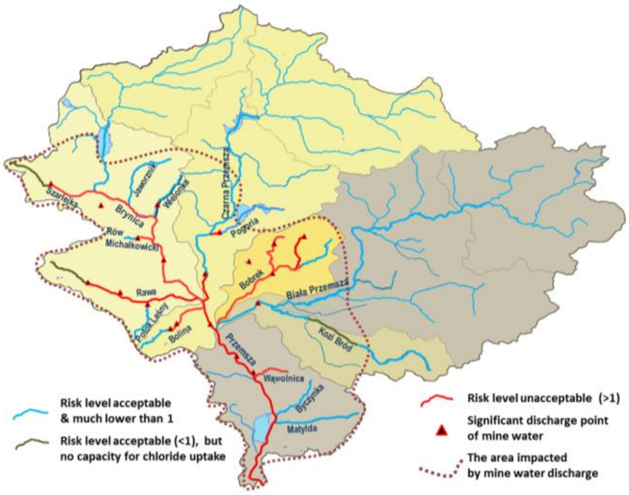

Figure 1 *Risk of chloride impact on aquatic ecosystems of Przemsza river basin – probabilistic approach*

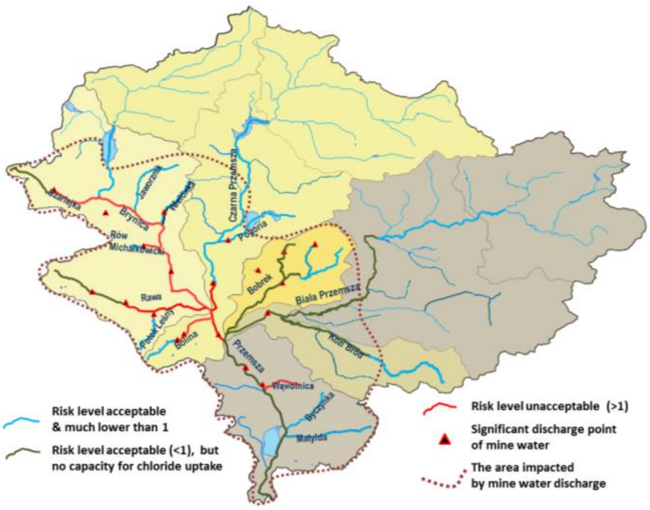

Figure 2 *Risk of sulphate impact on aquatic ecosystems of Przemsza river basin- probabilistic approach*

Data presented in tables and figures above revealed that high salinity in Szarlejka, Rawa and Rów Michałkowicki rivers as well as in middle and lower part of Brynica river is not accepted with respect to risk levels determined under ERA assessment. Moreover, high concentrations of chlorides and sulphates in river waters prevents the achievement of good or moderate ecological status/potential. Additionally in the middle and lower part of Brynica sub-basin the acceptable environmental risk level for chlorides (PNEC) has been exceeded several times. The possibility to reduce the potential environmental damages caused by high salinity is to limit the amount of discharged mine water to Brynica river basin, or to dislocate of mine water discharge points outside the Brynica river basin. However, it should be noted that biological degradation and bad chemical status of Brynica river is not only caused by impact of mine water but it is rather a cumulative effect of all anthropogenic activities carried out in the region (e.g. industrial emission, discharge from WWT, etc.). Therefore, the positive effects of the reduction of inflow of a highly saline water from mining areas will be seen only with simultaneous application of sewage management ensuring fulfilment of environmental requirements. Chemical degradation of water as well as poor/bad ecological status/potential in middle part of Przemsza river and its tributaries is the result of discharge of mine waters and pressure exerted by other users of the basin. The acceptable risk level for chlorides in the main part of Przemsza river was exceeded mainly due to a large load of salt introduced into the Przemsza river by its tributaries: Brynica and Bolina. The negative impact of sulphates ions introduced into the Przemsza river by its tributaries: Bobrek, Biała and Biała Przemsza rivers is relatively low according to ERA criteria, however, simultaneously, sulphates concentration is higher than the threshold value determined by Polish law. In general, the needs and the challenges concerning chlorides and sulphates risk reduction are similar to described for Brynica sub-basin. In the lower section of Przemsza river the acceptable risk level for chlorides was also exceeded. However, exceeded of risk levels were not as significant as in the case of Brynica river and in the middle part of Przemsza river. Most likely is that self-cleaning processes of river affected the reduction of nutrients concentrations. It seems that it is possible to reduce the impact of mine waters on the lower part of Przemsza river basin, however to achieve this a complete control over a mine water discharges is necessary (control of the quality and quantity of salt water discharges).

Conclusions

The main objectives of the management of Przemsza river basin in a field of mine water discharges should be set taking into account the environmental risk analysis including integrated data concerning: river flow, biological parameters/indicators of river ecosystems and physicochemical conditions (background conditions). The fact is, that even if the impact of mine water discharge on aquatic ecosystem will be skipped, or solved still a lot of streams and rivers of Przemsza catchment will not achieve a good status/ecological potential in the near future. The study confirmed that the assessment of water quality based on the ecotoxicological data illustrating the potential impact of pollutants on aquatic ecosystem (ERA) is more favorable than the mandatory classification of pollution. Due to the fact, that

ERA includes sensitivity of aquatic species to the pollution and/or background conditions, this methods allows to assess the real scale of exposure and predicted potential environmental effects. The regulations concerning the discharge of mine water into rivers currently fails to impose any discharge salinity limits on mine waters or on any other significant type of pollution (e.g. major cation or anion) (Wright et al. 2011). The area of legal regulation in respect to any discharge of mine water requires further examination. In view of the study results, as well as bearing in mind the guidelines of the WFD in particular the achievement of good water status of Przemsza river, there is still need for further research to provide evidence for authorities on direct and cumulative impacts of water chemistry changes on aquatic ecosystems.

Acknowledgements

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