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Short Communication

Effects of Mining Activities on River Water Quality

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Abstract

The purpose of this work was to assess development of the quality of surface water in the Svatava River in the Czech Republic from 1997 to 2008. Parameters typical for pollution as a result of mining activities (SO_4^{2-}, Fe, Mn) were monitored, as well as select heavy metals (Pb and Cd). A falling tendency in the values of annual averages of all the monitored indicators in all profiles is apparent. The least polluted water is in the profiles Hranice and Kraslice on the upper course of the Svatava River. Conversely, the most polluted water is in the Sokolov profile, in front of the site where the Svatava River flows into the Ohře. This applies to all the monitored indicators of the Sokolov profile that the greatest pollution values were recorded during 1997 and 2002, and for sulphurs also in 1999 and 2003. The analyzed ion concentrations are still significantly higher than in other profiles, with the exception of lead and cadmium, where pollution is the greatest in the Oloví profile. However, in 2008 the measured values for all indicators did not exceed valid limits.

Keywords: river water monitoring, Water Framework Directive, mining activities, dumps, sulphates

Introduction

Surface water quality has been monitored in the Czech Republic on observation profiles since the 1960s. Monitoring was gradually supplemented by additional indicators. As the effects of these substances on the environment were established, an extensive national network for monitoring water quality in watercourses was formed over time. According to its foundation documents the Czech Hydrometeorological Institute (CHMI) was responsible for operation of the network. The CHMI assured sampling and analysis of surface water by external accredited laboratories (the Povodí state companies, the T. G. Masaryk Water Research Institute, and others). The CHMI only compiled data, examined and stored it in a database, presented data, and performed basic routine evaluation of established data [1, 2].

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All data available from this monitoring is currently stored in the Assessment and Reference Reports of Water Monitoring (ARROW) database. Although monitoring on observation profiles is still managed to a limited extent by the individual Povodí state companies, the most recent data in the database is from March 2009. An agreement was not reached between the monitoring operators and the Ministry of the Environment of the Czech Republic (ME CR) after this date. The ARROW database is run by the CHMI as a national reference center for monitoring within the terms of activities assured for the ME CR and, despite some deficiencies, some unique timelines concerning water quality development in watercourses are stored here. The system allows storage and processing of the results of monitoring programs for monitoring of the chemical and ecological status of water as required by Council Directive 2000/60/EC, establishing a framework for Community action in the field of water management policy (Water Framework Directive) and publication of these results for professionals and the public [2].

After the Czech Republic (CR) joined the European Union (EU) it was obliged to fulfil the requirements of the three reference profiles specified by European legislation in the field of water protection.

The Water Framework Directive specifies that member states should take the necessary measures with the goal of gradually reducing pollution caused by priority substances and gradually eliminating emissions, discharges, and leakage of priority hazardous substances [3]. Directive 2008/105/EC determined environmental quality standards (EQS) for priority substances and some other pollutants [4]. These standards were integrated into the amended Government Regulation No. 61/2003 Coll., which fulfilled the requirement of implementation into CR legal regulations. This Directive also states that Member Countries shall prepare a list (potentially supplemented by maps) of emissions, discharge, and leakage of all priority substances and pollutants for each part of the catchment area lying within their territory [4].

This requirement was partially fulfilled on the hydroecological information system portal (HEIS) portal in September 2011 by publishing the results of evaluation according to the requirements of Government Regulation No. 61/2003 Coll., as amended by subsequent regulations for the water matrix. A significant part of the profiles for the CR, for all available indicators in the ARROW database during the last three years, which means for the period between 2006 and 2008 [5], were evaluated.

The requirements arising for the CR from the Framework Directive are not being fulfilled in most cases because monitoring data is not available after 2008, i.e. there are no materials for surface water quality evaluation and pollution source identification. This is an example of the careless approach by society to water and environmental issues in general. This is not just a national problem, and the issue was discussed much earlier in surrounding countries.

According to material from 2004, water managers in Germany have been complaining in the long-term about their own helplessness in regard to decisions about land usage, which has had a negative impact on water quality and water source availability. Despite their warnings, new urban development was still being established in flood plains and intensive agricultural production continued to pollute water sources. The problem was caused by administration of public affairs, partly territorial and partly administrative-political [6].

Problems concerning implementation of the Water Framework Directive were described in the Netherlands. The directive and its implementation is not just the responsibility of the water management branch, but also the agriculture and land use planning branch. The problem is assuring coordination between these sectors. However, interdepartmental coordination was limited in practice, especially due to conflicting interests that were not incorporated on the national and European levels and therefore could not be integrated on the regional level. Involvement of stakeholders in the process of implementation has been limited due to the highly technical character of this process and some involved parties were actually eliminated from the process completely. The whole Framework Directive resolves only two problems: determination of environmental protection objectives and development and implementation of measures for achieving these goals. Or maybe it is just about one issue: to obtain cleaner and more natural water at an acceptable cost [7].

The purpose of this paper was to evaluate select indicators typical for pollution caused by mining activities (SO_4^{2-}, Fe, Mn), and also select heavy metals resulting from anthropogenic activities (Pb and Cd) in the Svatava River. These indicators were evaluated according to legislation currently valid in the Czech Republic.

Material and Methods

Research Area

The Svatava river basin, which is significantly affected by pollution resulting from mining activities [8, 9], was chosen as a suitable area for evaluation of quality. The Svatava (Zwodau in German), rises on the Saxony side of the Ore Mountains (Krušné hory) near water. In the CR, the Svatava flows through the valley of these mountains at an elevation of 540.6 m and passes through the villages of Kraslice, Oloví, and Svatava to the city of Sokolov. At this point it flows into the Eger River on the 197th river kilometer, at an elevation of 388.15 m. The river is 30.26 km long in the CR. The total catchment area is 297.5 km^2, (239.8 km^2 in the CR). There are 196 water bodies in the Svatava basin, with a total area of 37.77 hectares. The largest tributaries of the Svatava River are Stříbrný potok (Silver Creek) and the Rotava, which are located on its left bank. Bublavský Creek, Novohorský Creek, Hluboký Creek (Deep Creek), and Lomnický Creek are additional major left-bank tributaries. Kamenný Creek (Stone Creek), Sněženský Creek, Mezní Creek, Dolinský Creek, and Radvanovský Creek [10, 11] are right-bank tributaries.

Water from the most extensive dump complex in the CR [12] and highly acidic mine water from the Jiří-Družba surface coal mines flows into the Svatava River [13]. This water has a low pH and contain calcium sulphate and metal ions, especially iron and manganese [14, 15]. As a result of metallurgic activities on its upper reaches the Svatava River also is polluted by some heavy metals, especially lead, which is corroborated by the name of the village of Oloví (Lead), which is situated on the river [16]. The whole Svatava river basin in the CR is part of the sub-basin of the Eger, the Lower Elbe and other tributaries of the Elbe, and the hydrological catchment area of the third order from the Eger to the Teplá River [10].

Data for Assessment of River Water Quality

Assessment of Svatava River water quality was carried out according to Government Regulation No. 61/2003 Coll., as amended by Government Regulation No. 23/2011 Coll. According to this regulation, the environmental quality standards (EQS-RP) were evaluated to obtain the annual average for monitored indicators. Although the EQS-RP specified in this regulation are valid until 2011, the regulation was applied to the whole assessed period between 1997 and 2008 for more objective evaluation of the measured values.

Indicators typical for pollution as a result of mining activities (SO_4^{2-}, Fe, Mn) and also select heavy metals (Pb and Cd) were monitored. The Sokolov profile has the longest history of monitoring select indicators. Sulphates, iron, and manganese have been monitored here since 1963, and lead and cadmium began being monitored here in 1990. All the indicators have been monitored on the Kraslice profile since 1981, but only until 1997; monitoring was subsequently renewed in 2007. In the meantime monitoring was carried out on the Hranice profile between 2004 to 2006 and it may be identical to the Kraslice profile. The Oloví profile has been monitored since 2007 [2].

Brief History of Mining Activities in the Research Area

Historically significant activities in the catchment area are chiefly ore mining and processing, glassmaking, and brown coal mining, which was initially conducted in underground mines and, subsequently, in extensive open-cast mines [8, 16].

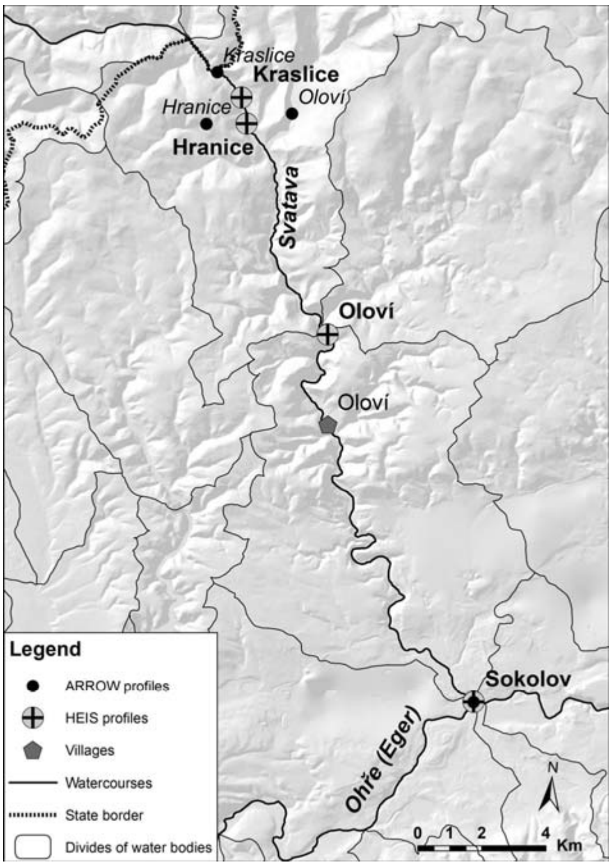

Fig. 1. Location of surface water monitoring profiles in Svatava River.
Source of primary data: the ARROW and the HEIS databases [2, 8].

Lead ore has probably been mined in the town of Oloví since the middle of the 14th century. The local mines were abandoned during the second half of the 19th century. The biggest potential water pollution source by lead is the glassworks in the town. The glassworks began operation at the end of the 19th century and were closed in 2002, with glass only being processed in the complex now [17].

The lower reaches of the Svatava River are significantly affected by the current mining activities (the left-bank tributaries are polluted by brown coal surface mining) and by the former technical areas of the Medard Libík Mine (smaller right-bank tributaries). Coal has been extracted from underground mines in the affected area since 1830, and open-cast mining activities began in the middle of the 20th century. Mining in the Medard Libík Mine ended in 2000. It is expected that mining activities in the Jiří-Družba open-cast mine complex will end around 2030. Hydric reclamation of the Medard Quarry residual pit began in 2008 and it is expected that Lake Medard will be filled in in 2013 [9, 15, 16, 18].

Monitoring Surface Water Quality

All profiles on the Svatava River were searched for in the ARROW database. A total of four profiles were found, during which time one profile was moved, renamed, and renumbered. Basically this monitoring was conducted at three locations on the Svatava. Some discrepancies were found within the terms of examination of profile localization in the ARROW database and therefore these profiles were subsequently checked on the Hydroecological Information System (HEIS) portal (Table 1).

During verification of available data it was established that the profiles are displayed according to coordinates (S-JTSK) on the ARROW portal, but apparently not all profile locations correspond to their position specified by river kilometer. This results in additional inaccuracies in profile locations on water bodies and in municipalities. The biggest discrepancies were found in the first two profiles in the CR (the Hranice and Kraslice profiles). It seems this might be the same profile according to river kilometers and the monitored years published in the ARROW portal. Monitoring of the Kraslice profile was discontinued between 1998 and 2006 and, conversely, the Hranice profile was only monitored between 2004 and 2006, and data has been available only from 2005 (Table 1) for the indicators evaluated in this article. However, according to the specified coordinates and their visualization on the ARROW portal, it is clear that the Hranice profile is not located on the Svatava River, but a fairly long distance up the right-bank tributary and further from the state border than the Kraslice profile. On the HEIS portal, the Hranice profile is located on the Svatava River but still further from the state border than the Kraslice profile. The location of the Kraslice profile also is not exactly the same on both portals.

The coordinates of the Oloví profile are completely wrong on the ARROW portal and the profile, which should be located at river kilometer 13.4 of the Svatava in the town of Oloví. It actually is located on the left-bank tributary to the Svatava near Kraslice village. These factors affected

Table 1. Identification and localization profiles on the Svatava River on both portals (ARROW and HEIS) [2, 8].

Profile identification	CHMI_3479	CHMI_3464	POH_1612	CHMI_1111
Profile name	Hranice	Kraslice	Oloví	Sokolov
River name	Svatava	Svatava	Svatava	Svatava
Municipality (ARROW)	Kraslice	no record	Kraslice	Sokolov
Municipality (HEIS)	Kraslice	Kraslice	Oloví	Sokolov
Water body (ARROW)	Svatava River to the confluence with Rotava River	no record	Svatava River to the confluence with Rotava River	Svatava River to the mouth into Ohře (Eger) River
Water body (HEIS)	Svatava River to the confluence with Rotava River	Svatava River to the confluence with Rotava River	Svatava River to the mouth into Ohře (Eger) River	Svatava River to the mouth into Ohře (Eger) River
X/Y coordinates (ARROW)	-875528/-995476	-875096/-993963	-872853/-995159	-867183/-1013548
X/Y coordinates (HEIS)	-874272/-995469	-874435/-994654	-871744/-1002057	-867180/-1013546
Data presented in ARROW	2004-2006	1981-2010	2007-2009	1963-2010
Data actually available in ARROW	2004-2006	1981-1997; 2007-2008	2007-2008	1963-2008
River km (ARROW)	27.6	27.6	13.415	0.1
River km (HEIS)	26.7	27.6	18.45	0.1

incorrect location on the water body and in the municipality. On the HEIS portal the profile is located on the correct body of water and in the right municipality, but a few kilometers above Oloví, below the confluence of the Svatava and Rotava rivers. There is no conflicting information concerning location on both portals only in regard to the Sokolov profile, except for minor differences in the specified coordinates. This profile is located at the point the Svatava flows into the Eger near the former Medard-Libík Quarry, where Lake Medard currently is being filled [2, 10].

Results

The valid EQS-RP limit for sulphate (SO_4^{2-}), 200 mg·l^{-1} [19], was exceeded on the Sokolov profile only in 1997, 1999, 2002, 2003, 2005, and 2006. However, in 2008 the annual average was 172 mg·l^{-1} on this profile, which is markedly higher than the annual average on the other profiles (Fig. 2). Based on these results it can be determined that the Svatava begins to be significantly polluted by the sulphates between the Oloví and Sokolov profiles. A high level of pollution is the consequence of the fact that the river flows near the dumps and surface coal mines around Sokolov city.

For total iron content (Fe_{total}), the valid EQS-RP limit of 1 mg·l^{-1} [19] was exceeded on the Sokolov profile only, in 1997 and 2002. In 2008 the annual average on this profile was 0.5 mg·l^{-1}, which is more than the annual average on the other profiles. Total iron content on the Oloví profile approximated the total iron content on the Sokolov profile (Fig. 3).

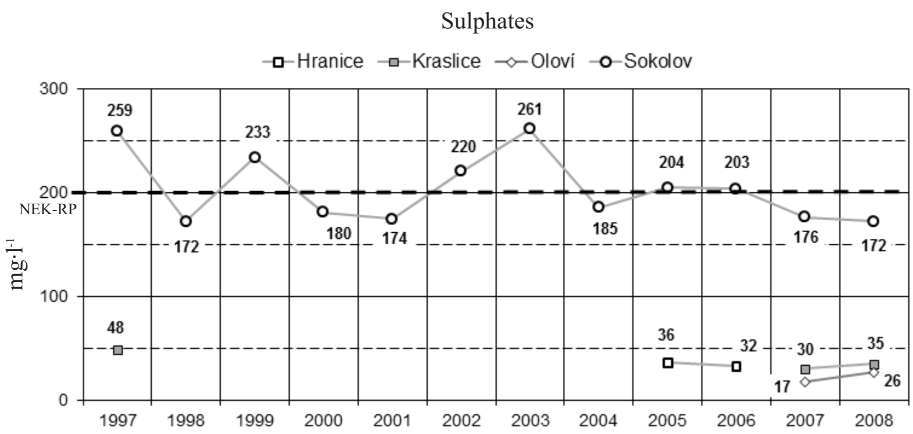

Fig. 2. Evaluation of surface water quality on monitored profiles for sulphate content in the Svatava River between 1997 and 2008. Source of primary data: the ARROW database [2].

For total manganese content (Mn_{total}), the valid EQS-RP limit of 0.3 mg·l^{-1} [19] was exceeded on the Sokolov profile only in 1997 to 1999, 2002, and 2003. In 2008 the annual average was 0.17 mg·l^{-1} on this profile, which is a higher value than annual average on the other profiles (Fig. 4).

The occurrence of iron is usually accompanied by the occurrence of manganese, and iron concentration usually exceeds the concentration of manganese. The results (Figs. 3 and 4) have confirmed this premise. Iron and manganese pollution trends were similar in all profilles. Again, the highest level of iron and manganese pollution was measured between the Oloví and Sokolov profiles. The high level of pollution is the consequence of the fact that the river flows near dumps and surface coal mines around

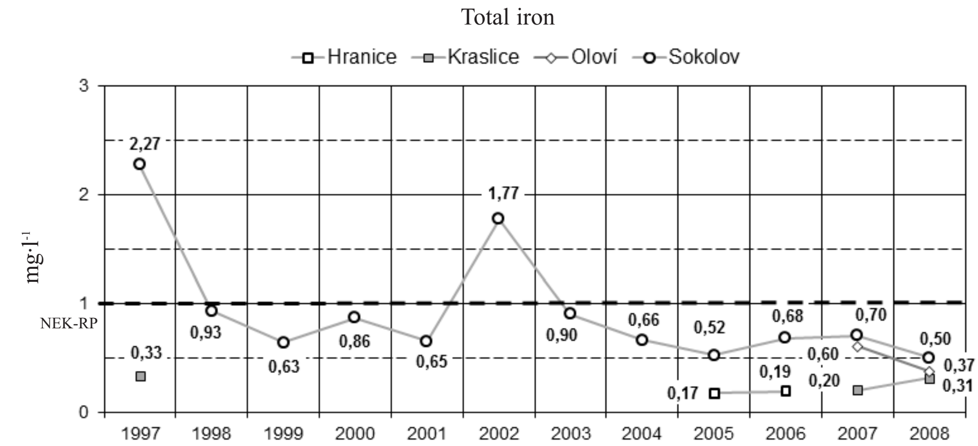

Fig. 3 Evaluation of surface water quality on monitored profiles for total iron content in the Svatava River between 1997 and 2008. Source of primary data: the ARROW database [2].

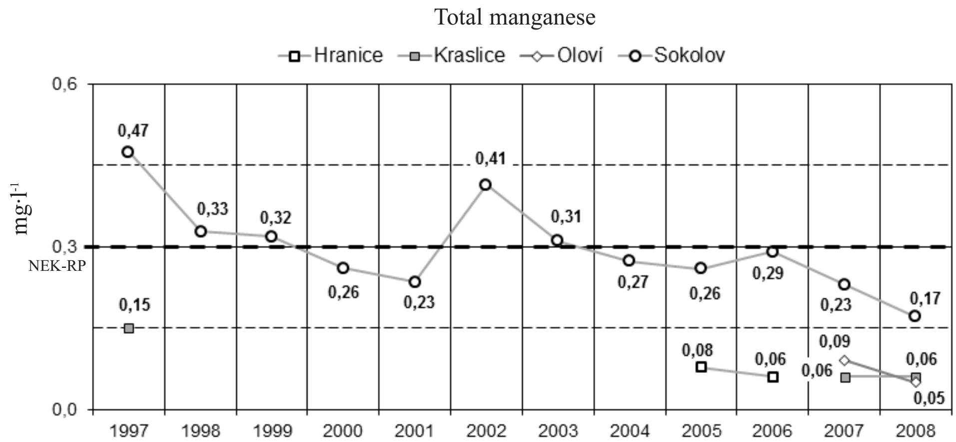

Fig. 4. Evaluation of surface water quality on monitored profiles for total manganese content in the Svatava River between 1997 and 2008. Source of primary data: the ARROW database [2].

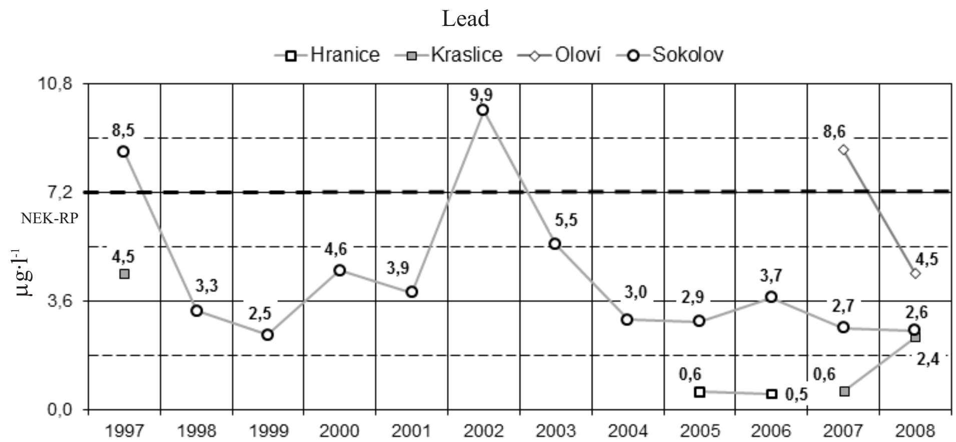

Fig. 5. Evaluation of surface water quality on monitored profiles for lead content in the Svatava River between 1997 and 2008. Source of primary data: the ARROW database [2].

Sokolov city as well. The level of pollution by iron in the Oloví profile didn't differ too much from the level in the Sokolov profile in 2007 and 2008. But the Oloví profile was measured only in 2007 to 2008. While the level of pollution by iron and manganese in border profiles (Hranice and Kraslice) is still almost as low as it was, the changes that occured in the Sokolov profile from 2003 to 2008 reduced the concentrations of these indicators, almost by half in both cases.

For lead (Pb), the valid EQS-RP limit of 7.2 μg·l^{-1} [19] was exceeded on the Sokolov profile in 1997 and 2002. In 2008 the annual average was 2.6 μg·l^{-1} on this profile, which is almost the same value as the annual average on the Kraslice profile. On the Oloví profile, the valid EQS-RP limit was exceeded in 2007, but in 2008 the annual average was only 4.5 μg·l^{-1}, which is still almost twice as much when compared to the other profiles (Fig. 5).

For cadmium (Cd), the valid EQS-RP limit of 0.3 μg·l^{-1} [19] was exceeded on the Sokolov profile in 1997, and between 1999 and 2003. In 2008 the annual average was 0.19 μg·l^{-1} on this profile, which is almost twice the annual average on the Kraslice profile. On the Oloví profile the annual average values were significantly higher compared to the other profiles in 2007 and 2008. These values approached the valid EQS-RP limit (Fig. 6).

Even though in the Oloví profile the measurement was conducted only in 2007 and 2008, it is apparent that Cd and Pb were the main sources of pollution in this profile. The pollution in the Oloví profile influenced the level of pollution by these elements in the Sokolov profile. Also, with regards to the measured values in the border profiles (Hranice, Kraslice) and Sokolov profile, the exception is being considered in 2008, when there was contamination by lead ahead of the border profile (Kraslice) (Figs. 5 and 6).

Discussion

Application of the average annual value is not the best solution in the event that most of the measured values are below the limit of detection (LOD) and the average annual limit is only slightly higher than the LOD. The LOD depends on the method of determination. This is the value at which it can be guaranteed that the measured data corresponds to actual fact to some degree of specified probability. It can be stated that the LOD value decreases over time as a result of the development of new methods and devices. In the event that the actual value is below the LOD, half the relevant LOD is included in the statistical evaluation [20], which may distort the results in some cases.

The falling tendency of the annual average values of all indicators monitored on all profiles (Figs. 2 to 6) is apparent on the basis of the specified values. The water was least polluted on the Hranice and Kraslice profiles, but the Kraslice profile also reported higher values for all the indicators than during other monitored years on this profile in 1997. This is probably due to pollution caused by the totalitarian and post-totalitarian economy in the CR and in neighboring Saxony in the former GDR. Sulphates and cadmium in particular are indicators resulting from burning of fossil fuels and these can enter surface water through atmospheric precipitation [21]. Continued monitoring began or rather was renewed in 2005 (Hranice) and 2007 (Kraslice), respectively [2], so the timeline was broken during this period and no assessment can be made regarding whether this was an unrepeated increase in value.

If monitoring had also been evaluated before 1997, there would be a problem with the LOD value. For example, in the case of lead in 2008 the LOD limit in the laboratory that performed the chemical analysis was 0.5 μg·l^{-1}, but in 1996 it was higher by an order of magnitude (5 μg·l^{-1}). In the case of cadmium, the LOD limit was 0.05 μg·l^{-1} in 2008, but in 1997 it was 0.2 μg·l^{-1} and up until 1996 it was 1 μg·l^{-1} [2]. Therefore, if the data was below the LOD then data evaluation before 1997 is unreliable due to the currently valid limit of 0.3 μg·l^{-1} [17].

According to the philosophy of the Water Framework Directive, not only should water quality be monitored, but sources of pollution should be eliminated. Although the indicators monitored in this study showed a falling tendency, sulphates on the Sokolov profile especially continue to demonstrate high values close to the valid NEK-RP limit. Additionally, official data from monitoring is only available until 2008 [2] and so this trend cannot be confirmed for the

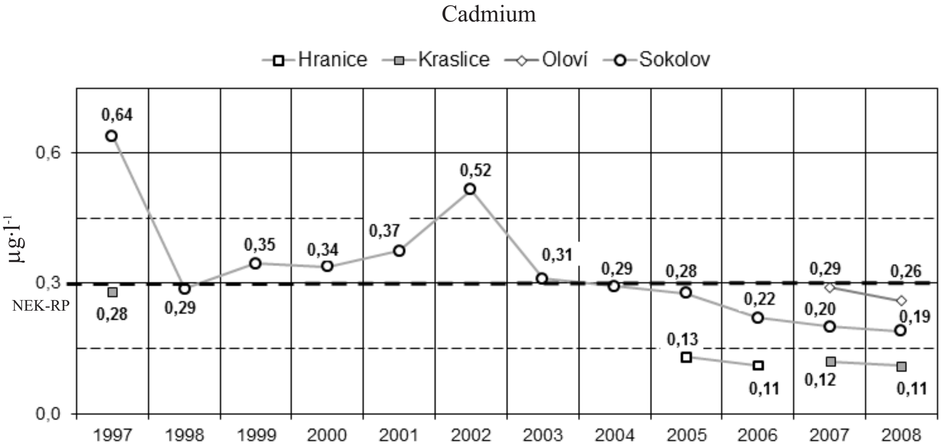

Fig. 6. Evaluation of surface water quality on monitored profiles for cadmium content in the Svatava River between 1997 and 2008. Source of primary data: the ARROW database [2].

last three years at present. It would also be interesting to compare this data to the on-going filling of Medard-Libík Lake [9, 15].

Dumps and wastewater from mining are one of the potential sources of pollution for the described and monitored indicators. There is high potential for acidification of surrounding surface water and groundwater in the areas where dumps are located, with resulting pollution of this water chiefly by sulphates and heavy metals [22-24]. In Germany, for example, water acidification near abandoned brown coal mining sites is a major problem. There are a great number of residual lakes resulting from mining activities in Eastern Germany, in which pH values of less than 2 were measured [25]. There also are similar problems in Spain, where pH values of wastewater from mining attained up to 0.7, and high concentrations of sulphates, iron, arsenic, zinc, cadmium, and lead also were measured [26].

Van Berk and Wisotzky [27] and Lenk and Wisotzky [22] were chiefly engaged in monitoring water pollution from brown coal mining dumps in Germany. For example increased values of the average concentration of sulphates (1535 $mg \cdot l^{-1}$) and iron (107 $mg \cdot l^{-1}$), respectively, were measured in wastewater from dumps in Inden [22]. Similar monitoring also was conducted in the Trzebinia and Rudka Wiesciszowice localities in Poland, where increased sulphate and iron concentrations were reported, but with an average 6.2 pH value [28].

Based on these facts, it would be useful to carry out water quality monitoring on the Svatava River, including tributaries as well as dump water, to locate pollution sources affecting the Sokolov profile.

Conclusions

The highest pollution values for all the indicators on the Sokolov profile were reported in 1997 and 2002, and for sulphates also in in 1999 and 2003. All the monitored indicators showed a falling tendency, with the exception of lead and cadmium, but those values were still considerably higher than on other profiles even if they met valid EQS-RP limits. Lead and cadmium values were highest on the Oloví profile, but in 2008 they did not exceed the valid EQS-RP limits. Due to termination of mining activities in the Libík-Medard locality in 2000 and the filling of Medard Lake, which began in 2008, it is likely that termination of mining and the subsequent recultivation have had a positive impact on surface water quality on the Sokolov profile, although measured sulphate values are still high.

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