Slovak Geol. Mag., 16, 1 (2016), 139 – 158

6. Mine Waters in the Slovak Part of the Western Carpathians – Distribution, Classification and Related Environmental Issues

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Abstract: The frequency of occurrence and amount of mine water in the country change in the longer term, depending on fluctuations in the intensity of mining activities and the availability of mineral deposits of interest to mining. Presented regional overview of the phenomenon in the Slovak part of the Western Carpathians depicts a situation which has changed significantly after 1990 due to the completion of ore deposits mining. Based on the collection of archive data and new field and laboratory measurements within 14 mining-deposit regions and 71 mining-deposit districts 1,041sources of mine water have been documented with a total discharge of 1.80 m^3 s^{-1}. Individual mine water resources and their characteristic discharge Q_{char} are divided into classes according to the hydrogeological type of deposit, Q_{char} value, the chemical composition of mine water and its quality in relation to the requirements for drinking water and water quality of surface streams. Of the said sum 0.381 $m^3 \cdot s^{-1}$ has confirmed and 0.448 $m^3 \cdot s^{-1}$ assumed suitability for drinking water preparation. The remaining amount with a poor quality represent potential sources of contamination of surface water. Overview of ongoing monitoring shows that persistent contamination of streams due to significant mine water discharges is a real environmental problem in many areas with abandoned mines presence, along with the risk of damage by sudden inrushes of mine water at the surface.

Key words: mine waters, mining hydrogeology, mining impacts, drinking water, surface water quality, Slovakia

6.1 Introduction

The territory of Slovakia is due to favourable hydrogeological and climatic conditions, famous for its abundant occurrences of mineral, thermal and natural waters. Thanks to rich history of mining, gradually – mostly since the Middle Ages – specific sources of water have appeared, as a consequence of drainage and accumulation effect of underground workings.

The Slovak historic mining was bound with mining centres in the Western Europe, mainly in Saxony and Austria. The birthplace of modern mining or at least recording of modern mining occurred during the 16th century in the Erzgebirge area of Germany. Methods of mining of the place, including dewatering and the environmental impacts associated with mining and mineral dressing are recorded in classic thesis *De Re Metallica* (Agricola, 1556). The peak of raw minerals extraction in Europe lasted from the end of the Middle Ages to the Early Modern Period. In Slovakia initially mainly gold, silver and copper were mined; in the last century iron had become a dominant mined metal. Production of iron ore reached its peak in the period 1911 – 1913 with an average annual extraction of 1.1 million tonnes (Stauch, 1938). After World War I in Slovakia developed mining of manganese and antimony, the production of precious metals was modernized and production of lead resumed. The youngest Slovak mining industry – coal and crude oil – developed as well. After a temporary decline, mining of magnesite increased, and the extraction of asbestos and gypsum was launched (Stauch, 1938). Last term of the recovery of mining and exploration activities in the period 1971 – 1985 was supported by government grants (Zámora, 2003). After the transition to a market economy after 1989, the State declared setback in ore mining programme and within a short time extraction at dozens of mines was terminated. All of them were abandoned after disposal of available equipment and safety measures at the mining works adit collars. Deep levels below the local erosion base have gradually filled-up by the water and on the surface have emerged new spontaneous outflows of mine water.

Deep mines drainage issues were initially dealt with by so-called mining experts, from the early 20th century by mining engineers. Only since 1955 hydrogeologists have begun to participate in solving them, particularly in the dewatering of extracted lignite/brown coal deposits and their relation to the significant sources of healing mineral waters. The hydrogeological service at the extraction of other types of minerals was rather an exemption in the mining plants. The first comprehensive survey on the occurrence of mine water in Slovakia, along with the hydrogeological characteristics of major deposits and common knowledge of the hydrogeology of mineral deposits, brought the third tome of Hydrogeology of Czechoslovak Socialist Republic (Homola & Klír, 1975). Later it was published a brief review of the occurrence and the possibilities of mine waters exploitation in Slovakia (Cicmanová et al., 1999), and their frequency, quantity, chemical composition and related environmental problems (Bajtoš, 2005).

In the years 2008 – 2011 SGIDŠ conducted regional hydrogeological research, the main objective of which was to collect, unite and analyse available data on mining waters in Slovakia and to develop a synthesis of knowledge about the quantities and formation of their chemical composition in relation to the deposit type and associated rocks drained by mining works (Bajtoš et al., 2011a). The purpose of the work was to ensure a missing comprehensive overview of sources of mine water in Slovakia in terms of their quantitative and qualitative parameters in respect of their practical use and the risk of negative impacts on the environment. This contribution presents the results of the research on the spatial distribution of mining waters in Slovakia, their hydrogeological classification, quantitative evaluation and classification of their chemical composition along with the evaluation of qualitative properties in relation to the requirements for drinking water quality. The paper discusses also the environmental problems associated with the occurrence of mine waters based on the actual results of the Monitoring of the impact of mining upon the environment at risk localities, implemented at SGIDŠ since 2007 (information is available at the website www.geology.sk), and results of the analysis of the potential risks generated by inrushes of mine water after completion of mining activities (Bajtoš et al., 2011b). Its aim is to document the present state of time-dependent occurrence of mine water resources, their negative impact on the environment and people's lives, eventually the beneficial uses, and at the same time to stimulate their further research.

6.2 Materials and methods

6.2.1 Input data

To characterize documented sources of mine water archival data are used amended on actual field measurements and laboratory analyses. The largest information archive base data are the final reports of regional hydrogeological research, hydrogeological surveys and deposit geological surveys of both search and detailed stages, stored in Geofond SGIDŠ, Bratislava. In our case the main source of data on one-off discharges of adit outflows were collected during fieldwork inventory at old mine workings (Záviš et al., 1996) situated outside the then mining fields. A large number of galleries with discharge was documented during the regional hydrogeological mapping of the Volovské vrchy Mts. in the basin of Hnilec (Malík et al., 1990), northern part of the Spiš-Gemer Ore Mts. (Scherer et al., 1999) and part of the Spiš-Gemer Ore Mts. in the Slaná River Catchment (Bajtoš, 2001). Sources of mine water in the Štiavnica-Hodruša ore field were documented in a detailed hydrogeological survey (Lukaj, et al., 1983) and then search for hydrogeological sources (Viest, et al., 1993). The assessment reflects the results of quantitative and qualitative regime observations of mining water sources, implemented in several hydrogeological surveys and studies of various mining-deposit areas. When collecting archive data it was necessary to individually evaluate the reliability and accuracy of laboratory analyses of mine water. The adopted analyses of the scope of a complete basic analysis (determined by the concentration of all macro-components) were checked by calculation ionic balance error. Those analyses were accepted with an error of less than 5%, in rare cases up to 10%. In the database of archive data have been collected 1,330 laboratory analyses with variable extent of the parameters determined.

The database of archive data was supplemented with actual field measurements of selected objects. The discharge of the effluent and basic physico-chemical water parameters were measured: temperature, specific electric conductivity (EC), water reaction (pH), and oxygen saturation. The discharge of outflow was measured according to local conditions by the volumetric method (using a container and stopwatch) or hydrometric wing A.OTT Kempten. On selected objects 120 water samples were taken for chemical analysis of water in the range: Na, K, Mg, Ca, Sr, NH_4, Mn, Fe, Fe^{II}, F, Cl, SO_4, NO_2, NO_3, PO_4, HCO_3, CO_3, SiO_2, Al, As, Ba, Cd, Cr, Cu, Hg, Pb, Sb, Se, Zn, Be, Ag, Ni, Co, B, Sn, V, Mo, aggressive CO_2 and COD_{Mn}. Of the 30 samples radiological indicators were determined: bulk activity of radon, bulk activity of radium 226 and uranium concentration. The above laboratory analyses of water were performed in an accredited laboratory GAL SGIDŠ in Spišská Nová Ves.

6.2.2 Ways of mine water sources classification

Documented sources of mine water in Slovakia have been categorized by place of occurrence, hydrogeological conditions of the deposit, the type of circulation of groundwater in the host rock environment, the amount of mine water, chemical type of mining water and its quality.

Regional classification rests in the on two levels definition of broad areas of occurrence of mining water. We distinguish mining-deposit regions and mining-deposit areas. The basis for the definition of mining-deposit regions is the spatial concentration of mining water sources occurrences within the boundaries of a particular region, corresponding to the regional geological division of Slovakia (Vass et al., 1988). Within mining-deposit regions mine water areas are delineated which correspond to the smaller territories areas or sites. In Slovakia, we have allocated 14 mining-deposit regions and 71 mining-deposit districts. They are listed in Table 6.2 and their spatial definition is shown in Fig. 6. 1.

Deposit-hydrogeological classification has been developed to indicate the source groups of mining water, which are characterized by an identical type of permeability of deposit rocks, similarities of circulation and draining of the groundwater by workings, common genesis type of chemical composition of mine waters and the similarity of their qualitative characteristics of water. It is based on a combination of definition of the basic deposit-hydrogeological types of deposit bodies and basic types of groundwater circulation in the host rock environment.

Delineation of basic hydrogeological types of deposit bodies is closely linked to the genetic breakdown of mineral deposits, because individual genetic types of deposits are developed at certain specific conditions in similar rocks and are characterized by an identical type of minerals associations. In Slovakia, we have allocated 18 hydrogeological types of deposits, whereas we relied on metallogenic division of Slovakia (Lexa et al., 2007). Their list, along with an overview of the number of occurrences of mining waters and basic quantitative indicators are given in Table 6.3, along with the basic types of groundwater circulation in the host rock environment.

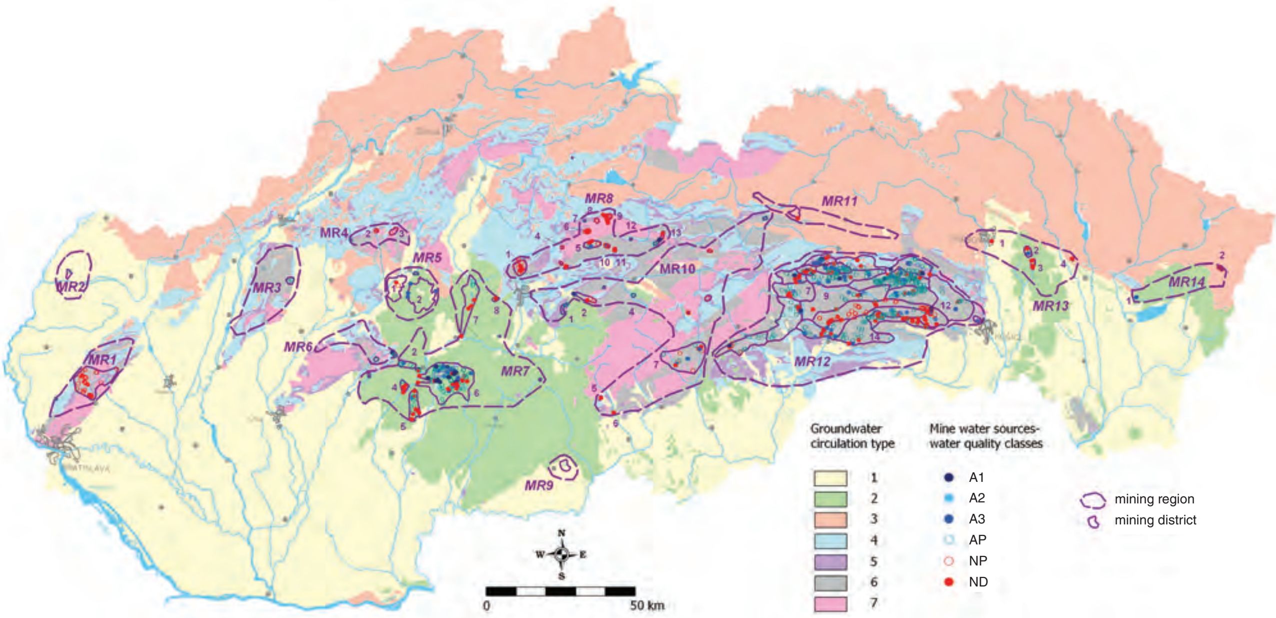

Fig. 6.1 Mining-deposit regions (MR) and mining-deposit districts (MD) of Slovakia with mine water occurrences.

6.2.3 Way of categorization of documented amounts of mine waters

Collected quantitative and qualitative data on documented sources of mine water have been used to categorize quantities of mine water, based on allocated deposit-hydrogeological types and regional data. This categorization takes into account the nature of the available groundwork material and the specific nature of resources evaluation. Documented quantities are categorized according to the value of the characteristic discharge Q_{char} of resources and also by the quality requirements for drinking water (Table 6.8). The categorization results give an overview of the amount of mine water suitable for drinking; they also indicate potential sources of contamination of surface waters, or groundwaters.

For the characteristic Q_{char} value we considered the arithmetic average of the available data set. The most aforementioned Q_{char} values – up to 938 from a total of 1,041 (90%) documented sources of mine water – is determined from single or repeated measurements.

In qualitative terms the documented sources of mine water are divided into classes according to suitability for treatment before being used for drinking purposes. The sources of mine water with the available laboratory analyses, we classified in categories A1, A2, A3 defined by Decree of the Ministry of the Environment 636/2004 Coll. as suitable for drinking purposes with varying intensity of treatment, or in the category of ND – water prohibited for drinking purposes. In the case of the absence of laboratory analyses the sources were assessed as likely complying with the class AP, and probably unsuitable in the class NP, individually by deposit hydrogeological type. For the assessment of the qualitative characteristics of the source of mine water there was available unconsolidated groundwork material, in particular as regards the scope of the determined indicators. The prevalence of cases there were available essential contents of ions, the extent of determined trace elements, however, was considerably variable and mainly data on the concentration of B, Se, Ag, and Sb were missing (Table 6.1).

Due to the uneven number of analyses available for the qualitative assessment of a particular source we derived for each quality indicator the so-called characteristic value. The method of calculating characteristic values depended upon the number n of available measurements of the relevant parameter in the reporting period:

provided $n \geq 24$: characteristic value corresponds to the value set of quality indicator with a probability 90% not exceeded (for dissolved oxygen with a exceeding probability 90%);

provided n = [11, 23): characteristic value is determined as the average of the three most unfavourable values of the set;

provided $n < 11$: characteristic value corresponds to the maximum value of the set.

Tab. 6.1 Number (n) and percentage (%) of objects with missing data on the content of individual water quality indicators established by laboratory analyses.

	Hg	Sb	As	Ag	Ni	Se	B	Zn	Pb	Cd	Cr	Cu	Al	F	Ba
n	14	40	4	67	54	42	126	9	5	10	11	5	30	23	53
%	5.2	15.0	1.5	25.1	20.2	15.7	47.2	3.4	1.9	3.7	4.1	1.9	11.2	8.6	19.8

Note: The total number of evaluated objects is 267

6.3 Classification of Slovak mining waters

Documented sources of mine water in Slovakia have been qualified by geographical, deposit-hydrogeological, quantitative and qualitative hydrochemical criteria.

6.3.1 Regional distribution

Mining water sources are spatially spread very unevenly, concentrated mainly in the historic mining district in the central part of Slovakia. Among allocated 14 mining-deposit regions (MR) Gemer zone (MR 12) in eastern Slovakia is the largest and richest in mine water occurrences, divided into 20 mining-deposit districts (MD). Boundaries of these districts are determined on the basis of general map of the Spiš-Gemer Ore Mts. and their names correspond to the occurrences of metamorphic-hydrothermal vein mineralisation (metamorphic-hydrothermal vein mineralisation) by monograph Grecula et al. (1995), which contains a detailed description of the geology of deposits and their ore minerals and quality, as well as history of exploration and mining. Among them Slovinky – Gelnica (MD 10) is the most important district in terms of mine waters occurrences and their quantity. Another important region is Central Slovakia Neovolcanites Field (MR7), where among 10 MD extremely important is Štiavnica-Hodruša ore district (MD 7 – 6). Thanks to the size and amount of mine water reserves of coal in the Upper Nitra (MR 5) are significant along with South-Slovakia Lowland (MR 2). The remaining MRs are relatively poor in the incidence of mine water.

6.3.2 Classification of sources of mine water according the basic hydrogeological types of deposit bodies

Nature of the circulation, regime and formation of the chemical composition of water in the reach of worked deposits depends primarily on the geological structure of deposits and on the type and mineral composition of deposit bodies, also on the elevation position deposit against the local erosion base level, geometry of mine workings, drainage rate of hydrogeological collectors and precipitation-climatic conditions of the territory. Whereas individual genetic types of deposits are developed under certain specific conditions in similar rocks and are characterized by an identical type of mineral associations, the basic hydrogeological types of the deposit bodies occurring in the territory of Slovakia can be derived from the genetic breakdown of mineral deposits (Lexa et al., 2007). The basic hydrogeological types include those types of deposits which have or had previously been mined and therefore they host the mine water. Of the 31 types of deposits (or mineralisation types) of this genetic division of deposits we derived 18 basic deposit-hydrogeological types:

1) Sn, W and Mo <u>greisen</u> pneumatolithic-hydrothermal and hydrothermal <u>mineralisation</u> (*phm*)
   Deposits of neo-Hercynian late- to post-orogene stage of this type represent a hydrothermally altered peripheral parts of the granitic bodies of irregular shape. They have a fissure permeability and are component of the hydrogeological massif of intrusive magmatic rocks, and their permeability is similar to encompassing rocks. Therefore, the groundwater has silicatogenic dissolved solids.
2) <u>syngenetic massive-sulphidic pyrite-pyrrhotite mineralisation (*ssu*)</u>
   Stratiform sulphides horizons originated in palaeo-Hercynian metallogenic stage. They are lenticular-shaped bodies with fissure permeability type whose class is not significantly different from the degree of permeability of host metamorphic Palaeozoic hydrogeological massif. Their groundwaters have sulphidogenic dissolved solids – metallosulphate acid waters are formed.
3) <u>uranium-molybdene-copper mineralisation</u> – syngenetic/diagenetic, infiltration or vein-stockwork-impregnation (*u*)
   This type of neo-Hercynian or even palaeo-Alpine mineralisation consists of irregularly shaped bodies tied to specific layer sequences and tectonic zones. Their fissure permeability is equivalent to permeability of Palaeozoic host rocks. Oxidation of sulphides at varying rates takes place in deposit bodies, along with dissolution of carbonates and hydrolysis of silicate minerals.
4) <u>vein and stockwork-impregnation gold-scheelite-arsenopyrite mineralisation</u> (*sche*)
5) <u>gold-antimonite vein and stockwork-impregnation mineralisation</u> (*az*)
6) <u>siderite-sulphidic vein and stockwork-impregnation mineralisation</u> (*sz*)
7) <u>copper vein and stockwork-impregnation mineralisation</u> (*mz*)
   Deposits of the type *sche* and *sz* belong to palaeo-Alpine to late-orogenic hydrothermal vein mineralisation. True hydrothermal veins reach small thicknesses (generally less than 5 m, maximum 20 m); they are usually situated in steeply inclined pre-Mesozoic host rocks and they are tectonically segmented. They are accompanied by stockworks and impregnation zones. They have fissure permeability which does not significantly differ from the permeability class of the host rock. From hydrogeochemical point of view it is a very variable environment with varying proportions of quartz, carbonate and sulphide minerals. Therefore, sulphidogenic, carbonatogenic and silicatogenic dissolved solids are present in various proportions.
8) <u>siderite-ankerite metasomatic mineralisation</u> (*sid*)
9) <u>magnesite metasomatic mineralisation</u> (*mag*)
10) <u>talc metasomatic mineralisation</u> (*mst*)
   The geometries of the deposit bodies of the types *mag*, *sid* and *mst* are very similar, since they represent metasomatically (palaeo-Alpine orogeny stage) altered bodies of synsedimentary carbonates deposited within Palaeozoic metamorphic sediments. Their original form is heavily modified by tectonic processes. Groundwater in these deposits is enriched in the carbonatogenic dissolved solids, and depending on

Tab. 6.2 Documented quantity Q_{Σ} in l·s[-1] of mine water outflows in mining regions (MR) and mining districts (MD)

MD number	Mining district (MD)	n	Q_{Σ}	Frequency of present HG types *n*	Summary yield Q_{Σ} (l·s^{-1}) of present HG types
MR 1 Malé Karpaty Mts.		**33**	50.67	**13 ssu, 13 az, 4 az/ssu, 3 mn**	**31.07 ssu, 11.41 az, 6.9 az/ssu, 1.29 mn**
1-1	Stupava	3	1.29	3 mn	1.29 mn
1-2	Pezinok - Pernek	30	49.38	13 az, 4 az/ssu, 13 ssu	11.41 az, 6.9 az/ssu, 31.07 ssu
MR 2 Záhorská nížina Lowland		**1**	25	**1 uh**	**25 uh**
2-1	Gbely-Kúty	1	25	1 uh	25 uh
MR 3 Považský Inovec Mts.		**2**	6	**2 zlt**	**6 zlt**
3-1	Zlatníky	2	6	2 zlt	6 zlt
MR4 Strážovské vrchy Mts.		**6**	0.82	**5 az, 1 sz**	**0.72 az, 0.1 sz**
4-1	Čierna Lehota - Vtáčnik	1	0.1	1 sz	0.1 sz
4-2	Čavoj	3	0.42	3 az	0.42 az
4-3	Chvojnica	2	0.3	2 az	0.3 az
MR 5 Upper Nitra Basin		**8**	333.7	**6 uh, 2 z**	**333.7 uh, 0.15 z**
5-1	Nováky	2	114	2 uh	114 uh
5-2	Handlová - Cigeľ	4	219.7	4 uh	219.7 uh
5-3	Kopanice	2	0.15	2 z	0.15 z
MR 6 Tríbeč Mts.		**7**	10.92	**4 z, 3 sz**	**9.82 z, 1.1 sz**
6-1	Jedľové Kostoľany	3	1.1	3 sz	1.1 sz
6-2	Veľké Pole - Píla	4	9.82	4 z	9.82 z
MR 7 Central Slovakia Neovolcanic Field		**190**	460.94	**185 z, 3 i, 2 uh**	**455.39 z, 2.35 i, 3.2 uh**
7-1	Obyce - Včeláre	1	3	1 uh	3 uh
7-2	Horné Hámre	7	2.6	7 z	2.6 z
7-3	Žarnovica (Kožený vrch)	8	0.53	8 z	0.53 z
7-4	Nová Baňa	8	1.86	8 z	1.86 z
7-5	Rudno-Pukanec	20	24.95	20 z	24.95 z
7-6	Štiavnicko-hodrušský rudný obvod	131	341.45	131 z	341.45 z
7-7	Kremnica	9	83.75	9 z	83.75 z
7-8	Malachov	3	2.35	3 z	2.35 z
7-9	Turová	1	0.2	1 uh	0.2 uh
7-10	Slatinské Lazy, Kalinka	2	0.25	2 z	0.25 z
MR 8 Nízke Tatry Mts.		**74**	129.29	**47 az, 14 mz, 6 sz, 5 sche, 2 phm**	**42.31 az, 39.72 sche, 15.54 mz, 1.32 sz, 0.4 phm**
8-1	Špania Dolina, Staré Hory	14	15.54	14 mz	15.54 mz
8-2	Hiadeľ	1	1	1 az	1 az
8-3	Medzibrod	5	2.78	5 az	2.78 az
8-4	Korytnica - Pustá dolina	1	0.1	1 az	0.1 az
8-5	Jasenie (-Soviansko, Lomnistá)	5	39.72	5 sche	39.72 sche
8-6	Magurka	11	13.45	11 az	13.45 az
8-7	Partizánska Ľupča	2	0.4	2 phm	0.4 phm
8-8	Rišianka	3	0.6	3 az	0.6 az
8-9	Dúbrava	11	45.42	11 az	45.42 az
8-10	Dolná Lehota (Dve vody)	7	3.78	7 az	3.78 az
8-11	Lom	6	4.94	6 az	4.94 az
8-12	Trangoška	1	0.2	1 sz	0.2 sz

MD number	Mining district (MD)	n	Q_Σ	Frequency of present HG types *n*	Summary yield Q_Σ ($l \cdot s^{-1}$) of present HG types
8-13	Nižná Boca	7	1.36	5 sz, 2 az	1.12 sz, 0.24 az
MR 9 Juhoslovenská nížina Lowland		1	75	1 uh	75 uh
9-1	Veľký Krtíš	1	75	1 uh	75 uh
MR 10 Vepor Zone		**42**	17.72	**12 mst, 9 lim, 6 az, 5 ssu, 3 mz, 3 sz, 2 mg, 2 u**	**10.36 mst, 2.95 lim, 1.54 az, 0.98 mz, 0.7 sz, 0.68 ssu, 0.48 mag, 0.03 u**
10-1	Poniky	6	1.75	6 lim	1.75 lim
10-2	Ľubietová	6	2.18	3 lim, 3 mz,	1.2 lim. 0.98 mz
10-3	Osrblie	1	0.5	1 sz	0.5 sz
10-4	Čierny Balog	2	0.2	2 sz	0.2 sz
10-5	Ružiná	1	0.43	1 mag	0.43 mag
10-6	Podrečany	1	0.05	1 mag	0.05 mag
10-7	Hnúšťa-Kokava	17	11.4	12 mst, 4 az, 1 ssu	10.36 mst. 0.94 az. 0.1 ssu
10-8	Tisovec-Magnetový vrch	3	0.9	2 az, 1 ssu	0.6 az. 0.3 ssu
10-9	Muráň - Hrdzavá dolina	1	0.1	1 ssu	0.1 ssu
10-10	Heľpa	2	0.18	2 ssu	0.18 ssu
10-11	Kravany-Sp.Bystré	2	0.03	2 u	0.03 u
MR 11 Popradská a Hornádska kotlina		2	8.16	2 mn	8,16 mn
11-1	Kišovce-Švábovce	2	8.16	2 mn	8.16 mn
MR 12 Gemer Zone		**656**	662.73	**535 sz, 68 az, 13 u/sz, 10 sid, 10 u, 7 mag, 4 sz/sid, 4 ssu, 2 phm, 1 ssu/sz, 1 sz/sa, 1 sa**	**455.72 sz, 56.96 az, 31.59 u/sz, 21.48 sid, 20.1 u, 18.15 mag, 17.75 phm, 16.37 ssu, 11.43 sz/sa, 10.0 sa, 2.38 sz/sid, 0.44 ssu/sz,**
12-1	Novoveská Huta - Hanisková	23	60.54	13 u/sz, 9 u, 1 sa	31.59 u/sz, 18.95 u, 10 sa
12-2	Dobšiná	23	24.16	23 sz	24.16 sz
12-3	Mlynky - Biele Vody	13	6.32	10 sz, 3 sz/sid	4.24 sz, 2.08 sz/sid
12-4	Gretľa - Ráztoky - Bindt	47	55.27	46 sz, 1 sz/sa	43.84 sz, 11.43 sz/sa
12-5	Rudňany - Poráč - Matejovce	6	32.75	6 sz	32.75 sz
12-6	Krompachy - Žakarovce - Jaklovce	27	33.32	27 sz	33.32 sz
12-7	Rejdová - Vyšná Slaná - Vlachovo	18	9.95	18 sz	9.95 sz
12-8	Hnilec - Čierna Hora - Nálepkovo	44	56.72	42 sz, 2 phm	38.97 sz, 17.75 phm
12-9	Henclová - Stará voda - Švedlár - Mníšek	21	10.29	21 sz	10.29 sz
12-10	Slovinky - Gelnica	141	123.35	141 sz	123.35 sz
12-11	Mníšek - Prakovce - Perlová dolina - Kojšov	52	26.75	52 sz, 1 ssu	25.23 sz, 1.52 ssu
12-12	Margecany - Opátka - Košická Belá - Košice	13	5.45	13 sz	5.45 sz
12-13	Turecká - Rožňava - Rákoš	25	32.47	25 sz	32.47 sz
12-14	Krásnohorské Podhradie - Drnava - Úhorná	23	12.81	23 sz	12.81 sz
12-15	Smolnícka Huta - Jedľovec - Humel - Trochanka	27	35.2	27 sz	35.2 sz
12-16	Štós - Medzev - Poproč	45	31.24	41 sz, 3 ssu, 1 ssu/sz	15.95 sz, 14.85 ssu, 0.44 ssu/sz
12-17	Brdárka - Kobeliarovo - Ochtiná - Čierna Lehota	21	22.72	14 sz, 5 sid, 1 sz/sid, 1 u	14.68 sid, 6.59 sz, 1.15 u, 0.3 sz/sid
12-18	Čučma - Bystrý potok - Poproč - Zlatá Idka	68	56.96	68 az	56.96 az
12-19	Jelšava - Lubeník- Sirk	17	20.1	mag 6, sz 6, sid 5	12.15 mag, 6.8 sid, 1.15 sz
12-20	Košice Bankov	1	6.0	1 mag	6.0 mag
MR 13 Šariš Region		**13**	13.56	**8 i, 4 z, 1 sol**	**7.18 i, 6.37 z, 0.01 sol**

MD number	Mining district (MD)	n	Q_{Σ}	Frequency of present HG types *n*	Summary yield Q_{Σ} ($l \cdot s^{-1}$) of present HG types
13-1	Prešov Solivar	1	0.01	1 sol	0.01 sol
13-2	Zlatá Baňa	4	6.37	4 z	6.37 z
13-3	Dubník	6	4.98	6 i	4.98 i
13-4	Merník	2	2.2	2 i	2.2 i
MR 14 Vihorlatské vrchy Mts.		**4**	2.15	**3 i, 1 lim**	**2.1 i, 0.05 lim**
14-1	Trnava pri Laborci	1	0.05	1 lim	0.05 lim
14-2	Ladomírov	3	2.1	3 i	2.1 i

Explanations: Hydrogeological types of deposits codes according Table 6. 3.

the type of ore mineralisation karst process is present. This is particularly valid for magnesite deposits, in which we can anticipate karst-fissure type of permeability. The deposits of talc and siderite are without significant manifestation of karstification.

11) syngenetic deposits of gypsum and anhydrite (*sa*)
These are fairly large synsedimentary anhydrite bodies that underwent hydration on the periphery and inside the bodies and along fracture zones and faults, resulting in gypsum formation. They have a fissure-karst permeability type and are often accompanied by collector layers of rauhwackes, dolomite or limestone. Sulphatogenic dissolved solids composition in groundwater is typical for them.

12) manganese sedimentary-diagenetic mineralisation (*mn*)
Deposits are formed by thin layers in sediments with fissure permeability type. Therefore, their impact on the overall deposit-hydrogeological conditions is relatively small and is dominated by the influence of accompanying rocks.

13) precious metal and polymetallic vein-stockwork and polymetallic veinlet-impregnation mineralisation (*z*)
This group involves intersecting true hydrothermal veins and irregular bodies of veinlet-impregnation mineralisation of neo-Alpine orogenic stage. Steeply inclined veins have a large depth range. Their permeability may differ significantly depending upon the neovolcanic host rocks permeability and therefore they can act either as a hydraulically substantially conductive structure or as a hydraulic barrier. Groundwater has silicatogenic dissolved solids and variable contribution of sulphidogenic and carbonatogenic dissolved solids.

14) mercury and opal stockwork-impregnation mineralisation (*i*)
Small bodies of stockwork-impregnation mineralisation of neo-Alpine orogenic stage are irregularly shaped. The degree and nature of permeability is not different from neovolcanic host rocks. Mine water is dominated by silicatogenic and sulphidogenic dissolved solids.

15) goethite-limonite mineralisation of cold springs and highly-sulphidation epithermal mineralisation (*lim*)
Small bodies of goethite and limonite of neo-Alpine orogenic stage in the near-surface zone of neovolcanites or different types of hydrogeological massif.

16) coal, lignite (*uh*)
Subhorizontally deposited layers of coal are part of the Neogene filling of intramountain depressions and are usually developed with large areal extent. They have low permeability of the fissure type. The presence of sulphides in them causes the increase of the share component of sulphidogenic dissolved solids in groundwater. Mine water of those deposits comes from overlying or underlying aquifers.

17) halite (*sol*)
Under the presence of water intensive leaching and formation of underground cavities occur in synsedimentary layers of halite. In this case, the permeability is of the karst type and the water attains halogenic dissolved solids in water – with resulting formation of brine.

18) gold placers
They are located in Quaternary sediments with intergranular permeability. Within the deluvial sediments on the metamorphic rock masses they are considered to create the near-surface zone of hydrogeological massif.

Individual hydrogeological types of deposit are usually formed in the typical environment of the host rocks. This applies to synsedimentary deposits, but also to younger deposit structures linked to tectonic predisposition and geochemical barriers. For the purposes of this assessment basic types of host rock deposits can be defined according to the type of groundwater circulation. These reflect the fundamental differences between different types of hydrogeological collectors, regarding the essential features of their geometry, the type and degree of their permeability and their type of hydraulic regime. We distinguish 7 types of host rocks: 1) hydrogeological massif of magmatic rocks, 2) hydrogeological massif of Palaeozoic metamorphites, 3) hydrogeological massif of non-karst Mesozoic, 4) karst Mesozoic, 5) hydrogeological massif of Palaeogene sediments, 6) stratovolcanic type, 7) basinal type. The usual types of the groundwater circulation in certain hydrogeological deposit type, along with the number and yield of the documented sources of mine water are given in Table 6.3.

Tab. 6.3 Classification documented sources of mine water by hydro-type deposit bodies

	Type code	Type of deposit	Type of groundwater circulation	n	Q_{Σ} $l \cdot s^{-1}$	$Q_{\varnothing}$ $l \cdot s^{-1}$	Q_{min} $l \cdot s^{-1}$	Q_{max} $l \cdot s^{-1}$
1	phm	greisen (Sn, W) and molybdene pneumatolithic-hydrothermal to hydrothermal mineralisation	hydrogeological massif of Palaeozoic metamorphites a	4	18.15	4.54	0.20	15.11
2	ssu	syngenetic massive-sulphidic pyrite-pyrrhotite mineralisation	hydrogeological massif of Palaeozoic metamorphites	27	55.46	2.05	0.03	11.89
3	u	uranium-molybdene-copper mineralisation (syngenetic/diagenetic, infiltration or vein-stockwork-impregnation)	hydrogeological massif of Palaeozoic metamorphites	26	54.72	2.11	0.01	15.0
4	sche	vein and stockwork-impregnation gold-scheelite-arsenopyrite mineralisation	hydrogeological massif of magmatic rocks	5	39.72	7.94	0.31	17.24
5	az	gold-stibnite vein and stockwork-impregnation mineralisation	hydrogeological massif of magmatic rocks, hydrogeological massif of Palaeozoic metamorphites	139	142.94	1.03	0.01	15.04
6	sz	siderite-sulphidic vein and stockwork-impregnation mineralisation	hydrogeological massif of Palaeozoic metamorphites	554	472.85	0.85	0.01	26.42
7	mz	copper vein and stockwork-impregnation mineralisation	hydrogeological massif of Palaeozoic metamorphites	17	16.52	0.97	0.03	5.45
8	sid	siderite-ankerite metasomatic mineralisation	hydrogeological massif of Palaeozoic metamorphites	10	21.48	2.15	0.05	10.0
9	mag	magnesite metasomatic mineralisation	hydrogeological massif of Palaeozoic metamorphites	9	18.63	2.07	0.05	10.0
10	mst	talc metasomatic mineralisation	hydrogeological massif of magmatic rocks	12	10.36	0.86	0.18	2.67
11	sa	syngenetic deposit of gypsum and anhydrite	hydrogeological massif of non-karst Mesozoic	1	10.0	10.0	10.0	10.0
12	mn	manganese sedimentary-diagenetic mineralisation	hydrogeological massif of non-carbonate Mesozoic or Palaeogene sediments	5	9.45	1.89	0.19	4.77
13	z	precious-metal and polymetallic vein and stockwork-impregnation mineralisation	stratovolcanic type	195	471.73	2.42	0.01	252
14	i	mercury and opal stockwork-impregnation mineralisation	stratovolcanic type, hydrogeological massif of Palaeogene sediments	14	11.63	0.83	0.05	2.0
15	lim	goethite-limonite mineralisation of cold springs	stratovolcanic type, hydrogeological massif of magmatic rocks or of Palaeozoic sediments	10	3.00	0.30	0.05	1.0
16	uh	coal, lignite	basinal type	10	436.9	43.69	0.20	112
17	sol	halite	basinal type	1	0.01	0.01	0.01	0.01
18	zlt	gold placers	hydrogeological massif of magmatic rocks	2	6	3.0	2.0	4.0

6.3.3 Classification of resources by mining water discharge

In quantitative terms, we register the documented source of mine water in 5 classes, according to the characteristic yield Q_{char} (Table 6.4). The second class outnumbers the others at an interval of values Q_{char} = 0.1 – 1 $l \cdot s^{-1}$. The most significant in terms of the total amount documented is, however, the fourth class, where 24 sources with a yield in the range from 10 – 100 $l \cdot s^{-1}$ give a summary discharge of 552 $l \cdot s^{-1}$. The biggest of them are: Hlavná dedičná štôlňa (Main Heritage Gallery; Fig. 6. 2) dewatering Kremnica ore district (MD 7-7, Q_{char} = 75 $l \cdot s^{-1}$ – without the amount of surface water conveyed into the mine to drive an underground hydroelectric power plant), two drainage pits at the coal deposit Nováky (5-1 MD, totally 115 $l \cdot s^{-1}$), the main gallery of the coal seam in Cigeľ (MD 5-2, Q_{char} = 68 $l \cdot s^{-1}$), Baňa Dolina in Veľký Krtíš (MD 9-1, 75 $l \cdot s^{-1}$). To the class V belong Voznická Drainage Gallery, which drains Štiavnica-Hodruša ore district (MD 7-6, Q_{char} = 252 $l \cdot s^{-1}$) and Stará štôlňa (Old Gallery) at Handlová coal deposit (MD = 5-2, Q_{char} = 112 $l \cdot s^{-1}$).

6.3.4 Classification of mine water sources by chemical composition

In terms of total dissolved solids (TDS content) the mine waters are classified by Alekin's classification used for fresh groundwater (Table 6.5). The most frequent is the moderate mineralisation in the range of 200 to 500 $mg.l^{-1}$.

Fig. 6.2 Mouth of Main Heritage Gallery of Emperor Ferdinand near Žiar nad Hronom, draining Kremnica ore district

Tab. 6.4 Discrimination of quantitative classes of mining water resources

Class	Discharge class	**Q** l·s⁻¹	n	Q_{Σ} l·s⁻¹	RL_A mg·l⁻¹
I	very low,	< 0.1	231	10.66	88
II	low	0.1 – 1	574	210.06	87
III	moderate	1 – 10	209	551.77	312
IV	high	10 – 100	24	662.96	731
V	very high	>= 100	2	364.00	1048

Explanation: Q_{Σ} - the sum of the yield characteristic Q_{char} of objects pertaining to the quantitative class; RL_A - the arithmetic mean of the characteristic values of total dissolved solids (TDS content) in the relevant quantitative class.

Tab. 6.5 Classification of sampled mine water sources by the total dissolved solids

Class	Dissolved solids class	Dissolved solids values range mg·l⁻¹	n	DS_A mg·l⁻¹	Prevailing macrochemical class
S^{I}	very low,	< 100	19	78	CH^{IV}
S^{II}	low	100 – 200	68	149	CH^{II}, CH^{I}
S^{III}	moderate	200 – 500	120	323	CH^{I}, CH^{II}
S^{IV}	high	500 – 1,000	57	712	CH^{I}, CH^{IV}, CH^{II}
S^{V}	very high	>= 1,000	30	2,137	CH^{IV}, CH^{V}

In terms of the macrochemical composition of mine water we distinguish 7 basic groups of chemical types. Their overview along with a large representation of sampled objects is presented in Table 6.6. The allocated groups according the type of chemical composition document the fact that the variability in macrochemical composition of mine water is mainly determined by the ratio among the four basic components – calcium, magnesium, bicarbonate anion and sulphate anion. Only in rare cases aluminium or iron have a high proportion of TDS. The mean TDS of water rises in designated classes from CH^{I} to CH^{VI} with the transition of chemical species from distinct through indistinct and intermediary to mixed types.

Qualitative characteristics of mine waters are evaluated according to current legal standards and the results of this assessment are set out below.

6.4 Categorisation of mine water quantities according to the quality requirements for drinking water

The quantity of mining waters bound to various hydrogeological types of deposits, documented in Slovakia in mining-deposit regions and districts, we have divided by quality classes. As described in the methodological part of this text, we have categorized different sources of mine water according to the requirements for drinking water pursuant to Decree of the Ministry of the Environment 636/2004 Coll. We have carried out the categorisation in the range of selected physical and chemical indicators of quality that reflect well the risk from natural geochemical conditions at sites. There are not evaluated microbiological and biological indicators or organic indicators that reflect the current state of exploited deposits or anthropogenic load of the site and in the long run may be highly variable. Generally it can be assumed that in the case of microbiological and biological indicators a risk of occasional presence exists, which necessitates the installation and operation of a disinfection facility. In the case of organic indicators we assume in abandoned mining works mostly very low risk of exceeding the limit for drinking water, as confirmed by laboratory analyses available from some mining water sources. The levels of radiological indicators in mining waters according to available studies meet the requirements for drinking water. This is valid even for the mine water of U – Mo – Cu mineralisation (s), occurring dominantly in Novoveská Huta area (MD 12-1); at the time of extraction the mine water was characterized by a high level of radiation. The high content of radon is documented only in mining water of stibnite veins (*az*) and greisen Sn-W mineralisation (*phm*), flowing out from galleries in Gemeride granites (MD 12-18, or MD 12-8).

The breakdown of the quantities of mine water documented by the quantity (as defined in Table 6.4) and the quality classes are shown in Table 6.7 and in Figs. 6. 3 and 6. 4. Of the total amount of documented Q_{AN} = 1,799.55 l·s⁻¹ in the recorded sources of mine water corresponds qualitatively suitable Q_A proportion 829.53 l·s⁻¹ (46%) of mining water. Most of the quantity Q_A (54% Q_A) was assigned to the quality class AP by analogy – for lack of laboratory analyses. The amount 970.02 l·s⁻¹ (66.9%) is considered unsuitable for water quality purposes; the predominant proportion of the amount (82%) is documented by laboratory analyses. These resources are mostly the

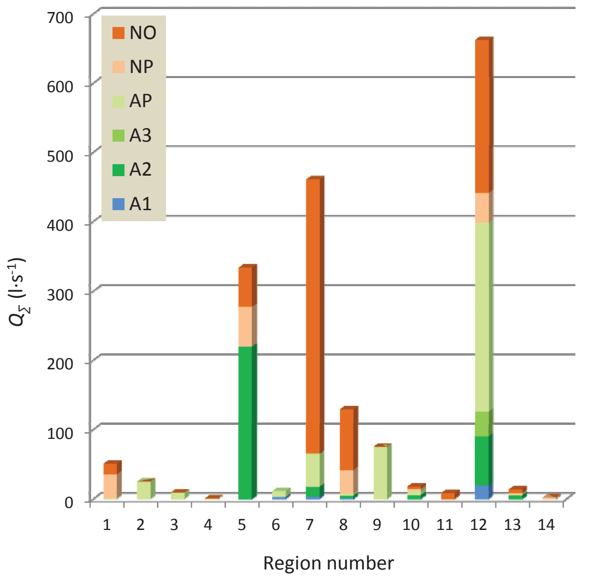

Fig. 6.3 Amounts of mine water of mining deposit regions divided in quality classes. Region labels are conform to Tab.6.3.

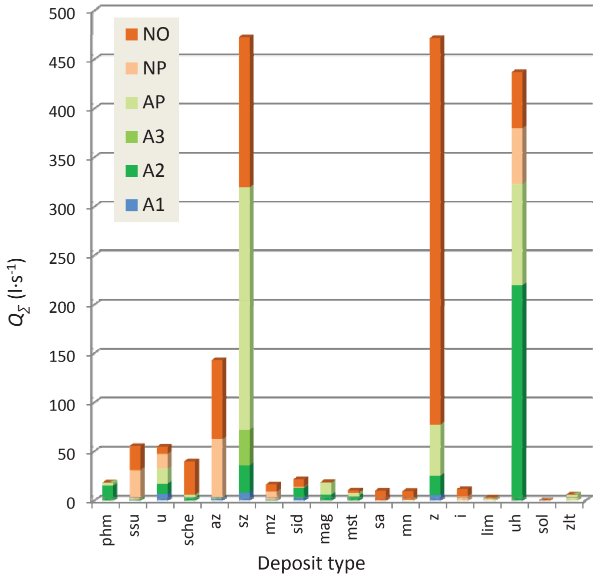

Fig. 6.4 Amounts of mine water of hydrogeological deposit types divided in quality classes. Codes of deposit types are stated in Tab.6.4.

Tab. 6.6 Allocation of classes by macrochemical mine water composition

Class	Chemical type according prevailing ions	Gazda's chemical type	*n*	RL_A mg·l^{-1}
CH^{I}	Ca-Mg-HCO_3	A_2 distinct	90	376
CH^{II}	Ca-Mg-HCO_3	A_2 indistinct	82	414
CH^{III}	Ca-Mg-SO_4-HCO_3	A_2-$S_2(SO_4)$ intermediary, A_2-$S_2(SO_4)$ mixed, A_2 intermediary, A_2 mixed	30	439
CH^{IV}	Ca-Mg-SO_4	$S_2(SO_4)$ indistinct and intermediary	48	638
CH^{V}	Ca-Mg-SO_4	$S_2(SO_4)$ distinct	32	984
CH^{VI}	Al(Fe)-Ca-SO_4	$S_3(SO_4)$ distinct and indistinct, $S_2(SO_4)$-$S_3(SO_4)$ intermediary	6	658
CH^{VII}	Na-Cl	S_1(Cl) distinct	1	5,000

potential sources of contamination. In terms of summary discharge of evaluated sources the class IV is the most represented (sources with Q_{char} = 10 – 100 l·s^{-1}) with the class yield of Q_{AN}^{IV} = 663 l·s^{-1} (37% of the total discharge Q_{AN}). Of the total number of documented sources of mine water n_{AN} = 1041 the majority (55%) belongs to the class Q^{II} (Table 6.8).

Tab. 6.7 Quantities of mine waters in documented sources according to quantity and quality classes

Q = l·s^{-1}		Quality classes of mine waters						
		A1	**A2**	**A3**	**AP**	**NP**	**ND**	**AN**
Quantity classes	**I**	Q_{A1}^{I} = 0.22	Q_{A2}^{I} = 0.25	Q_{A3}^{I} = 0.31	Q_{AP}^{I} = 8.39	Q_{NP}^{I} = 0.81	Q_{ND}^{I} = 0.68	**Q_{AN}^{I} = 10.66**
	II	Q_{A1}^{II} = 6.63	Q_{A2}^{II} = 12.41	Q_{A3}^{II} = 2.54	Q_{AP}^{II} = 118.21	Q_{NP}^{II} = 30.39	Q_{ND}^{II} = 39.88	**Q_{AN}^{II} = 210.01**
	III	Q_{A1}^{III} = 18.94	Q_{A2}^{III} = 61.43	Q_{A3}^{III} = 33.54	Q_{AP}^{III} = 200.75	Q_{NP}^{III} = 61.55	Q_{ND}^{III} = 175.56	**Q_{AN}^{III} = 551.77**
	IV	Q_{A1}^{IV} = 0	Q_{A2}^{IV} = 25.11	Q_{A3}^{IV} = 0	Q_{AP}^{IV} = 228.7	Q_{NP}^{IV} = 83.0	Q_{ND}^{IV} = 326.15	**Q_{AN}^{IV} = 662.96**
	V	Q_{A1}^{V} = 0	Q_{A2}^{V} = 0	Q_{A3}^{V} = 0	Q_{AP}^{V} = 0	Q_{NP}^{V} = 0	Q_{ND}^{V} = 364.0	**Q_{AN}^{V} = 364.0**
In total		Q_{A1} = 25.79	Q_{A2} = 318.9	Q_{A3} = 36.39	Q_{AP} = 448.35	Q_{NP} = 175.75	Q_{ND} = 794.27	**Q_{AN} = 1,799.45**
		Q_A = 829.43				Q_N = 970.02		

Explanations: I-V – classes of characteristic yield mine water sources (according to the criteria set out in Table 6.4); A3, A2, A1 – category of water quality according to the Ministry of Environment Decree No. 636/2004 Coll. verified by laboratory analyses; AP, NP - quality categories determined by the analogy for objects with missing laboratory testing; ND – water not meeting the requirements of the Decree of the Ministry of the Environment 636/2004 Coll.; *Q* – summary of the amount of mine water resources assigned to a certain class of quantity (^{superscript}) and quality ($_{subscript}$).

Tab. 6.8 Frequency of documented sources of mine water by quantitative and qualitative classes

n		Quality classes of mine waters						
		A1	A2	A3	AP	NP	ND	AN
Quantity classes	I	$n_{A1}^{I} = 5$	$n_{A2}^{I} = 4$	$n_{A3}^{I} = 5$	$n_{AP}^{I} = 179$	$n_{NP}^{I} = 21$	$n_{ND}^{I} = 17$	$\mathbf{n_{AN}^{I} = 231}$
	II	$n_{A1}^{II} = 20$	$n_{A2}^{II} = 31$	$n_{A3}^{II} = 6$	$n_{AP}^{II} = 353$	$n_{NP}^{II} = 94$	$n_{ND}^{II} = 70$	$\mathbf{n_{AN}^{II} = 574}$
	III	$n_{A1}^{III} = 6$	$n_{A2}^{III} = 21$	$n_{A3}^{III} = 8$	$n_{AP}^{III} = 84$	$n_{NP}^{III} = 27$	$n_{ND}^{III} = 63$	$\mathbf{n_{AN}^{III} = 209}$
	IV	$n_{A1}^{IV} = 0$	$n_{A2}^{IV} = 4$	$n_{A3}^{IV} = 0$	$n_{AP}^{IV} = 4$	$n_{NP}^{IV} = 3$	$n_{ND}^{IV} = 13$	$\mathbf{n_{AN}^{IV} = 24}$
	V	$n_{A1}^{V} = 0$	$n_{A2}^{V} = 1$	$n_{A3}^{V} = 0$	$n_{AP}^{V} = 0$	$n_{NP}^{V} = 0$	$n_{ND}^{V} = 1$	$\mathbf{n_{AN}^{V} = 2}$
In total		$n_{A1} = 31$	$n_{A2} = 61$	$n_{A3} = 19$	$n_{AP} = 620$	$n_{NP} = 145$	$n_{ND} = 164$	$\mathbf{n_{AN} = 1,040}$
		$n_A = 731$				$n_N = 309$		

Explanations: n – the number of sources of mine water assigned to a certain class of quantity (^{superscript}) and quality ($_{subscript}$). Other indicators the same as in Table 6.7.

From the evaluation of the place of occurrence of the most important mining-deposit regions of Slovakia the Gemer zone is the most prominent, both in terms of the total amount of documented mining waters and in terms of their frequency. The region hosts 63% of the total resources of mine water and 37% of their yield summary (Table 6.2). The quality classes A1, A2 and A3, which are satisfactory for drinking purposes, involve 126 $l \cdot s^{-1}$ documented mine water (Table 6.7), and in further sources with total yield of 272 $l \cdot s^{-1}$ satisfactory quality can be assumed (quality category AP). The second significant region – Central Slovakia Neovolcanites – total amount of mine water is slightly lower (26% of the total), but the frequency is much less represented (18%). In this region we register sources qualitatively suitable for drinking purpose of a total yield of only 17 $l \cdot s^{-1}$ and probably satisfactory in the amount of 47 $l \cdot s^{-1}$, while up to 396 $l \cdot s^{-1}$ is assigned – mainly due to the extremely high yield of the Voznica Drainage Gallery (MD 7-6) – into NO class with proven improper quality. Among the other regions particularly significant in terms of quantities documented mining water are the regions of Upper Nitra and Nízke Tatry Mts. A graphical comparison of the frequency and yield of documented sources of mine water by deposit-hydrogeological types and regional data is in Figs. 6.3 and 6.4.

Tab. 6.9 Documented quantities of mine water in $l \cdot s^{-1}$ in mining – deposit regions according to quality classes

Region	Q_{A1}	Q_{A2}	Q_{A3}	Q_{AP}	Q_{NP}	Q_{NO}	Q_A	Q_N	Q_Σ
1 Malé Karpaty Mts.	0	0	0	1.29	34.00	15.38	1.29	49.38	50.67
2 Záhorská nížina Lowland	0	0	0	25	0	0	25	0	25
3 Považský Inovec Mts.	0	0	0	9	0	0	9	0	9
4 Strážovské vrchy Mts.	0	0	0	0.1	0.72	0	0.1	0.72	0.82
5 Upper Nitra Basin	0	219.7	0	0.15	57	57	219.85	114	333.85
6 Tribeč Mts.	2.7	0	0	8.22	0	0	10.92	0	10.92
7 Central Slovakia Neovolcanites	2.95	14.31	0.18	47.32	0	396.18	64.76	396.18	460.94
8 Nízke Tatry Mts.	1.04	3.52	0	3.27	33.52	87.94	7.83	121.46	129.29
9 Juhoslovenská nížina Lowland	0	0	0	75	0	0	75	0	75
10 Vepor zone	0.03	5.38	0	5.81	3.13	3.37	11.22	6.5	17.72
11 Popradská and Hornádska Basins	0	0	0	0	0	8.16	0	8.16	8.16
12 Gemer zone	19.07	70.71	36.21	272.27	43.19	220.92	398.26	264.11	662.37
13 Šariš region	0	5.23	0	0.92	2.09	5.32	6.15	7.41	13.56
14 Vihorlatské vrchy Mts.	0	0.05	0	0	2.1	0	0.05	2.1	2.15

Explanations to symbols are stated in Table 6.7.

Table 6.10 shows categorisation of documented quantities of mine water by deposit-hydrogeological types. The most significant in terms of the total amount of documented amount are mine waters bound to deposits of siderite-sulphide mineralisation (*sz*) and the precious metal and polymetallic mineralisation of neovolcanites (*z*). To these types of deposits binds total yield Q_{Σ} of approximately 0.47 $m^3 \cdot s^{-1}$ of mine water, while at the deposits of the type *sz* there are 554 sources and the type *z* 195 sources. The comparatively high overall yield of mining water is bound to only 10 sources in coal deposits (*uh*). Relatively high total yield of 143 $l \cdot s^{-1}$ have 139 sources on stibnite veins (*az*), while for other types of deposits their total amount does not exceed the level of 60 $l \cdot s^{-1}$.

Tab. 6.10 Documented quantities of mine water in $l \cdot s^{-1}$ according hydrogeological types of deposits and quality classes

Deposit type	Q_{A1}	Q_{A2}	Q_{A3}	Q_{AP}	Q_{NP}	Q_{NO}	Q_{A}	Q_{N}	Q_{AN}
phm	0	15.11	0	3.04	0	0	18.15	0	**18.15**
ssu	0	1.52	0	0	29.48	24.46	1.52	53.94	**55.46**
u	6.77	10.41	0	15.05	15.15	7.34	32.23	22.49	**54.72**
sche	0	3.05	0	2.5	0.31	33.86	5.55	34.17	**39.72**
az	2.17	0.57	0.08	0	59.4	80.72	2.82	140.12	**142.94**
sz	8.12	27.57	36.13	247.73	0	153.2	319.55	153.2	**472.75**
mz	0.03	0.9	0	0	8.2	7.39	0.93	15.59	**16.52**
sid	3.0	10	0	0.05	1.02	7.41	13.05	8.43	**21.48**
mag	0.05	6.0	0	12.1	0	0.48	18.15	0.48	**18.63**
mst	0	4.48	0	3.33	0	2.55	7.81	2.55	**10.36**
sa	0	0	0	0	0	10	0	10	**10**
mn	0	0	0	1.29	0	8.16	1.29	8.16	**9.45**
z	5.65	19.54	0.18	52.11	0	394.25	77.48	394.25	**471.73**
i	0	0	0	0.2	4.19	7.24	0.2	11.43	**11.63**
lim	0	0.05	0	1.75	1	0.2	1.8	1.2	**3**
uh	0	219.7	0	103.2	57	57	322.9	114	**436.9**
sol	0	0	0	0	0	0.01	0	0.01	**0.01**
zlt	0	0	0	6	0	0	6	0	**6**

Explanation: Codes of deposit type according to Table 6.3. Classes of water quality according to Table 6.7.

6.5 The environmental problems related to mining water

Currently in Slovakia mining is underway only in 12 underground mines and from the environmental point of view it is a subject to strict control, in accordance with national legislation that is approximated to EU legislation. Environmental problems therefore relate in particular to the numerous abandoned mines and particular threat of contamination of water and sediment of the surface flows with heavy metals, which are loaded in mining water. In recent years, dangerous inrushes of mine water from abandoned mines have been experienced locally.

6.5.1 Mine water as a source of surface water contamination

Mine water freely flowing from abandoned mines or pumped during their drainage, according to local conditions can affect the quality of surface water. The negative influence of surface water in Slovakia was confirmed at several locations (e.g. Bačová, 2001; Lintnerová et al., 2004; Bajtoš, 2009 and 2012; Chovan et al., 2010; Ženišová et al., 2015). Since 2007, the state monitoring of the effects of mining on the environment takes place on the selected risk areas; in the scope of the project the effect on the quality of surface water is pursued (Bajtoš et al., 2012).

To obtain a regional overview and to identify other possible sources of contamination, we evaluated the results of laboratory analyses of mine water collected in a database. We defined the characteristic values (typical value – TV) of water quality indicators and compared them with the limits (required value – RV) under Government Regulation no. 269/2010 Coll., which stipulates the quality of surface waters. From the results of this assessment it follows, that the most common risk pose increased concentrations of arsenic (35% of the evaluated cases), antimony (33%), copper

(31%), zinc and manganese (over 29%) and too low value of dissolved oxygen (29%). Other potential contaminants are: sulphate anion (18%), mercury (17%), calcium (16%), nickel, iron and aluminium (14%), or pH (12%). In less than 10% of the cases as potential contaminants act nitrite nitrogen, ammonium nitrogen, cadmium, chromium, cobalt, lead, silver, magnesium and sodium.

Ongoing monitoring of risk sites affected by mining activity is documented by the continuing adverse impact of the presence of mined deposits on surface water quality (Table 6.11). Given the rapid circulation of groundwater in near-surface zone of the hydrogeological massif of Palaeozoic metamorphic rocks in the areas affected by ore deposits mining in Gemer region (sites Rudňany, Nižná Slaná, Slovinky, Rožňava, Smolník, Novoveská Huta), the components released by weathering of minerals quickly get into local surface waters and they impair their quality. The worst situation is at the site Smolník (MD 12-16), where the water of Smolnícky potok Creek in the profile below the deposit is contaminated by Fe, Mn, Al, Zn and Cu, with a high excess of the limit values (Table 6.12). Said elements are brought in to the stream by acid mine water and leachate from a flooded pyrite mine. Results of the mass flow balance at the Smolník site showed (Bajtoš et al., 2013) that 3.92 to 9.82 tons of sulphate anions; 0.34 to 1.04 tons of iron; 37.6 to 107.6 kg of manganese; 69.1 to 300.7 kg of aluminium; 9.0 to 32.6 kg of zinc; and 1.2 to 25.9 kg of copper is released daily as dissolved solids into the stream water. Most of this originates in the monitored objects (Pech Shaft, Karoli Adit, Nová Adit, and two drainage effluents from settling pit): 55 to 79% of SO_4; 39 to 100% of Fe; 44 to 79% of Mn; 27 to 100% of Al; 38 to 93% of Zn; and 26 to 100% of Cu. The primary source of contamination is the mine water discharged from the Pech Shaft, which releases more than 90% of SO_4 and Mn, and more than 99% of Fe, Al, Zn and Cu. In the Slovinský potok Creek, in the profile below the deposit Slovinky (MD 12-10) the content of Sb varies in the range 6 – 20 $\mu g\cdot l^{-1}$. The results of the balance of Sb in the waters of Slovinky showed that in the period between 2008 – 2011 the mass flow of this element varied in the range of 264 – 772 $g\cdot d^{-1}$. Increase of the Sb amount in the stream coming from the balancing area was 217 – 544 $g\cdot d^{-1}$. Only a small fraction of this amount (9 – 58 $g\cdot d^{-1}$) represented antimony loaded in mining water of the Alžbeta Gallery (main drainage work on the deposit). The summary amount of Sb carried in water from the Alžbeta Gallery and seepage water from the tailings represent only 15 – 91 $g\cdot d^{-1}$ (Bajtoš, 2012a). Therefore, the main source of Sb in the water stream in the Slovinský potok Creek in the Slovinky area not the most important monitored objects with mining water and the drainage of the tailing ponds, but probably smaller sources and mining leachate scattered in the area, or soil contaminated by air pollution from thermal operations in Krompachy. In contrast, these monitored objects are the major sources of arsenic contaminating the Slovinský potok Creek.

At the site Rudňany (MD 12-3) the main contaminant of water of Rudniansky potok Creek is antimony, which concentration averages 10 $\mu g\cdot s^{-1}$. About a quarter of the amount of mining water contribution comes from the Rochus Gallery, flowing out from flooded Fe, Cu mine. At the site Rožňava (MD12-13) the contaminated mine waters from the galleries are sufficiently diluted in terms of the required water quality of the Slaná River, as regards the content of potentially toxic metals As, Sb, Ni, Zn and Cu. The risk pose iron and manganese in the period of lower flow of the Slaná River, which may cause deterioration in the quality of the river water. At the site Novoveská Huta (12-1) mine waters only locally worsen the water quality of local streams, while its radiological indicators are satisfactory despite of present uranium deposit positions.

Significantly contaminated are surface streams on the locations Dúbrava, Pezinok and Špania Dolina. The amount of antimony entering in the Paludžanka stream at the abandoned antimony deposit Dúbrava (MD 8-9) in dissolved form, determined on the basis of balance measurements repeated for seven times in the years 2008 to 2011, reached here 4.5 – 15.3 $kg\cdot d^{-1}$ (more than 2 tonnes per year), whereby an average of 74% share of this amount is linked to the water flowing from 6 mining galleries (Bajtoš, 2012). The water of Blatina Creek in the profile below the Sb deposit, in front of the inlet to the urban area of Pezinok (MD 1-2) contains on average 7 times higher concentrations of Sb and As, as appropriate limit values for surface water. The dominant source of contamination are mine waters from three galleries. At the site Špania Dolina (8-1) with a historical mining of copper veins (*mz*), in the waters of the Banský potok Creek, Richtársky potok Creek and Zelená Creek the monitoring documented greatly exceeded limit value of Cu (5 – 6 to 80 fold), Sb (19 –1 2 – 128 fold) and As (5 – 1.3 – 6 times), largely due to mine water of the old galleries.

The most important source of contamination at the site Banská Štiavnica (MD 9-6) is mine water of the Voznica Heritage Gallery (VDS) and New Drainage Gallery (NOŠ), which drain almost entire Štiavnica-Hodruša ore district. Mass flow rate of zinc dissolved in the VDS water amounts to 75 – 160 $kg\cdot d^{-1}$, manganese 60 – 100 $kg\cdot d^{-1}$, cadmium 0.2 – 0.5 $kg\cdot d^{-1}$. Mass flow rate of zinc from NOŠ is approximately 0.5 $kg\cdot d^{-1}$. Model calculations indicate that the zinc content in the Hron River below the VDS and NOŠ mine water inflows tends to be higher than the desired value for most of the year – mostly in the winter, summer and autumn. The expected concentrations of cadmium, nickel, copper and lead in the Hron River below the adit collar of VDŠ and NOŠ are below required levels.

In the Upper Nitra area the chemical composition of surface water is affected by discharged mine water draining the coal deposits. They cause increase in the concentration of sulphates (also TDS), iron, manganese and arsenic. The rate of increase does not cause unacceptable deterioration in the quality of local watercourses. Among the four mining water discharges only water from the gallery in Lehota pod Vtáčnikom exceeds the limit values for arsenic. Increased levels of NO_2 and Hg, documented in monitored surface flows don't originate from the mine water of the coal deposits.

Tab. 6.11 Indicators which do not meet the requirements of Government Ordinance SR No. 269/2010 Coll. for surface water quality and risk criteria of groundwater quality by Guideline of MoE SR 1/2012-7 detected at monitoring sites in the period from 2007 to 2014 (Bajtoš et al., 2015)

Site	**MD number**	**Deposit type**	**Parameters not meeting criteria for surface water quality**	
			Mine water, drainage water from tailing ponds	**Surface streams**
Upper Nitra	5-2	*uh*	NO_2, Mn, Hg, As	NO_2, As, Hg
B.Štiavnica-Hodruša	7-6	*z*	EC, SO_4, Fe, Mn, Al, Zn, Pb, Cu, Cd, Ca, NO_2	Zn, NO_2
Kremnica	7-7	*z*	SO_4, Mn, Zn, As, Sb, Cu	As
Dúbrava	8-9	*az*	Sb, As	Sb, As
Pezinok	1-2	*az, ssu*	EC, SO_4, Fe, Mn, Zn, As, Sb, Ni, Cd	Sb, As
Špania Dolina	8-1	*mz*	SO_4, Zn, As, Sb, Cu	As, Sb, Cu
Rudňany	12-5	*sz*	EC, SO_4, Mn, Hg, Sb, Ba	Sb, Cu, Mn
Nižná Slaná	12-17	*sid*	SO_4, Mn, As	
Slovinky	12-10	*sz*	EC, SO_4, Mn, As, Sb, Cu, Ni, Co	As, Sb, Cu
Rožňava	12-13	*sz*	EC, pH, SO_4, Fe, Mn, Al, Hg, Zn, As, Sb, Cu, Ni	
Smolník	12-16	*ssu*	EC, pH, SO_4, Fe, Mn, Al, Hg, Zn, Pb, As, Cu, Ni, Co, Cd	pH, Fe, Mn, Al, Zn, Cu
Novoveská Huta	12-1	*u, sz, sa*	EC, RL, SO_4, As, Sb, Cu, Ca	EC, RL, SO_4, Mn, Cu, Al, Ca

Tab. 6.12 A comparison of the characteristic values of water quality parameters at the Smolník area with quality requirements for surface water (2008 – 2013)

Object	**Value**	**EC**	**pH**	**SO_4**	**Fe**	**Mn**	**Al**	**Hg**	**Zn**	**Pb**	**As**	**Cu**	**Ni**
Sm1	TV	10.4	7.26	16	0.34	0.06	0.05	<0.1	26	3	2	6	1
	TV/RV	0.20	V	0.06	0.16	0.19	0.22	0.50	0.75	0.39	0.15	0.20	0.04
Sm8	TV	32.5	**6.14**	142	**13.29**	**1.46**	**2.67**	<0.1	**405**	5	7	**134**	12
	TV/RV	0.28	**N**	0.54	**6.09**	**4.50**	**11.52**	0.50	**12.08**	0.53	0.67	**4.57**	0.39

Explanations: Sm1 – Smolnícky potok Creek deposit upstream, Sm8 – Smolnícky potok Creek below deposit. Specifications TV/RV represent the share of determined characteristic values of quality indicator (typical value – TV) for the reporting period and the setpoint (required value – RV) according to the SR Government Ordinance No 269/2010 Coll . Values greater than 1 mean the exceeded required values.

Increased concentrations of contaminants released in the aqueous solution from the ground disturbed by extraction cause contamination of sediments accumulated in local surface flows. The major contaminant elements at the monitored sites are arsenic and antimony; their content in sediments exceeded by the results of the one-shot sampling in 2012 the intervention criterion for the industry at all monitored ore mining sites with the exception of Novoveská Huta (Table 6.13). Further documented risk contaminants in stream sediment are Pb, Zn, Cd, Hg, As, Cu.

Among the sites that are not monitored under the state Monitoring of the effects of mining on the environment significant negative impact on the quality of surface water is documented mainly in Dubník in Slanské vrchy Mts. (MD 13-3 Dubník). Surface water of Jedľovec Creek is here contaminated by compounds carried in the mine water (Bajtoš & Cicmanová, 2005). The pH of the water stream is in the range from 3.01 to 3.48, the concentration of the aluminum ranges from 14 do 20 $mg \cdot l^{-1}$, so it is 70 to 100 times higher than RV for surface water and the content of Zn 77 – 101 $\mu g \cdot l^{-1}$ exceeds the RV 7 – 10-fold. The contents of other polluting components (Fe, Mn, SO_4) are unsatisfactory only occasionally. The results of the acute ecotoxicity samples of mine water from the Slávik Gallery and surface water of the Jedľovec Creek showed that these waters are toxic to aquatic organisms (Cicmanová & Lučivjanská, in Bajtoš et al., 2003).

The above regional evaluation of mine water quality has allowed to identify other sites of high risk in terms of harm to the quality of surface water by discharges of mining water. Antimony contamination poses a risk in Jasenie location in the Nízke Tatry Mts. (MD 8-5), where the water from the galleries no. 3 and no. 4 reaches the concentration of this metal 0.09 or 0.06 $mg \cdot l^{-1}$ at daily summary 0.2 kg. Sb. Daily released amount of arsenic reaches 2 kg. The next location in the Nízke Tatry Mts. is Magurka (MD 8-6),

Fig. 6.5 Mouth of Dolnosirkovská Gallery near Sirk with intense Fe-ochre formation.

where only from the Gallery Dedičná Russeger escapes daily about 0.2 kg Sb. In the Central Slovak Neovolcanites there are several galleries with high contents of metals. Through the Gallery Neufang Dedičná in Nová Baňa (MD 7-4) daily mass discharge in mine water equals to ca 0.1 kg As, 0.01 kg Ni and 4 kg Fe, through the Gallery Anna Božena in Rudno nad Hronom (MD 7-5) 43 kg Fe, 22 kg Al, 3 kg Mn, 4 kg Zn and 0.02 kg Cu. In Ľubietová in Veporicum Zone (MD 10-2) about 0.15 $kg \cdot d^{-1}$ of copper escape in mine water. Dolnosirkovská Gallery (Fig. 6. 5) in Sirk (12-19) in Gemer zone releases 20 kg Fe, 37 kg Mn and 0.1 kg Ni a day.

6.5.2 Inrushes of mine water from abandoned mine workings

A specific problem in the last years in Slovakia is the danger of sudden inrushes of mine water from the adit collars of the abandoned workings localised over inhabited areas or directly in them. The most dangerous situation occurred in Novoveská Huta (MD Gemer zone, MD 12-1: Novoveská Huta – Hanisková) where the evaporite overburden caving-in sealed the passage of the Nová Gallery, leading to increase in the water column due to inflowing of mine water with consequent gradual enlargement of the accrued amount. Sudden break of this collapsed material by water due to high hydrostatic pressure caused the formation of extreme discharge waves, which after reaching the surface ruined adit collar of the gallery (Fig. 6.6), damaged the road leading to the Nová Gallery (Fig. 6.7) and also caused damage in the gardens and the houses of Teplička residents in the catchment of Tepličský Brusník Creek. The unexpected outburst of mine water occurred also in Gelnica, part Turzov (MR Gemer zone, MD 12-10 Slovinky – Gelnica). This mine (mine-deposit type *sz*) has been abandoned since 1993 (Bajtoš et al., 2011b) and this was for the first time that such event occurred. According to information publicized water suddenly surged 3.6.2010 morning from the adit collar of Stará Krížová Gallery and flooded the local land and damaged local roads. During this flood risk period there were observed extremely high yields of local galleries, accompanied by the risk phenomena, and the inhabitants of the Zlatá Idka (MR Gemer zone, MD 12-18 Čučma – Bystrý potok – Poproč – Zlatá Idka). In 2005, the outpouring of water from the Slávik Gallery at Dubník (MD 13-3 Dubník) eroded part of the heap and polluted creek Jedľovec with 400 m^3 of sediment with high mercury content.

The conditions and the course of these events were analysed in the context of geo-environmental studies (Bajtoš et al., 2011b), which were followed by risk analysis. The existing estuaries of workings were assessed as potentially dangerous in terms of mine water inrushes. Discharges of

Tab. 6.13 Indicators of sediment quality which do not meet the criteria by Guideline of MoE SR 1/2012-7 for the rock environment and soil found at monitoring sites in the period from 2007 to 2013

Site	Indicators exceeding indicative criterion	Indicators exceeding intervention criterion for residential zones	Indicators exceeding intervention criterion for industrial zones
Upper Nitra	As	As	As
B.Štiavnica-Hodruša	Pb, Zn, Cu, Cd, As, Sb, Hg	Pb, Zn, Cu, Cd, As	Pb, Zn, Cu, Cd
Kremnica	Zn, As, Sb, Co	As, Sb, Co	As
Dúbrava	As, Sb	As, Sb	As, Sb
Pezinok	As, Sb	As, Sb	As, Sb
Špania Dolina	Hg, As, Sb, Cu	As, Sb, Cu	As, Sb, Cu
Rudňany	Hg, As, Sb, Cu	Hg, As, Sb, Cu	Hg, Sb
Slovinky	Hg, As, Sb, Cu	As, Sb, Cu	As, Sb
Smolník	Pb, As, Sb, Cu	Pb, As, Sb, Cu	As, Sb
Novoveská Huta	-	-	-

Fig. 6.6 Mouth of Nová Gallery destroyed by mine water inrush from abandoned mine (photo Baláž).

Fig. 6.7 Local road eroded by flood wave of mine water inrush from Nová Gallery (photo Baláž)

water from the adit collars of the old workings occur in the land of 147 settlements. Most of them are located in Spiš-Gemer Ore Mountains (MR12) and Štiavnica-Hodruša ore district (MD 7-6). Within the municipalities there are 150 sources of mine water, out of which 82 can be considered as potentially high-risky, requiring closer examination of the status in order to propose measures to eliminate the risk.

6.6. Discussion

Mining waters are characterized by high variability of the chemical composition, even within the allocated hydrogeological types of deposits. Therefore, even in a single mine-deposit region or even a single deposit sources can often be found next to each other inconvenient but also meeting the quality requirements for drinking water. Their yield is usually higher than the yield of natural springs of groundwater at the site; hence they are interesting in quantitative terms to use.

In terms of water management potential of mine water use the most promising among mining-deposit regions of Slovakia's is the Gemer zone region (Spiš - Gemer Ore Mountains). Currently there are 21 local water sources of mine waters of summary yield of approximately 25 $l \cdot s^{-1}$, which represents 8% of the total amount documented. In Štiavnica-Hodruša mining district there are registered 16.6 $l.s^{-1}$ of exploitable amounts of mine water (Viest, 1993) and water-managed are outflows from 8 galleries with a total yield of 19.0 $l \cdot s^{-1}$. Other exploited mine water sources can be found in Pukanec (MD 7-5) and at Kokava (MD 10-7). Local discharges from abandoned galleries are potential water sources of local importance that in the present dispersed nature of settlement may be interesting objects to use for local self-government bodies, legal entities and individuals. The most significant factor limiting their wider use for drinking purposes is quite common necessity of physico-chemical treatment due to elevated levels of some metals (especially Fe, Mn, Sb, As), more of the occasional than of the permanent nature. Provided cost-effective treatment technologies of such waters would be ensured, it could lead to a significant increase in the use of their exploitation. For example, at selected locations in the Gemer zone, at the VDŠ in Štiavnica-Hodruša ore district (MD 7-6) and the site Dubník (MD 13-3), it has been demonstrated high efficiency of natural sorbents in removing contaminants from the mine water (Kovaničová et al. 2014).

Presented overview of the regional mining water quality shows that in many locations in Slovakia the resources adversely affect the quality of surface water flows. Currently ongoing monitoring studies the size of this impact and its changes over time on the most risky locations. Although the sources of contamination have been known for a long time, no one of the abandoned mines has been equipped with a system for cleaning of contaminated mine water. This is primarily due to persisting under-financing because of non-existent object owner. In addition to contaminants in dissolved form the problems arise also from the formation of iron ochre and sediment rich in heavy metals. These are formed by precipitation of the mine water at the number of deposits, both in the underground and also in the mine water runoff trickles on the surface (Fig. 6. 8). The ochre formation in underground is usually very intense. At the siderite (type *sid*) deposit Železník in Sirk (MD 12-19) variations of this amount during the year, by measuring the yield of the mine water effluent from the Dolnosirkovská Gallery (Fig. 6. 5), laboratory analyses of mine water and geochemical modelling were estimated at 0.7 to 6.4 tons per day (Bajtoš, 2012b). Their precipitation in the form of ochre sediment or ochre coating of the sand-gravel fluvial sediments occur during lower water levels in the case of heavily contaminated mine water in the riverbed surface flow. Length of the stream section with the formation of ochre, which can be identified visually (Fig. 6. 9), changes over time in proportion of the dilution of the source of contamination by the recipient. The periods of high water levels and flooding lead to erosion and outwashing of ochre sediment and this load is transported downstream. Their deposition takes place at points of flow deceleration, the most favourable environment for the accumulation process are the reservoirs (Brehuv et al., 2007; Šestinová et al., 2006; Hucko, 2005). However, it must be recalled that elevated concentrations of metals in sediment flows and water basins don't originate exclusively from precipitates of mine water but also from precipitates in drainage water of tailing ponds and seepage through heaps, and during the rainfall periods they enter the streams thanks to water erosion of heaps and tailing ponds.

Fig. 6.8 Mouth of Budúcnosť Gallery near Pezinok with mine water discharge with precipitating Fe-ochre (photo Baláž).

In addition to environmental contamination by toxic elements contained in mine waters in recent years a new phenomenon emerges of risk associated with mining water. The last few years, and particularly extreme rainfall in 2010 revealed the potential risk of experiencing sudden inrushes of mine water from abandoned mines that can cause damage to the linear structures, building structures, land and environment. In terms of prevention of damage and threats to the population it is appropriate in this context to focus attention on finding an effective method of identifying the objects of risk in terms of the mine water inrushes emergence, to identify risk objects in local municipalities and their vicinity

Fig. 6.9 Inflow of mine water from Pech Shaft into Smolnícky potok Creek. The bottom is coated with Fe-ochre from seepage through dumps situated atop the Pech Shaft. Al-precipitates from mine water are indicated by pale stripe downstream

and to inform the local authorities, to suggest a method of their technical arrangements for prevention of that risk, or – where appropriate – to put into practice monitoring for early warning prior to accident. Currently, with the maintenance of the most important estuaries of drainage galleries is entitled the organization Rudné Bane, š. p. Banská Bystrica. In urgent cases, this company proceeds with the opening and renovation of collapsed adit collars, to ensure a controlled outflow of mine water (Figs. 6. 10, 11).

Fig. 6.10 Situation of caved-in adit collar of Všechsvätých Gallery in Rudňany prior to its opening and reconstruction.

6.7 Conclusions

Presented regional overview of the incidence and nature of mining waters in Slovakia captures a situation which changes in the long term, depending on fluctuations in the intensity of mining activities and the availability of mineral deposits of interest to mining. Since massive completion of the extraction of the Slovak ore deposits after 1990 they have emerged to the then (historic and modern) mine water discharges from abandoned mines with stable runoff dozens of new ones. In the future, the existing number of sources of mine water will change only slightly and the hydrological regime will change only in a few of them. It can be expected that the attention of experts dealing with the issue of mine water will be mainly focused on the elimination of their negative impact on water quality and sediment of surface flows, on the intensifying of their exploitation for drinking or household water purposes, or even on utilisation of their geothermal energy potential.

Fig. 6.11 Portal built in 2013 at former caved-in adit collar of Všechsvätých Gallery in Rudňany

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