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2. Groundwater Quality Presentation in Basic Hydrogeochemical Maps at a Scale of 1:50,000 by Digital Data Treatment Applied in the Slovak Republic

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Abstract: Hydrogeochemical maps have been compiled in Slovakia for more than 40 years. While till 1990 there were issued only print versions of the maps, a new generation of maps, especially since 1994, has been innovated by digital processing of hydrogeochemical information. Uniform principles for their digital imaging are based on the requirements of simplicity, clarity and reproducibility, as well as the relevant Guidelines for the compilation of basic hydrogeochemical maps released by the Ministry of Environment in 2004. The hydrogeochemical maps contain basic information on the chemical composition and quality characteristics of groundwater. The information value of the map has been divided into levels of basic information consisting of qualitative and geochemical (genesis) characteristics of the groundwater, water management criteria and a database of chemical analyses. Therefore the hydrogeochemical maps display three essential criteria, namely: quality (colour in area), geochemistry (raster in the area) and water-management (contour marks - isolines). The quality and water management criteria are derived from the relevant Slovak standards for potable and raw water and geochemical criteria reflect the particular genetic types and chemical types of groundwater. The information value of a new generation of maps is highlighted in a modern approach that is sufficiently custom-friendly to a lay user and the wider scientific community addressing issues of water management.

Keywords: Hydrogeochemistry, hydrogeochemical maps at 1:50,000 scale, groundwater quality, GIS processing, Slovakia

2.1 Introduction

Resources and available volumes of groundwater resources both in the world as well as in Slovakia already cease to be limited only by their quantitative characteristics. In the context of the full-area anthropogenic overburden increased attention is given to their quality characteristics, which are the relevant subjects of the hydrogeochemical maps. A detailed discussion of the history and development of hydrogeochemical mapping in Slovakia was already discussed several times in Slovak literature (e.g. Rapant et al., 1996; Vrana & Rapant, 1999), and therefore we do not deal with it in this paper. We present only the methodology of compiling the hydrogeochemical maps of 1:50,000 (Rapant & Bodiš, 2002), which was developed under the project solution 12-02-9/200 Basic hydrogeological maps of selected regions of Slovakia (Malík, 2006). The methodology is based on the eponymous methodology (Rapant & Bodiš, 1994), by which there were developed in the years 1994 – 1999 the hydrogeochemical maps of seven regions of Slovakia (Malík, 1999; Kordík et al., 2000), between 2002 – 2007 the hydrogeochemical maps for seven regions more and in the years 2007 – 2013 for ten regions of Slovakia. The methodology has reflected knowledge and experience gained in dealing with the above hydrogeochemical maps and amendments to the legal standards and regulations in force in the period of its formation (Ministry Decree No. 29/2002 Coll., later Government Ordinance No. 354/2006 STN 75 7214), which at the time of this paper have been already replaced by new legislative documents (Slovak Government Regulation No. 496/2010 Coll.). In 2004 through the regulations were codified by the issuance of the Directive of the Ministry of Environment No. 9/2004-7, dated October 26, 2004 on the Compilation of Basic Hydrogeochemical Maps.

Significant development of information technology, which by the turn of millennia started to affect almost all areas of human activity, including geology, caused a shift in the methodology for the compilation of basic hydrogeochemical maps closer to the digital way of efficient handling, processing, storage and use of spatial data. In accordance with the "Directive of the Ministry of Environment of the Slovak Republic from April 13, 2000 No. 2/2000 on the Principles of Processing and Transfer of Tasks and Projects in a Geographic Information System (GIS)" there was raised requirement of amendment analogue data and outputs (printed maps, etc.) on digital processing that is the bearer of a more comprehensive and flexible information. One of the limitations of this Directive, however, was its general focus, which did not reflect the specific chara- cteristics of individual geological tasks (Kordík & Slaninka, 2005). In practice, there occurred large differences among submitted outputs of the geological projects of the same or similar focus. For example, for the processing of maps of "Geological Factors of the Environment" (Vrana, 1991) there was not established an uniform binding methodology of results submission in GIS and likewise, compiled basic or thematic hydrogeochemical maps used to offer different information depending on the value of the research team and the purpose of an issue studied. As an example, within the framework of geological research and exploration there was designed GIS spatial database structure information layer for digital vector map in engineering geo- logical zoning of small and medium scales of 1:200,000 and 1:10,000 and in a similar manner have been processed maps of important geological environmental factors, territory susceptibility to landslid-

ing, etc. (Pauditš et al., 2000). The basic principles of compiling digital maps of natural waters quality suggested Kordík & Slaninka (2005).

Based on the current needs of hydrogeochemistry and development of computer technology for the internal needs of the compilation of basic hydrogeochemical maps at a scale of 1:50,000 binding approach was drawn up in the period after 2002 by Kordík & Slaninka (2009), or a form of their digital transfer, taking into account the information value of these map series. The system takes into account the complexity of the information, that the hydrogeochemical map requires and increases its informative value by breaking down data in a relational database with the possibility of interlinking data tables related to the map objects. The way of the information provision pursuant to these principles allows for the use of maps and graphical information in a database, and further analytical and synthetic processing in the sphere of geo-information systems.

2.2 Overview and development of compiling of hydrogeochemical maps issued in Slovakia

As the oldest hydrogeochemical maps of a complex nature can be considered "The groundwater chemistry maps at 1:200,000" which originated as part of the compilation of basic hydrogeological maps at a scale of 1:200,000. During the years 1971 – 1978 these maps covered the entire Slovak territory in manuscript form, and for the whole set of 12 map sheets the same methodology was applied. Printed maps were published a decade later - between 1983 and 1991. Editors of the individual leaves the territory of Slovakia were: map sheet 44 Bratislava – Kullman et al. (1973); map sheet 34 Znojmo – Kullman et al. (1974); map sheet 27 Poprad – Hanzel et al. (1974); map sheet 46-47 Lučenec, Rimavská Seč – Škvarka et al. (1975); map sheet 37 Košice – Hanzel et al. (1975); map sheet 35 Trnava – Kullman et al. (1975); map sheet 38 Michalovce – Škvarka et al. (1976); map sheet 26 Žilina – Zakovič et al. (1976); map sheet 25 Gottwaldov/Zlín – Jetel (1991); map sheet 45 Nitra – Franko et al. (1976); map sheet 28 Svidník – Zakovič et al. (1977) and map sheet 36 Banská Bystrica – Kullman et al. (1978). The authors of the final report on the entire course of the compilation of the basic hydrogeological maps and "maps of the groundwater chemistry" in the scale of 1:200,000 were Kullman & Gazda (1978). Hydrogeochemical maps at 1:200,000 were the first basic information within a comprehensive view of hydrogeochemical conditions. By colours in the polygons chemical types of groundwater according prevailing cations and anions were expressed, by colour intensity degree of total dissolved solids (TDS) of groundwater, the underlying grid and indexes displayed the chemical types of groundwater according the classification by Gazda (1972) and by Roman numerals chemical types of groundwater under Alekin's classification (Alekin, 1970). By independent symbols springs of mineral and thermal waters were displayed, groundwaters of anomalous chemical composition and so on. Since the Slovak Republic has so far been completely covered just by hydrogeological and "hydrogeochemical" maps at 1:200,000, these maps along with explanatory notes (however, prepared only for 6 map sheets) are still a source of the basic information about the hydrogeological and hydrogeochemical conditions of individual regions of Slovakia.

Besides the above maps of groundwater chemistry in the scale of 1:200,000, in the 60s, or 70s of the last century another purpose hydrogeochemical maps were compiled (e.g. Pospíšil & Gazda, 1967; Kullman et al., 1972; Kullman & Gazda, 1973; Hanzel & Gazda, 1973; Orvan et al., 1974; Hanzel et al., 1979, 1981; Dovina et al., 1980; Gazda et al., 1982). In early 80s hydrogeochemical maps were issued mostly as annexes to the final reports of search hydrological surveys (Šalaga et al., 1983; Šalagová et al., 1983). Methods of hydrogeochemical maps compilation at that time were different, and in some cases similar methodical principles were used as in drawing up maps of groundwater chemistry at 1:200,000.

In the next period (before 1991) there were compiled in Slovakia mainly thematic hydrogeochemical maps at a scale of 1:50,000, which formed separate annexes to the final reports of regional hydrogeological research (e.g. Chochol et al. 1984, Kullman et al. 1985, Malík et al. 1986, Malík et al. 1990), or search hydrogeological surveys related to the calculation of natural resources and exploitable groundwater resources (Dovina et al., 1985). Compilation of hydrogeological and hydrogeochemical maps along with explanatory notes was further implemented in the regions of the northern part of Košice Basin and Slanské vrchy Mts. (Jetel et al., 1989), Myjavská pahorkatina Upland, Brezovské and Čachtické Karpaty Mts. (Čechová et al., 1990), Chočské and Skorušinské vrchy Mts. (Dovina et al., 1990), Nízke Tatry Mts. (Kullman et al., 1983; Dovina et al., 1985b; Hanzel et al., 1990), Hornádska kotlina Basin (Jetel et al., 1990), Eastern part of Cerová vrchovina Upland and Rimavská kotlina Basin (Zakovič et al., 1989) and Lučenská kotlina Basin (Škvarka & Bodiš, 1988). Separate hydrogeochemical maps at a scale of 1:50,000 are archived for example in the works of Rapant & Vrana (1983, 1985) and Vrana et al. (1984, 1987).

Compilation of hydrogeochemical maps in the 80s of the last century, in principle, was based on the methodology proposed in the regional geochemical research of groundwater (Vrana & Rapant, 1985 in Gbelský et al., 1985). In these maps colours in the area display the chemical composition of water (distinct, indistinct, mixed types), and rasters display underlying genetic types of groundwater in terms of the classification by Gazda (1974). Contour labels depict, for example, borders of distinct and indistinct chemical composition types, isolines of TDS distribution, etc. Point marks represent the location of sampling sites of common waters and groundwaters, and mineral and thermal waters, if necessary, to which the attached symbols referred to basic information such as the label of the documentation point, the value of TDS, geological labels of aquifers, major components content, etc.

Among the other thematic hydrogeochemical maps typically submitted as attachments to the final reports of

search, or preliminary hydrogeological surveys, belong works by Orvan et al. (1981), Halešová et al. (1982), Bačová et al. (1984), Bím et al. (1986), Orvan et al. (1995a,b,c).

Most of these works contain valuable information on the chemical composition and quality of groundwater. The degree of their compatibility with fundamental hydrogeochemical maps at a scale of 1:50,000, compiled since 1994, is however different, due to the fragmentation of methodologies. Part of the map series is valuable and, in many cases in the corresponding period a prestigious documentary material (chemical analyses) archived at the Division of Informatics SGIDŠ, but in most cases it was not digitally processed (personal experience of the authors).

In the period of 1991 – 1993 there were compiled, according to a new uniform methodology first 11 hydrogeological maps at a scale of 1:50,000 (mountain ranges: Branisko, Šarišská vrchovina, Levočské vrchy, Kривánska Malá Fatra, Chvojnická pahorkatina, Spišská Magura, NW slopes of Pezinské Karpaty; basins: Hornonitrianska kotlina, Zvolenská kotlina, Breznianska kotlina; Northern part of Záhorská nížina Lowland). The great pity is that to these maps there were not compiled hydrogeochemical equivalents and review of hydrogeochemical conditions was just part of the explanatory text (Malík et al., 2004).

Following the progress in geochemical information processing using computer technologies and according to the current level of professional approach, in the early 90s of the last century a methodology for the compilation of hydrogeochemical maps at a scale of 1:50,000 was developed (Rapant & Bodiš, 1994). This map generation asked for uniform methodology for hydrogeochemical maps bound with a methodology for hydrogeological maps at the same scale, so that both sets of maps should reflect the qualitative and quantitative characteristics of groundwater in their display area in relation to each other. After a review of methodological principles for drawing up maps based on the experience during the development of the first maps, the methodology for preparing basic hydrogeological and hydrogeochemical maps was finalised (Malík et al., 2003; Rapant & Bodiš 2003; Directive of ME SR No. 9/2004).

From 1994 to 1999 (Malík et al., 2004) basic hydrogeochemical maps of the following regions were compiled within double-sheet set of basic hydrogeological and hydrogeochemical maps at a scale of 1:50,000: Čierna Hora Mts. (Bodiš in Zakovič et al., 1997), Pezinské Karpaty Mts. (Vrana in Hanzel et al., 1999), NE part of Podunajská nížina Lowland (Slaninka in Malík et al., 1999), E part of Veľká Fatra Mts. (Kordík in Malík, Kordík, 1999), S part of Záhorská nížina Lowland (Bodiš, Kordík in Marcin et al., 1995), Ľubovnianska vrchovina Mts. (Jetel, 1999) and N part of Spišsko-gemerské rudohorie Mts. (Slaninka in Scherer et al., 1999). The aim of basic hydrogeochemical maps was to comprehensively identify, describe and evaluate the chemical composition and qualitative characteristics of groundwater. In the maps qualitative and geochemical criteria are primarily spatially expressed. Point marks show the sampling points of groundwater with the specification of the source of groundwater sampling, source type and scope of the analysis. Symbols display additional hydrogeochemical characteristics (anomalous water quality, character of pollutants).

Maps from this series were first completely digitally processed works. In this period, however, the perception of the information value by the individual authors and compilers of maps was diverse. A compromise in providing the information in these maps release was edition on CD in a single information system (Malík ed., 2001). The contents of the CD can be accessed in Windows environments using Internet Explorer (Browser HTML pages). At activating Start.htm the home page opens with a map of Slovakia and shows processed regions. A simple mouse click over selected region, the home hydrogeological map of the region is displayed in which the client can also open the window to display hydrogeochemical maps and explanatory notes. Within the home maps display, interactive viewing of the selected database data of hydrogeological and hydrogeochemical information is enabled.

In terms of methodology by Rapant & Bodiš (1994) within the search hydrogeological survey some other regions were processed, for instance: Mesozoic of W part of Slovenský kras Mts., Železnícke podhorie and part of Licinská pahorkatina Upland (Bodiš in Malík et al., 2000), Vtáčnik and Pohronský Inovec Mts. (Bučeková et al., 2001), Považský Inovec Mts. (Slaninka in Scherer et al., 2004).

In the years 2002 – 2006 there was carried out the compilation of basic hydrogeological and hydrogeochemical maps at a scale of 1:50,000 of the other 9 regions of Slovakia (the "Basic hydrogeological maps of selected regions of Slovakia" Malík, 2006): Medzibodrožie (Bajtoš and Stupák in Bajtoš et al., 2004), Vihorlat Mts. (Bajtoš in Olekšák et al., 2006), Žiar Mts. (Slaninka in Černák et al., 2004), Čergov Mts. (Cicmanová in Marcin et al., 2005), Muránska planina Plateau (Slaninka in Švasta et al., 2004), W part of Veľká Fatra Mts. (Kordík in Malík et al., 2006), Turčianska kotlina Basin (Kordík in Michalko et al., 2005), Ipeľská kotlina Basin (Slaninka in Scherer et al., 2005) and region Podunajská rovina – Žitný ostrov Plain and right bank of the Danube River (Bodiš in Benková et al., 2005). In the years 2007 to 2013 within the project "Basic hydrogeological maps at a scale of 1:50,000" (Malík, 2013) the following basic hydrogeochemical maps of regions were compiled: Žitavská pahorkatina Upland and Pohronský Inovec Mts. (Kordík in Mikita et al., 2011), Slovenský kras Mts. (Kordík in Malík et al., 2013), Rimavská kotlina Basin (Slaninka in Bačová et al., 2012), Bukovské vrchy Mts. (Bajtoš in Bajtoš et al., 2013), Bánovská kotlina Basin (Bodiš and Kordík in Bahnová et al., 2010), Žiarska kotlina Basin (Kordík in Kováčová et al., 2009), Súľovské vrchy Mts. and Žilinská pahorkatina Upland (Slaninka in Marcin et al., 2013), Slovenský raj Mts. (Cicmanová in Bajtoš et al., 2010), E part of Cerová vrchovina Mts. and Gemer terraces region (Slaninka in Švasta et al., 2013) and N part of Podunajská rovina Plain (Bodiš in Bottlik et al., 2013).

2.3 General principles of hydrogeochemical maps compilation

The aim of basic hydrogeochemical maps at 1: 50,000 is to display spatially the most important qualitative and geochemical characteristics of groundwater of the first aquifer at the surface and other major at near-depth. The hydrogeochemical map directly relates to hydrogeological map and expresses and reflects therein mainly qualitative, geochemical, environmental, water management, genetic and prospecting criteria. The hydrogeochemical map is an essential professional basis for characterisation of quality and degree of contamination of groundwater, serving for the rational use and purposeful protection of groundwater.

Basic principles of used concept and cartographic representations of the main hydrogeochemical characteristics consist of Spatial (A), Point marks (B), Symbols (C), Contour markings (D) and Additional maps (E) displays.

A) SPATIAL DISPLAY

In the map are spatially expressed three basic hydrogeochemical criteria, namely:

- Qualitative,
- Geochemical,
- Water management.

QUALITY CRITERIA

Qualitative criteria reflecting the qualitative properties of groundwater are expressed in colour spatial objects based on a comparison of individual analyses of groundwater against defined criteria (see hereinafter) under Government Regulation No. 496/2010 Coll. On the grounds of groundwater division into quality classes the mapped area is divided into areas with the same class of water quality.

GEOCHEMICAL CRITERIA

Geochemical criteria are based on the natural conditions of the region. They are expressed in the form of allocation of hydrogeochemical groups of groundwaters, which are shown with a black grid in the area. Allocated hydrogeochemical groups of water represent regions with the same characteristics of groundwater comprising:

- Genetic types of groundwaters,
- Chemical groundwater types,
- The total dissolved solids of groundwater,
- The nature of the groundwater circulation.

WATER MANAGEMENT CRITERIA

Water management criteria reflect the suitability of raw groundwater in terms of its treatability for drinking purposes. Distinction is made between four categories: A, B, C, D according to STN 75 7214, Water Quality. Raw Water for Treatment at Drinking Water. The territory of a region is segmented through contours and symbols into territories with the same categories of groundwater treatability.

B) POINT MARKS

Point marks show the sampling points of groundwater with the specification of the source groundwater intake, type of source and scope of the analysis.

C) SYMBOLS

They are used to express additional hydrogeochemical characteristics, especially for the display of:

- Groundwater anomalous quality,
- Nature of contaminants and important groundwater components,
- Recommended and advanced analysis of groundwater,
- Time trends in groundwater quality.

D) CONTOUR MARKINGS

They are used to indicate:

- Areas containing elements and components far exceeding the limit values for drinking water,
- Areas with the same category of groundwater treatability,
- Bordered areas with recommended more detailed work.

E) ADDITIONAL MAPS

They are used to express the important additional properties of water, for example:

- Aggressiveness,
- The content of Ca + Mg,
- Other major components of the groundwater by the nature of the mapped area.

2.4 HYDROGEOCHEMICAL CHARACTERISTICS OF THE BASIC DOCUMENTATION MATERIAL

Essential documentary material for the construction of hydrogeochemical maps provide analyses of groundwater samples, i.e. sampling from springs, boreholes, galleries, drainage systems and wells.

A) DOCUMENTATION POINTS DENSITY

For the hydrogeochemical map at 1:50,000 is the mandatory minimum average density of groundwater samples analyses (in a binding analytical range) 1 sample to 3 km^2. In the case of the proposed methodology for the scale of 1:25,000, the recommended average density of water samples analyses ranges from 1 to 1.5 to 1 km^2, and at the scale of 1:200,000 is the recommended density of one sample at 8 km^2. Density of groundwater samples analyses should be considered statistically and has to be adjusted according to natural, human and socio-economic conditions of the mapped area.

B) GROUNDWATER SAMPLING, FIELD MEASUREMENTS AND TESTING

Water sampling was carried out at the time of stable climatic conditions. Samples and other conditions (type and number of sample containers, their sterilization, etc.) should be defined by the laboratory in which the samples are analysed.

The sampling consists of the following tasks performance:

- Measurement - temperature, pH, conductivity (converted to 25 °C), the O_2 content ($mg.l^{-1}$) and yield ($l.s^{-1}$),
- Testing - acidity and alkalinity (neutralization titration, or potentiometry),
- Chemical stabilization of the samples in accordance with the instructions of the laboratory.

C) RANGE OF ANALYSES

1. Mandatory: Na, K, Mg, Ca, NH_4, Mn, Fe, 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, COD,
2. Recommended: a) organic pollutants,
   b) radiochemical indicators,
3. Extended: microbiological and biological indicators.

Mandatory scope of analyses represent determined range of inorganic components in groundwater within the solution of the Geochemical Atlas of the Slovak Republic, part Groundwater (Rapant & Bodiš 1996) (1 sample/3 km^2) and includes all the major inorganic indicators in terms of the Government Decree No. 29/2002 Coll. In justified cases it is possible to extend analyses purposefully on additional indicators of special inorganic analyses of water.

Analyses of organic pollutants are executed strict-purposely, without any planned density of water sampling in the range of particular groups of indicators – TOC, PAH, AOX, ES, NES. In the case evidently increased content of group characteristics, it is recommended to proceed to analyse specific organic compounds.

Among radiochemical indicators radon is recommended to be analysed with a statistical density of 1 sample/20 km^2 and in the groundwater samples containing radon over 50 $Bq.l^{-1}$ to determine uranium and radium contents.

Microbiological and biological indicators are defined strict-purposely, without any planned density of water sampling in the range of indicators by Ministry Decree No. 29/2002 Coll., particularly from the most important water resources.

D) LIMIT OF DETERMINATION

All analysed water components must be analysed with a margin of about one order of magnitude lower than the standard value in Government Regulation No. 496/2010 Coll.

E) QUALITY AND REPRODUCIBILITY OF ANALYSES

The quality and reproducibility of analyses must be guaranteed by internal and external audit. Internal control is provided in the form of internal laboratory control analyses and in the form of control charts. The external audit is carried out by external control samples and control samples of reference materials in the number of 3 – 7% of the total number of samples.

Analyses of groundwater, not fulfilling the above criteria (mainly in older tests), are used to construct hydrogeochemical maps only as auxiliary. Author of a map assesses individually their significance, reproducibility and validity in time and in appropriate cases, he/she decides on their inclusion in the database analysis of water processed maps.

2.5 Way of map compilation

A) DISPLAY OF GROUNDWATER QUALITY PROPERTIES

Groundwater qualitative properties are expressed through 8 classes of groundwater quality (A to H).

Tab. 2.1 Method of allocation of groundwater quality classes

Groundwater quality properties

Groundwater quality class				Assessed indicators and their limit values				
Class label	Class quality characteristics			Assessed groups of indicators	Assessed indicators	Symbol	Unit	Limit values
	1	2	3					
◯	+	+	+	1	Aluminium	Al	mg/l	0.2
					Arsenic	As	mg/l	0.01
					Barium	*Ba*	*mg/l*	*1*
◯	+	+	-		Cadmium	Cd	mg/l	0.003
					Chromium	Cr	mg/l	0.05
◯	+	-	+		Copper	Cu	mg/l	1
					Mercury	Hg	mg/l	0.001
◯	+	-	-		Ammonia	NH_4	mg/l	0.5
					Nitrites	NO_2	mg/l	0.1
					Nitrates	NO_3	mg/l	50
					Nickel	Ni	mg/l	0.02
◯	-	+	+		Antimony	Sb	mg/l	0.005
					Lead	Pb	mg/l	0.01
					Selenium	Se	mg/l	0.01
◯	-	+	-	2	Chlorides	Cl	mg/l	100
					Fluorides	F	mg/l	1.5
					Iron	Fe	mg/l	0.2
◯	-	-	+		Manganese	Mn	mg/l	0.05
					Phosphates	*PO_4*	*mg/l*	*1*
					Sulphates	SO_4	mg/l	250
◯	-	-	-		Zinc	Zn	mg/l	3
				3	Calcium and magnesium	Ca + Mg	mmol/l	1.1 to 5
					Chem. ox. demand ($KMnO_4$)	COD_{Mn}	mg/l	3
					Magnesium	Mg	mg/l	125
					Oxygen saturation	O_2	%	>50
					Water reaction	pH		6.5-8.5
					Soluble matter	RL	mg/l	1,000

\+ meets defined limit values

\- doesn't meet defined limit values

In *Italics* elements are dispayed which are not listed in Ordinance ME SR, No. 29/2002 Coll. on requirements on potable water and its quality control

groundwater of anomalous quality (compared to selected area)

Groundwater quality classes are allocated based on the groupings of limit indicators in terms of Government Regulation No. 496/2010 Coll. into three groups according to their increasing toxicity and complexity of groundwater treatment technology. The method of allocation of groundwater quality classes is shown in Table 2.1. Based on the allocation of individual groundwater samples into classes, the territories are delineated into the areas with the same class of groundwater. The approach requires a minimum of 80% of the membership of the same classes of water quality in the defined area. Groundwater with substantially different qualitative characteristics from the defined area is highlighted by specific symbol as an anomaly.

For colour expression of the groundwater quality "traffic light" method of area display has been selected, from bold blue colour – the area with the best groundwater quality till dark red – the area with the worst groundwater quality characteristics. It is necessary to clearly distinguish "doesn't exceed" of the first group of indicators (metals and toxic forms of nitrogen) by blue and green tones from "exceeds" - red shades of colours.

B) DISPLAY OF GEOCHEMICAL CHARACTERISTICS OF GROUNDWATER

Geochemical characterisation of groundwater is based on an allocation and cartographic delineation of the hydrogeochemical groups of groundwaters. The hydrogeochemical groups are subject to natural conditions of the territory of interest and they are allocated on the basis of genetic types of groundwater, which are further broken down by:

- Groundwater chemical types (according to the Gazda's 1974 characteristics and to the prevailing ions),
- Values of total dissolved solids,
- Geological nature and type of aquifer permeability.

Genetic types of groundwater express the origin of soluble substances. Gazda (1974) distinguished naturally and anthropogenically (Rapant, 2001) conditioned origin of elements and compounds contents in the chemical composition of the groundwater. These properties are amended on Gazda's characteristics (e.g. A_2 distinct, S_2 (SO_4) indistinct, $A_2 – A_1$ intermediary (Gazda, 1972).

The following genetic types and subtypes are distinguished:

1. PETROGENIC:
   a) carbonatogenic,
   b) silicatogenic,
   c) sulphatogenic,
   d) sulphidogenic,
   e) halogenic,
   f) hydrosilicatogenic,
   g) their intermediary types.
2. FLUVIOGENIC
3. MARINOGENIC
4. POLYGENIC
5. ANTHROPOGENIC:
   a) partly anthropogenically affected groundwaters,
   b) anthropogenically affected groundwaters.

As partly anthropogenically affected groundwater such groundwater is delineated, which in its basic chemistry outline (genetic and chemical types) corresponds to geological environment of its circulation, but there occur a partial metamorphosis of the primary chemical composition due to substances and salt influence of anthropogenic origin. This impact is reflected in the increases of TDS (typically in the range 25 – 50%), shifts of the chemical composition towards indistinct types (e.g. from A_2 distinct to A_2 indistinct and intermediary) and the common occurrence of one or several economically important components above the limits under Ministry Decree No. 29/2002 Coll. This groundwater has still a significant proportion of its primarily conditioned chemical composition.

As anthropogenically affected groundwater the groundwater is allocated, which chemical composition and quality characteristics do not correspond to its geological environment circulation. The chemical composition of these groundwaters is heavily altered due to substances and salt of anthropogenic origin. This change is reflected in the change of chemical types (e.g. from the basic to intermediary and mixed ones), increase of total mineralization (usually more than 50%) and regular appearance of several water-management important components exceeding the limits of Government Regulation No. 496/2010 Coll. In these groundwaters it is practically impossible to identify the chemical composition formed by primary processes.

Chemical water types according prevailing ions are expressed by the symbols of elements and components

Tab. 2.2 Scheme of delineation of chemical types according Gazda's characteristics

Type		**Characteristics content in meq.l^{-1} %**	**Example**
basic	distinct	one characteristics > 66	S_1(Cl) dist. S_2(SO_4) dist. A_2 dist.
	indistinct	one characteristics 50 – 66	A_1 indist.
intermediary		two characteristics	A_2-S_2(SO_4) interm. A_1-S_1(Cl) interm. A_2-S_1(SO_4) interm.
mixed		one characteristics 33 – 50 and others < 33	S_1(SO_4) mixed
		all characteristics < 33	A_2-S_1(SO_4)-S_1(Cl) mixed

according to the results of chemical analyses of equivalent values (meq.l^{-1} %) for basic compounds (Na, K, Mg, Ca, NH_4, NO_3, Cl, HCO_3). The criterion for determining the chemical type is equivalent proportion of compounds more than 25 meq.l^{-1} % of the amount 100% of cations and anions, separately. The individual elements and compounds of the chemical composition of groundwaters are arranged according to their equivalent representations.

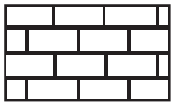
Intervals of values of total mineralization are formed on the basis of mathematical and statistical processing of data, depending on the regional conditions. In the geological features the basic characteristics of the rock environ are specified and permeability type of aquifer. As a basis for allocating groundwater hydrogeochemical groups, genetic types of groundwaters are crucial and the other three characteristics are affiliated to them.

Hydrogeochemical groundwater groups are cartographically illustrated in the form of grid objects. Selection of the grid type must be based on geological structure of the territory of interest, so that genetic types of water comply logically with geological environment of their circulation. For example, for carbonatogenic groundwater of limestones and dolomites "bricks-grid" is used; for silicatogenic crystalline groundwaters grids "+", "x" are used; for silicatogenic volcanites groundwaters "**v**"-grid; for fluviogenic water rings, etc. Variations in TDS, chemical types and the type of permeability shall be resolved by marks modifications and marks magnitude.

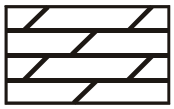
PRINCIPLES AND EXAMPLES OF GRID USE

Petrogenic groundwaters

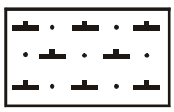
For **carbonatogenic** and **silicatogenic** groundwater grids are used according to the prevailing geological environment forming the chemical composition of the groundwater within the meaning of the guidelines for the compilation of hydrogeological maps of 1:50,000, for example:



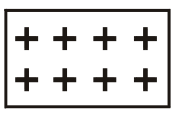
carbonatogenic groundwaters of limestones



carbonatogenic groundwaters of dolomites



carbonatogenic groundwaters of calcareous sandstones



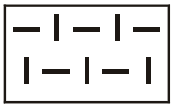
silicatogenic groundwaters of granitoids

silicatogenic groundwaters of basic effusives

Sulphatogenic groundwaters

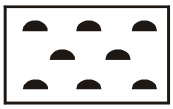
A more detailed rock environ specification of the chemistry formation should be made only in the text to the legend

Sulphidogenic groundwaters



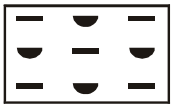
A more detailed rock environ specification of the chemistry formation should be made only in the text to the legend

Halogenic groundwaters



A more detailed rock environ specification of the chemistry formation should be made only in the text to the legend

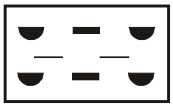
Hydrosilicatogenic groundwaters



A more detailed rock environ specification of the chemistry formation should be made only in the text to the legend

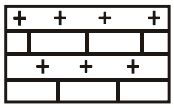
In cases where it is possible and advisable to further specify the nature of the mineralogical and petrographic environment of sulphatogenic to hydrosilicatogenic water, basic grid of these bodies of groundwater is supplemented on mark expressing lithological character of groundwater collectors within the meaning of the compilation of hydrogeological maps at 1:50,000, for example:

sulphidogenic groundwaters of basic neovolcanites



hydrosilicatogenic groundwaters of claystones

Intermediary types are displayed in the form of alternating grids above. Carbonatogenic and silicatogenic nature of groundwater is expressed through the grid according to the predominant environ of the groundwater chemistry formation (in the sense Directive of the Ministry of the Environment 9/2004-7 for the compilation of basic hydrogeochemical maps) and the proportion of present sulphatogenic to hydrosilicatogenic groundwaters is displayed by their basic raster mentioned above, e.g.

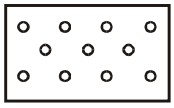


silicate-carbonatogenic groundwaters

hydrosilicate-halogenic groundwaters

silicate-sulphidogenic groundwaters

FLUVIOGENIC GROUNDWATERS



A more detailed rock environ specification of the chemistry formation should be made only in the text to the legend

MARINOGENIC GROUNDWATERS

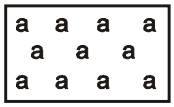
A more detailed rock environ specification of the chemistry formation should be made only in the text to the legend

POLYGENIC GROUNDWATERS

Petrogenic-fluviogenic groundwaters

A more detailed rock environ specification of the chemistry formation should be made only in the text to the legend

ANTHROPOGENIC GROUNDWATERS



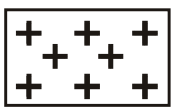
partly anthropogenically affected groundwaters

anthropogenically affected groundwaters

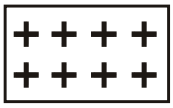
EXAMPLES OF GRIDS AND DESCRIPTION OF HYDROGEOCHEMICAL GROUPS OF GROUNDWATER

HYDROGEOCHEMICAL GROUPS OF GROUNDWATERS

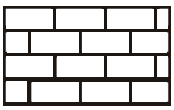
1. Petrogenic



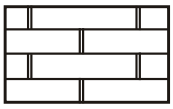
silicatogenic, A_2 basic, less A_2-$S_2(SO_4)$ intermediary, Ca-Mg-HCO_3 and Ca-Mg-HCO_3-SO_4 types, with TDS less than 50 mg.l^{-1}, in granitoids and metamorphites of crystalline, with fissure permeability



silicatogenic, A_2 basic indistinct, Ca-Mg-HCO_3 type, with TDS 50 – 150 mg.l^{-1}, in granitoids a metamorphites crystalline, with fissure permeability



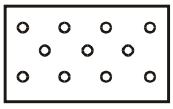
carbonatogenic, A_2 distinct, Ca-HCO_3 type, with TDS 250 – 400 mg.l^{-1}, in Late Triassic limestones, with karst permeability



carbonatogenic, A_2 distinct, Ca-Mg-HCO_3 type, with TDS 300 – 500 mg.l^{-1}, in Mesozoic limestones and dolomites, with fissure permeability

sulphatogenic, $S_2(SO_4)$ basic, A_2-$S_2(SO_4)$ intermediary, Ca-Mg-SO_4, Ca-Mg-SO_4-HCO_3 types with TDS more than 1,000 mg.l^{-1}, in Werfen and Keuper sandstone-shale complexes, with fissure permeability

2. Fluviogenic



A_2, basic, less A_2-$S_2(SO_4)$ intermediary, Ca-Mg-HCO_3, Ca-Mg-Na-HCO_3-SO_4 type, with TDS 300 – 500 mg.l^{-1}, in fluvial sediments of bottom fill, river terraces, with intergranular permeability

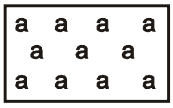
3. Marinogenic

S_1(Cl) basic, S_1(Cl)-A_2 intermediary, Na-Cl, Na-Ca-Cl-HCO_3 type, with TDS more than 1,000 mg.l^{-1}, in sands and clays of Eggenburgian, with intergranular-fissure permeability

4. Polygenic

petrogenic-fluviogenic, silicato-carbonatogenic, A_2 basic, Ca-Mg-HCO_3 type, with TDS 400 – 600 mg.l^{-1}, proluvial sediments, with intergranular permeability

5. Anthropogenic



A_2 basic indistinct, A_2-S_1(Cl) intermediary Ca-Mg-HCO_3 a Ca-Mg-Na-HCO_3-Cl types with TDS 500 – 700 mg.l^{-1}, proluvial sediments, with intergranular permeability

A_2-S_1(Cl), A_2-$S_1(NO_3)$ intermediary, Ca-Mg-HCO_3-Cl, Ca-Mg-Na-HCO_3-NO_3 types, in fluvial sediments, with intergranular permeability

C) WATER MANAGEMENT CRITERIA DISPLAY

Water management criteria refer to the adequacy of raw groundwater in terms of its treatability for drinking water. The chemical composition of the groundwater from the sample is compared with the limit concentrations under STN 75 7214 and the category of the treatability is determined (A, B, C, D). Using contours and symbols, the territory is divided into areas with the same category of treatability. 80% representation of the same category of water treatability in the defined area is required.

D) EXPRESSION OF DEEPER COLLECTORS OF GROUNDWATER

Quality properties and hydrogeochemical characteristics of groundwater of major deeper aquifers are displayed through stripes; the width of the stripes depends on the depth level of a collector displayed. A distinction is made in the two following cases:

- The incidence of groundwater of second or third collector,
- presence of different properties of groundwater (a depth) in a single collector.

Alternation of horizontal stripes indicates:

- Qualitative properties of groundwater - groundwater quality classes (point 4.A),
- geochemical characteristics of groundwaters – hydrogeochemical groups of groundwaters (point 5.B).

Groundwater of the Ist aquifer, or Ist groundwater table level within a single aquifer depicts a horizontal stripe whose width corresponds to the width of the base grid of hydrogeochemical groups.

Groundwater of the IInd aquifer (located up to a depth 100 m), or groundwater level depth up to 100 m in one aquifer is depicted by a strip whose width is equal to 1.5 times of the width of the base grid of hydrogeochemical groups of groundwaters.

Groundwater aquifer located deeper than 100 m, or groundwater level depth of over 100 m in one aquifer is depicted by a strip whose width is doubled compared to the basic grid hydrogeochemical groups of groundwaters.

In the case of changed quality properties of groundwater with a depth and hydrogeochemical characteristics of the groundwater do not change with depth – the colour strips alternation indicates only change in the groundwater quality. Similarly, if the qualitative properties of groundwater in the overlying and underlying collectors do not change and there is only a change of hydrogeochemical characteristics of groundwater, alternating stripes of different grids show the incidence of various hydrogeochemical groups of groundwater.

Areas with several major collectors in different depth groundwater horizons:

1	Ist groundwater aquifer
2	2nd groundwater substrate collector horizon to a depth of 100 m
3	3rd groundwater substrate collector horizon at a depth above 100 m

E) POINT MARKS

Point marks are used for determining the location of groundwater sampling for chemical analysis with specification of the source and the number corresponding to the number of analysis in the database. The sampling points are ranked according to ascending x-axis of the sampling point(s).

spring

borehole

well

drainage

gallery

Mineral and thermal waters shall be expressed by the above marks. In the case of mineral water dark purple colour is used, in the case of thermal waters dark blue colour is used.

mineral water spring

borehole with thermal water

F) SYMBOLS

The symbols are used to express additional hydrogeochemical characteristics:

- anomalous groundwater quality,
- the nature of contaminants and important water compounds,
- recommended and extended scope of groundwater analyses,
- temporal evolution of groundwater.

Groundwaters of anomalous quality

Groundwater resources substantially different in their qualitative characteristics (at least on 2 classes) from defined groundwater quality class are plotted by ring of 8 mm size and colour of appropriate quality.


groundwaters of ***D*** quality class

Display of contaminating compounds character

Character of exceeding the limit values of a binding scope of groundwater analyses above criteria of Government Regulation No. 496/2010 Coll. is expressed by the symbol of exceeded compound right up to point mark of

sampling point. In the case of several exceeded indicators only the three most exceeded ones are displayed, depending on their degree of toxicity.

source of groundwater containing As>0.01 mg.l^{-1}

source of groundwater containing As>0.01 mg.l^{-1}, NO_3>50 mg.l^{-1} and Fe>0.2 mg.l^{-1}

Display of recommended and expanded scope of analyses

Analyses of groundwater samples with recommended and expanded scope are expressed by the symbol of analysis scope placed at the bottom right of indications of water sampling. In the case of exceeding the limit indicators of analysed substances the symbol is highlighted.

org — analysed organic substances, limit values under Government Regulation No. 496/2010 Coll. not exceeded

org — analysed organic substances, limit values under Government Regulation No. 496/2010 Coll. exceeded

Ra — analysed radiologic indicators, indicative values under Regulation of the MoE SR No. 12/2001 Coll. not exceeded

Ra — analysed radiologic indicators, indicative values under Regulation of the MoE SR No. 12/2001 Coll. exceeded

Mb — analysed microbiologic and biologic indicators under Government Regulation No. 496/2010 Coll. not exceeded

Mb — analysed microbiologic and biologic indicators, under Government Regulation No. 496/2010 Coll. exceeded

DISPLAY OF TEMPORAL EVOLUTION OF GROUNDWATER QUALITY

Time evolution of the groundwater quality is expressed in groundwater resources with multiple repeated monitoring of the chemical composition (at least 5 analyses within a time span of at least five years). Character of such groundwater sources in the map is displayed by a light brown arrow through the centre of the point mark of sampling.

Character of groundwater temporal change

stable

improvement

worsening

POINTS OF CONTAMINANTS TRANSFER TO THE AQUIFER

The areas are displayed where transfer of pollutants into aquifers has been confirmed, or assumed. The nature of these places is expressed in map by dark red double arrow in the direction of contamination spread. By the symbol nature of the contaminant is displayed.

Transfer of contamination to aquifers

identified

assumed

GROUNDWATERS DYNAMICS

Dynamic characteristics of groundwater are expressed by groundwater flow direction in the first aquifer and the direction of flow of water in significant deeper situated collector in hydrogeochemical section. Groundwater flow direction is expressed on the map by violet arrow.

flow direction in the first aquifer

flow direction in deeper situated collector in hydrogeochemical section

G) CONTOUR MARKS

Contour marks are used for:

– Display of spatially defined characteristics of groundwater,
– an indication of the quality characteristics – quality classes of surface waters,
– border areas with increased content of contaminants,
– definition of the territory of recommended for more detailed works,
– display of hydrogeochemical section.

boundaries of defined hydrogeochemical groups of groundwater

areas containing chemical elements and components in excess of the Government Regulation No. 496/2010 Coll., by the symbol the elements/components are indicated

quality class of surface waters

limit category of groundwater treatability

Quality class of surface water shall be indicated by the streams observed in the national monitoring network. The map displays the resulting class of surface waters (I to V) under STN 75 7221, Surface water quality classification.

area recommended for more detailed works

The areas are depicted, where based upon the achieved results, more detailed works are recommended – surveying, monitoring, restoration and so on. The nature of the proposed work shall be indicated in the text of the explanatory notes to the map.

H) ADDITIONAL MAPS

Through additional maps at a scale 1:200,000 to 1:500,000, other important additional information on the chemical composition of groundwater in the mapped area shall be expressed, or, depending on the availability of data on the properties of precipitation or surface water. The additional maps in form of mono-element colour maps, or isolines reflect the spatial distribution of concentrations of the component under study.

The maps reflect additional spatial distribution of economically important groundwater components, namely:

a) aggressiveness,
b) the content of Ca + Mg (hardness),
c) the content of nitrates,
d) category of treatability under STN 75 7214,

and other groundwater compounds, according to the nature of natural waters in the mapped area.

I) HYDROGEOCHEMICAL SECTION

The aim of the hydrogeochemical section is to express zoning and spatial characteristics of the chemical composition and qualitative properties of groundwater. The hydrogeochemical section is compiled mainly in the areas with several aquifers, or in the areas where the aquifer hydrogeochemical zonation has been observed. The section is depicted on a joint sheet with the map and its scale (length, height) is possible to magnify two to five times according to the need for transparency and clarity, compared to the scale of the map. The scale of section is marked on the map sheet. In the hydrogeochemical section are displayed the prevailing hydrogeochemical characteristics listed in the map, and in particular:

– hydrogeochemical groups of groundwater,
– groundwater quality classes,
– dynamics of chemical composition and qualitative properties of groundwater (groundwater flow direction, spread and her character).

line of hydrogeochemical section

TOPOGRAPHIC GROUND DOCUMENT

Hydrogeochemical map is compiled into a simplified topographic document shown in grey. Topography includes:

– river network,
– topography (definition and description of towns and municipalities),
– simplified altimetry (designation and name of the altitude points, contours each 50 meters).

TEXT EXPLANATIONS

Explanatory notes are component of each map. Text explanations include:

– summary of natural conditions (in the case, when the hydrogeochemical map is prepared in parallel with the hydrogeological map, they are not described),
– level of hydrogeochemical survey,
– character of reproducibility of the used hydrogeochemical documentation material,
– characteristics of the processes of formation of the chemical composition of the groundwater of the region (including anthropogenic factors)
– characteristics and classification of the chemical composition of the groundwater,
– characteristics of qualitative properties of groundwater,
– detailed characteristics of the territories proposed for further more detailed work and the justification of the proposed works.

HYDROGEOCHEMICAL DOCUMENTATION

The hydrogeochemical map and the annexed text part are inextricably linked containing the documentary material used in their preparation. Hydrogeochemical documentary materials represent the analyses of groundwater samples used to construct hydrogeochemical maps. Each analysis has a number identical to the number specified in the hydrogeochemical map. On the map and in the database analyses are listed in the order of the increasing x-axis. In addition to the results of analytical data and field measurements there are shown the date of groundwater sampling, coordinates, sampling sites and resources.

2.6 PRINCIPLES OF COMPILING UNITE DIGITAL GROUNDWORK OF THE HYDROGEOCHEMICAL MAPS AT A SCALE OF 1:50,000

In order to achieve unified submission of the results of basic hydrogeochemical maps it was compiled a mandatory internal procedure, in which the emphasis is also on digital presentation of information value of map series (Kordík & Slaninka, 2009). Single procedure assumes that all the basic information listed in the hydrogeochemical map can be processed as separate thematic layers that consist of graphics, database and descriptive digital data. According to the rules of compiling information systems (Directive of the Ministry of Environment of the Slovak Republic from April 13, 2000 No. 2/2000 on the Principles of Processing and Transfer of Tasks and Projects in Geographic Information Systems) the unity of thematic layers must be preserved in the method of displaying objects in the layer (point, line, polygon) and in the way it is characterized in the connected database. As main information base layers of the hydrogeochemical maps are considered:

• groundwater qualitative properties,
• geochemical characteristics of the groundwater circulation in the environment,

- water management characterization of groundwater,
- database of the chemical composition of groundwater.

As required by the Directive No. 9/2004 of the Ministry of the Environment on the Compilation of Basic Hydrogeochemical Maps among additional required information in the hydrogeochemical map belong mainly point marks and symbols (local sources of anthropogenic pollution, anomalous groundwater quality, nature of groundwater pollutants and relevant constituents and others), line and contour objects (e.g. bounding of spatially defined characteristics) and additional maps indicating the distribution of economically important constituents in water.

INFORMATION LAYER – GROUNDWATER QUALITATIVE PROPERTIES

Qualitative properties of groundwater are shown by the colour of an area (polygon, surface entity), based on a comparison of individual analyses of groundwater with the criteria defined under Government Regulation No. 496/2010 Coll., laying down requirements for water intended for human consumption. On the grounds of groundwater quality classes defined, the mapped area is divided into areas with the same class of water quality; up to eight classes of groundwater quality (A to H) can be defined. Each basic thematic unit, which represents the possible combinations of eight classes of groundwater quality, has in the column *kvalita_ID* quality label in the map (tab. 2.3). As the graphic entities with the same class of groundwater quality may not contain identical information on qualitative characteristics and nature of environmental pollution (in the field *kvalita_popis*), for this thematic layer the code table is not proposed. Through field *kvalita_vyclenenie* additional information on how allocation of groundwater quality classes can be obtained, in particular information on the physico-chemical parameters and limit values in the waters which are the most important in terms of allocation of classes. Example of the information presented on the qualitative properties of the groundwater is shown in Fig. 2.1. The darkest red area in Fig. 2.1 expresses an example of the worst H quality class due to municipal and agricultural pollution.

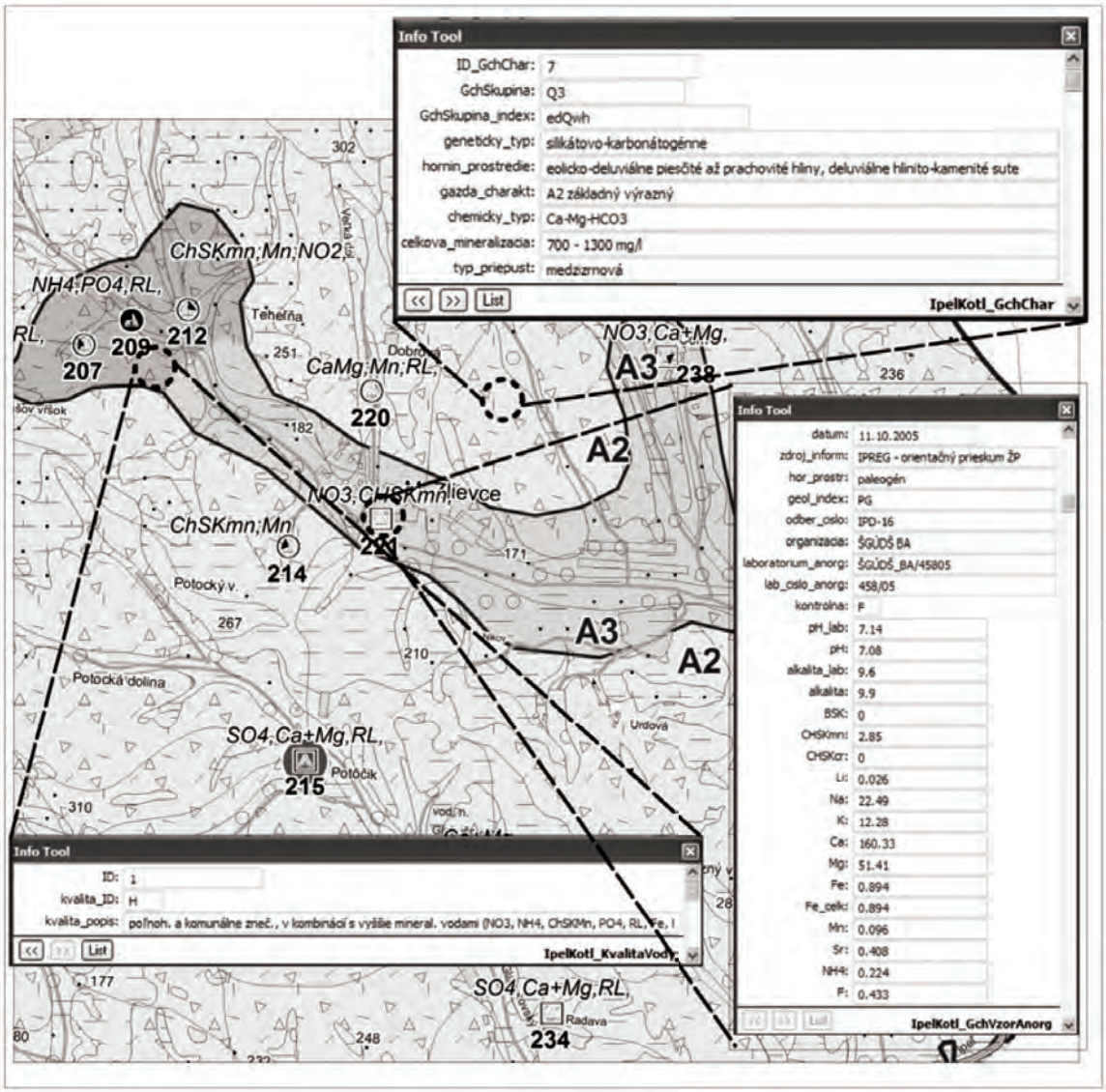


Fig. 2.1 Example of presented information obtained from basic hydrogeochemical map at a scale 1:50,000 (following Slaninka in Scherer et al., 2005)

Tab. 2.3 Structure of information layer "Qualitative properties of groundwater"

Field designation	Data type	Characteristics and description of data field
ID	Integer	Unique database identifier of graphical entities (1...n)
kvalita_ID	Char(2)	Class designation of groundwater quality on the map (A to H)
kvalita_popis	Char(200)	Description of the qualitative characteristics and nature of pollution
kvalita_vyclenenie	hyperlink	Link to a diagram of allocation of groundwater quality classes under Rapant, Bodiš (2003)

INFORMATION LAYER – WATER MANAGEMENT CHARACTERISTICS OF GROUNDWATER

Water management criteria refer to the adequacy of raw groundwater in terms of its treatability for drinking water. The chemical composition of groundwater from individual samples is compared to the cut-off concentration given in the Regulation No. 636/2004 of the Ministry of Environment Coll. laying down requirements for raw groundwater quality and groundwater quality monitoring at public water supplies and the category of the treatability is determined. In the former STN 75 7214 the treatability was divided into categories A, B, C, D; in the Regulation No. 636/2004 it is divided in categories A1, A2, A3). Using contours and symbols the area is divided into territories with the same category of groundwater treatability. Each thematic base unit, which represents possible combinations of the four criteria of water treatment (A1, A2, A3, or untreatable groundwater), is indicated in the field *vodohosp_krit_ID* code 1-4 (Tab. 2). More detailed information on water management characteristics of groundwater is expressed in the description of the particularities of the environment (*vodohosp_krit_popis*).

Tab. 2.4 Structure of information layer "Groundwater characteristics for water management"

Field designation	Data type	Characteristics and description of data field
ID	Integer	Unique database identifier of graphical entities (1...n)
vodohosp_krit_ID	Integer	Code of environmental characteristics (1...4)
vodohosp_krit _popis	Char(254)	Description of the particularities of the environment

INFORMATION LAYER – GEOCHEMICAL CHARACTERISTICS OF THE ENVIRONMENT OF GROUNDWATER CIRCULATION

Geochemical characterisation of groundwater circulation environment is based on the natural conditions of the region. It is expressed through the delineation of hydrogeochemical groups of groundwaters, which are shown on the map by black patterns in the area. The allocated hydrogeochemical groups of groundwater represent areas with the same genetic and chemical types, a range of values of total water mineralization and similar properties of geological environment of groundwater circulation. Genetic types of groundwater express the origin of soluble substances. A distinction is natural (Gazda, 1974) and anthropogenic (Rapant, 2001) conditional origin content of elements and components of the chemical composition of the groundwater. They are amended on Gazda`s characteristics (e.g. A_2 distinct, $S_2(SO_4)$ indistinct, $A_2 – A_1$ intermediary type of groundwater – Gazda (1972). Based on the prevailing ions the chemical water types are expressed by the symbols of elements and components according to the results of chemical analysis, for example, Ca-HCO_3 type. Intervals of values of total mineralization are broken down on the basis of mathematical and statistical data processing. The geological characteristics contains basic characteristics of the rock environ type and permeability of aquifer. It follows that each basic thematic unit (Tab. 2.5) describes the origin of dissolved solids in water (fields *geneticky_typ* or *Gazda_charakt*), chemical water type (field *chemicky_typ*), prevailing values of total mineralization (field *celkova_mineralizacia*) and collector bedrock (field *hornin_prostredie*). Information on the collector`s rock environment must be linked with

Tab. 2.5 Structure of information layer "Geochemical characteristics of aquifer"

Field designation	Data type	Characteristics and description of data field
ID	Integer	Unique database identifier of graphical entity
GchChar_ID	Integer	ID of geochemical characteristics, according to legend of geochemical characteristics of specific map (1 - n / number of delineated groups)
geneticky_typ	Char(20)	Expresses origin of the soluble substance (natural or anthropogenic)
gazda_charakt	Char(30)	Gazda`s characteristics of groundwater (e.g. A_2 distinct, $S_2(SO_4)$ indistinct, A_2-A_1 intermediary type of groundwater)
chemicky_typ	Char(30)	Chemical type of groundwater under prevailing ions is expressed in the symbols of elements and components according to the results of chemical analyses
celkova_mineralizacia	Char(20)	Interval of total mineralization values based on mathematical and statistical processing of data
hornin_prostredie	Char(200)	Basic characteristics of the rock environ (age, stratigraphic affiliation, lithologic-petrographic character) type and permeability of aquifer

the information in the relevant basic hydrogeological map. Example of information provided under this thematic layer is shown in Fig. 2.1, which displays geochemical group Q3 (petrogenic silicate-carbonatogenic TDS groundwater with A_2 basic distinct, Ca-Mg-HCO_3 type of chemical content).

INFORMATION LAYER – DATABASE OF CHEMICAL COMPOSITION OF GROUNDWATER

Database of the chemical composition of groundwater is very important in terms of methodology and mandatory part of the map presenting the results of research and exploration. Database presents documentary material representing mainly chemical analysis of groundwater samples used to construct the hydrogeochemical map. Significant information value that the primary database presents, is subject to several limitations, which are necessary to take into account at the breakdown and structuring of relational database of chemical composition (chemical analyses are obtained from various sources, contents of chemical parameters representing different periods of time, samples are analysed in different laboratories or by various analytical methods, etc.). When interpreting these data, it is therefore important to assess and express the relevance of the information obtained.

Database of the chemical composition of the groundwater is interactively assigned to point marks of groundwater sampling points (point entities). Given the complexity of hydrogeochemical information it is inevitable to build up geochemical relational database. Scheme of relational linking of database tables representing the chemical composition of water, or hydrochemical database structure has been extensively discussed in Kordík & Slaninka (2009). Hydrochemical database structure for the purposes of the compilation of basic hydrogeochemical maps at a scale of 1:50,000 is an intermediate step in the preparation of a comprehensive information system of geological information that is continuously implemented at SGIDŠ. Example of the information on the chemical composition of groundwater is shown in Fig. 2.1.

2.7 CONCLUSIONS

Basic or various thematic hydrogeochemical maps represent the initial background information on the chemical composition and quality of groundwater in Slovakia. The significant development of information technology, especially after 1991, greatly influenced the development of hydrogeochemical presentation of information in Slovakia. While up to 1991 there were built in our practice only traditional forms of printed hydrogeochemical maps, after 1991 a shift has been experienced, mainly in the direction of compiling digital maps and later also in the direction of building information systems to the relevant map series.

The oldest hydrogeochemical maps of the complex nature compiled by unified methodology may be considered "Maps of the chemistry of groundwater in the scale of 1:200,000" which originated as part of the compilation of basic hydrogeological maps at 1:200,000 mainly in the 70s of the last century (in total 12 map sheets). Other mostly thematic hydrogeochemical maps compiled in the period before 1980, were marked by inconsistency of methodical processing of hydrogeochemical information, while hydrogeochemical maps elaborated in the 80s of last century, in principle, were based on a methodology proposed in regional geochemical research of groundwater (Vrana & Rapant, 1985 in Gbelský et al., 1985).

The first map works completely processed into digital data were carried out within the assembled two-sheet basic hydrogeological and hydrogeochemical maps at a scale of 1:50,000 in the years 1994 – 1999 for 7 regions of Slovakia (hydrogeochemical part was processed according to the methodology Rapant & Bodiš (1994), later modified in 2003). The problem with the first digital data, however, was a different view of individual authors of maps to digital information value of the information provided. It was therefore necessary to develop at SGIDŠ a binding procedure for the compilation of basic hydrogeochemical maps at a scale of 1:50,000, or presentation of these maps in digital form and in the form of a simple information system (Kordík & Slaninka 2009).

Basic hydrogeochemical maps display the most important quality and geochemical characteristics of groundwater of the first aquifer, eventually other major deeper aquifers. For main information base layers of the hydrogeochemical maps have been proposed:

- groundwater qualitative properties,
- water management characterization of groundwater,
- geochemical characteristics of the groundwater circulation environment,
- database of the chemical composition of groundwater.

Each of these thematic layers contains in addition to a unique database identifier and the designation of the relevant characteristics of groundwater or the environment of circulation also descriptive information, very valuable for users of hydrogeochemical information. The practice has proved the need for interconnection of hydrogeological and hydrogeochemical information; quantitative and qualitative parameters of the rock environment and groundwater circulating in it are therefore displayed on two-sheet basic hydrogeological and hydrogeochemical maps. The compilation of text explanations to these maps also follows the above principles pursuant to the Regulation No. 8/2004-7 of the Ministry of Environment of the Slovak Republic on Compilation of basic hydrogeological maps at 1:50,000, the explanations are processed into one text whole with interrelated and clearly defined content.

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