project LIFE+

KRASCAVE

Implementation of Sustainable Groundwater Use in the Underground Karst System of the Krásnohorská jaskyňa Cave

LAYMAN'S REPORT

CONTENTS

Project title:
Implementation of Sustainable Groundwater Use in the Underground Karst System of the Krásnohorská jaskyňa Cave

Acronym:
KRASCAVE

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LIFE11 ENV/SK/001023

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Project partners:

State Geological Institute
of Dionýz Štúr
Bratislava (ŠGÚDŠ)
Coordinating beneficiary

EnviSlovakia, o.z.
Civic association EnviSlovakia
Bratislava (OZ EnviSlovakia)
Associated beneficiary

Project manager:
RNDr. Peter Malík, CSc.

Project web page:
www.geology.sk/krascave

Motto:
Effective measures for reducing the risk of deterioration of fragile Krásnohorská jaskyňa Cave ecosystem can be designed, based on detailed investigation of the site and processing of numerous environmental-geologic data. This ecosystem is strongly dependent on quantity and quality of water contained in the karstified rocks of the Silická planina Plateau. Development of monitoring device functional prototype continuously inspecting key water quality parameters offers platform for immediate information input both to water source managers and general public especially in the case of prompt solutions in critical moments. Without public involvement, especially of local community, protection of precious underground hydrologic system of the Krásnohorská jaskyňa Cave would be impossible.


Krásnohorská jaskyňa Cave entrance


Trail for visitors inside the Krásnohorská jaskyňa Cave

Project **LIFE11 ENV/SK/001023** "Implementation of sustainable groundwater use in the underground karst system of the Krásnohorská jaskyňa Cave" (acronym KRASCAVE) was focused on reducing the risk of drinking water source contamination in the underground ecosystem of the Krásnohorská jaskyňa Cave through the implementation of innovative activities. At the same time it, was contributing on the local level to meet the requirements of the Water Framework Directive (2000/60/EC). Proposed measures based on project knowledge should reduce the risk of environmental damaging of fragile ecosystem in the area of the Krásnohorská jaskyňa Cave, which is strongly dependent on groundwater quantity and quality.

Project activities were primarily focused on detailed monitoring of groundwater quality and quantity. In the next step models of supposed interaction of biotic and abiotic components of the Krásnohorská jaskyňa Cave underground hydrologic system were developed. As the key project element, functional prototype of the device securing the water source protection was created and tested.

By means of various project activities, connecting the local community but also broader public including professionals, the State Geological Institute of Dionýz Štúr as the coordinating beneficiary in close cooperation with the associated beneficiary of the civic society EnviSlovakia were trying to raise public awareness on potential risks to underground karstic ecosystem and the needs of proper maintenance of local groundwater sources.

Project goals:

- to reduce the risk of contamination of drinking water source in the karstic underground ecosystem of the Krásnohorská jaskyňa Cave through the implementation of innovative activities,
- on the local level, to contribute to meet the requirements of the Water Framework Directive (2000/60/EC),
- to formulate measures for reducing the risk of environmental damaging of the fragile underground ecosystem of the Krásnohorská jaskyňa Cave, dependent on the groundwater quantity and quality.

Tuffa cascades under the cave

Speleothemes inside the cave

Preparatory actions:

- **A.1**: Quantitative and qualitative analysis, detailed interdisciplinary field reconnaissance in order to state precisely the threat to groundwater and ecosystems
- **A.2**: Spatial reconnaissance and spatial monitoring of groundwater quality
- **A.3**: Water sampling and field measurements in the underground hydrological system in a daily time step
- **A.4**: Comprehensive assessment of the components of the underground landscape and defining of interactions between biotic and abiotic parts of an underground landscape structure
- **A.5**: Preparatory activities for creation of the prototype device – technical drawings
- **A.6**: Getting permission to install a prototype
- **A.7**: Meetings with local residents in order to clarify the reason of the project and potential risks posed to the drinking water source for the village

Implementation actions:

- **B.1**: Creating models of chemical composition development by water interaction with rock environment and the development of rainfall-runoff interactions in the rock environment
- **B.2**: Creation and testing of the prototype device, protecting the source of drinking water supplying population of the Krásnohorská Dlhá Lúka municipality and its installation in continuous operation
- **B.3**: Delineation of environmentally sensitive sites ("hot spots") of surface anthropogenic activities interactions with the underground landscape system
- **B.4**: Developing rules of improvement or maintaining the status suitable for the protection of natural interaction of individual system components in the area of the Krásnohorská Cave, design of measures for improvement and maintaining the status
- **B.5**: Implementation of the proposed measures in agriculture and land use in the catchment area of the underground hydrologic system of the Krásnohorská Cave

Monitoring of the impact of the project actions:

- **C.1**: Monitoring of groundwater quality after installing the prototype and implementation of the measures
- **C.2**: Prototype operation monitoring – monitoring of functioning, unsoundness, resistance
- **C.3**: Monitoring the impact of project activities and communication to change behaviour of inhabitants and land users in the surroundings of the cave
- **C.4**: Monitoring of the impact of the project activities on local urban development and municipal land-use behaviour

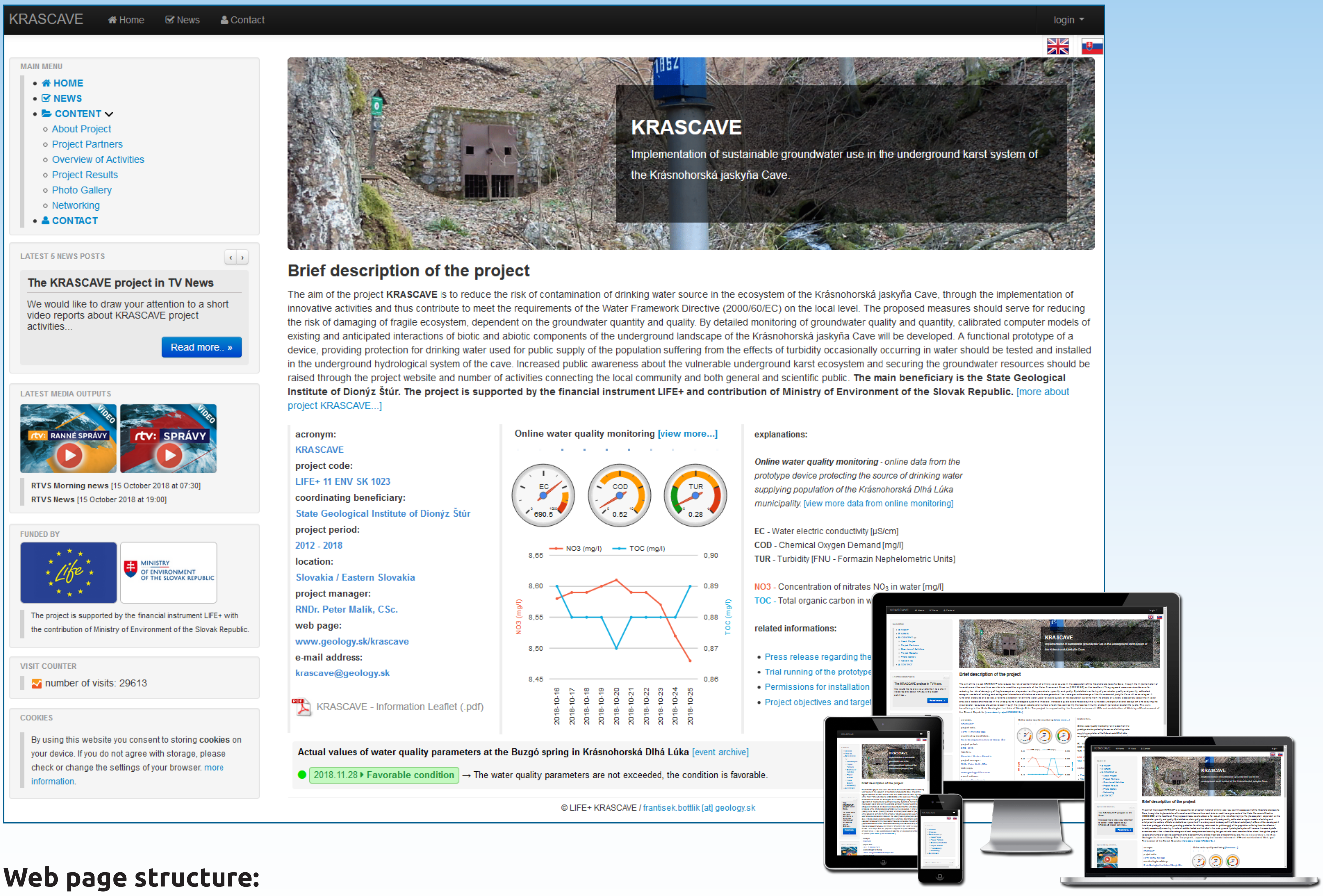
Communication and dissemination actions:

- **D.1**: Communication activities for the residents of the village Krásnohorská Dlhá Lúka to implement the proposed measures in agriculture and land-use
- **D.2**: Communication activities for different target groups in Slovakia, to promote the project results – government, local government, professionals, general public, schools, speleologists
- **D.3**: Project Website
- **D.4**: Layman's Report – report of the project for general public
- **D.5**: Media activities – articles, press releases, radio inputs
- **D.6**: Installation of information boards
- **D.7**: Participation at the kick-off meeting
- **D.8**: Post-project communication

Project management and monitoring of the project progress:

- **E.1**: Project management
- **E.2**: Monitoring project progress
- **E.3**: Project audit
- **E.4**: Networking with other LIFE projects in similar areas – at both national and international level

The project results can be found on the project website: **www.geology.sk/krascave**

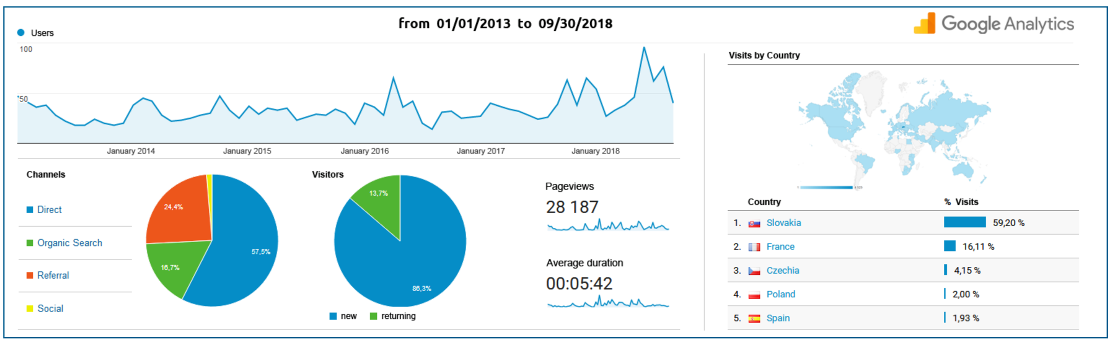


Web page structure:

- **HOME** – Brief project description and online water monitoring data
- **NEWS** – Up to date information related to the project
  - About Project – Basic information about KRASCAVE project
  - Project Partners – Information about project partners
  - Overview of Activities – Description and brief aim of project activities
  - Project Results – Files to download categorised by content
  - Photo Gallery – Photo albums
  - Networking – Cooperation agreements with other LIFE projects
- **CONTACT** – Contact information

Web page traffic statistics

Web page uses an analytical web service Google Analytics, that offers detailed statistic data about web page traffic (fig. 1). According to this data, in the period of January 1st 2013 to September 30th 2018 there were **28,187 website visit**. The majority of access (59.2 %) was from Slovakia, but other countries were also represented, e.g. France (16.11 %), Czech Republic (4.15 %), Poland (2 %) and Spain (1.93 %). About 16.7 % of users visited our website using a search engine (Organic search), 24.4 % via a link (Referral), 1.8 % of visitors used social networks (Social) and 57.5 % used the direct address into a browser (Direct).



Google Analytics service gathers anonymous traffic information without identification of specific visitor, the data is only collected for the purpose of statistical analysis of web page traffic.

Fig. 1. Web page traffic statistics.

WHAT IS KARST
What does karst in country mean

With the term **KARST** we describe the type of landscape, where rocks undertake slow dissolving process and the particles are carried away in solution. In scientific terms – the rocks are subject to the process of chemical dissolution and mechanic erosion, a process referred to as karstification. We can see the outcome of karstification both on the surface, as well as in the underground.

On the surface of karst area we can notice sinkholes, collapsed depression – depressed surface after old cave collapses, karst canyons, ponors (sinks) of surface water, karst springs, and karren fields – furrows on a bare rock surface. Chasms, abysses, single caves or large cave systems are results of subterranean karstification. The above mentioned represent primary forms of karstification. As secondary karst features we classify different sinter types, formed by re-precipitation of dissolved substances from water. Sinter can have various sorts: soda straws and stalactites growing from cave ceiling, stalagmites growing from bottom, stalagnates (columnar connection of stalactite and stalagmite), flowstone drapes, drums, cave pearls, dams and many other eccentric forms.

Gradual karstification processes in karst areas can, under suitable conditions, result in creating extensive **cave systems**, which consist of connected system of corridors, abysses, siphons and domes. Most of these cave systems are still undiscovered and unexplored due to their difficult accessibility. On the other hand, many important cave systems are now available to the public. Besides the description of cave formation, curious visitors can also find information on cave discovery and exploration history. Every cave has its unique story to tell.


Karstic chasm of Nová krv


Karren fields

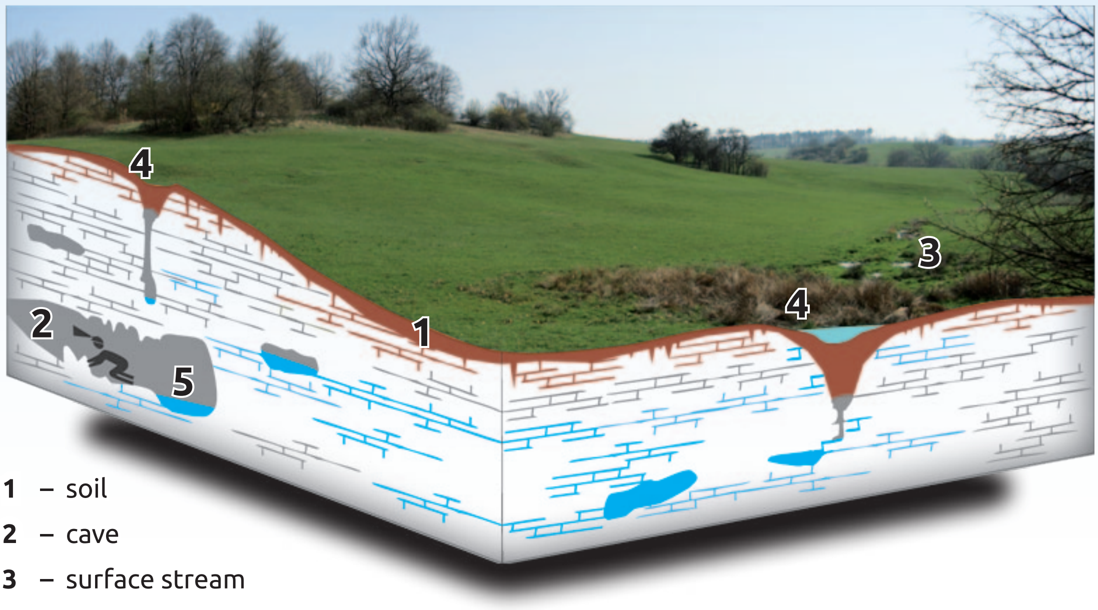

Unnamed chasm on the Silická planina Plateu


Hlivákova priepasť Abyss


Karstified limestones

Karst is formed by water (by dissolving rocks) and is perfectly adapted for water intake, its flow, and concentration into large springs. Frequent and typical are surface water ponors (sinks), where massive replenishment of groundwater occurs, as well as transport of dissolved and undissolved particles.

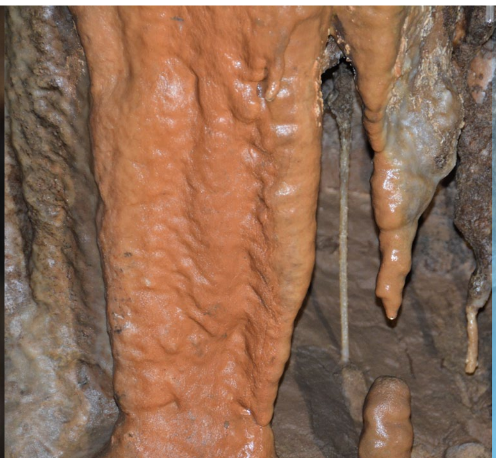
Karst structures on the surface of Silická planina Plateau are ideal for infiltration of precipitation water into groundwater, although ponors here are small and only occasional. Bare limestone rocks on the surface are opened up by the process of karstification, which allows the rain or snowmelt water to freely, without any obstacles enter the underground. Due to its low mineralization and CO_2 presence, the precipitation water is quite aggressive for the limestone rock environment. Flowing down the fissures, it can dissolve surrounding rocks, what makes it easier to infiltrate further deep. For us – on the surface – often only slightly visible karst features can create a network of smaller and bigger cracks or even cave corridors in the underground (fig. 2). This drainage system brings precipitation water and sunken surface streams all the way to the point of karst springs.



1 – soil
2 – cave
3 – surface stream
4 – sinkhole
5 – underground lake

Fig. 2. Water in karstified rocks.

These are often important **drinking water sources** that provide refreshing water even in the hottest summer. However rapid water flow in the complicated karst system can cause its unexpected pollution. Unfortunately, fast circulation of water in karst system can also result in unstableness or drying out of some springs in dry periods. However, if the springs are bound to deep karst paths, they can be a stable and reliable source of drinking water supply.



Krásnohorská jaskyňa Cave – speleothemes inside

Water course in the country of karst

Karstifying **limestones and dolomites** are relatively rare in Slovakia: they cover less than 1/20 of its total territory. In spite of this, more than one half of the total drinking water consumption is covered by water from these aquifers. On illustrative map below (fig. 3) we shall not find many areas filled by blue colour for limestones and dark violet colour for dolomites. Their conjunctive areal extent is only 2,324 km^2, while area of Slovak Republic is somewhat above 49,000 km^2. Every second, in average 10.72 m^3 of groundwater is consumed by Slovak population, from which approximately 5.80 m^3 flows into the taps directly from karstic springs. Ratio of karstic groundwater in drinking water supply coverage is therefore as much as 54%.

All available karstic **groundwater sources** in the country count as much as 19.7 m^3/s. If their currently still persisting good water quality would be maintained, karstic groundwater should be able to supply the doubled contemporary drinking water consumption in Slovakia. However, karstic aquifers are very sensitive to human intervention – improper actions can cause karstic water to easily disappear and even more quickly to be contaminated!

Comparing total available groundwater resources from all aquifer types on the territory of Slovak republic (ca 76.5 m^3/s) with those from karst (19.7 m^3/s) we can see that approximately 1/20 of the country area yields about ¼ of all groundwater resources here.

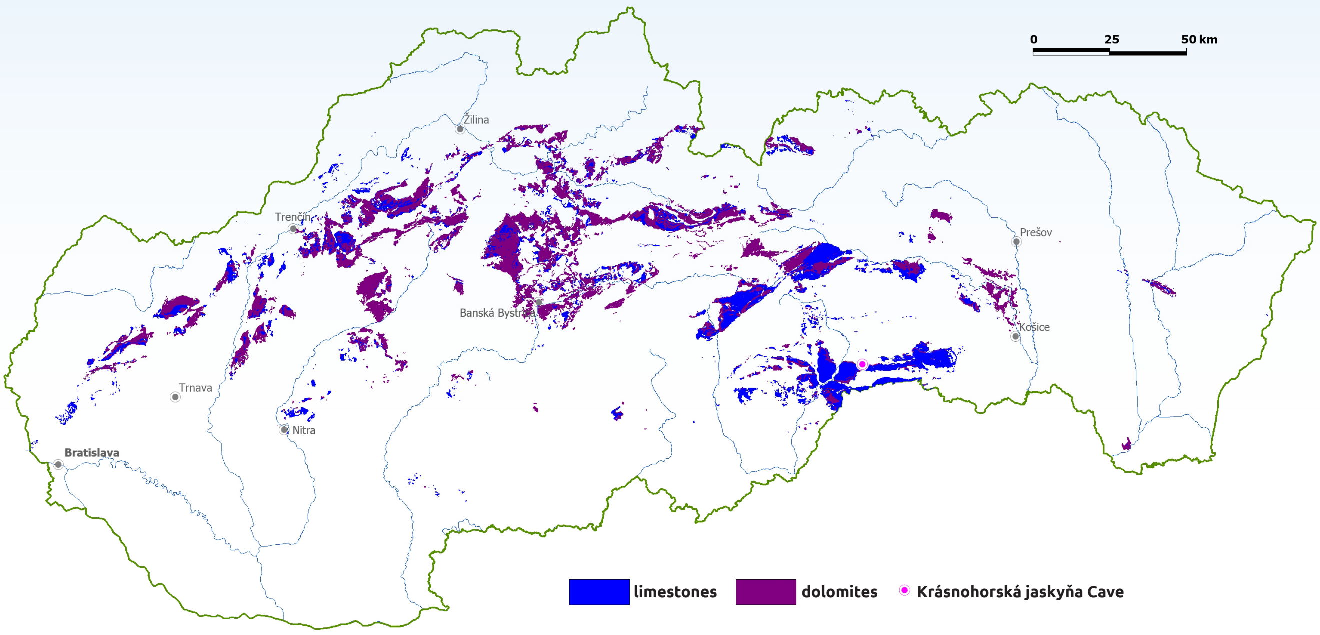
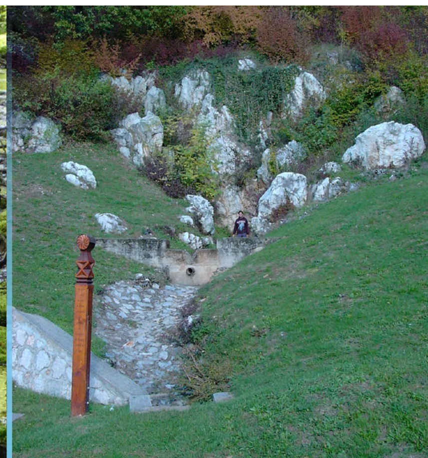


Fig. 3. Karstifying limestones and dolomites on the territory of Slovak Republic.

Thomson-type weir on the Pod kameňolomom spring

Tuffa cascades under the Buzgó spring



Pivničná diera water outlet

Karstic aquifers thus fivefold overcome "average properties" of "common" aquifers to concentrate groundwater resources. This is because limestones and dolomites are able to receive nearly the whole volume of unevaporated precipitation and centralize groundwater flow in the underground into huge karstic springs. This is also the case of Buzgó spring, which is draining waters from the Krásnohorská jaskyňa Cave.

Comparably huge groundwater sources exist only in some parts of gravel and sandy sediments along big rivers. Here, groundwater has to be pumped out from wells and boreholes. Advantage of using water freely running out from springs is energetic austerity: from karstic spring, water can by its own weight come through pipeline directly into your household.

Looking at the map (fig. 4) of various **types of groundwater sources** one can see that south or east of the Slovak countryside is lacking major groundwater sources – both non-karstic and karstic. This unequal distribution of water sources given by natural settings should be a reason for greater respect which should be devoted to groundwater. Can this be only the case of inhabitants of water-scarce regions? We also have to be aware that karstic groundwater can be easily spoiled, become undrinkable or scarce goods by inappropriate intervention even in water-rich regions!

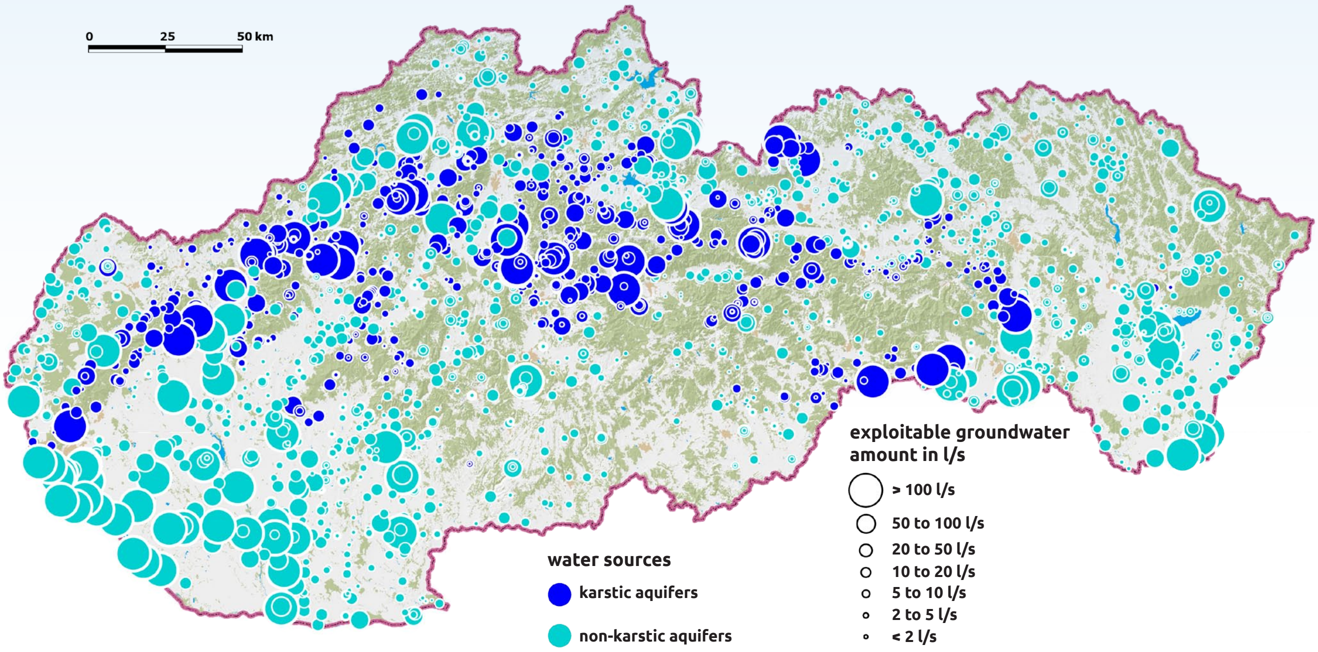


Fig. 4. Significant groundwater sources in Slovakia, distinguished by their origin in karstic or non-karstic aquifers.

Under the Babot kút site

Biela vyvieračka Spring near Gombasek

Water is essential to our lives. For this reason, we need to value and protect our drinking water supplies – both their quantity and quality. Water in karst environment requires special protection. Unlike sand and gravel environment, where water flows slowly through individual grains and cleans itself, water in karst doesn't have this chance.

Fast infiltration of precipitation water is typical for all karst surfaces, but at the site of sinkholes, ponors and abysses precipitation and surface water passes to the underground with extreme speed. Once underground, the water amount divides in two parts: one part slowly passes through small cracks in the rocks, the second part flows quickly in underground fissures and caves all the way to the point of its outflow – a spring.

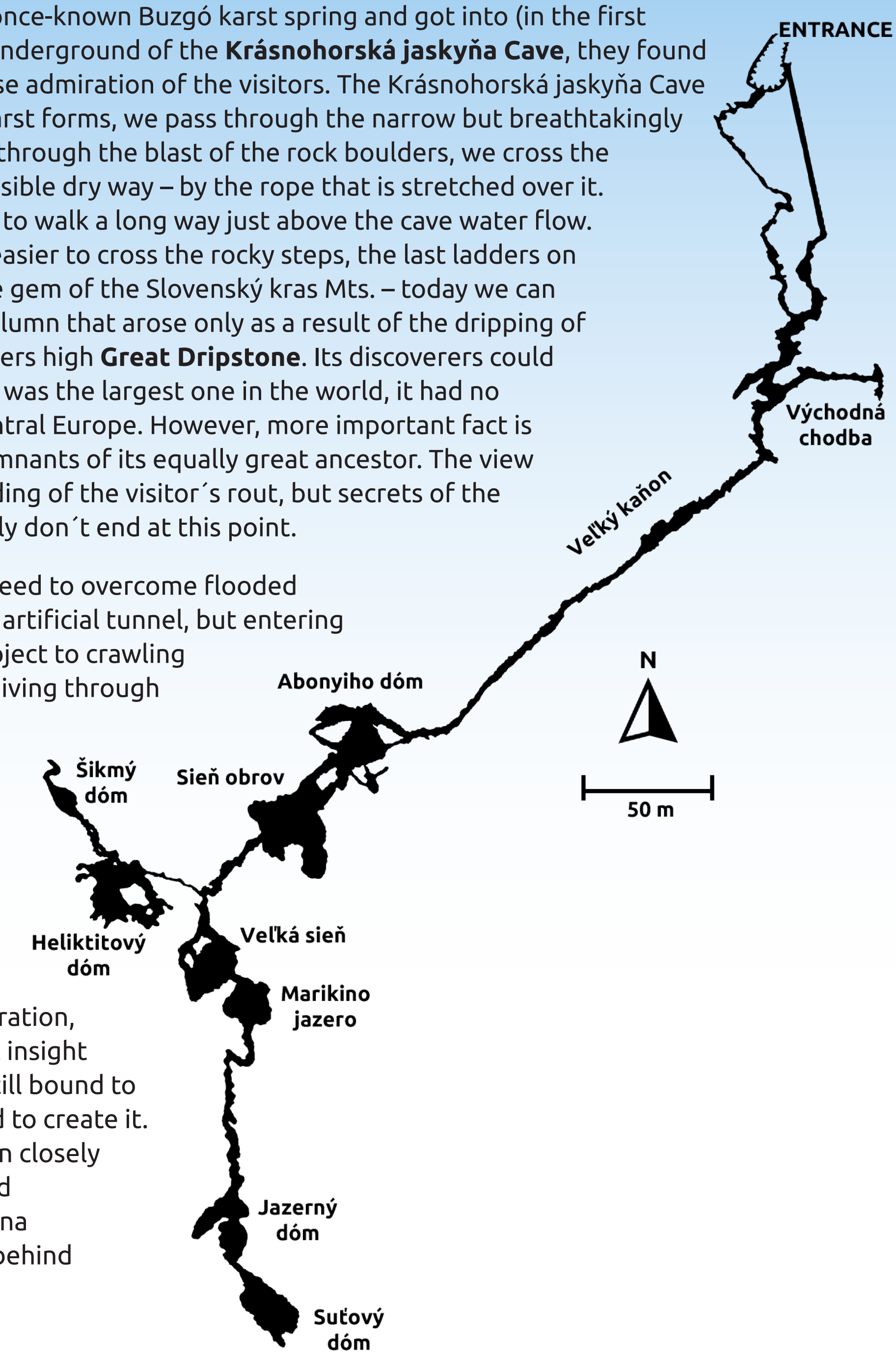
Contamination of precipitation and surface water, as well as pollution of karst surface (landfills, waste dumps, cattle breeding, forest logging, etc.) is a threat to the groundwater quality. Therefore, the water quality in karst environment needs to be protected in the entire length of its journey, while very important are infiltration spots in the entire infiltration area of springs – drinking water resources.

In order to prevent water quality and quantity endangerment, water resource **protection zones** with various degree of protection were established. **First-degree** protection zone is set up directly around water resource site. They are fenced and marked with a sign. The specificity of karst is that a first-degree protection zone must also be established around ponors and sinkholes, which are directly connected to the protected water resource. In a **second-degree** protection zone no activities endangering water quality and quantity are allowed.


Water source protection – Eveteš spring


Water source protection – protection zones

When, **in 1964**, the group of cavers from the city of Rožňava succeeded in the break through narrow rocky corridors behind the once-known Buzgó karst spring and got into (in the first moments rather crawled into) the underground of the **Krásnohorská jaskyňa Cave**, they found themselves in spaces that still arouse admiration of the visitors. The Krásnohorská jaskyňa Cave will surprise you with a variety of karst forms, we pass through the narrow but breathtakingly high underground canyon, we pass through the blast of the rock boulders, we cross the underground lake over the only possible dry way – by the rope that is stretched over it. Built-in catwalks now allow tourists to walk a long way just above the cave water flow. Built-in ladders and chains make it easier to cross the rocky steps, the last ladders on the visitor‘s route will lead us to the gem of the Slovenský kras Mts. – today we can comfortably walk up to the giant column that arose only as a result of the dripping of water – to the more than thirty meters high **Great Dripstone**. Its discoverers could enjoy for years the illusion that this was the largest one in the world, it had no competitor in the frames of the Central Europe. However, more important fact is that dripstone has grown on the remnants of its equally great ancestor. The view of this majesty means the great ending of the visitor´s rout, but secrets of the Krásnohorská jaskyňa Cave definitely don´t end at this point.



Contemporary visitors have no need to overcome flooded crevasses as they enter the cave via artificial tunnel, but entering the back parts of the cave is still subject to crawling through really narrow corridors or diving through 30 m deep flooded cave corridor. Beyond these nature-well-guarded barriers there are spaces where nobody ever stepped and which are still waiting to be discovered.

For tourists, Krásnohorská jaskyňa Cave represents a set of concentrated natural beauties, for cavers a challenge for further exploration, but **for hydrogeologist** it is a direct insight into the underground. The cave is still bound to underground waterflow that helped to create it. Here, in the “live broadcast“, one can closely observe mutual activity of water and surrounding rock massif – phenomena that one can only guess elsewhere behind many great karst springs similar to the source of Buzgó.


Krásnohorská jaskyňa Cave entrance

In 1963 we would not find such a direction mark


Stalagmite inside the Veľká sieň

The Great Dripstone (Kvapeľ rožňavských jaskyniarov Dripstone)

The discovery of the Krásnohorská jaskyňa Cave in July 1964 was accompanied by the **discovery of a colossal dripstone** – the first visitors who saw it knew, that this one exceeds the world highest stalagmite, according to then available information, in the nearby Hungarian Baradla Cave at locality Jósvafő. The Hungarian one, named Csillagvizsgáló/Observatory, was 26 m high, but the newly discovered one in the Sieň obrov Hall (Hall of Giants) was estimated to more than 30 meters.

Today its height is set to 32.6 m and its weight is estimated at about 2,000 tons. There was a time when the Guinness Book of Records referred to the **Kvapeľ rožňavských jaskyniarov Dripstone** as the biggest stalagmite in the world. The Age of Informatics also brings disappointment: it is much easier today to find out that there are number of caves in the tropical zone of our planet, rich in not only extraordinary large spaces but also in dripstones of few times larger dimensions.

Effective co-acting of temperature and humidity of tropes in the creation of large sinter accumulations and even larger underground cavities can hardly be overcome in our climatic conditions. However, this ever-gigantic rock still attracts attention. Why is it at least ten to hundred times bigger than other big dripstones in other caves far and wide? Why is this particular dripstone able to reproduce itself? The Kvapeľ rožňavských jaskyniarov Dripstone is on the ruins of its ancestor, perhaps more ancestors. The previous dripstone collapsed probably due to its own high weight, an unstable footwall, although the last drop into this instability could be an earthquake.

More interesting, however, is that the material for the “construction“ of new successive giants has been continuously supplied to these areas for the entire millenniums or decades of millennium. On average, the water brings **every three to four minutes** about **one gram of stone** which then remains here. Today's dripstone has been created by the successive joining of a number of simultaneously growing columns and is now firmly connected with a sinter bridging with a ceiling – it is a stalagnate (sinter column). It is in this place where there are unique conditions, which are not found elsewhere in the underground or its connection with the surface of Silická planina Plateau. To begin to dissolve the limestone on the surface in sufficient quantity, it must be covered with soil where the soil air is sufficiently rich in CO_2. In order for the dissolved limestone to be transferred to the same place in the underground, there must be a very stable pathway due to which the water constantly leaks from the surface to the Sieň obrov Hall (Hall of the Giants).

Careless human intervention on the surface of the Silická planina Plateau, however, can easily disturb this millennial steady circle.

The Great Dripstone (Kvapeľ rožňavských jaskyniarov Dripstone)

The Krásnohorská jaskyňa Cave galleries have been undoubtedly developed in mutual interaction of gravitation and flowing water. Today, however, the known length of the cave corridors is about 1,550 m, but the groundwater course one can find along only 400 m long section of the lowest passages.

The entire collecting system of the cave groundwater is named the **underground hydrological system** of Krásnohorská jaskyňa Cave. The origin of its waters should be unambiguously searched on the surface of the northern slopes of the Silická planina Plateau. The un-evaporated part of precipitations enters (recharges) the underground – most often during spring thawing of snow, but large regional or local storm rainfalls represent an important source as well. The most important water source in the underground of the Krásnohorská jaskyňa Cave is the tributary to Marikino jazero Lake. However, cave-divers had discovered another lake connected with Marikino jazero Lake by the 28 m deep siphon and one more lake behind next siphon in the Suťový dóm Dome.

Water is flowing here from the massive rock-fall and higher situated tributaries we don´t know yet. Inside the cave **two bigger side streams** are evident. The first one, the left side tributary, could be find bellow the Veľká sieň Hall and brings water from Heliktitový dóm Dome. Second bigger inflow, right side one, is in Abonyiho dóm Dome. Both tributaries bring more-less equal amount of water. Discharge of both these inflows is significantly smaller in comparison with groundwater flow coming from the Marikino jazero Lake: it is only some 10 % of total cave discharge – remaining 90 % of water comes from Marikino jazero Lake, respectively from the spaces behind this lake.

Very small, difficult to measure, inflow with discharge about circa 0.02 – 0.04 l/s could be find in the "Chodba perál" Gallery ("Pearls Gallery") approximately at halfway between left side tributary bellow the Veľká sieň Hall from the Heliktitový dóm Dome and ladders nowadays used to ascend to Kvapeľ rožňavských jaskyniarov Dripstone. This is the water which is the **breadwinner of the great dripstone**, this water supplies the dripstone by dissolved limestone and seeps down its surface to the main waterflow.

Quality of the mentioned tributaries is different; interesting is that the lowest mineralization has water seeping from the Kvapeľ rožňavských jaskyniarov Dripstone. In the past, detailed measurements of electrolytic conductivity and water temperature have been performed on the underground watercourse in the cave to identify other possible hidden tributaries. However, no other tributaries could be found.

Detector checking during the tracing test

Marikino jazero Lake

Inlet inside the Abonyi Dome

Groundwater in the surroundings of the Krásnohorská jaskyňa Cave

In the lowest nowadays visited part of the Krásnohorská jaskyňa Cave its underground flow is lost in a rock massif – the underground hydrological system of the cave ends here, so that after overcoming several tens of meters of hardly accessible underground the water can reach the surface of the earth – as the **karst spring Buzgó**. It looks like ordinary groundwater outflow, although concrete blocks help it in the last few meters.

However, on the foothills of the northern slope of Silická planina Plateau, this spring is not lonely – about 200 m to the east there is a smaller karst **spring Pod kameňolomom** ("Under the quarry"), and about 100 m to the west there is even a smaller spring **Pri kaplnke** ("Near the chapel") surrounded by an interesting pilgrimage place. After another 500 m to the west, at the southern edge of Krásnohorská Dlhá Lúka village, we can find the smallest of the karst springs – the **spring Pri mlyne** ("Near the mill"). The location of these karst springs is not accidental: the northern edge of the Silická planina Plateau consists mostly of impermeable shales, and only on a short stretch this almost continuous strip is interrupted by limestones. The geological structure of this part forms a sunken block that opens the path to limestone bound karst waters up to the stream Čermošná, which flows all over the North of the Silická planina Plateau. However, each of these karst outflows is different than its neighbours: this is why their common features and differences in the chemical composition were studied in the frame of the project.


Buzgó karstic spring


Pod kameňolomom spring


Pri kaplnke spring


Pri mlyne spring


Thomson-type weir on the Pod kameňolomom spring


Žedem spring

Generating precious tuffa cascades

The most interesting manifestation of the chemical composition of Buzgó spring water is the **formation of calcareous tufa**: immediately after discharge from underground, porous limestones are precipitated directly in the water, creating a network of wonderful water cascades over 150 m long. It can be said, that this is a second phase of creating a "new stone" – the first is the giant dripstone in the cave, that the second one is the "multi-floor" stream below the cave.

At foothill on the opposite, southern side of Silická planina Plateau, directly above the Hrušov village and bellow the Soroška pass, the **karst spring Eveteš** rises. One can find traces of old tufa here as well; in the past it may have looked like the stream bellow Krásnohorská jaskyňa Cave. Today, the Eveteš spring water is taken to the water supply network. This spring, however, shares the water from the Silická planina Plateau limestones with springs in the Krásnohorská Dlhá Lúka village vicinity – borders of their catchment areas can be determined only very roughly.

Since there are **small non-karstic springs** in the same area, we had to evaluate at least some of them as well, in order to identify the differences between possible areal contamination in their immediate vicinity and pollution that can be spread from far away via underground karst paths.

Tuffa cascades under the Buzgó karstic spring

Eveteš karstic spring

ENVIRONMENTAL THREATS IN THE KRÁSNOHORSKÁ JASKYŇA CAVE VICINITY

Conditions of the Krásnohorská jaskyňa Cave are affected by **human activities** not only in the immediate vicinity of the cave but also in the wider surroundings of the Silická planina Plateau from where rain and surface water flow into the cave – with everything it meets on its way and what is able to dissolve.

Waste landfills, use of agrochemicals, livestock farming, road transport, timber harvesting, but in the imagination of the far future, potentially once also the management of pipelines or the creation of industrial zones – in short, all activities that may threaten the groundwater should be carried out and placed in the country up to an expert assessment by the appropriate authorizing authorities. In addition to the prevention of water pollution, the protection of karst formations should not be neglected.

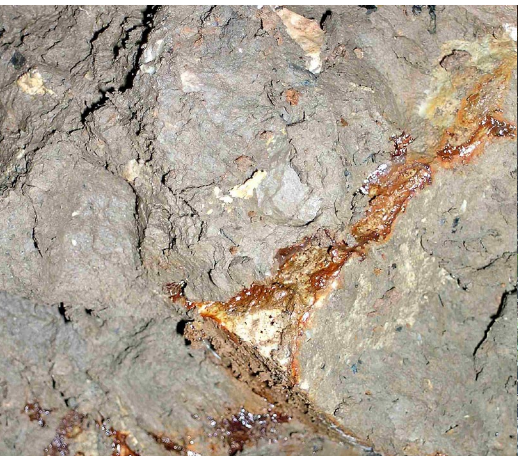
In the recent past, unfortunately, illegal waste landfills hidden in shafts and sink holes on the Silická planina Plateau were not rare. Unlawfully deposited material that was in them was directly in preferential ways of groundwater infiltration into the underground of karst and thus posed the highest risk of its contamination.

The rapid transfer of water from the surface of the plateau through the karstified limestone massif to the cave systems can be at least somewhat slowed down by the presence of vegetation and developed soil horizon. This fragile self-defence system of nature against contamination, however, man often disrupts by his insensitive use of natural resources only for his own benefits. The beauty of the cave passages and their decoration, the quality of the water in the Buzgó karst spring, and the unique tufa cascades below this spring and their precious microfauna are riches that must not be endangered.

The way we treat the karst land reflects in the quality of water we drink.

Cleaning of Snežná Abyss

Cleaning of Zvonivá Abyss



Contamination in sediments – Dvojitá priepasť

Illegal landfills

The area of the Krásnohorská jaskyňa Cave is primarily **protected** as part of the Slovenský kras National Park, declared in 2002. However, since 1973 this area has been protected as a Protected Landscape Area; since 1977, it was first registered in Slovakia in the international network of biosphere reserves UNESCO – Man and the Biosphere Programme; in 1995 the caves of the Slovak Karst and the adjacent Aggtelek Karst in Hungary were listed in UNESCO's World Cultural and Natural Heritage.

As one of the few among the more than 7,000 caves in Slovakia, Krásnohorská jaskyňa Cave has a declared **protection zone**. The Protected Area of the National Natural Monument Krásnohorská jaskyňa Cave, established by Decree 2/2007, has an area of 195.626 ha. If we look around the Krásnohorská jaskyňa Cave vicinity today, we certainly get a feeling that the protection should be written in the hearts and minds of the people rather than in the pages with paragraphs...

Within the protection zone of the Krásnohorská jaskyňa Cave there is prohibited:

- to carry out an activity changing the state of watercourses, lakes and places of rainwater leakage,
- to carry out technical geological work, mining activities and mining operations,
- store or manufacture industrial products, agricultural products and other materials,
- place the construction,
- to carry out land and air application of chemicals and fertilizers, in particular pesticides, herbicides, toxic fertilizers, industrial fertilizers and silage juices for agricultural, forestry and agricultural purposes and other activities,
- to stable livestock or to place a sheepfold,
- to extract wood in a holistic economic way,
- set fire outside closed buildings.

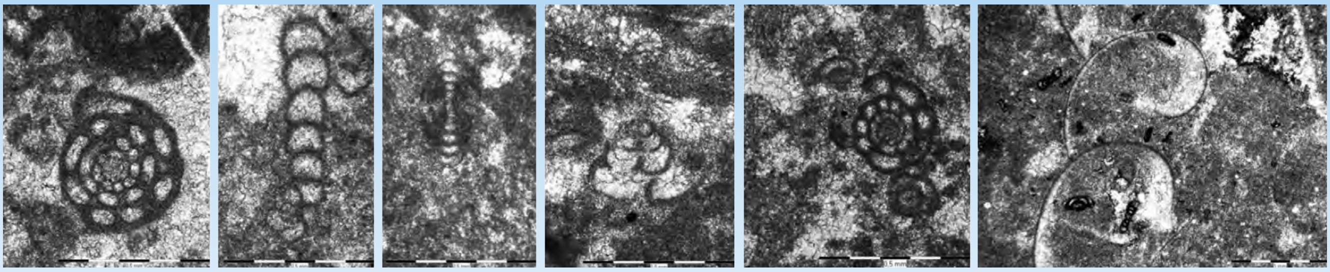
In the protection zone of the Krásnohorská jaskyňa Cave,
the Nature Conservation Authority (ŠOP) is required to:

- the implementation of training or training and related activities by armed corps, armed forces, civil protection, fire and rescue or components of an integrated rescue system,
- discharge of a water tank or pond,
- location of the device on a watercourse or other water surface not conducting water flow management
- disposal of a geological work or geological object,
- the construction of a forest path or a weighbridge,
- disruption of existing permanent grasslands,
- camping, climbing, rock climbing or ski touring,
- the entry and staying of a motor vehicle or a van on a plot outside of a built-up area outside the motorway, roads, local communications and parking,
- organizing a physical, sport or cultural-educational event, as well as other publicly accessible social events.

Water source protection

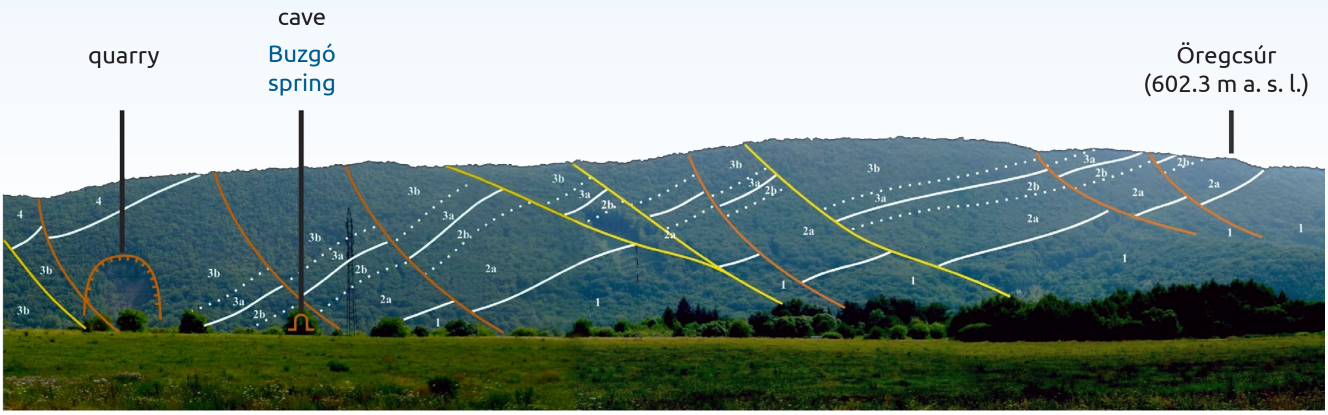
Slovenský kras National Park boundary

From the rocks found by **geologists** during detailed walks around the Silická planina Plateau a number of samples was taken, which underwent complex analyses in **paleontological and mineralogical** laboratories.



Based on the detailed investigation of microfossils, rock composition, modes of deposition and tectonic deformation of the rocks, a very **detailed geological map** of the area was compiled.

The seemingly unilateral geology of the plain spread out before the eyes of the geologist into a complex system of diverse rocks arranged in the folded structures and mutually segmented by the **systems of faults and nappes**.



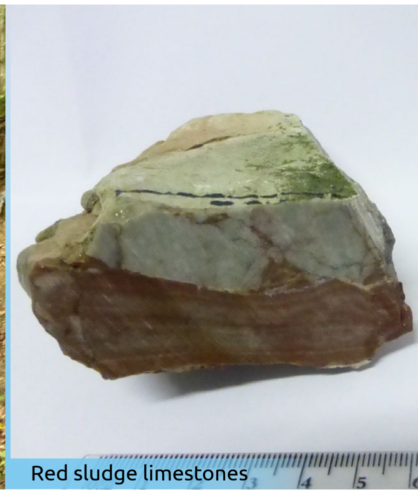
LEGEND:

1 – Szin and Szinpetri Members (Lower Triassic)
2 – Gutenstein Layers (Middle Triassic – Lower Anisian) – 2a: limestones, 2b: dolomites
3 – Steinalm Layers (Middle Triassic – Upper Anisian) – 3a: dolomites, 3b: limestones
4 – Wetterstein Limestones (Middle Triassic – Ladinian)

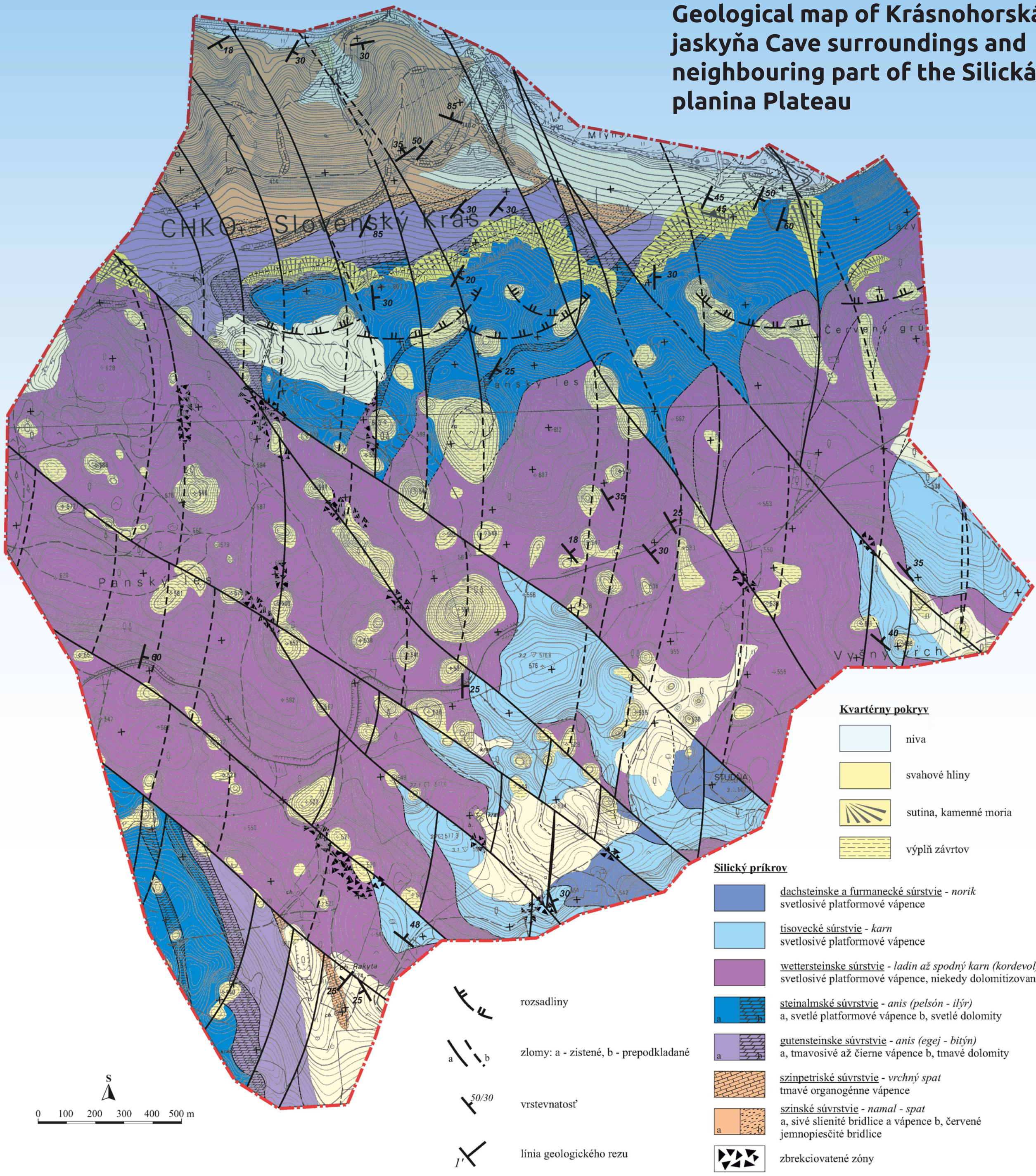
The **geological map** reflects the complexity of this geological environment, which also manifests itself in the extreme complexity of conditions for groundwater circulation.


Limestones with karren field


Folded shales of Szin layers


Red sludge limestones

Geological map of Krásnohorská jaskyňa Cave surroundings and neighbouring part of the Silická planina Plateau



Fosiliferous horizon – Szinpetri Member

Karstified wetterstein limestones

Dolomitic zone

In the protection of groundwater quality, the strategic aspect is the knowledge of its **quantitative status**, respectively knowledge of the way in which underground water is formed and accumulated. The quantitative status of the waters was recorded by continuous observation of the discharge at the measured points defined in the watercourse. Within the KRASCAVE project, 5 profiles (fig. 5) were built on which the water level was continuously recorded. The height of the recorded water column was later converted to the total flowrate across the given profile.

A suitable method for a good understanding for the water wealth formation was to monitor the course of changes in discharge **continuously** along the entire known flow pattern in the cave. These measurements, however, were performed indirectly by measuring changes in temperature and electrical conductivity of water (fig. 6). Their changes indicate invisible hidden transitions of water from the surrounding rock environment into the flow. However, the detailed measurements in Krásnohorská jaskyňa Cave did not confirm the existence of hidden water inflow to underground watercourse of cave.

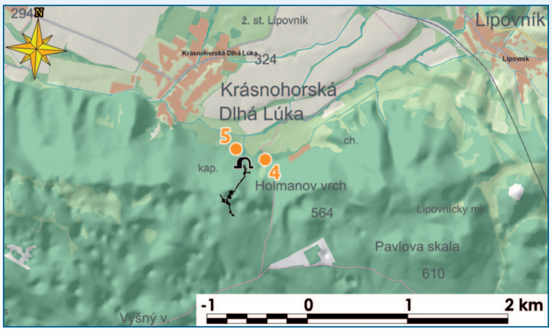


Fig. 5. Location of quantitative water monitoring stations inside Krásnohorská jaskyňa Cave and its surroundings:

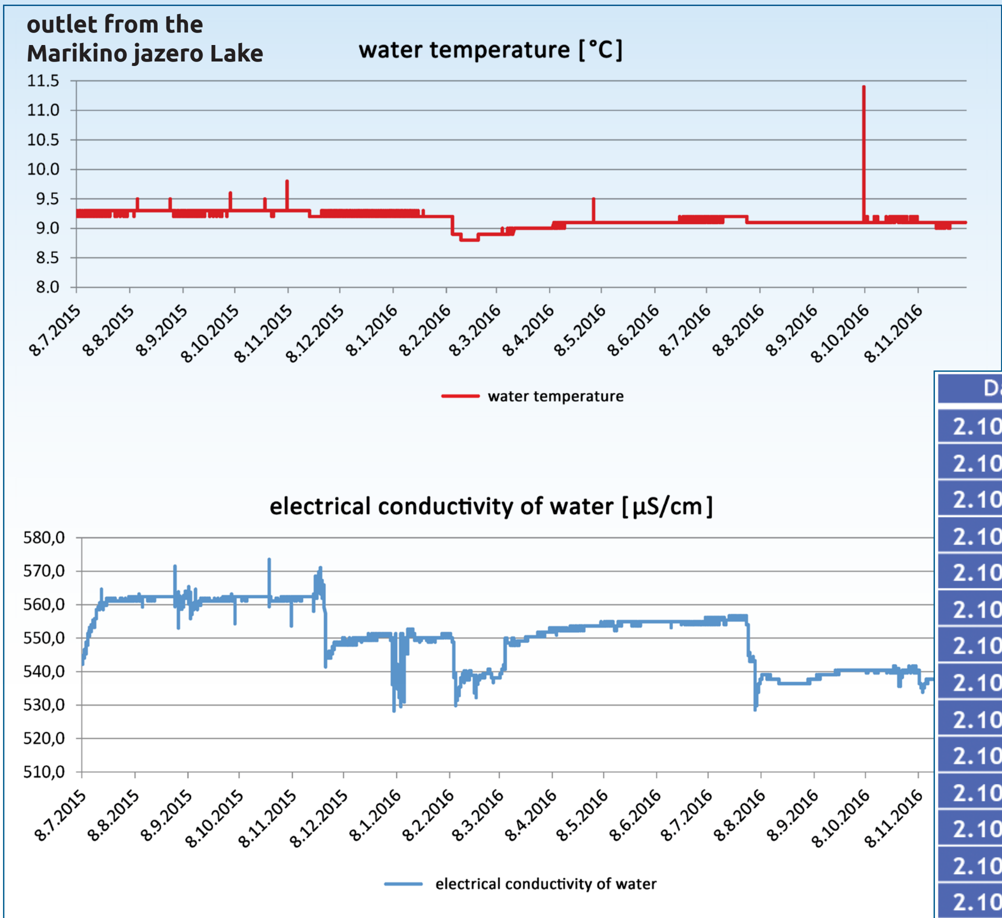
1. Outlet from the Heliktitový dóm Dome,
2. Heliktitový dóm Dome,
3. Marikino jazero Lake outlet,
4. Pod kameňolomom spring,
5. Pod kaplnkou spring,

* Cave – entrance
in 2016 the equipment was moved into the Heliktitový dóm Dome (2)

Monitoring device installation inside the Krásnohorská jaskyňa Cave

Monitoring device

A **series of measurements** over more than three year (2015 – 2018) period allowed us to get an idea of changes in water conditions within the hydrological system of the Krásnohorská jaskyňa Cave. This is a **typical karst regime of water circulation**, with a very rapid increase in discharge and flow as an immediate response to heavy rain or intense snow melting. Under such conditions, more than 1,300 l/s flows from the cave (historical estimates claim a discharge of 2,000 to 4,000 l/s, however at that time the gauging object was already destroyed and taken away by high flood wave). However, high water levels do not last long, their decline is almost as fast as their increase. The drought periods are also accompanied by the long-lasting extremely low yields of the Buzgó karst spring, when long-term discharges between 5 and 10 l/s are recorded.



Measurements are recorded every 15 minutes, but are simplified to averaged daily values as shown on charts.

Date	Time	water level
2.10.2016	9:17:56	0.602
2.10.2016	9:32:56	0.608
2.10.2016	9:47:56	0.608
2.10.2016	10:02:56	0.606
2.10.2016	10:17:56	0.606
2.10.2016	10:32:56	0.602
2.10.2016	10:47:56	0.602
2.10.2016	11:02:56	0.61
2.10.2016	11:17:56	0.61
2.10.2016	11:32:56	0.606
2.10.2016	11:47:56	0.6
2.10.2016	12:02:56	0.606
2.10.2016	12:17:56	0.608
2.10.2016	12:32:56	0.606
2.10.2016	12:47:56	0.608
2.10.2016	13:02:56	0.608

Fig. 6. Results of water monitoring – outlet from the Marikino jazero Lake.

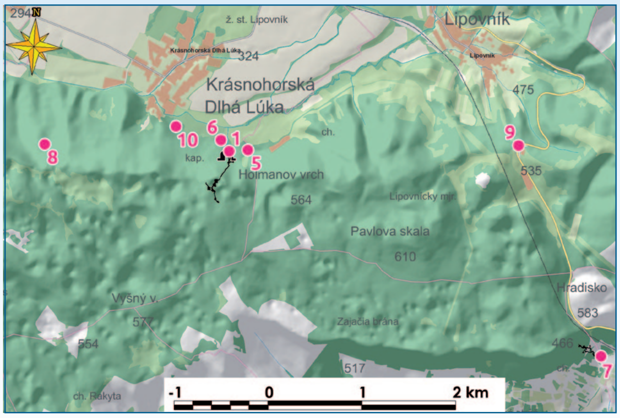
Collecting of precipitation samples for isotope analyses

Gauging device on the spring

SHMI monitoring device on the Buzgó spring

In order to better understand the hydrological system of the Krásnohorská jaskyňa Cave it was necessary to find out to what extent the chemical composition of its water is stable over time, and that its karst water only contains components naturally occurring in the karst environment or those whose occurrence is critically related to human activity. That is why we studied the **chemical composition** not only for spring Buzgó, but also the composition of the main tributaries inside the cave and the water of the surface springs located in the cave vicinity.

Water samples for **detailed analysis** of its chemical composition were taken during 2015 from 10 groundwater sources in the cave and its surroundings together. Besides the Buzgó spring, there were 3 main tributaries to the cave, 2 springs in the immediate vicinity of the Buzgó spring and 4 in the wider neighbourhood (fig. 7). Sampling from all these sources was repeated 8 times, with a time interval of approximately 1 month.



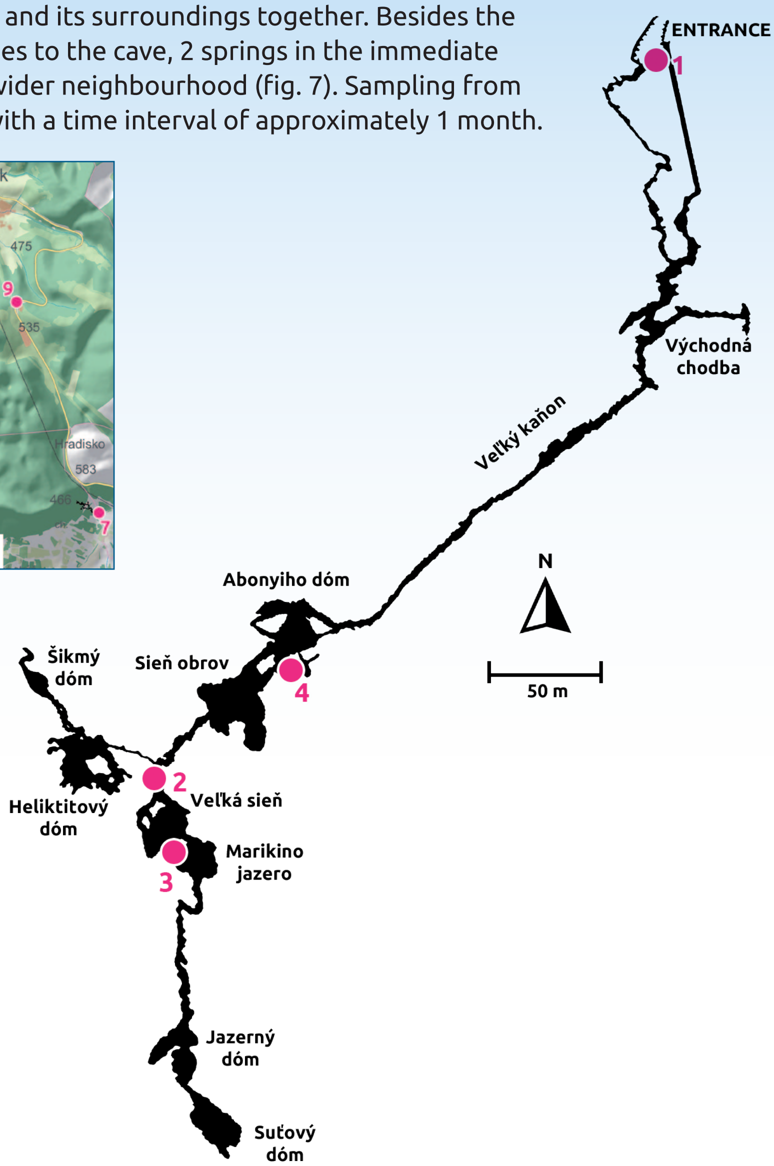


Fig. 7. Location of sampling places inside Krásnohorská jaskyňa Cave and its surroundings:

1. Buzgó karstic spring,
2. Left tributary “pod Veľkou sieňou“,
3. Marikino jazero Lake outlet,
4. Right tributary “v Abonyiho dóme“,
5. Pod kameňolomom spring,
6. Pri kaplnke spring,
7. Eveteš spring,
8. Matejova studňa spring,
9. pod Soroškou spring,
10. Pri mlyne spring.

Water sampling and measurements inside the Krásnohorská jaskyňa Cave

The **concentration** of 35 chemical constituents, 2 radiological indicators and the presence of organic, microbiological and biological contamination in terms of drinking water criteria were detected.

Results of this monitoring showed that karst water does not have an increased concentration of substances related to human activity. The only exception is the content of dissolved sulphate anions SO_4^{2-}. The threshold limit for drinking water of 250 mg/l was overstepped in 3 water samples of the left tributary from the Heliktitový dóm Dome inside the cave. High sulphate content in this water is of natural origin, caused by gypsum dissolution. Gypsum layers are often present in Lower Triassic shales, which are possibly found also in the recharge area of this tributary. It was also found that SO_4^{2-} content in the Buzgó spring water is more intensively varying in time than contents of calcium Ca^{2+} and bicarbonate HCO_3^- ions (fig. 8). Water can therefore be characterised by dominant presence of calcium and bicarbonates (Ca-HCO_3 water type). Geochemical modelling showed that the determining factor influencing final chemical composition of the Buzgó spring water, but also of other karstic springs around is the CO_2 content in the underground – in the soil and also in the deeper subsurface zone atmosphere of the Silická planina Plateau.

Contrary to the non-organic and organic substances content in the water, which fulfil the qualitative requirements of the drinking water standard, our monitoring revealed microbiological contamination both in the Buzgó spring and in all tributaries inside the Krásnohorská jaskyňa Cave. The same was found also at all the sampled water sources (springs) in the vicinity. Thresholds were exceeded for *Escherichia coli*, coliform bacteria and also enterococci. Presence of microorganisms in karst water is generally a commonplace phenomenon and when the water is abstracted for drinking purposes, this contamination is easily solved by water disinfection.

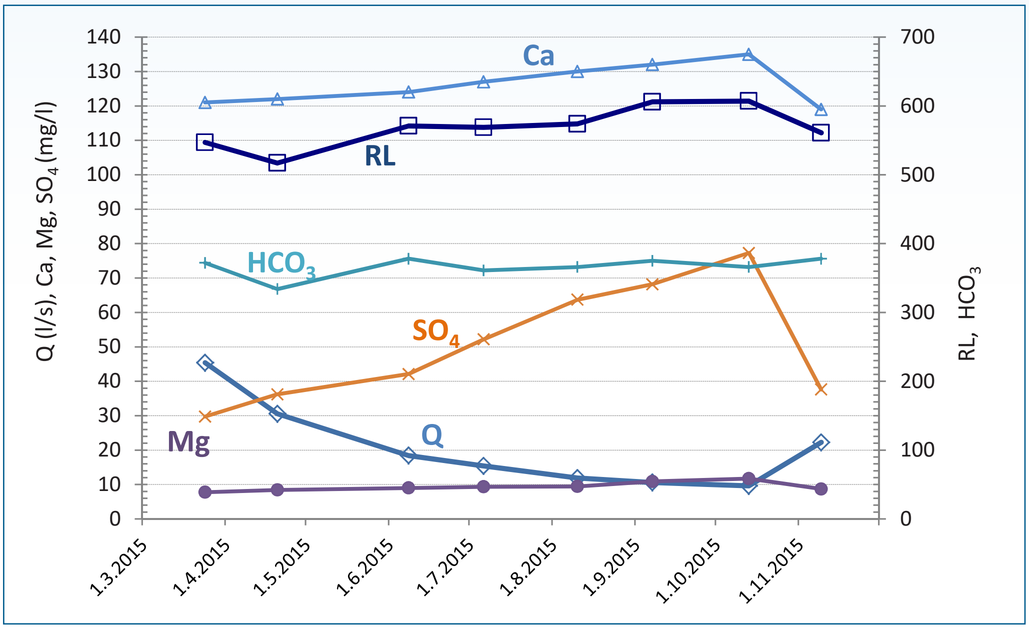


Fig. 8. Results of water quality monitoring.

Water sampling and measurements inside the Krásnohorská jaskyňa Cave

Between 31st May 2015 and 30th June 2016, at about weekly intervals, six groundwater sources were **sampled** in the Krásnohorská jaskyňa Cave and its vicinity, as well as rainwater at the Soroška pass (fig. 9). Sampled sources of groundwater were karst springs Pod kameňolomom, Pri kaplnke and Buzgó, the left-side tributary under the Veľká sieň Hall coming from the Heliktitový dóm Dome, the right-hand side tributary in the Abonyiho dóm Dome in the Krásnohorská jaskyňa Cave, and finally the RHV-4 hydrogeological borehole just before cave entrance. A total of **600 samples** were taken to determine content of the HCO_3^-, Ca^{2+}, Mg^{2+}, K^+, Na^+, Cl^-, NO_3^- and SO_4^{2-} in water, the isotopic composition of water ($\delta^{18}O$ and δ^2H) and the presence of tritium (^3H) were studied in **200 samples** as well.

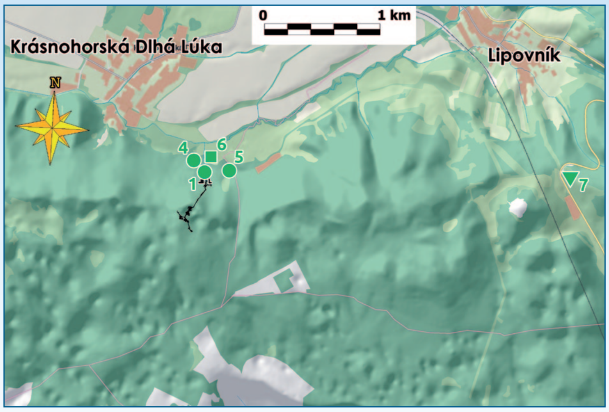
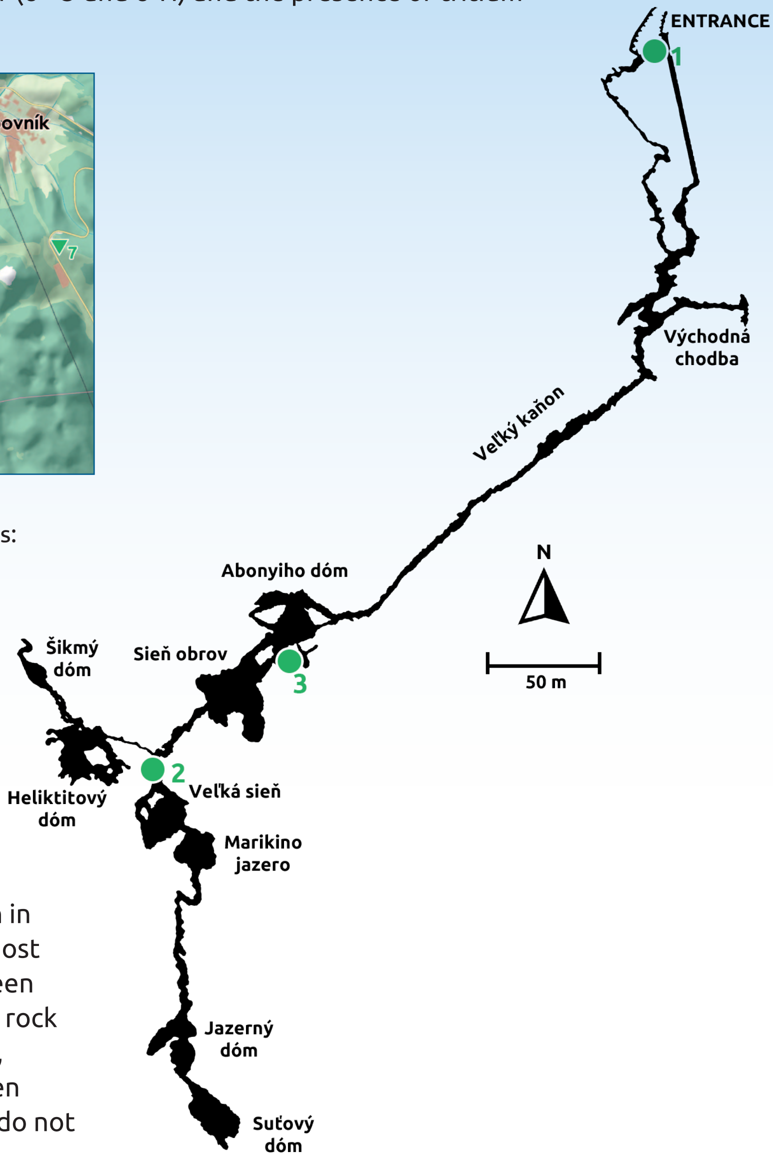
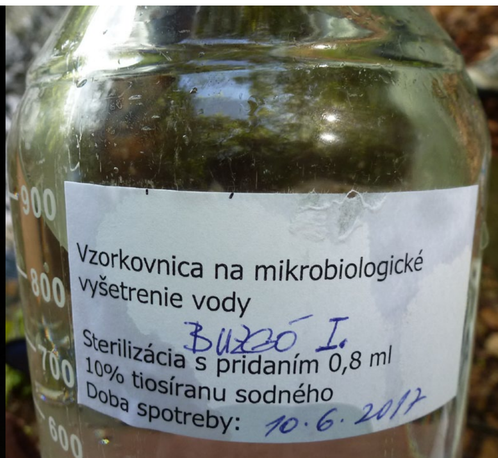


Fig. 9. Location of sampling places inside Krásnohorská jaskyňa Cave and its surroundings:

1. Buzgó karstic spring,
2. left tributary "pod Veľkou sieňou",
3. right tributary "v Abonyiho dóme",
4. Pri kaplnke spring,
5. Pod kameňolomom spring,
6. RHV-4 borehole,
7. rainwater at the Soroška pass.



At first glance, the results showed great stability of the basic chemical composition in all groundwater sources with respect to most dissolved cations and anions. It has also been shown that components not originating in rock dissolution (nitrates – NO_3^-, chlorides – Cl^-, sodium – Na^+ and potassium – K^+) have been equally presented in all sources, and they do not change even during high water levels.



Water sampling and measurements inside the Krásnohorská jaskyňa Cave

The small differences between them are apparently due to a slightly different length of water circulation for individual sources. Content of dissolved sulphates (SO_4^{2-}) is very typical but also variable. The time evolution of the chemical composition of the water in individual sources has shown that one part of the groundwater circulation pathways in the Krásnohorská jaskyňa Cave area is strongly influenced by the dissolution of the sulphates which we usually find in the shales of the so-called Szin Member Layers. However, the geological mapping on the surface of the karst plain above the Krásnohorská jaskyňa Cave did not reveal the Sinské vrstvy Layers. However, their presence in the familiar vicinity of groundwater´s pathways is very notable and we can at once decipher the relations between the sampled sources. It is manifested especially in the waters of the tributary down the Veľká sieň Hall and far downward in the springs Buzgó and Pri kaplnke. Taking into account the water levels, it seems that two components are mixed in the water of tributary down the Veľká sieň Hall: a stable but small flow with a high concentration of dissolved sulphates, which is then mixed in a different ratio with a less concentrated component.

Although the **results of the chemical analysis** of sources Buzgó, Pri kaplnke and tributary below the Veľká sieň Hall are never the same, a clear common trend in the development of their chemical composition let us to conclude that the water of the spring Pri kaplnke is derived from the waters of the Buzgó spring. The question remains only whether they have been split already in the Krásnohorská jaskyňa Cave or only as late as they rise up at the surface after they passed through a massive tufa body situated between the cave and the pilgrimage chapel.

Higher but more stable sulphate content was also found in the water of the borehole RHV-4 in which the shales of Szin Member were also drilled. On the contrary, the water of the right-hand inflow in the Abonyiho dóm Dome and also in the spring Pod kameňolomom has a sulphate content low and very similar. Their temporal development is similar as well and both sources have a clear common origin, similar to the waters of Marikino jazero Lake. This “eastern circulation branch“ is distinctly different from the “sulfate rich waters of the western circulation branch“.

Water sampling and measurements inside the Krásnohorská jaskyňa Cave

During the project, 680 water samples were taken for analysis

TO BE ABLE TO EFFECTIVELY PROTECT, WE NEED TO KNOW
Sulphur isotopes help to determine the groundwater pathways

Detailed monitoring of the chemical composition of groundwater in the Krásnohorská jaskyňa Cave and its surroundings revealed a significant presence of sulphate anions. We used the knowledge about their **isotopic composition** to determine their origin.

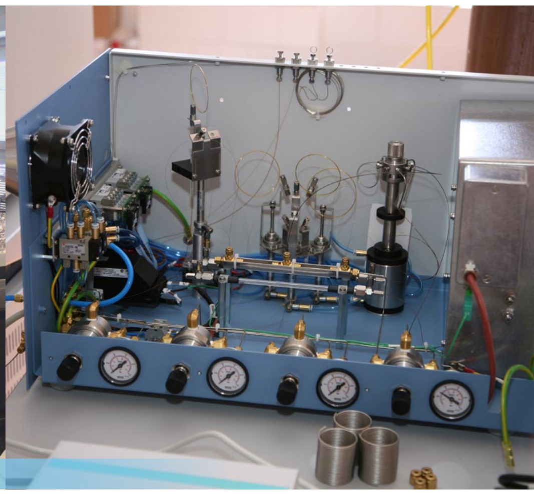
In the water of all oceans of our planet dissolved sulphates have a virtually uniform isotope composition of **sulphur** ($\delta^{34}S$ = 21.0 ‰) in the whole volume. This isotope composition of sulphur is preserved as well in minerals that become the part of sea sediments formed on present. However, during the millions of years of the Earth history, the isotope composition of the sulphur in oceans has gradually changed. As an example the period some 300 to 200 million of years ago could serve; begins as so-called Permian minimum ($\delta^{34}S$ values about some 10 ‰), later heavy isotopes of the sulphur gradually increased. The highest abundance of the heavy sulphur isotopes with characteristic values of $\delta^{34}S$ of 25 ‰ to 29 ‰ occurred about 240 million years ago. Then, in period from 230 to 200 million years ago, the depletion of the content of heavier sulphur isotope in the sea sulphate occurred again, down to values $\delta^{34}S$ of about 14 to 18 ‰.

Potential sources of the isotopically “light“ (depleted) sulphates in the surroundings of the Krásnohorská jaskyňa Cave could be found in sediments of the Permian age ($\delta^{34}S \approx$ 10 ‰) and “heavy“ (enriched) sulphates in the Lower Triassic shales ($\delta^{34}S \approx$ 29 ‰). The Permian sediments are present somewhere deep in the bedrock, the Triassic shales on the northern slopes of the Silická planina Plateau. If the groundwater is in the contact with these rocks, it is also enriched for dissolved sulphates with a corresponding isotopic composition. Such a mark can help in finding directions of groundwater flow to the cave. However, its interpretation is not easy because sulphates dissolved in the groundwater can also come from precipitation and soil surface (of bacterial origin) and one has to consider mixing of sulphates from individual sources. Based on the findings from other regions of Slovakia, however, we know that sulphates which come from the rainwater that passes through the soil layer are contained in the groundwater only up to about 20 mg/l and their $\delta^{34}S$ is about 4 to 6 ‰. These are present in each sample of water and therefore we call them a basic sulphate component. For the area of Krásnohorská jaskyňa Cave, this is specified by SO_4^{2-} content ~ 20.7 mg/l with an average value of $\delta^{34}S_{SO4}$ ~ 6.24 ‰.

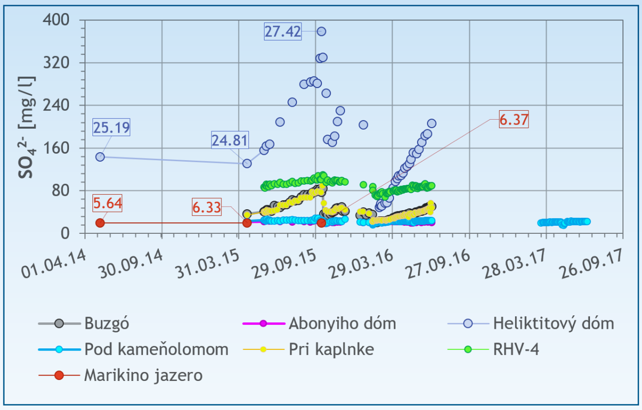
By analysing the samples, we found that the waters flowing out from the Marikino jazierko Lake, waters of the tributary in the Abonyiho dóm Dome and waters of spring Pod kameňolomom 200 m west of the entrance to the Krásnohorská jaskyňa Cave (points 3, 4 and 5 in fig. 7) contain only the basic sulphate component, at any water-level stage.

If the water contains more sulphates, these will come from rock environment or human activity, and the ratio of the individual components one has to find by means of the mixing equation (fig. 11). This was the case of the water from tributary from the Heliktitový dóm Dome (point 2), the main karst spring Buzgó (point 1), the smaller spring Pri kaplnke (point 6) and the RHV-4 borehole just before the entrance to the Krásnohorská jaskyňa Cave. The presence of this second sulphate component in groundwater increases at lower flow rates, and probably comes from the shales of the Lover Triassic in the cave surroundings – according to our results from the area west of cave. In the sulphates of these sediments, then the $\delta_{34}S$ value approximates to 28.86 ‰.

Mass spectrometer for isotope analyses



The hidden position of these sediments in the area above the left-hand tributary of the Heliktitový dóm Dome below the Veľká sieň Hall (point 2), which is characterized by the very high and strongly fluctuating content of dissolved sulphates (fig. 10), is the most unknown. In the area above the cave, these rocks were not even found in very detailed geological mappings, but they must be clearly present at least in the basement of the deeper parts of the Silická planina Plateau in these places. Here, however, they can also represent an important impermeable barrier within the underground hydrological system of the Krásnohorská jaskyňa Cave.



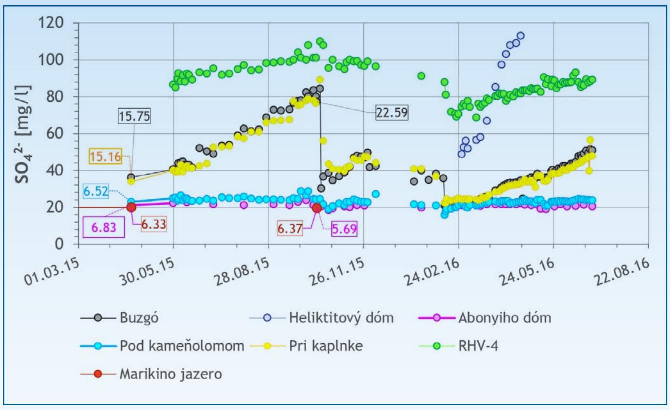


Fig. 10. Sulphate concentration changes in time for selected sources with marking of the $\delta^{34}S_{SO4}$ values in (a) and detailed view to 2015 – 2016 period in (b).

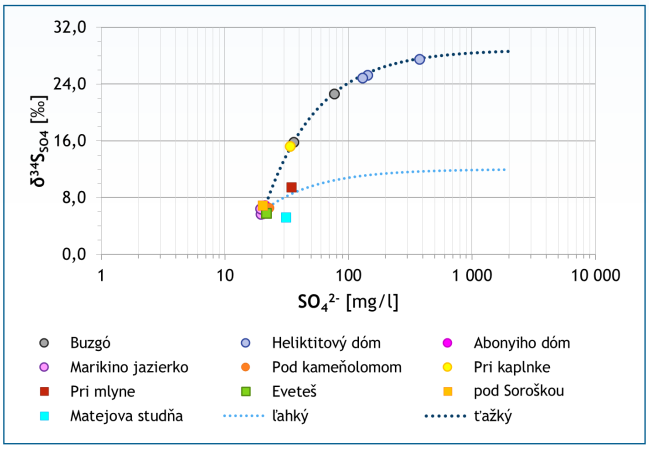
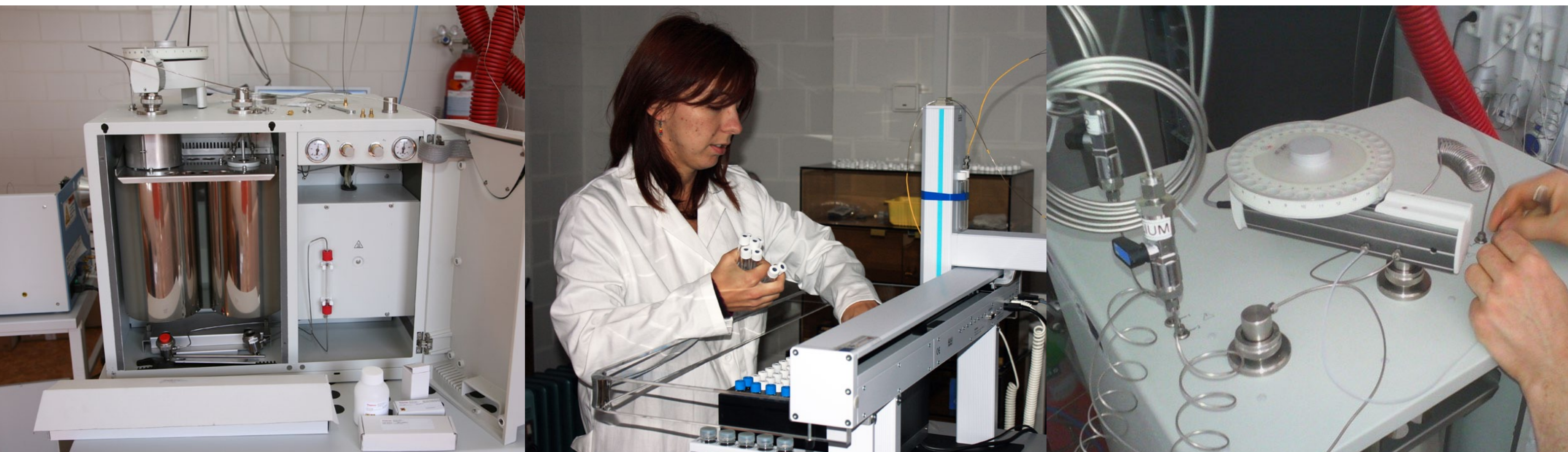


Fig. 11. Two-component mixing in semilogarithmic scale showing $\delta^{34}S_{SO4}$ dependency on sulphate concentration. Endmembers are: sulphates of the basic sulphate component (20.7 mg/l; $\delta^{34}S$ = 6.24 ‰), light oceanic sulphates (2,000 mg/l; $\delta^{34}S$ = 14.0 ‰) and heavy oceanic sulphates (2,000 mg/l; $\delta^{34}S$ = 28.6 ‰).



Mass spectrometer measurements

Monitoring cave air quality

Just after entering any cave system under the ground, the focus turns to a most important aspect, the air – indeed, one feels safe only as long as one can inhale deeply. **Air quality** in caves is often clearly different when compared to open outdoor spaces: in terms of temperature, humidity and the carbon dioxide content (CO_2). Although air temperature and humidity stability is well known in most caves of Slovakia, we only know little about air quality dynamics, the more when considering its apparent insensible variations in time and space within the system.

What is interesting about the Krásnohorská jaskyňa Cave is its **ventilated-type character**, even the second, upper air entrance has not been discovered yet. At given climatic conditions, the air flow through the system changes with air temperature. As long as the air temperature above the surface is less than that in cave, app. 9 °C, cooler and, thus, denser air is compressed into the cave through its (already known) lower entrance inside the system. Then, the interior atmosphere within the cave is pushed upwards and out at (still undiscovered) chimneys. And vice versa. Owing to a greater atmospheric temperature out of the cave that switches the air flux direction during a summer period, we often can enjoy refreshing, cooling fan from the cave.

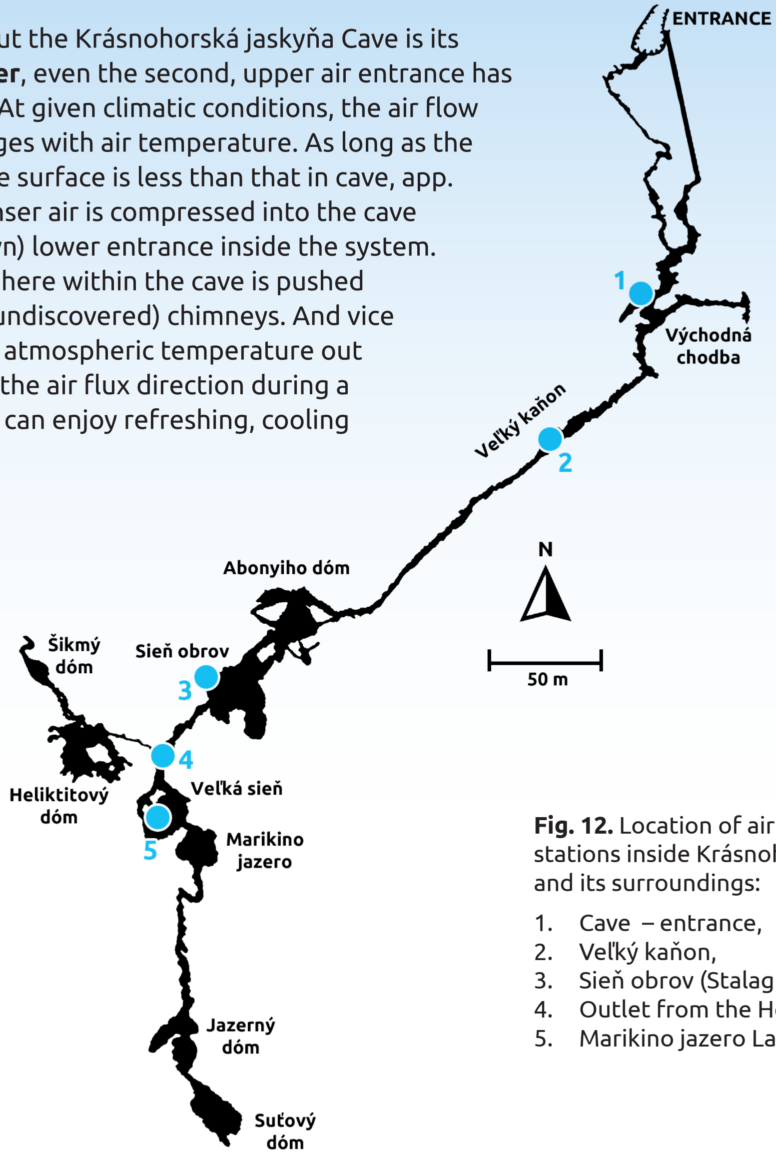


Fig. 12. Location of air quality monitoring stations inside Krásnohorská jaskyňa Cave and its surroundings:

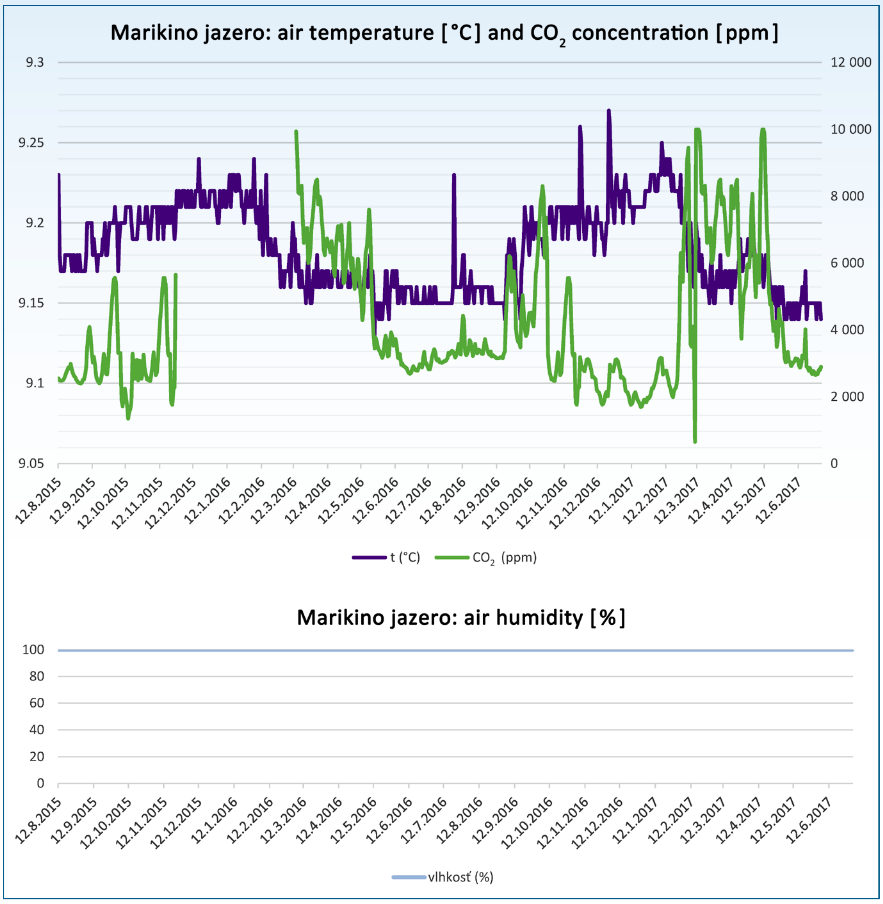
1. Cave – entrance,
2. Veľký kaňon,
3. Sieň obrov (Stalagmite),
4. Outlet from the Heliktitový dóm Dome,
5. Marikino jazero Lake.

Installation of monitoring devices in the Krásnohorská jaskyňa Cave

A question on the atmospheric **carbon dioxide** content is not only a dispute of a climate change. Deep in the ground, the CO_2 controls karst corrosion, i.e. a process, during which sidewalls of fractures and fissures in limestones and dolomites are perpetually dissolved and transported. Important is also the atmospheric CO_2 content variation in caves. Formation of sinter decoration and speleothemes through precipitation is possible only at low CO_2 content in the cave atmosphere.

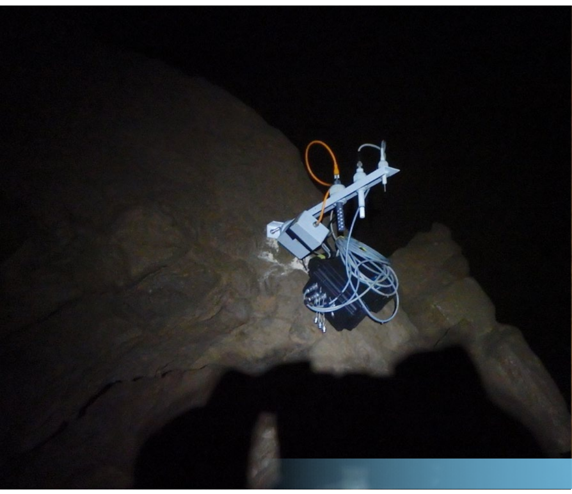
This is the reason why we deployed devices on a **continuous** air quality monitoring at five spots in the Krásnohorská jaskyňa Cave (fig. 12). Installation allowed us to simultaneously record CO_2 content in the air, air temperature and its humidity (fig. 13).

Along with setting up the devices, we also realized several horizontal profiles on CO_2 content, temperature and humidity through the cave, between the entrance and Marikino jazero Lake. Measurements have been conducted to map spatial variations in the air quality within the cave system under different climatic and hydrological conditions.



Measurements are recorded every 15 minutes, but are simplified to averaged daily values as shown on charts.

Fig. 13. Results of air quality monitoring at Marikino jazero Lake station.




Monitoring devices

Measurement of CO_2 content in air

Why did such a great dripstone grow here?

The Krásnohorská jaskyňa Cave was formed by **karstification process** of the Silická planina Plateau rock massif, when limestones dissolution and water erosion enlarge fissures and cavities. A slow propagation of the process makes it, however, tough for direct measures. Thus, a long-term discharge and a cave groundwater chemistry monitoring apply in calculation of karstification intensity. Carried geochemical modeling of the Krásnohorská jaskyňa Cave hydrological system implies expansion of void fissures and fractures for 100 m^3 per year. This is, actually, well comparable with a void space of a small apartment. Nowadays (similar to mountain streams), a mechanical groundwater erosion by a flow of water during rainfall seasons contributes on enlarging the cave system mostly, replacing an effect of chemical rock dissolution dominant in a past. A part of the rock (limestone) dissolved above the cave system precipitates from the karst groundwater to form various speleothemes, so seductive to admirers of nature's striking beauty. Measures of stalactite evolution (dripstones accumulating downwards from a ceilings) provide an estimation to an increment for 1 gram per 17 years. Stalagmites (rising from the floor upwards) evolve on a different scale. When considering an estimated weight of the Kvapeľ rožňavských jaskyniarov Dripstone for 2,000 tons and an expected age of the system for 13,000 years, then the average vertical increment to the stalagmite is 1 gram in roughly 4 minutes. Yet a fortune combination of several favouring factors triggers such a tremendous intensity.

At first, an optimal karst groundwater influx from a cave ceilings realized where the system is opened to the most that is in the Hall of giants. An actual majestic height of the hall of 32.6 m is not documented elsewhere. To provide conditions of a sinter precipitation, a favourable groundwater inflow chemistry turns into an objection for a high carbonate and carbon dioxide content, and, at the same time, the carbon dioxide content in the cave air to be much lower than that within a rock massif above the cave. This allows sinter microcrystals precipitation at the inflow through equilibrating the CO_2 content between the feeding water and the cave atmosphere.

Fig. 14. Speleothem cross-cut resembles us to rings on the tree trunks.

The sinter forms at a surface of a former dripstone or a cave walls in a thin film and grows in tiny layers well seen in a cross-section (fig. 14). These, similar to a well-known tree rings identify periodical changes in external karstification conditions. **Use of geochemical modeling** based on laboratory water analyses and CO_2 content measurements in a cave atmosphere provided us with a finding that per each 1 litre of a karst groundwater dripping on a stalagmite 150 mg of calcite precipitates at recent conditions. This means, that assuming steady conditions during the period of a stalagmite formation, an average inflow should be about 0.033 l/s. Yet the optimum inflow is just another fortuity in rising the dripstone in its dimensions and shape. Indeed, the less would the inflow had been, the smaller stalagmite could have been formed. For instance, a feeding with a 1 drip per minute would result in a weight of 200 kg in 13,000 years, whilst a drip per second is capable to produce a weight of 10.5 t per the same period of time. Increasing the influx to 0.001 would provide a rise of 61.5 t of a sinter precipitate (see fig. 15). At the same time, increase in an inflow above the optimum would create a speleotheme at less height but more area, giving it a shape of a mound instead that of a pillar. However, at significantly greater inflow, precipitation of a sinter is no more such concentrated at the entrance to the hall, and, consequently, rather terrace sinter lakes and irregular sinter features along the outflow stream would form.

Another trigger for an unbroken evolution of the **dripstone** is combination of favourable climatic and geological conditions. In fact, rainfall deficiency at the Silická planina Plateau along with each earthquake and a subsequent self-destruction by its own weight could slow down or terminate its growth significantly. Presence of found residua of elder dripstone in the Sieň obrov Hall (Hall of giants) indicates such an earthquake in a past. Differentiation of groundwater flow and its mechanical erosion within a cave system, or a bedding load pose another remarkable threat to the growth and preservation of the dripstone. Thankfully, such an event haven't took place during its history, so that the fortune combination of above noted factors lets us to admire that glamorous natural gem in the Krásnohorská jaskyňa Cave – the monumental Kvapeľ rožňavských jaskyniarov Dripstone.

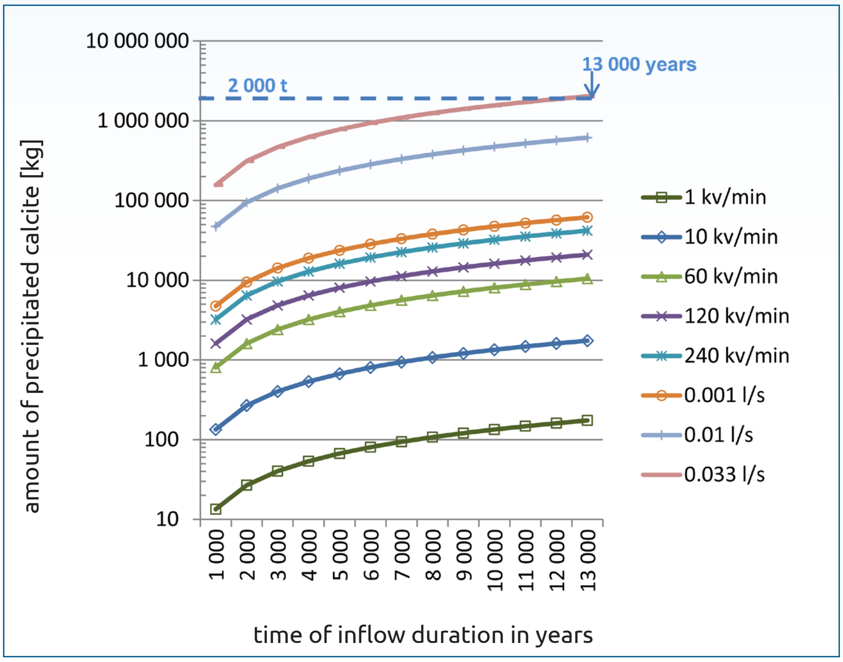
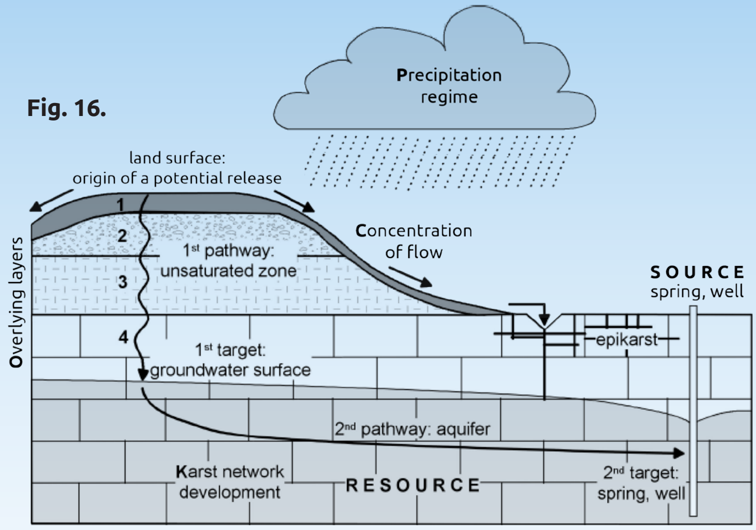


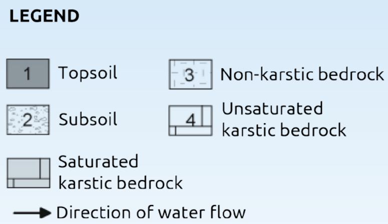
Fig. 15. A model dripstone growth rate at various inflow: from a drip (kv) per minute to 0.033 l/s.

In order to better protect karst groundwater and **underground karst ecosystem** of the Krásnohorská jaskyňa Cave from any contamination, we must first understand the functioning of karst water circulation. (fig. 16) [1].

It is important to thoroughly examine all the major processes involved in water flow as a transport medium from the points of its entry into the system on the surface (top of the soil layer) to the accumulation area in the underground and its re-emerging in the form of karstic springs.

Fig. 16.





Identification of water pathways and its internal connections in the karst circulation pattern, but also verification of the soil and rock ability to retain and eventually suppress possible pollution input from the surface of the karst plateau is carried out using **tracing experiments**. Here, environmentally harmless dye tracers are applied. In our case, the **tracers were applied** in several places of the karstic Silická planina Plateau surface in the vicinity of the Krásnohorská jaskyňa Cave, where the entry of rainwater into the underground can be expected. These were first of all bottom parts of the fossil dolines – sinkholes, but also deep chasms and abysses.

[1] Goldscheider N., Klute M., Sturm S., Hötzl H. (2000): The PI method – a GIS-based approach to mapping groundwater vulnerability with special consideration of karst aquifers. Z Angew Geol Hannover 46(2000)3:157-166.

Preparations before the start of tracing tests

Dye tracers were applied on several places

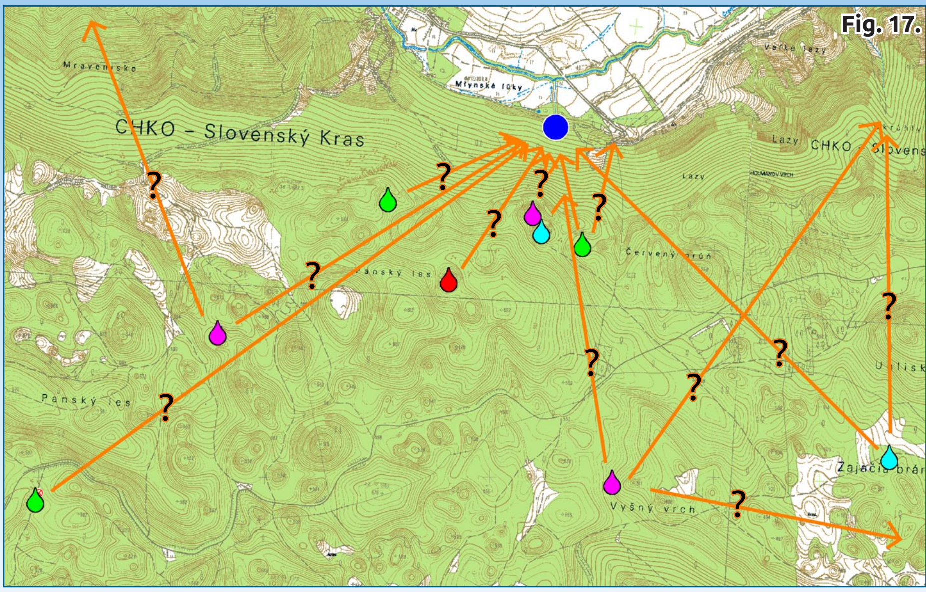


Fig. 17.

Dye tracer, transported by **coloured water,** gradually reaches groundwater table inside the karstified rock environment. This is simply due to gravity, but its flow can be enhanced naturally by precipitation water or artificially by adding amounts of pure water to push the dyes downwards. After reaching the groundwater level, the dyes can be further transferred to the karstic channels, cave system and finally to the karstic springs (fig. 17).

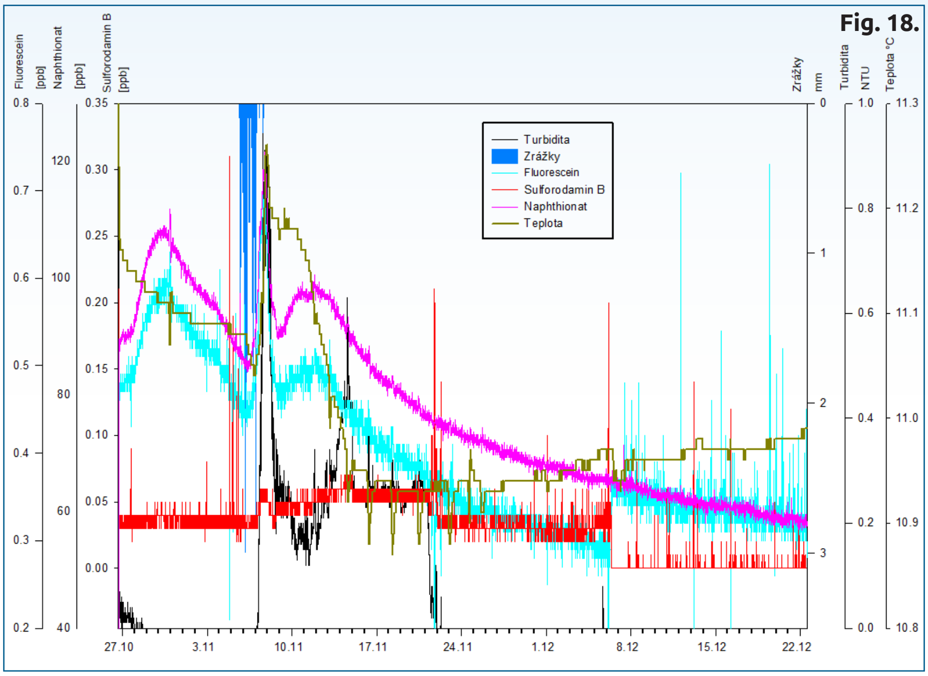


Fig. 18.

Results of tracing tests help us to reveal the degree of interconnection between the surface karst structures and the underground hydrological system in the cave with its permanent flow (fig. 18). Strong and quick interconnection means increased vulnerability to possible contamination caused by human activity.

The presence of the tracers was monitored by **detectors** installed in the Krásnohorská jaskyňa Cave and other karstic groundwater sources located in its vicinity. These detectors were able to analyse groundwater continuously for several months.

Detectors inspecting presence of dyes were positioned on various places

Behind every spring, a place where water freely flows out from the underground, there should be a territory from which this groundwater source is supplied. In this territory, water seeps into the rocks and slowly flows through rock fissures and joints to reach the spring. This **spring's water collecting area** (hydrogeologists use the term "infiltration area") is small in the case of small springs, but for large groundwater sources there must be sufficient space to collect enough water from rain and melted snow to feed these throughout the year. **Delineating boundaries** of this area is one of the most difficult tasks in hydrogeology. Several factors are considered, first of all knowledge of geological settings, results of trace experiments, mathematical models of groundwater flow, but also **water balance**. Water balance in its principle compares the amount of unevaporated precipitation with the amounts of outflowing water. By its help, we can determine the size of the water collecting area. However, the exact course of infiltration area boundaries must be determined by help of other methods.

Determination of evaporation levels is the most difficult task in water balancing. Water usually evaporates from the soil surface, but also through the vegetation. Peculiarity of the problem is, that although water could evaporate in some periods, evaporation does not occur because no water is available at the moment. Therefore, precipitation totals, possibility of evaporation, but especially existing amount of moisture in the soil must always be considered and compared to each other. Such a calculation should be performed over a sufficiently long period, as otherwise it would be affected by the high variability of climatic factors. From previous calculations we know, that in the area of Silická planina Plateau in the Slovenský kras Mts., only about 105 to 190 mm of precipitation per year would remain unevaporated. Thus, average water outflow from the area of one square kilometre can be 3.3 to 6.0 l/s. This amount, of course, fluctuates continuously depending on past meteorological phenomena from practically zero to several hundred l/s.

Average value of 160 mm unevaporated precipitation totals was calculated for the particular part of the Silická planina Plateau, taking into account meteorological data in the period of 2001 – 2015. In average, about 5.08 l/s of groundwater can be generated on the surface area of 1 km^2. The average yield of the Buzgó spring (55.96 l/s) should be then supplied by the open limestone surface on the area of about 11.0 km^2. If we take into account the joint discharge of all three adjoining karstic springs (Buzgó, Pri kaplnke, Pod kameňolomom, together about 66 l/s), their underground watershed – water supply area – would require an open space of about 12.9 km^2. When estimating a **particular boundary of this inner watershed** (fig. 19), it is necessary to consider the extension of limestones and dolomites and also the results of the dye trace experiments. Still, one should keep in mind that the overall size of the area needs to be preserved.

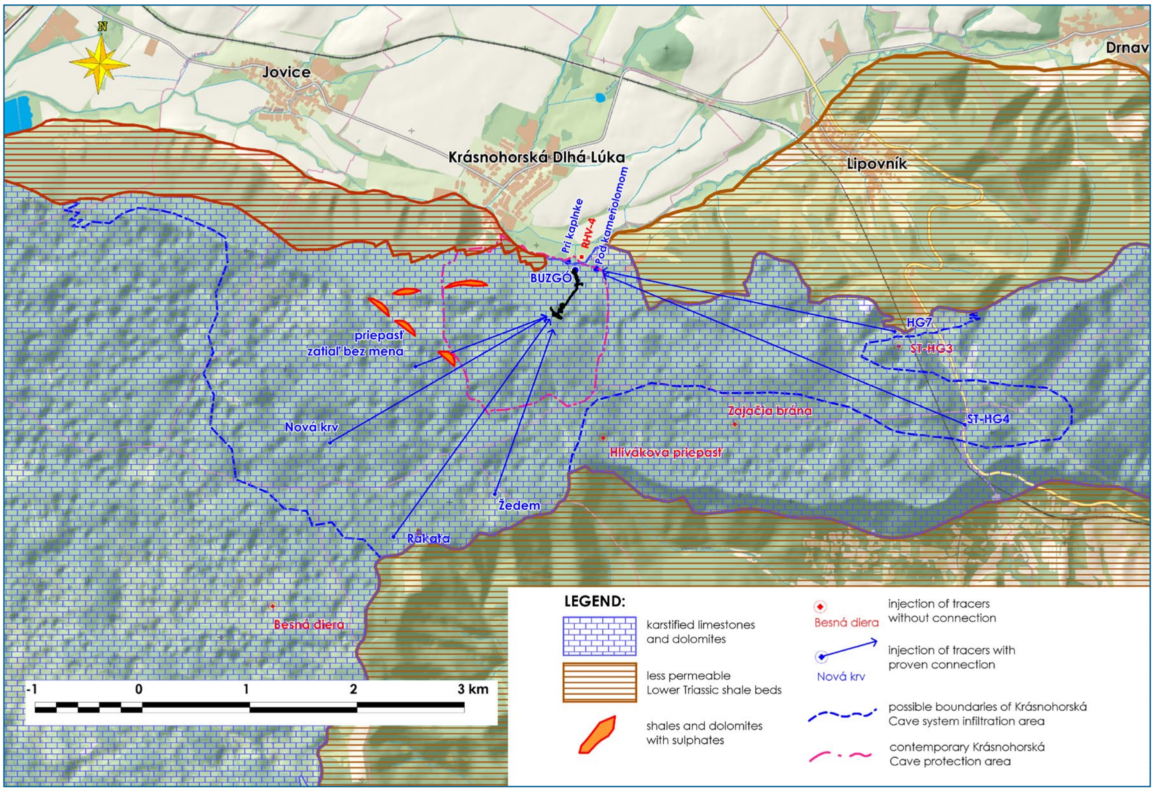


Fig. 19. Estimation of infiltration area boundaries.

In the sake of groundwater protection in a karst land, a focus must be paid on water protection in the area where the water infiltrates into the massif. Protection of the entire drainage basin is necessary, because connectivity of karst filtration channels triggers groundwater drainage from the periphery rather than from the vicinity of a spring. Connectivity of karst channels remains, however, often unrevealed and experimental studies are rather scarce. Indirect karstification evaluation methods give, at least, some hint on presumable pathways. One of our project outcomes is delineation of **"hot spots"** – areas of increased risk on groundwater contamination. We based our own methodics on karst phenomena and surface manifestations spatial distribution and density analysis (*Kernel density estimation*). This resulted in a final 2D grid plotting spatial index of groundwater vulnerability (fig. 20).

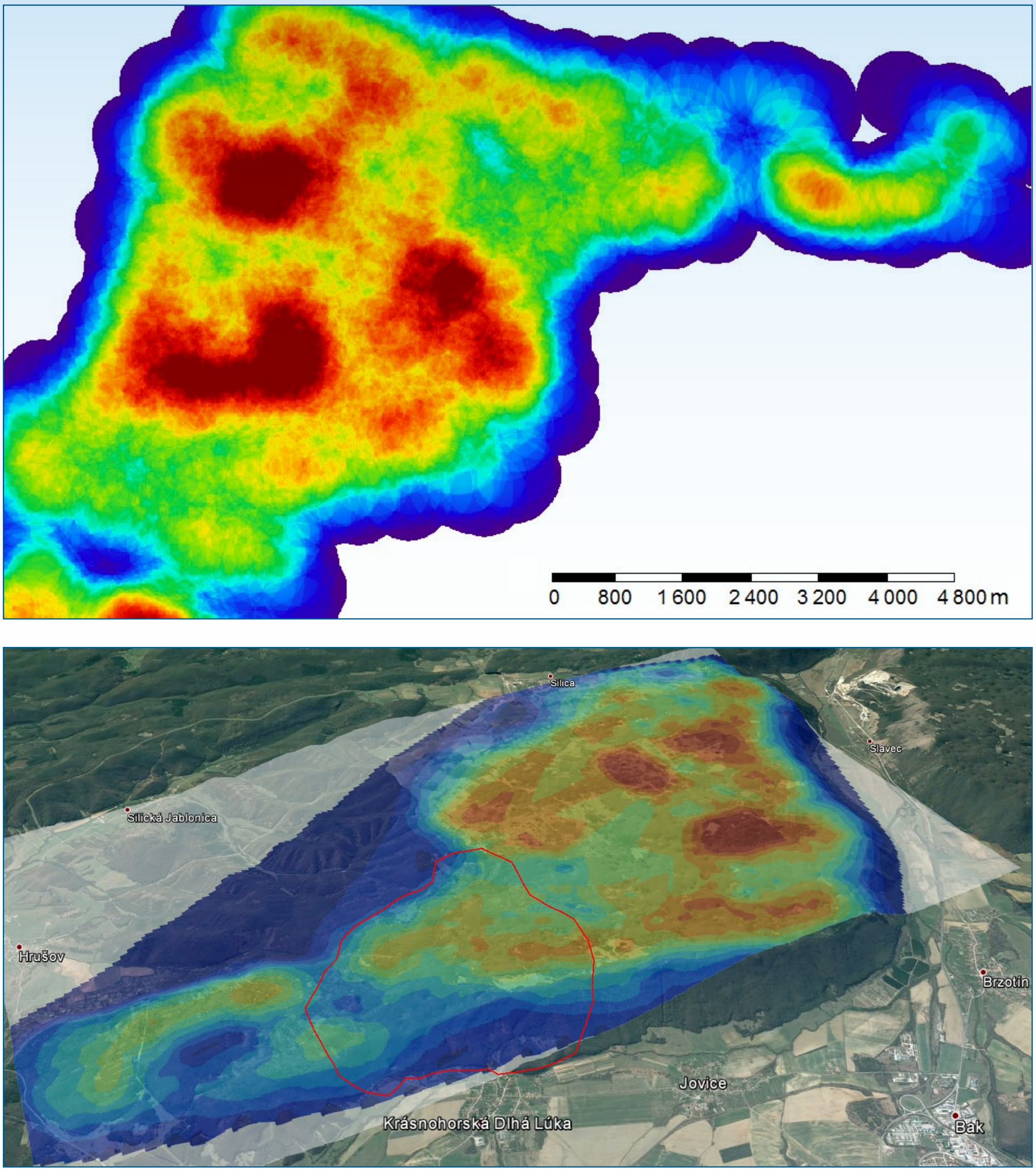


Fig. 20. Spatial delineation of hotspots.

As given by hot spots identification and evaluation, we found that the greatest groundwater susceptibility of the **entire Silická planina Plateau extends to the northwest, and at a periphery** of the domain in a line of Gombasek – Silica municipalities, nearby the Fabiánka, and in the Bukovec vicinity. Hot spots thus represent most vulnerable areas with a great risk of intense groundwater contamination and its further transport within hydrogeological system of karst-fissured permeability.

The **Silická planina Plateau** is an inhabited land known for agricultural land-use and a significant tourism, including four walking and three cycling trails. Asphalt roads cross the plain via the Silica village, however, the Soroška mountain pass becomes the most frequent route connecting Košice and Bratislava during a winter season. Moreover, a 4,280 m long tunnel is projected beneath the Soroška pass as a planned extension of the R2 motorway. Even nowadays, a 3,148 m long Jablonovský Tunnel provides mountain railway connection between Rožňava and Turňa nad Bodvou, opened in the 50's of 20th Century. In addition, a solid forest road at a surface of the Silická planina Plateau extends all along a southern rim of the Krásnohorská jaskyňa Cave protection zone.

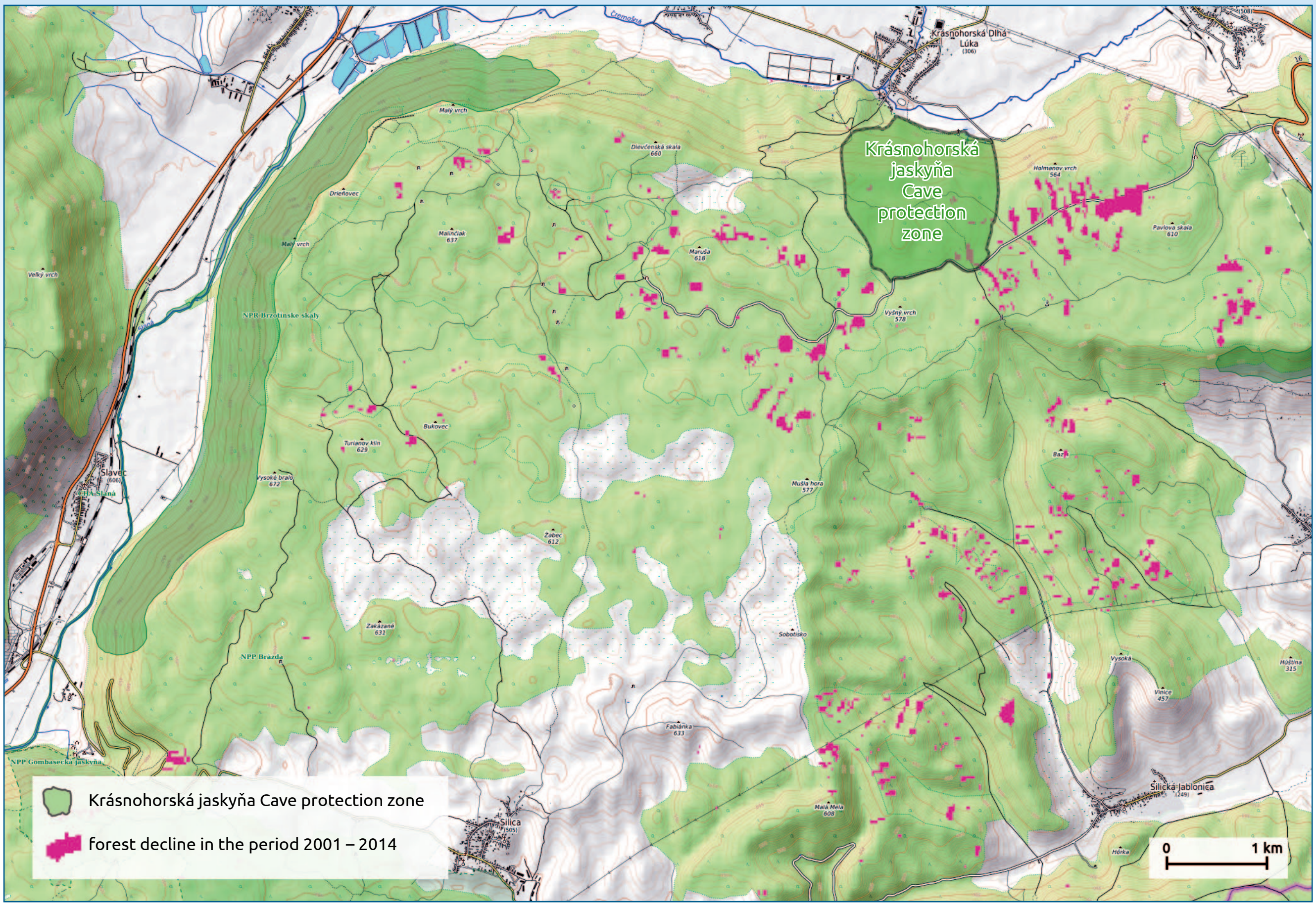


Fig. 21. Cave protection zone and timber harvesting in its neighbourhood (*source: http://maps.sopsr.sk*).

Soroška road pass

Timber harvesting on the Silická planina Plateau

The Krásnohorská jaskyňa Cave **protection zone**, at its current limits, delineates only the cave's instant massif only (see the fig. 21). An expected infiltration area for karst springs within a cadastre of Krásnohorská Dlhá Lúka (i.e. the Buzgó spring), characteristic with a great distribution and density of karst phenomena of a highest groundwater susceptibility to contamination (hot spots) extends far to the central parts of the Silická planina Plateau.

Forests occur at a surface of the Silická planina Plateau, catalogued into all three categories of woods. Special purpose forests yield the most of the area, followed by protective forests, while economic woods contribute on minor part. In last years, an intense harvesting took place only 2 km away from the cave protection zone (fig. 21), using heavy mechanisms along (according to the ŠOP SR map explorer).

Pastures extend over the central part of the plain in the vicinity of the Silica village. A permission to graze, water feed and to overnight livestock in the Slovenský kras National Park and its protection zones is issued by the Rožňava District office based on an expert opinion of the State Nature Conservation Agency of the Slovak Republic. There are mostly semi- to intensively grazed pastures, rich in species. Indeed, presence of dozens of protected plant species requires a regulated mowing or grazing. Meanwhile, intensive pasturing leads to a robust drop in species diversity.

The Krásnohorská jaskyňa Cave domain, including its infiltration area extends well within the Slovenský kras National Park, so that the legislative protection of the cave's karst ecosystem and a subsequent groundwater is expected generally adequate. However, violating the rules on nature protection, any malicious change in land use, or founding illegal waste disposals in chasms, abysses and sinkholes at the karst plain are still a tremendous threat for groundwater quality in present, and also for future generations.

Silická planina Plateau

Zajačia brána site

Removal of chemicals from the bottom of the Snežná priepasť Abyss

Protecting the water source supplying potable water to Krásnohorská Dlhá Lúka village was the KRASCAVE project's specific goal.

To warn about the natural deterioration of water quality, a testing **prototype of a sophisticated device** has been designed to continuously monitor the broad range of water parameters. The device measures and records water's turbidity, specific electrical conductance, content of organic carbon, dissolved nitrates, chemical oxygen demand as well as amount of suspended micro particles. This set of parameters has been chosen to represent the main quality changes of water typical for karstic springs.

The device works in a fully autonomous regime, while a **remote control** of all its functions is still possible:

The aim of the KRASCAVE project was water source protection


Buzgó spring


Sophisticated device prototype

The data is stored in the memory, being **continuously analysed** (fig. 22). In the case of an adverse trend in the chosen parameters the device **sends a warning** to the responsible persons.

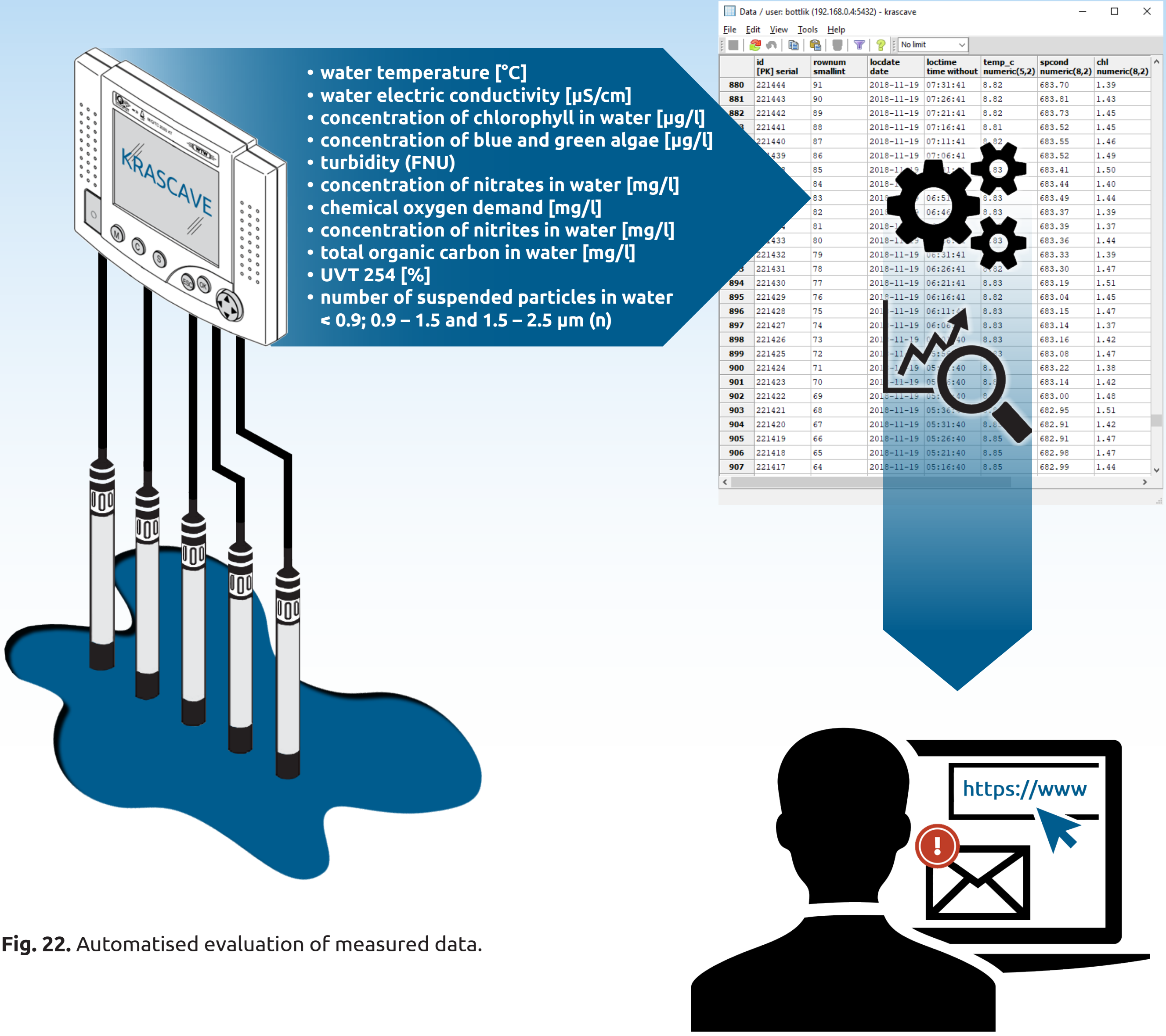
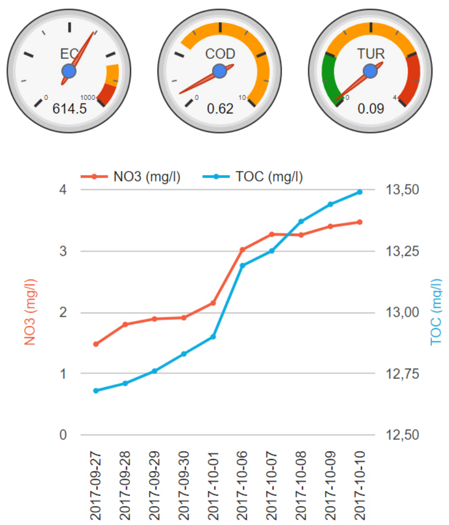


Fig. 22. Automatised evaluation of measured data.

Prototype of a sophisticated device

The recorded data, together with the **degree of source's water quality threat** can be seen on the project's web page.

Online water quality monitoring [view more...]



EC - Water electric conductivity [μS/cm]
COD - Chemical Oxygen Demand [mg/l]
TUR - Turbidity [FNU - Formazin Nephelometric Units]
NO3 - Concentration of nitrates NO_3 in water [mg/l]
TOC - Total organic carbon in water [mg/l]

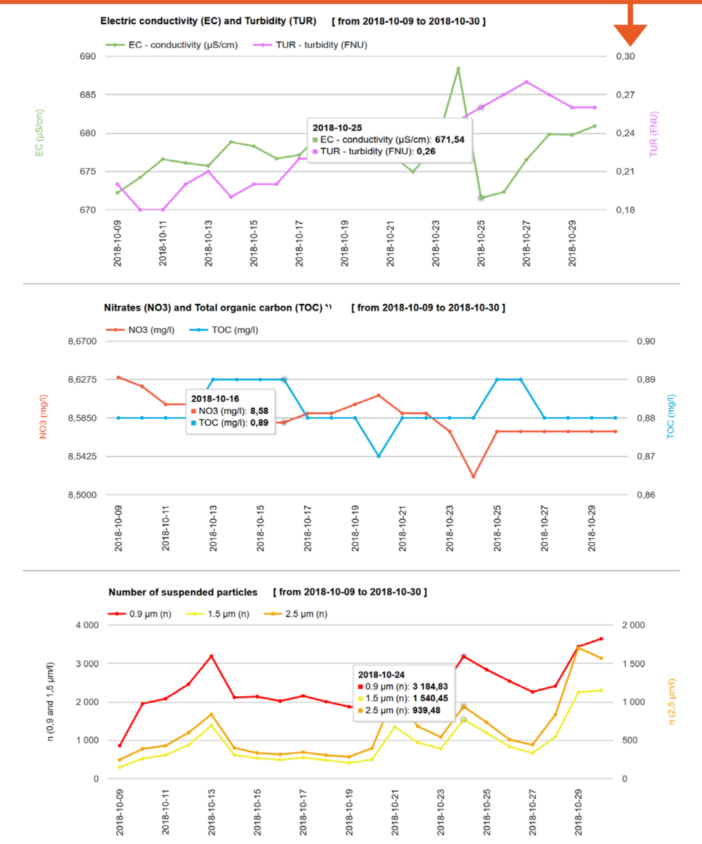
The prototype device records measurements every 5 minutes (**in moment values**), but are simplified to **averaged daily or hourly** values as shown on charts.

averaged **daily** values »

averaged **hourly** values »

in moment values »

2018-10-09 2018-10-30 → View charts



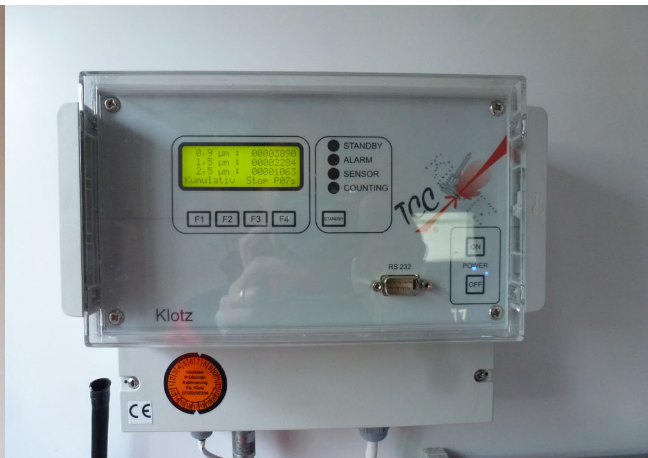
OVERSTEPPING OF WATER QUALITY PARAMETERS

3 degrees of water quality endangering on the spring Buzgó in Krásnohorská Dlhá Lúka:

1 2018.11.28 ▸ **Favorable condition**

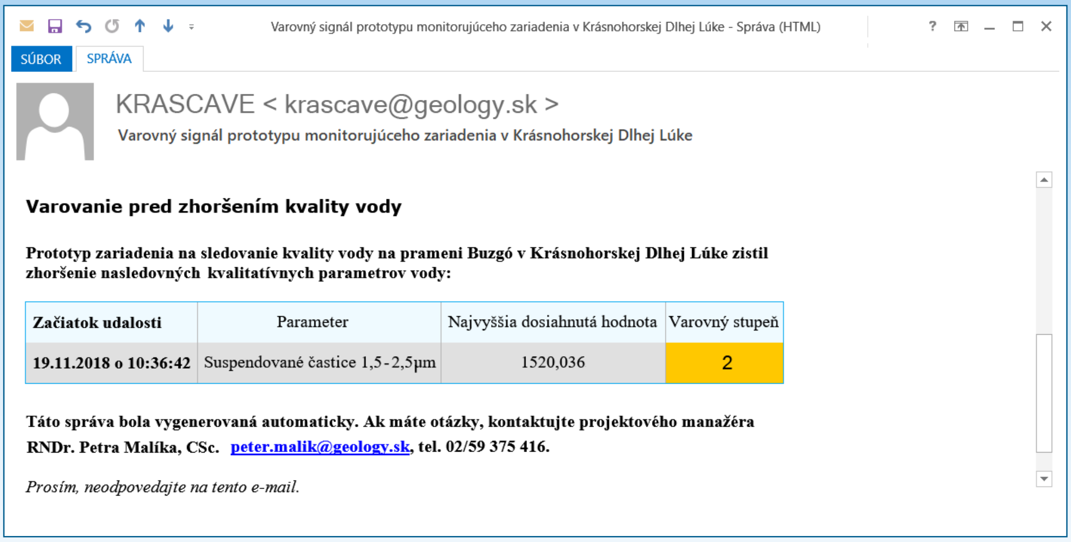
2 2018.11.19 at 10:36 ▸ **Potentially unfavorable condition**

3 2018.11.06 at 10:45 ▸ **Unfavorable condition**



Prototype of a sophisticated device continuously monitor the broad range of water parameters

Example of **e-mail** warning in the case of unfavourable trend of selected values development:



Varovný signál prototypu monitorujúceho zariadenia v Krásnohorskej Dlhej Lúke - Správa (HTML)

SÚBOR SPRÁVA

KRASCAVE < krascave@geology.sk >
Varovný signál prototypu monitorujúceho zariadenia v Krásnohorskej Dlhej Lúke

Varovanie pred zhoršením kvality vody

Prototyp zariadenia na sledovanie kvality vody na prameni Buzgó v Krásnohorskej Dlhej Lúke zistil zhoršenie nasledovných kvalitatívnych parametrov vody:

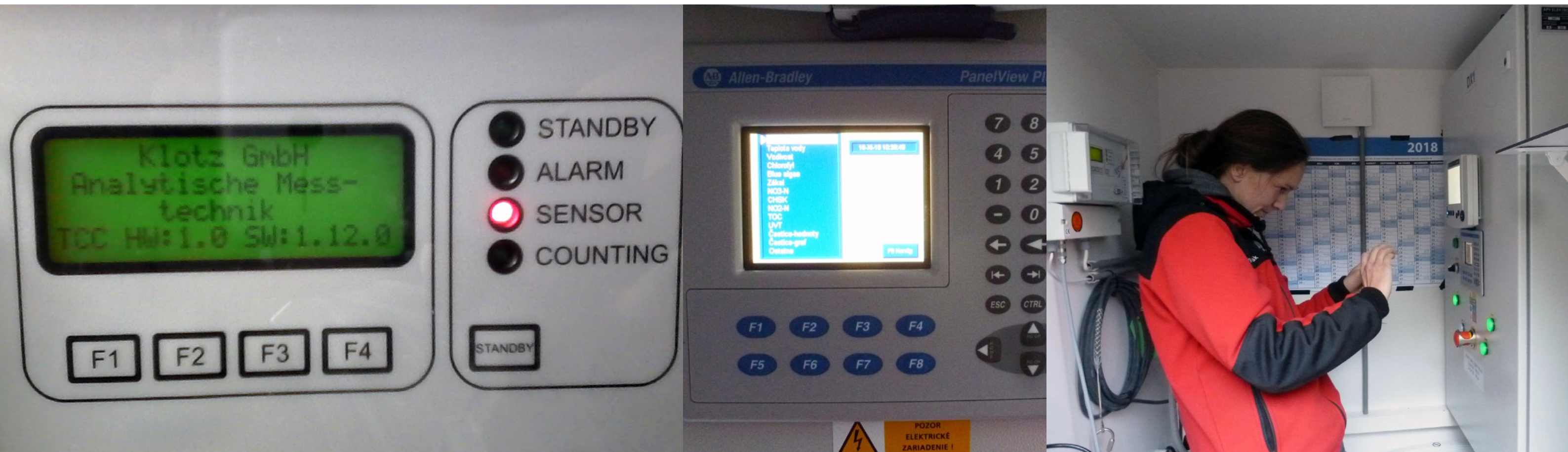
Začiatok udalosti	Parameter	Najvyššia dosiahnutá hodnota	Varovný stupeň
19.11.2018 o 10:36:42	Suspendované častice 1,5-2,5μm	1520,036	2

Táto správa bola vygenerovaná automaticky. Ak máte otázky, kontaktujte projektového manažéra RNDr. Petra Malíka, CSc. peter.malik@geology.sk, tel. 02/59 375 416.

Prosím, neodpovedajte na tento e-mail.

The device also contains an **automatic sampler**, which regularly takes a small amount of water and collects it in an air-conditioned container for further physical and chemical analyses.

Automatic sampler



Prototype of a sophisticated device continuously monitor the broad range of water parameters

ARE PEOPLE OF KRÁSNOHORSKÁ DLHÁ LÚKA VILLAGE AWARE OF WHAT CAN DAMAGE THEIR CAVE?

For a **real protection of groundwater sources** and the underground karstic ecosystem of Krásnohorská jaskyňa Cave together with the neighbouring part of Silická planina Plateau the obviously most important is public awareness and cooperation with the local inhabitants. Their activities and environmental consideration have the crucial and inimitable influence. The public's influence is based not only on limiting their economic activities, when posing threat to precious natural values, but also on controlling obedience of protection demands by third parties and on future planning of activities in vulnerable areas within the local government.

Krásnohorská Dlhá Lúka village, due to its pivot position from the Krásnohorská jaskyňa Cave protection point of view, has a crucial role. Therefore we focused on doing the largest possible spectrum of edifying activities there, targeted on raising awareness of the ongoing project and on groundwater protection in karstic areas. The activities had been aimed at direct **contact with the local people**. These meetings took place at different levels – from local government and experts, public discourses to adventure activities for children at nursery and primary schools locally and in the wider surroundings.

Project KRASCAVE in TV news of RTVS

Information board in the village

Information board near the cave

Practical activities for children

Residents could be informed not only from news in the state television, but also from information panels and printed leaflets about the following performances:

- **public assembly of citizens** on 4th October 2014 (presentation of project goals, succession of project steps, and introduction of the benefits for inhabitants),
- **adventure activities** for pre-school children, their siblings and parents on 4th October 2014 (presentation of basic aspects of groundwater and surface water protection by an adventurous form for children in pre-school age),
- **Saturday trip to the cave** on 4th October 2014 (narrated walk along the educational pathway to the Krásnohorská jaskyňa Cave and the nearby water source),
- **appointment with the major and deputies** of Krásnohorská Dlhá Lúka local council on 3rd October 2014 (explanation of the project motives, assessment of conflicts of interests),
- **meeting with pupils** of the Krásnohorská Dlhá Lúka Primary School on 3rd October 2014 (popularizing lecture about the Krásnohorská jaskyňa Cave and its connection with water),
- **children's theatre performance** "About dry water" with environmental subject on 22nd March 2017 for children of the Evangelical Church Primary School in Rožňava, on 23nd March 2017 for pupils of Primary School with 1st to 4th classes (Alapiskola 1. – 4. évfolyam) and Nursery School with Hungarian educatory language (Magyar Oktatási Nyelvű Óvoda) in Krásnohorská Dlhá Lúka, on 12th October 2018 for pupils of Nursery School at Kyjevská street in Rožňava, on 13th October 2018 for children during the Gastrofest in Krásnohorská Dlhá Lúka,
- **meeting with wider public** at the regional event Gastrofest in Krásnohorská Dlhá Lúka on 7th October 2017, on 28th July 2018 and on 13th October 2018.

Meeting with local inhabitants

Information leaflets

Public meeting on the regional happening

WHAT CAN HELP TO MAKE THE CAVE ADMIRABLE EVEN AFTER HUNDRED YEARS?

One of the largest weaknesses of the current state of land protection around the Krásnohorská jaskyňa Cave and its fragile underground ecosystem is the fact, that a substantial part of its catchment area (recharge area of the underground hydrologic system of the Krásnohorská jaskyňa Cave) located at the Silická planina Plateau is not included in the cave's protection area. Krásnohorská jaskyňa Cave, or karst spring Buzgó bound to it, respectively, drains about 10 to 12 km^2 of the area of Silická planina Plateau. Hydrologic connectivity with the plateau surface has been proved by the tracing experiments (1967, 1986, 2016, 2017, 2018).

Therefore a part of the LIFE+ KRASCAVE project was to elaborate guidelines **to improve or maintain the state** of protection of natural interactions of individual system components in the Krásnohorská jaskyňa Cave area, with a proposal of conditions improving and maintaining measures.

The measures proposal has been elaborated based on the documents already handling the issue of land protection of the Krásnohorská jaskyňa Cave and its broader surroundings, new project outcomes (tracing experiments, sampling of ground water) and consultations with the employees of the Slovak Water Management Enterprise, esp. its branches Watershed Slaná, Rimavská Sobota, Watershed Hron, Operating Centre Plešivec, as well as Urban and Pasture Land Community Krásnohorská Dlhá Lúka, Forests of Slovakia, branch Rožňava, State Nature Conservancy of the Slovak Republic (ŠOP SR), Slovak Karst National Park administration, with the mayor of Krásnohorská Dlhá Lúka village and with the land owners and users during the years 2016 to 2018.


Dye trace experiments to to verify the connection of plateau surface to water in the cave

Detector inspecting presence of dyes

Meeting with local inhabitants


Meeting with land users

The main strategy of the Krásnohorská jaskyňa Cave system protection must be to assure a suitable land use regime and an adequate intensity of surrounding land utilisation. It can be established by an excellent public awareness and by a proper steering of human activities with respect to:

the karst system, where it is necessary to:

- initiate an adjusting of the Krásnohorská jaskyňa Cave protection area border,
- assure continuous monitoring of the cave system's water quality,
- remove existing illegal waste dumps;

meadows and pastures, where it is necessary to:

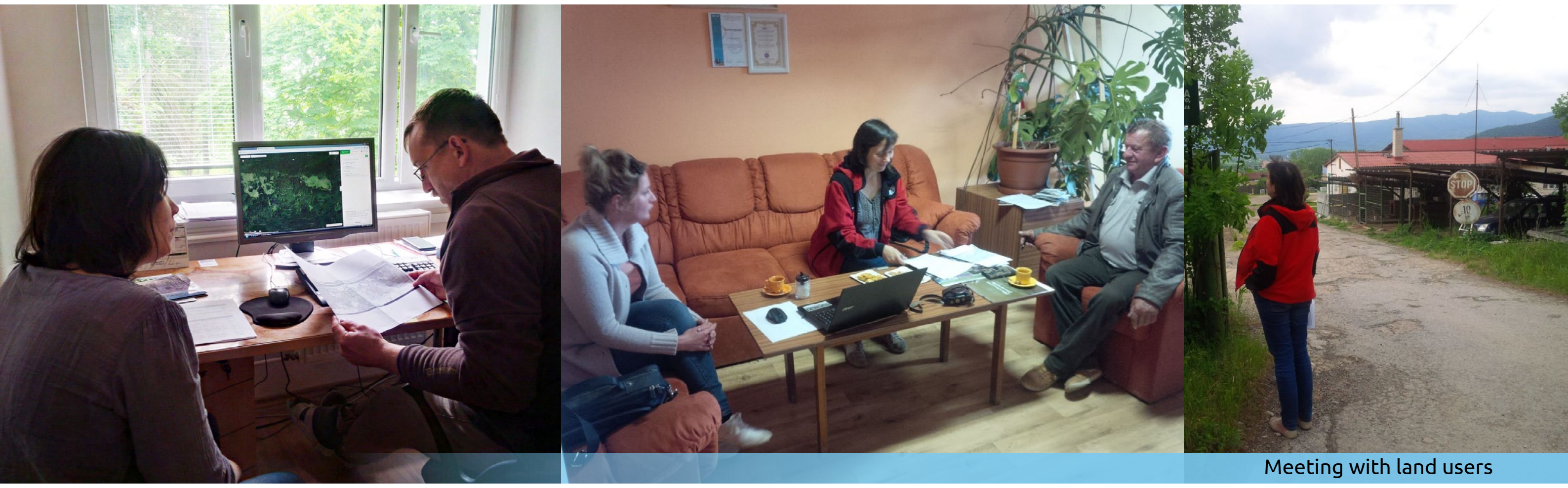
- ensure cutting down of dispersed trees and eliminating of invasive plants,
- support regular meadows mowing,
- control the pasturing of sheep and cattle,
- apply adequate fertilisation with matured organic manure at selected meadows,
- limit or completely abate pesticides usage;

forests, where it is necessary to:

- apply selective forestry approach with minimised use of heavy machinery,
- gradually reduce non-native tree species and prefer planting of native ones,
- constrain chemical spraying;

inhabitants, where it is necessary to:

- educate all people with emphasis on the youngest generation,
- inform visitors and tourists on landscape protection and its reasons,
- govern economically active groups in relation with land vulnerability.



Meeting with land users

The future of the giant stalagmite is in the hands of these small children

The future is in the hands of our children. In the spirit of this thought the substantial part of the LIFE+ KRASCAVE project activities was held, which were oriented towards the youngest. In contrast to complicated administrative regulations, by educating and good governance of the young generations there is a better chance to provide a protection of important landscape components, in which the Krásnohorská jaskyňa Cave with its unique karstic features belongs. After all, those are the people of the region, who will inhabit and manage the land the forthcoming decades. The children are very curious, they need to find the reason and understand the problem.

The goal of the project's activities was to motivate the children to find more interest in the nature and its protection, to know the unique natural sights, appearing only a few kilometres from their homes.

During the five-year duration of the project the children were given a lot of information about the nature and the means how to protect it. They had a chance to try different environmental activities directly in their village Krásnohorská Dlhá Lúka. One of the activities was building of a well in a sandpit of their nursery school, imitating its pollution and subsequent self-remediation through a gravel sample. The emphasis was put on the cleanness of their closest neighbourhood, which is well known and dear to their heart, and on endangering of ordinary things, such is the purity of water in a domestic well or a nearby spring. We were floating paper boats on Krásnohorský potok Creek with kids and their parents to observe the direction of water flow, but also a possible pollution. We had a great joy together during the common cleaning of the creek from garbage, children's watchful eyes noticed a dumping of bio-waste from orchards at the banks of the creek.

The theatre performance about dry water, prepared by the actors, suggested the pupils of nursery school of Krásnohorská Dlhá Lúka village and city of Rožňava, as well as the visitors of the craftsmanship fair, how important and precious is a glass of good clean water. During the performance children learned, that waste must not only be piled-up and buried in a cave or a karst chasm, but we have to separate, recycle it, and eliminate it.


Environmental activities for children



Theatre performance for children "about Dry Water" written by Igor Strinka

PROJECT PARTNERS:

State Geological Institute
of Dionýz Štúr
Bratislava (ŠGÚDŠ)
Coordinating beneficiary

EnviSlovakia, o.z.

Civic association EnviSlovakia
Bratislava (OZ EnviSlovakia)
Associated beneficiary

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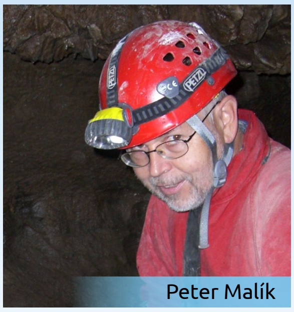
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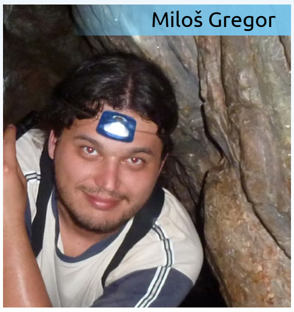
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