

Groundwater Drought Occurrence in Slovakia



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Abstract Groundwater regime and drought occurrence studies are very important for Slovakia, where groundwater is preferentially used for drinking water supply. It was shown by several studies that the groundwater drought occurs in Slovakia more often since the 1980s, causing problems in various sectors of the Slovak economy. Groundwater drought can be described either through groundwater heads, baseflow, groundwater storage or by the spring yield change. As the main reasons for groundwater drought occurrence, the natural factors and human activities can be mentioned. The amount of groundwater stored in the rock environment primarily depends on the water availability in the area and on the storage capacity of the rock environment itself. The lack of precipitation, high air temperature and the unfavourable storage properties of the rock environment belong to the main natural factors conditioning the groundwater drought occurrence. The groundwater over-abstraction also could increase the sensitivity of the local hydrological system to drought development. The groundwater drought studies for the Slovak territory were first published in the 1990s as a result of drought which hit the territory in the 1982–1984 period. After that, several important scientific works were performed to

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analyse the factors of drought development, occurrence and impacts on nature and social sphere. Baseflow drought, groundwater head drought and spring yield decrease were studied as presented in the chapter.

Keywords Baseflow, Drought, Groundwater, Groundwater head, Over-abstraction, Spring yield

1 Introduction

Drought belongs to major natural hazards together with floods, tornadoes, hurricanes, blizzards, volcanic eruptions and earthquakes. However, the perception of drought as a hazard was less intense in the past. The reason for the smaller public awareness of drought was [1] that droughts develop slowly and imperceptibly and may thus remain unnoticed for a long time. The series of drought events occurring since the 1980s of the last century attracted more attention to drought phenomenon in the scientific community, state authorities and also public. Meteorological, soil moisture and hydrological droughts were widely described in many studies. The fundamental works were published already in 1967 [2], later in 1987 [3] and in 2004 [1], among many others. The authors showed that there could not be one unique definition of drought because of manifold effects of drought in various parts of the climate system of the Earth, either in the system of its natural spheres (atmosphere, biosphere, lithosphere and pedosphere) or in the noosphere, ruled by the society. One of the first lists of definitions was published in 1985 [4] when the interest in drought issue started to rise, and one of the latest drought definition list was published in 2010 [5].

The meteorological drought is accepted as the initial input for the soil moisture and hydrological droughts development. The lack of precipitation or its presence in solid form (snow), in combination with other climatic factors, different in various parts of the year (the cold and the warm seasons) conditions the meteorological drought development. The lack of water starts in the atmosphere and propagates further through the soil up to the surface and subsurface part of the hydrosphere. Its influence reaches in the end the societal life and manifests itself in the socio-economic sphere.

Hydrological drought in the majority of studies includes drought in the two parts of the hydrosphere – the surface and the subsurface ones. The surface water drought concerns the streamflows (river stages or discharges), and lake or water reservoirs heads. The subsurface water drought includes: the (1) soil moisture and (2) groundwater droughts. Therefore, the groundwater drought is often considered as a type of hydrological drought.

Groundwater drought can be described either through groundwater heads, baseflow, groundwater storage or spring yield changes [1]. However, taking into account the influence of hydrogeological conditions on groundwater run-off formation, groundwater level and spring yield fluctuation, as well as the changes in physical properties and chemical composition of groundwater during the period of drought,

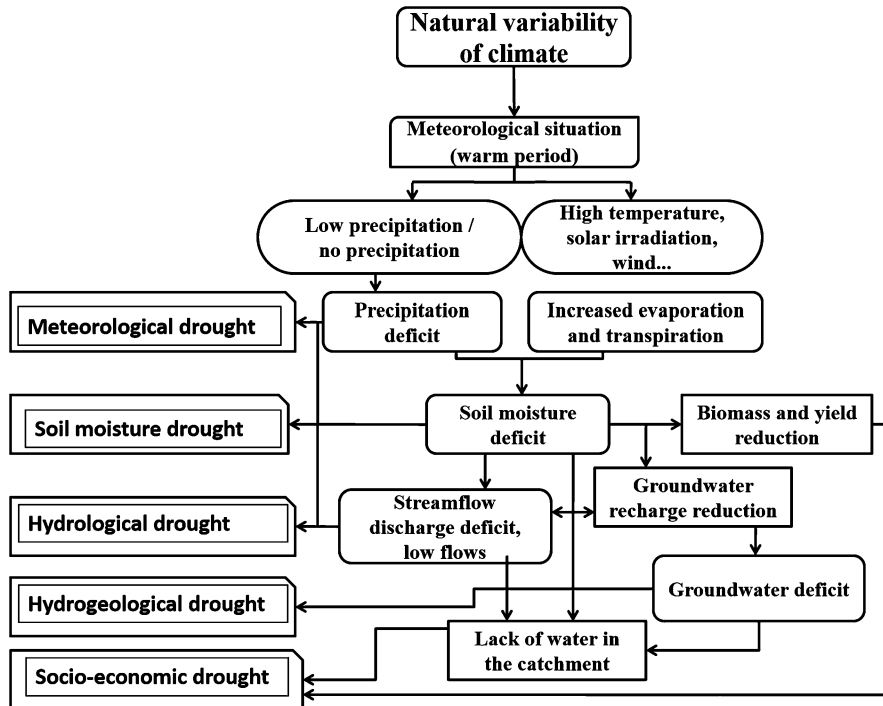


Fig. 1 Drought propagation through the hydrosphere – warm period conditions (modified from [7])

it is correct to regard this type of drought as hydrogeological drought [6]. The scheme of drought propagation modified from [7] is in Fig. 1 for the warm period conditions and in Fig. 2 for the cold period conditions.

Discussion on climate change effects in hydrological balance elements on the Slovak territory is being lasted among specialists in climatology, hydrology, hydrogeology and water economy mainly since the 1980s of the last century. Increasing air temperature was proved for the majority of the Slovak catchments, changes in precipitation amounts differ spatially [8, 9]. It was concluded [10] that there is still no significant decrease of water amount in Slovak catchments because decreasing interflow compensates the increasing evapotranspiration (due to the air temperature increase). The most serious affecting was documented for discharge values on surface streams in the southern, eastern and southeastern part of Slovakia [11].

2 Groundwater Drought

Groundwater regime and drought occurrence studies are very important for Slovakia, where groundwater is preferentially used for drinking water supply [12]. The amount of groundwater is affected by many factors among them the most important role play: the

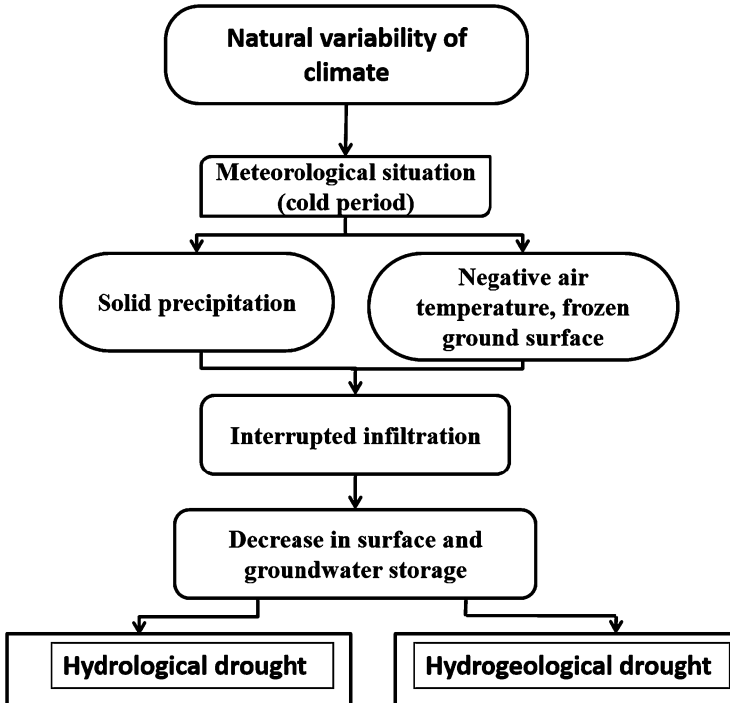


Fig. 2 Drought propagation through the hydrosphere – cold period conditions

(1) natural factors, among them the climatic, geomorphological, geological and hydrogeological conditions, and (2) artificial factors as the result of human influencing of the natural regime.

2.1 Natural Factors of Drought Occurrence

The amount of groundwater stored in the rock environment primarily depends on the water availability in the area and on the storage capacity of the rock environment itself. The water availability is conditioned by the climatic parameters – precipitation and evapotranspiration depths. Both parameters are altitude dependant – the precipitation depth increases with the increasing altitude. On the contrary, the air temperature, conditioning the evapotranspiration depth, decreases with the increasing altitude.

The storage capacity of the rock environment is conditioned by the rock type and kind of the rock permeability. The unconsolidated rocks with the larger grain size have larger storage capacity expressed by the storage coefficient. The best storage capacity is typical for porous fluvial sediments – alluvial deposits consisting of sands and gravels with various ratios of the sandy and gravelly compounds.

The lesser amount of water is stored in the loamy and clayey sands, and gravels where also the groundwater flow velocity is lower than in pure sand or gravel (see the chapter titled “an overview of water resources in Slovakia”, in volume I of this book). Larger amounts of groundwater can also be stored in certain types of consolidated rocks, being represented by carbonates – limestones and dolomites. Particularly, karstified limestones can store huge amounts of groundwater in the underground spaces (small and large fissures, canals, caves, etc.). Good storage properties also have certain types of dolomites (see the chapter titled “an overview of water resources in Slovakia”, in volume I of this book).

During the warm periods of the year with low precipitation and high air temperature (summer season), the precipitation is consumed mostly by vegetation for its growth and the recharge of the rock environment is decreasing rapidly (see Fig. 1). Therefore, the summer season is very typically the season during which the groundwater drought occurs. The spring yields, having their maxima in the end of the snow melting period, start to decrease with the minimum values occurring during the summer and early autumn period, often continuing also during the next winter period. The soil and rock permeability type and groundwater circulation depth play also the important role in groundwater storage depletion and drought occurrence. The groundwater levels react in most cases slower on the lack of precipitation than springs. The decrease of groundwater table depends on the existence of the hydraulic connectivity between the groundwater and streamflows, and the distance from the stream, and also on the depth of groundwater table below the surface. If the groundwater table is close to the surface (within 1–2 m), the water consumption by the plant roots through the capillary rise could lead to high evapotranspiration and thus to soil moisture and groundwater drought development.

There were several types of the winter droughts distinguished for streamflows [13, 14]. However, the groundwater winter drought was not studied in such details yet. Winter drought in the baseflow, groundwater storage, groundwater level and spring yields is connected to the interrupted groundwater recharge because of below zero air temperatures, frozen ground surface and precipitation in the solid form (snow cover).

2.2 Groundwater Over-Abstraction

The over-abstraction of groundwater also could lead to the development of the groundwater drought, at least increasing the hydrosphere sensitivity to possible drought occurrence locally. The over-abstraction of groundwater can be caused either by groundwater pumping from wells or by tapping of springs which followingly do not recharge the surface streams. In both cases, there are consequences endangering and damaging the stability of the aquatic ecosystems and also, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems [15].

The primary negative consequences of the groundwater over-abstraction are mostly:

- The decrease of groundwater levels in the surroundings
- Interruption of hydraulic connectivity between the surface and groundwater
- The decrease of streamflows, mainly during the low flow periods, in the worst cases leading to drying of the small surface streams
- The disappearance of the natural springs

The secondary consequences are mostly connected to surface water quality deterioration during the low flow period, damaging of aquatic habitats, the disappearance of valuable aquatic species and others.

The lack of water caused by natural factors of groundwater drought occurrence is often strengthened by the increased water consumption in the household, tertiary sphere, industry and agriculture during the drought period.

The natural systems are able to recover after the over-abstraction is ended. However, it could take even several years. The over-exploitation of groundwater resources could become a major problem in a foreseeable future when some slowly rechargeable aquifers become exhausted [16].

3 Groundwater Drought in Slovakia

The groundwater drought studies for the Slovak territory were first published in the 1990s as a result of drought which hit the territory in the 1982–1984 period [17, 18]. Later on, they were followed by a complex study of trends of 98 springs and 99 monitoring wells of the groundwater monitoring network of the Slovak Hydrometeorological Institute (SHMI) [19] in the period since the beginning of observation (mostly from the late 1960s) up to 2009. The results documented that the climate changes after 1980 negatively influenced the stage of groundwater resources and reserves. It was documented that 70% of the Slovak territory was hit by groundwater resources decrease. However, the impact does not cover the whole territory homogeneously. The most serious impact was found in the central and southern part, the moderate one in the northern and north-eastern part of Slovakia. The intensity of the negative changes was stronger after 1991. The decrease in groundwater resources in the most affected areas reached 25%, locally up to 35%. The total decrease in groundwater resources was calculated totally on $-250,000 \text{ m}^3 \text{ km}^{-2}$. On the other hand, the surprising moderate increase in groundwater resources (both, spring yields and groundwater levels) was documented for the area of the south-eastern part of Slovakia (Eastern Slovakian Lowland, Košice basin), and for the central part of the Váh River Basin (Turiec Basin, Veľká Fatra Mts.) [19].

The baseflow drought was studied in the upper Torysa River sub-basin [6, 20], in the upper Nitra River sub-basin [21] and also in the Topľa River Basin [22, 23]. Groundwater drought studies were performed for different parts of Slovakia. The comparative study of the streamflow and groundwater drought was performed in the Topľa River Basin (north-eastern part of Slovakia) [22, 23].

Topľa River (Fig. 3) belongs to Bodrog River Basin. Topľa has its spring in Čergov Mts., north-eastern Slovakia. The altitude changes from 1,152.2 m.a.s.l. (Minčol, the highest point of the catchment) to 160.4 m.a.s.l. (Hanušovce nad Topľou, closing profile of the studied area). The average annual air temperature and annual precipitation totals are altitude dependant. The average annual air temperature reaches 4–8°C, and annual precipitation totals vary between 700 and 900 mm. The catchment belongs to the less permeable ones, being built of flysch sediments (alteration of sandstone and claystone) and covered by Quaternary alluvial deposits and slope sediments. Run-off is dominated by rainfall; high flow periods are predominantly in March–April, and low flow periods occur in September.

Following data were used for surface and groundwater drought evaluation (Fig. 4):

- Daily precipitation at Bardejov station
- Daily discharges at Bardejov and Hanušovce nad Topľou stations
- Weekly groundwater levels at Tarnov (1,308), Komárov (1,311), Dubinné (1,313), Marháň (1,359), Hanušovce nad Topľou (3,317), Vyšný Žipov (1,318), Hlinné (1,321) and Parchovany (1,160) villages

The hydrological drought was evaluated using the method of sequent peak algorithm (SPA) [1]. The fixed threshold of the 90th percentile of the long-term flow–duration curve and variable threshold based on the 80th percentile of the long-term monthly flow–duration curves were used.

It was documented [23] that the short-term drought prevailed in stream discharges. Results also showed that only three periods of the discharge drought longer than 100 days occurred during the evaluated period: in 1986–1987, 1997 and 2003–2004. Discharge drought at Bardejov gauging station usually lasts longer

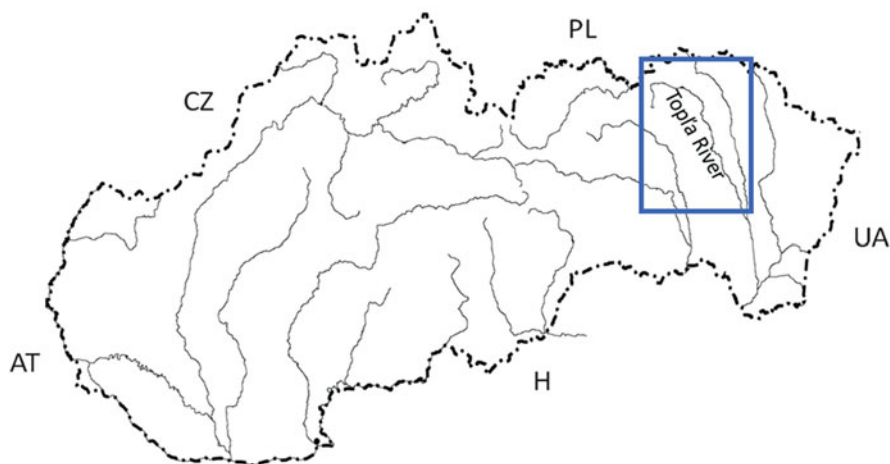


Fig. 3 Location of the Topľa River Basin

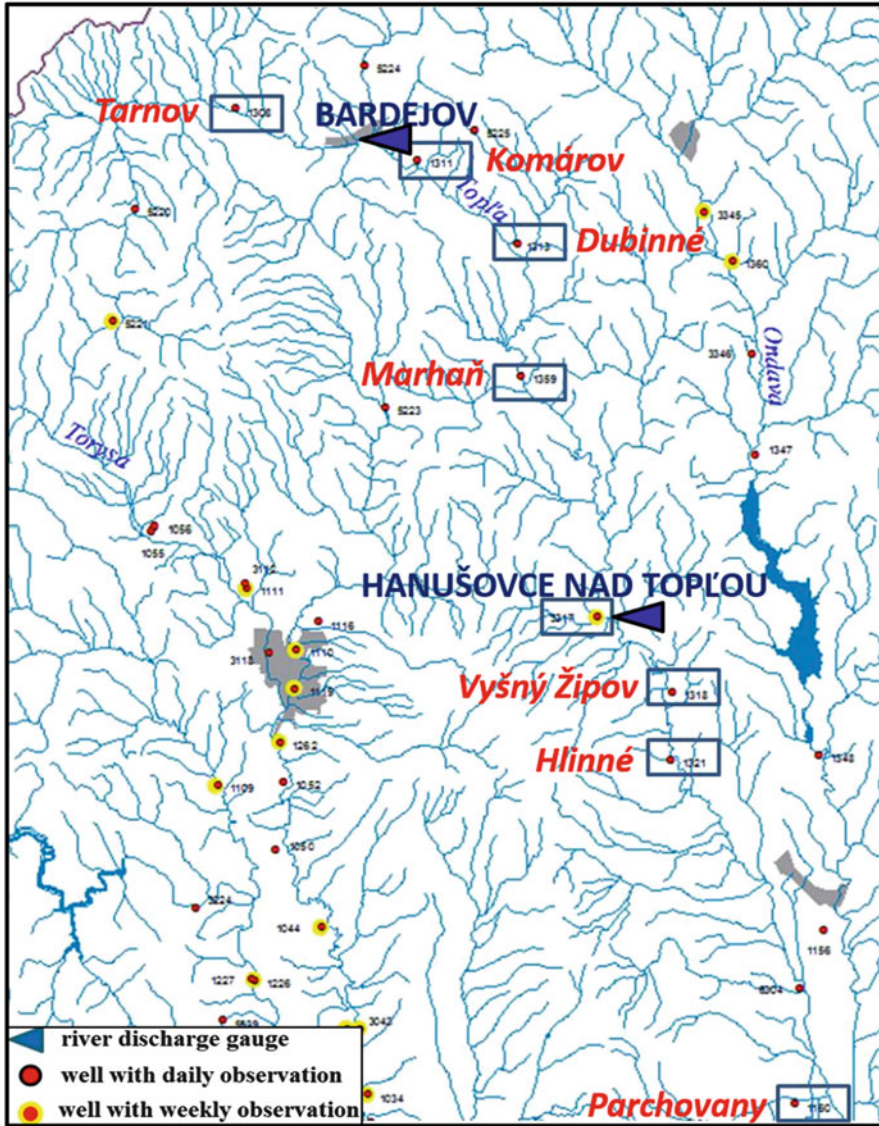


Fig. 4 Location of evaluated objects of the State monitoring network of the Slovak Hydrometeorological Institute (SHMI) (adopted from [22])

than in Hanušovce nad Topľou station being located downstream of the Bardejov station (see Fig. 4). More long-term droughts were estimated by all methods for groundwater levels. Those droughts lasted for tens of weeks since summer until the spring of the next year. No regularity in temporal groundwater level drought propagation downstream the Topľa River was discovered. However, results of the

cluster analysis showed some common features of long-term drought periods (more than 100 days) occurrence for two groups of wells. The first one includes three wells in the upper part of the basin (Tarnov, Komárov and Dubinné, see Fig. 4), and the second one four other wells in the middle part of the basin. Specific conditions for groundwater drought occurrence were found in the well at Parchovany, which is the southern-most located and deepest well among all, with the highest amplitude of the level fluctuation. A higher number of short-term droughts were also estimated for groundwater level in Marháň, which has the smallest depth of groundwater table below the surface. In this case, the influence of evapotranspiration can be the reason.

Areal groundwater drought occurrence evaluation was performed by Slivová, Gavurník and Kullman for 123 objects of the State groundwater monitoring network of the SHMI in 2017 [11]. The drought intensity was evaluated using the SANDRE method [11] – see Table 1.

The results showed that the majority of dry years within the evaluated period 1981–2015 occurred before 1993, even with the 5-year drought between 1989 and 1993. The most intense drought among these 5 years occurred in 1990 and 1993. The results of groundwater drought occurrence evaluation correspond very well with the results of the discharge trends evaluation which also documented the important share of the period before 2001 on the identified discharge decreasing trends in Slovakia [11]. After the 1993 water year, the drought occurred only in 2003 and 2004, 2007, 2012 and 2015. The most intense was the 2012-year drought. September was the month with the most intense drought in the years 2003, 2012 and 2015 (see Fig. 5).

The occurrence of drought in the groundwater regime for different hydrogeological conditions in Slovakia was studied in [25]. Vrablíková in [26] evaluated the spring yields seasonality. Seasonality of the yields of 78 springs

Table 1 Categories of groundwater drought evaluation according to SANDRE method (<http://www.sandre.eaufrance.fr/>)

	Distinctly lower than the long-term average (1981–2010) $< \varphi_{10\%}$, $< Q_{10\%}$	Lower than the long-term average (1981–2010) $\varphi_{10\%} - \varphi_{40\%}$, $Q_{10\%} - Q_{40\%}$	Matching the long-term average (1981–2010) $\varphi_{40\%} - \varphi_{60\%}$, $Q_{40\%} - Q_{60\%}$	Higher than the long-term average (1981–2010) $\varphi_{60\%} - \varphi_{90\%}$, $Q_{60\%} - Q_{90\%}$	Distinctly higher than the long-term average (1981–2010) $> \varphi_{90\%}$, $> Q_{90\%}$
Groundwater level and spring yield					
Value	1	2	3	4	5

Explanation 1 – groundwater level (quantile value lower than $\varphi_{10\%}$) and spring yield (quantile value lower than $Q_{10\%}$) is distinctly lower than the long-term average of the reference period (drought), 2 – groundwater level (quantile value lower and equal to $\varphi_{40\%}$) and spring yield (quantile value lower and equal to $Q_{40\%}$) is lower than the long-term average of the reference period, 3 – groundwater level (quantile value lower and equal to $\varphi_{60\%}$) and spring yield (quantile value lower and equal to $Q_{60\%}$) are equal to long-term average of the reference period, 4 – groundwater level (quantile value lower and equal to $\varphi_{90\%}$) and spring yield (quantile value lower and equal to $Q_{90\%}$) is higher than the long-term average of the reference period and 5 – groundwater level (quantile value higher than $\varphi_{90\%}$) and spring yield (quantile value higher than $Q_{90\%}$) is distinctly higher than the long-term average of the reference period (wetness)

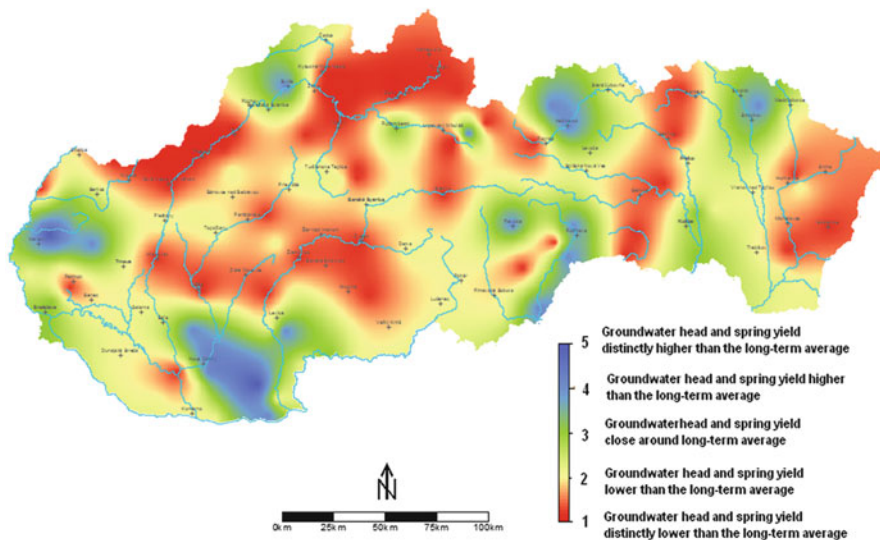


Fig. 5 Groundwater drought in September 2015 on the Slovak territory (adopted from [24])

in the mountainous areas of Slovakia was studied in detail. The study period included the years 1980–2012. The special attention was devoted to minimum yield occurrences. The minimum yield parameters were represented by $Q_{90\%}$ and Q_{Amin} . The $Q_{90\%}$ yield was calculated from the long-term yield–duration curve, representing the yield which was reached and overstepped during the 90% of the whole observed period 1980–2012. The Q_{Amin} represented the absolute minimum spring yield within the evaluated period. Seasonality of the average and minimum spring yields was evaluated using the Burn’s vector and frequency histograms. The seasonality evaluation was followed by the regionalisation of the minimum spring yields based on a combination of physical–geographical factors (precipitation, air temperature, spring discharge area altitude, slope orientation and hydraulic properties of the rock environment expressed by transmissivity coefficient), the Burn’s vector values and the frequency histogram values. The best results were reached using the physical–geographical parameters and the Burn’s vector for both, the $Q_{90\%}$ and Q_{Amin} yields, respectively. Results of regionalisation for both of the minimum spring yield parameters are similar to each other, reflecting the dominant influence of the spring discharge area altitude. Three regions were delineated. The first regional type includes all evaluated springs with the discharge area altitude between 100 and 460 m (in a few cases in 550 m). Minimum yields occurred mostly from August to the first half of November. The discharge areas of the springs belonging to the second regional type are concentrated at the altitudes of 700 m and more. The minimum spring yields occur during the winter months – from December until February. The third regional type of springs spatially stretches between the first two regions; the spring yields are typical by minimum discharges during the summer–autumn period. So, the assessment showed that the spring

yield droughts in the low to mid-altitudes occur in Slovakia in the summer-autumn months and those with the discharge area at the altitudes over the 700 m in the winter period – from December till February.

The over-abstraction causing groundwater drought occurrence can be illustrated on the example of the Podzámčok water-supply source. The water-supply source is located in the southern part of central Slovakia in the Neresnica brook catchment. The Neresnica brook catchment has an area of 139.33 km², the stream flows in the south-north direction towards the Hron River. The catchment area is built of Neogene volcanic rocks of the Štiavnické vrchy Mts. (western part of the catchment) and Javorie Mts. (eastern part of the catchment). The Neresnica stream follows the tectonic line dividing the Štiavnické vrchy Mts. and the Javorie Mts., acting at the same time as the deep drainage zone. The deep circulation of groundwater, coming from the depth of 150–200 m is demonstrated by the increased groundwater temperature reaching up to 16.9°C [27]. The average annual precipitation in the area reached 666 mm in the period 1963–2015, and the average annual air temperature varies around 8°C. Further information on the natural conditions can be found in [28] and in the chapter titled “an overview of water resources in Slovakia”, in volume I of this book).

The groundwater abstraction in the catchment is documented since 1973 when the first wells were drilled in the area. The amount of abstracted water has been increasing gradually, reaching the highest amounts of more than 200 L s⁻¹ since the 1980s up to the early 1990s, see Fig. 6 in which the course of precipitation amounts, average annual discharges and abstraction amounts during the evaluated period 1963–2015 are shown.

Such amount was too high for the natural recharge of the area, and the streamflows of the Neresnica reacted on the over-abstraction by an enormous decrease together with the groundwater heads. The groundwater heads decreased

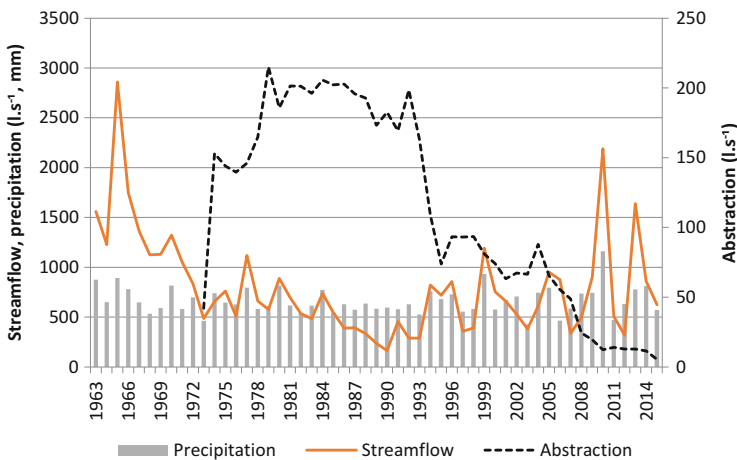


Fig. 6 Course of precipitation, average annual discharges and abstraction amounts in the Neresnica brook in the period 1963–2015

from the previous 1.5–3 m below the surface up to 15–23 m below the surface. The hydraulic connection of the surface and groundwater was interrupted, and the minimum annual discharges of the surface stream decreased from 180 L s^{-1} in 1964 to $20\text{--}10 \text{ L s}^{-1}$, reaching the absolute minimum of 9 L s^{-1} on August 30, 1990.

The decrease in groundwater abstraction since the mid-1990s had a positive influence not only on groundwater heads, which after approx. 5 years reached the previous values but also on the streamflow discharges, which increased importantly (see Fig. 6).

4 Conclusions and Recommendations

Groundwater is preferentially used for drinking water supply in Slovakia. However, the groundwater resources are endangered by increasing frequency of drought events, occurring also on the territory of Slovakia. These events, as the result of the climate changes, already caused the decrease in groundwater resources in $-250,000 \text{ m}^3 \text{ km}^{-2}$ since 1981 as documented by the results of the study performed by the SHMI. Therefore, the possibility of groundwater drought occurrence on the territory of Slovakia should be continuously studied and the operational monitoring and warning system should be put into operation, as it was already done for the flood warning.

The European Water Framework Directive [15] put the strong accent not only on water quality in all parts of the hydrological cycle but also on prevention of deterioration of the good ecological status of the surface water bodies and good quantitative status of groundwater bodies. Therefore, the adoption of measures for mitigation and prevention of the groundwater drought impacts on the groundwater quantity should be one of the primary actions of the sustainable water policy. The groundwater over-abstraction and over-exploitation should be restrained because of possible undesirable impacts on surface and groundwater systems on which the natural ecosystems are dependent. This recommendation is in full agreement with the European legislation, e.g. European Water Framework Directive, which request to ensure the full implementation and enforcement of existing environmental legislation for the protection of waters [15].

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