

# Major Droughts in Slovakia in the Twenty-First Century



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**Abstract** It is supposed that because of the climate change, the extreme hydrological events are going to be more pronounced and more frequent in the future also on the territory of Slovakia. The occurrence, duration and severity of hydrological droughts in Slovakia were studied during 3 years of the twenty-first century – 2003, 2012 and 2015. Mainly the 2003 and 2015 belong to the warmest years of the twenty-first century with the occurrence of hydrological drought on the Pan-European scale. Data on average daily discharges at twelve discharge gauging stations across Slovakia were used. The data covered the period 1981–2016. Hydrological drought in discharges was evaluated using the sequent-peak algorithm (SPA) method; the fixed threshold value of the 80th percentile was applied. The threshold value was estimated for the reference period of 1981–2010. The theoretical Weibull and GEV frequency distributions were used for drought parameters calculation, their evaluation and comparison of the 2003, 2012 and 2015 droughts. Data calculated for the evaluated years were compared with the reference period of 1981–2010. Spatial distribution of hydrological drought occurrence was discussed in connection to meteorological drought occurrence analysis.

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## 1 Introduction

Drought is a natural phenomenon, which is defined as the sustained and extensive occurrence of below-average water availability, caused by climate variability [1]. The drought has hit Europe hard over the last decades [2]. The increased attention paid to drought could be observed since the 1990s of the last century when the extreme meteorological drought occurrence and its consequences in the early 1980s and early 1990s attracted the attention of the scientific community, both the climatologic and the hydrological ones. The attention paid to drought further increased in the first decade of the twenty-first century after the Pan-European drought in 2003 which hit almost the whole Europe.

The interest in drought is also reflected in the number of publications which could be found in scientific databases. The keyword “drought” inserted into the search engine of the Scopus database (<https://www.scopus.com/results>) identified 244,559 documents, within them 62,326 scientific papers with the word drought in the title. There were 1,637 papers already published in 2017, belonging to various scientific disciplines. The highest number of publications belonged to hydrology; water economics; water resources; landscape ecology; geochemistry; atmospheric, soil, agricultural and forestry sciences; and also eco-toxicology, vegetable and zoological physiology, molecular genetics or anthropology.

It is generally supposed that because of the climate change, the extreme hydrological events, including drought, are going to be more pronounced and more frequent in the future also on the territory of Slovakia. Therefore, the Slovak hydrologists led by the author participated actively in hydrological drought research within the frame of the VIII International Hydrological Programme of UNESCO, FP5 and FP6 EU projects and the projects of the Slovak Agency for Research and Development (APVV). The three most intense droughts of the twenty-first century, 2003, 2011–2012 and 2015 droughts, which hit Slovakia were studied. These years belong to the warmest years of the twenty-first century with the occurrence of meteorological and hydrological droughts on the Pan-European scale. Part of the research results is presented in this chapter.

## 2 Data and Methods

Data on daily discharges at 12 discharge gauging profiles were used as the input data. The time series of daily discharges of the period 1 January 1981–30 June 2016 was used. The discharge data were provided by the Slovak Hydrometeorological Institute within the solution of the APVV-0089-12 project: Prognosis of the hydrological drought development in Slovakia (principal investigator Miriam Fendeková). The

necessary information on discharge gauging profiles is in Table 1. The item river km in Table 1 refers to the distance of the gauging profile from the river mouth, which has the value of the river km equal to zero. The location of the evaluated river basins is in Fig. 1.

The river km values (Table 1) for the Váh and Ipeľ streams indicate that only the upper parts of the river basin are represented by the discharges in the respective gauging profile. The reason for selection of these two gauging profiles was as follows. The Váh River is the stream at which a number of water works are operated; therefore, the discharges in the downstream gauging profiles do not represent the natural conditions. There is one water reservoir also over the Liptovský Mikuláš gauging profile (Čierny Váh water reservoir at the Čierny Váh tributary), but the area of the water reservoir is not very large in comparison with the downstream reservoirs, and there are other essential tributaries mouting into the Váh River downstream the Čierny Váh tributary. Selection of the Holiša gauging profile at the Ipeľ River was conditioned by the fact that there are tributaries from the Hungarian side downstream the Holiša profile and Ipeľ River starts to create the state boundary along its whole course up to the river mouth to the Danube River.

Data were processed statistically using the Statgraphics Centurion 17 software package [5]. The statistical processing included calculation of necessary statistical parameters, analysis of the seasonal component and analysis of the interrelationships among the discharge time series. The seasonal component was assessed using the seasonality index. A seasonal index represents the expected percentage of “normal value” in a given month. The normal value is defined by the monthly average for the whole surrounding year.

**Table 1** Basic data on discharge gauging profiles [3]

Database no.	Gauging station	River	River km	Gauge zero [m a.s.l.]	Area (km <sup>2</sup> )
5030	Saštín-Stráže	Myjava	15.18	164.25	644.89
5550	Liptovský Mikuláš	Váh (upper)	346.60	567.68	1107.21
5840	Trstená	Oravica	3.55	585.49	129.95
6200	Kysucké Nové Mesto	Kysuca	8.00	346.09	955.09
6730	Nitrianska Streda	Nitra	91.10	158.27	2093.71
6820	Vieska nad Žitavou	Žitava	34.20	154.27	295.46
7290	Brehy	Hron	93.90	194.27	3821.38
7400	Holiša	Ipeľ (upper)	157.20	172.40	685.67
7900	Vlkyňa	Rimava	1.60	150.77	1377.41
8320	Chmelnica	Poprad	60.10	507.41	1262.41
8870	Košické Oľšany	Torysa	13.00	185.70	1298.30
9500	Hanušovce nad Topľou	Topľa	47.50	160.40	1050.05

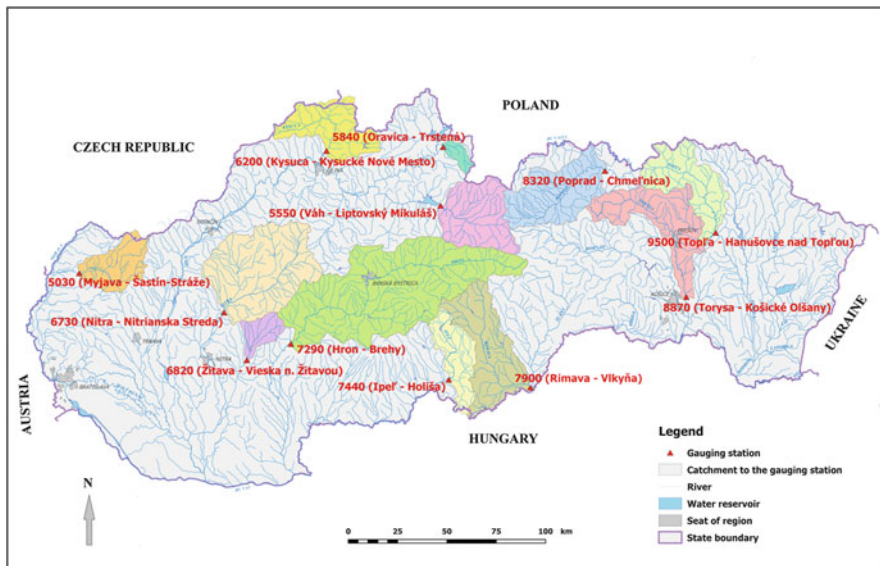


Fig. 1 Location of the evaluated river basins within Slovakia (Adapted according to [4])

The interrelationship among the time series of discharges was assessed using the Spearman rank correlation which is suitable also for data deviating from the normal frequency distribution, as expected for the discharge time series values.

After that, the drought parameters were estimated using the Istat program (version 0.9.2) [6, 7] developed at the Institute of Applied Statistics and Computing of BOKU Vienna. The hydrological drought was evaluated using the sequent-peak algorithm (SPA) method with the fixed threshold value of the 80th percentile ( $Q_{80}$ ) applied [1]. The calculation of  $Q_{80}$  was based on the time series of the reference period 1981–2010. Identification of low flow periods within the complete time series (1981–2016) enabled to select the drought period with the most massive volume for each of the years 2003, 2012 and 2015. The drought parameters consisted in (1) the annual minimum discharge  $AM7$  ( $m^3 s^{-1}$ ) obtained by 7-day moving average filter, (2) maximum drought duration  $D$  (days) obtained as a number of days between the drought onset and termination, (3) maximum deficit volume  $V$  ( $m^3$ ) calculated as sum of differences between the real discharge (below the threshold value) and discharge required to sustain the threshold and (4) drought intensity  $I$  ( $m^3 day^{-1}$ ) calculated as the ratio of the deficit volume and duration. The parameters were further processed by calculation of the return periods for each of the drought parameters [7]. The results were compared with the same parameters calculated for the reference period 1981–2010.

The three-parametric Weibull distribution was used to calculate the return period of the annual minimum values, and the generalized extreme value (GEV) distribution was used to calculate the return periods of maximum drought duration,

maximum deficit volume and drought intensity. The timing of drought and its seasonality were also studied.

The Weibull cumulative distribution function can be expressed by the formula [8]:

$$F(x) = 1 - e^{-\left(\frac{x-\gamma}{\beta}\right)^\alpha} \quad (1)$$

where  $x > 0$  and  $\alpha, \beta > 0$ ,  $\alpha$  location parameter,  $\beta$  scale parameter,  $\gamma$  form parameter.

The generalized extreme value (GEV) distribution, which was used for return period calculation of the maximum values (drought duration, deficit volume and intensity), can be expressed by the formula [8]:

$$F(x) = e^{-\left[1 - \frac{\kappa(x-\xi)}{\alpha}\right]^{1/\kappa}} \quad (2)$$

where  $\kappa \neq 0$  and  $\xi$  location parameter,  $\alpha$  scale parameter,  $\kappa$  form parameter.

The conformity of the empirical distribution to the theoretical one was assessed using the L-moments method [9].

Method of clustering (Ward's method, squared Euclidean distance) was used for assessment of interrelationships among the evaluated drought parameters.

## 3 Results

### 3.1 Primary Assessment of Discharge Time Series

Calculation of the basic statistical parameters included the values of the central tendency, among them the arithmetic mean, median, minimum and maximum values. Parameters of variability were represented by the standard deviation and the coefficient of variation. Of particular interest here are the standardized skewness and standardized kurtosis, which can be used to determine whether the sample comes from a normal distribution. Values of these statistics outside the range of  $-2$  to  $+2$  indicate a significant departure from normality. Totally 12,965 complete cases were used in the calculations. The results of the discharge time series statistical evaluation are in Table 2.

The statistical evaluation showed that the average discharge values range between  $2.267 \text{ m}^3 \text{ s}^{-1}$  for Oravica River at Trstená gauging station and  $42.007 \text{ m}^3 \text{ s}^{-1}$  for Hron River at Brehy gauging station. The value of median was for all streams lower than the value of the arithmetic mean, which points to the departure of the time series data from the normal frequency distribution. The deviation was also confirmed by values of the standardized skewness and kurtosis. The extremely high positive values of the standardized skewness out of the range from  $-2$  to  $2$  confirm the prevalence of the low values in all processed time series. The high values of the standardized kurtosis point to frequency distribution steeper than the normal one. The values of the coefficient of variation, as a standardized measure of the data

**Table 2** Results of statistical processing of the daily discharge data ( $\text{m}^3 \text{s}^{-1}$ )

	Mýjava	Váh (upper)	Oravica	Kysuca	Nitra	Žitava	Hron	Ipeľ (upper)	Rimava	Poprad	Torysa	Topľa
Count	12,965	12,965	12,965	12,965	12,965	12,965	12,965	12,965	12,965	12,965	12,965	12,965
Average	2.656	19.245	2.267	15.716	13.694	1.364	42.007	2.494	5.797	14.858	7.476	7.394
Median	1.741	14.060	1.750	7.747	9.020	0.825	27.390	1.305	3.257	10.470	4.486	4.414
St. deviation	3.543	15.189	1.794	24.098	14.819	1.759	44.647	4.082	8.450	16.385	11.476	11.043
C. of variation	133%	79%	79%	153%	108%	129%	106%	164%	146%	110%	154%	149%
Minimum	0.208	4.200	0.002	0.989	2.121	0.060	7.870	0.037	0.251	2.240	0.891	0.787
Maximum	72.5	259.9	67.7	488.1	263.7	50.9	753.4	79.7	159.9	447.5	292.4	219.5
Std. skewness	332.3	133.9	297.0	265.5	244.6	346.1	186.1	282.9	281.5	325.9	442.8	340.7
Std. kurtosis	1898.4	377.1	3739.7	1329.9	1128.0	2847.1	627.7	1383.2	1380.1	2214.6	3457.3	1988.0

variability, were also high. The lowest coefficient of variation with the value of 79% has Váh and Oravica River discharges; in all other cases, the values of the coefficient were higher than 100%, reaching from 106% up to 164%.

The evaluation of the time series seasonality showed the different development of discharges during the hydrological year (1 November to 31 October next year) which is still used in Slovakia for hydrological data seasonality evaluation. Three types of discharge seasonality can be distinguished among the basins (Fig. 2).

The first type represented by the Myjava, Kysuca, Nitra, Žitava, upper Ipeľ and Topľa Rivers can be characterized by the maximum discharges in March. The river basins have the rain-snow combined runoff regime (for explanation see the chapter titled “key facts about water resources in Slovakia”, in volume I of this book). The typical feature is the steep increase of discharges since January to March and the occurrence of the second but much smaller maxima in July. The second type, represented by the Oravica, Rimava, Hron and Torysa River discharges, has the maxima in April. It can be seen in Fig. 2 that also the March maxima are quite high except the Oravica discharges. On the other hand, the decrease of Oravica discharges after the April’s peak is the smoothest one among all evaluated basins; the difference between the April and the May to July discharges is not too significant. The third type is represented by the upper Váh, and Poprad River discharges with the maxima shifted to May which is typical for temporary snow regime runoff type (for explanation see the chapter titled “key facts about water resources in Slovakia”, in volume I of this book).

What the minima is concerned, the minimum values are dispersed throughout the broad time span. The autumn minima (September to November) prevail in the majority of the river basins, represented by the Kysuca, Nitra, Hron, upper Ipeľ, Rimava, Torysa and Topľa Rivers. The winter minima (January to February) occur in

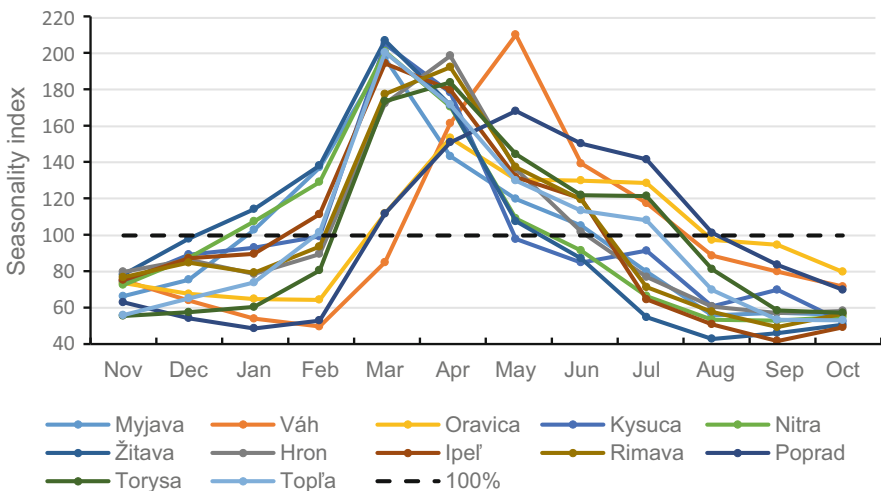


Fig. 2 Values of the seasonality index for evaluated river basins

typically high river basins, represented by the upper Váh, Oravica and Poprad Rivers, and the summer minima (August) are typical for Myjava and Žitava Rivers.

The interrelations among the discharge time series were assessed using the Spearman rank correlation, which is usable also in the case of data significantly departing from the normal frequency distribution (see Table 3). Values of the correlation coefficients are put in the first-row corresponding to each river; the  $P$ -values are given in the second row.  $P$ -values lower than 0.05 indicate the statistically significant interrelationship between two variables.

All relationships between pairs of variables are statistically significant as all  $P$ -values are lower than 0.05. The highest correlation coefficient of 0.928 was obtained for the relation of the Ipeľ and Rimava River discharges. These are two neighbouring basins located in the Southern Slovakia (Fig. 1) with the similar geological, geomorphological and climatic conditions. Another high correlation coefficient with the value of 0.899 was obtained for the discharge relationship of Torysa and Topľa Rivers, the two neighbouring basins located in the Eastern Slovakia (Fig. 1), also with very similar geological, geomorphological and climatic conditions. The lowest values of correlation coefficients were obtained for Oravica River; however, also there were some quite strong correlations, e.g. with the Poprad, Torysa and Topľa River discharges.

### 3.2 Hydrological Drought Assessment Results

The drought periods with the most significant deficit volume were selected in each of the evaluated years using the fixed threshold value of the reference period. The estimated values of the  $Q_{80}$  for each of the evaluated river basin are in Table 4.

Four examples were selected to illustrate the different drought developments in various parts of Slovakia in evaluated years. The Myjava River basin is located in Western Slovakia (see Fig. 1), the Kysuca River in Northwestern Slovakia, the Žitava River basin in the Southern Slovakia and the Torysa River basin in Eastern Slovakia. Time series of discharges separately for each of three evaluated years are in Fig. 3 for the Myjava River, in Fig. 4 for the Kysuca River, in Fig. 5 for the Žitava River and in Fig. 6 for the Torysa River.

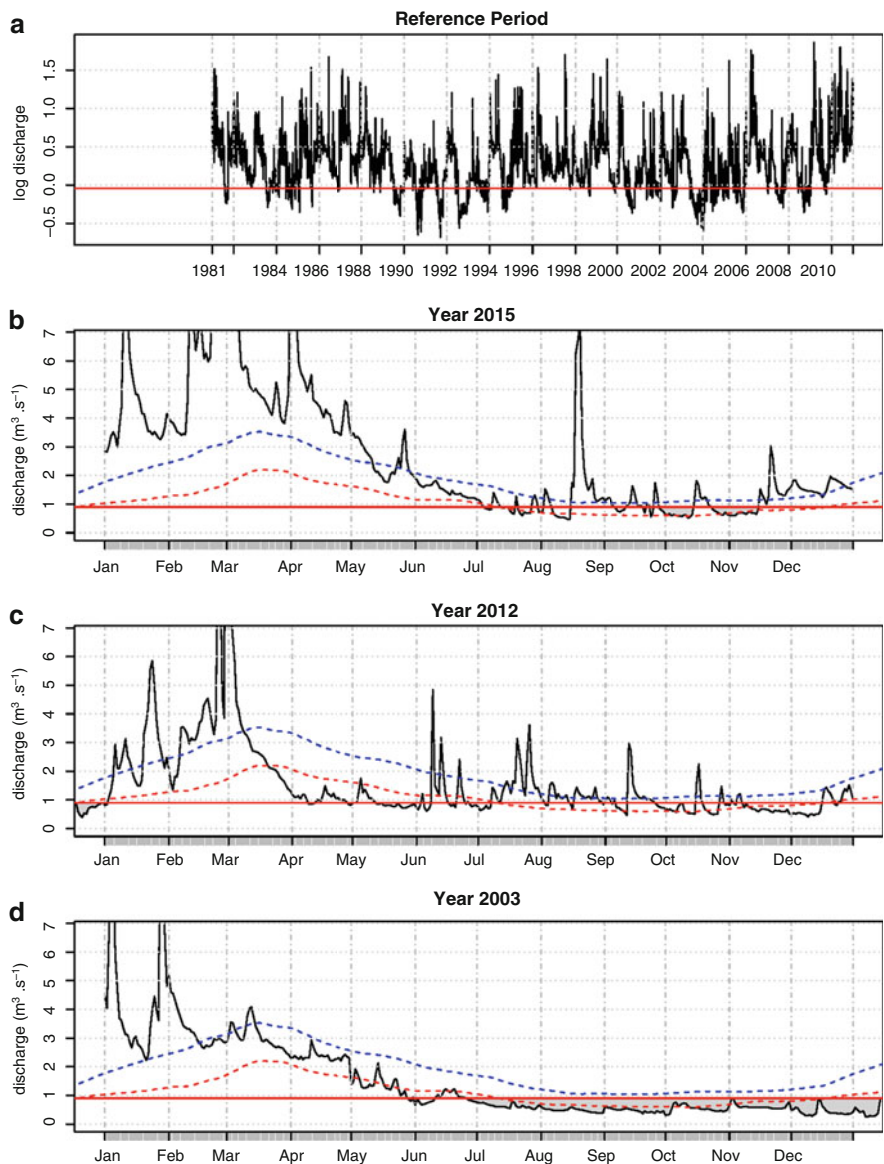
Each figure is divided into parts *a*, *b*, *c* and *d*. The logarithmic values of discharges in the reference period 1981–2010 are in the upper (*a*) part of each figure. The logarithmic transformation enabled to stress the minimum values, which are of interest by the drought assessment. The threshold value, calculated as  $Q_{80}$  for the entire reference period, is drawn by the full red line. Each value below the threshold represents the discharge under drought. Discharges of three evaluated years are drawn separately in Figs. 3*b*, 4*b*, 5*b*, and 6*b* (2015); 3*c*, 4*c*, 5*c* and 6*c* (2012); and 3*d*, 4*d*, 5*d* and 6*d* (2003). In accordance with [10], the grey polygon in *b*, *c* and *d* parts of each figure represents the maximum annual low flow event below the threshold. The area of the polygon corresponds to the deficit volume, and its length (between the onset and termination day) is the event duration. Dashed lines represent



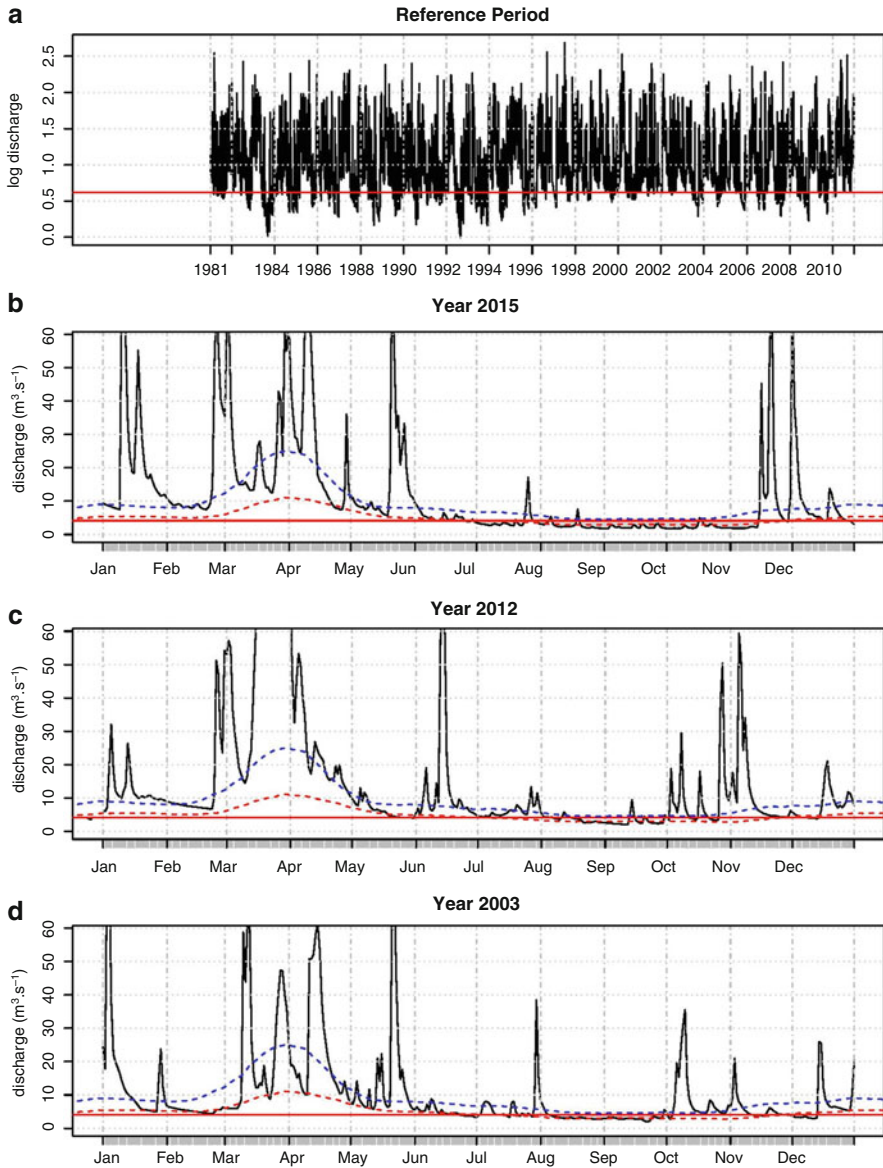


**Table 4** The  $Q_{80}$  values ( $m^3 s^{-1}$ ) used as threshold limits for drought period delineation

Basin	Myjava	Váh	Oravica	Kysuca	Nitra	Žitava	Hron	Ipeľ	Rimava	Poprad	Torysa	Topľa
$Q_{80}$	0.90	8.69	1.11	4.15	5.61	0.47	15.30	0.638	1.74	5.92	2.48	2.45

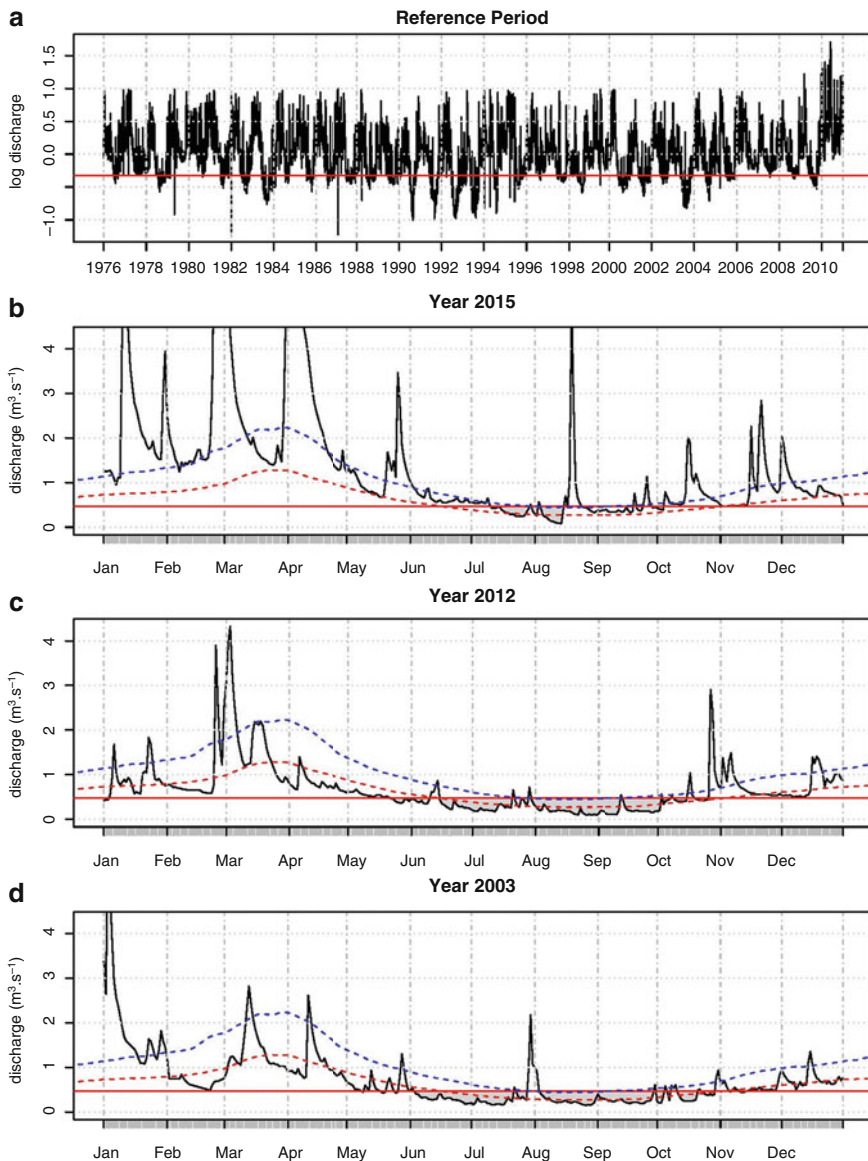


**Fig. 3** Delineation of the drought periods with the most significant deficit volume for the Myjava River discharges: (a) discharge values in the reference period, (b) 2015 drought delineation, (c) 2012 drought delineation, (d) 2003 drought delineation



**Fig. 4** Delineation of the drought periods with the most significant deficit volume for the Kysuca River discharges: **(a)** discharge values in the reference period, **(b)** 2015 drought delineation, **(c)** 2012 drought delineation, **(d)** 2003 drought delineation

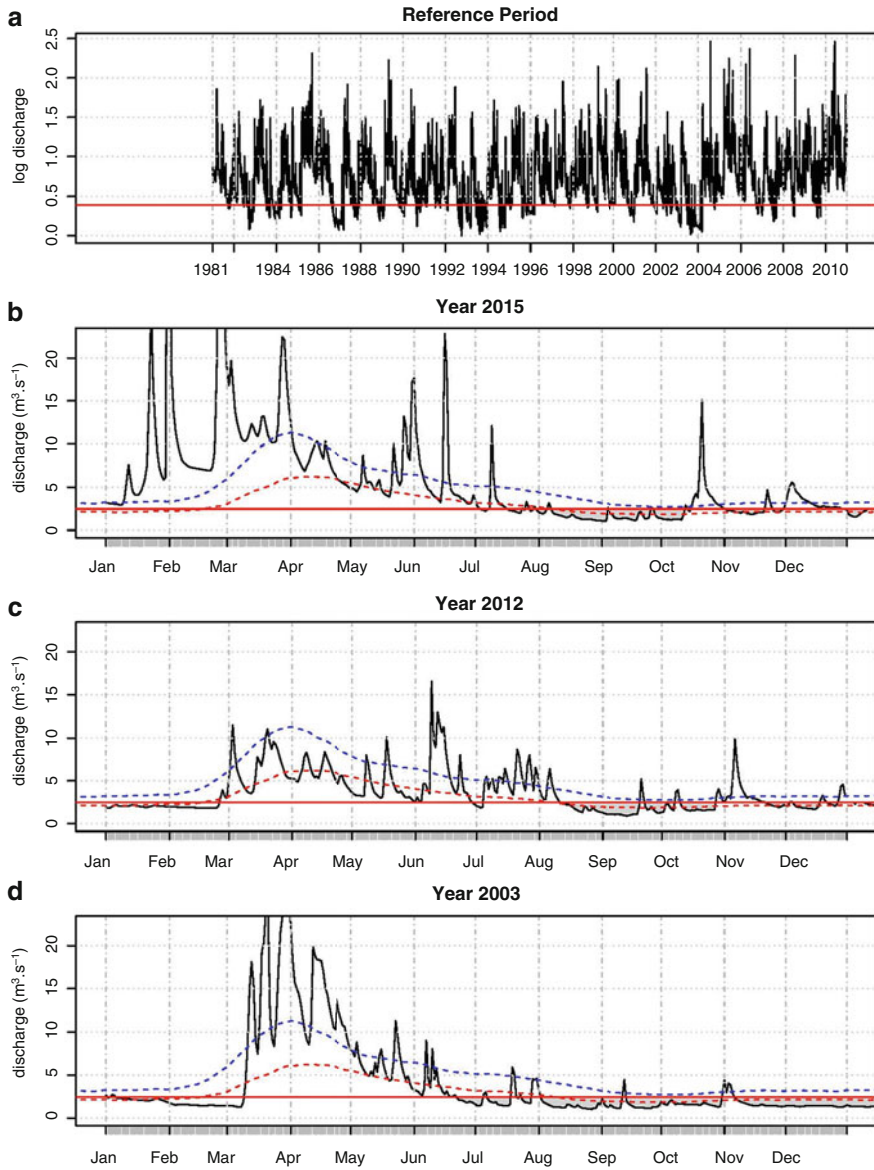
varying seasonal thresholds. The blue (upper) one is the  $Q_{50}$  representing the long-term average; the red (lower) one is the  $Q_{80}$ , representing the benchmark dry seasonal conditions. Both correspond to smoothed (30-day moving average



**Fig. 5** Delineation of the drought periods with the most significant deficit volume for the Žitava River discharges: (a) discharge values in the reference period, (b) 2015 drought delineation, (c) 2012 drought delineation, (d) 2003 drought delineation

procedure) daily flow quantiles with an exceedance probability of 0.5 (the blue one) and 0.8 (the red one).

The results for the Myjava River discharges show that the longest low flow period occurred in 2003 (see Fig. 3d). The average discharges of the year 2003 were far



**Fig. 6** Delineation of the drought periods with the most significant deficit volume for the Torysa River discharges: (a) discharge values in the reference period, (b) 2015 drought delineation, (c) 2012 drought delineation, (d) 2003 drought delineation

below the long-term average conditions except for the January–February period. Discharges of the period April–May 2012 were also low (see Fig. 3c), but the increase in discharges during the June–July period prevented the drought occurrence. The years 2012 and 2015 were almost without longer drought periods.

The results for the Kysuca River discharges (Northwestern Slovakia) differed significantly from those in the Myjava River basin. Almost no drought occurred in 2003 and 2012 (Fig. 4c, d), but in the year 2015, low flows during the June to November period caused long-term drought period occurrence (see Fig. 4b).

Another different picture of the drought period occurrence in Southern Slovakia illustrates the situation in the Žitava River basin (see Fig. 5).

The most extended drought period occurred in the year 2003 because of low discharges during the June–November period and similarly in the year 2012. The shortest drought period occurred in the Žitava River basin in 2015.

The last example is represented by the eastern Slovakian Torysa River basin drought period occurrence (see Fig. 6).

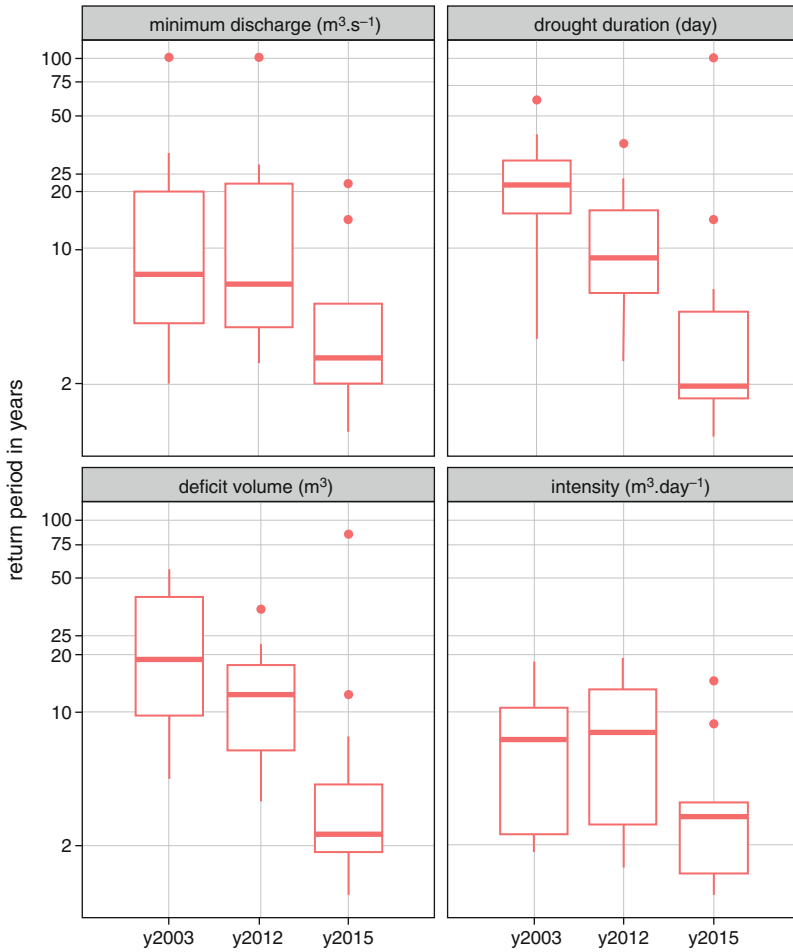
The area of Eastern Slovakia was hit by drought in all three evaluated years. The most extended drought period occurred in 2003 continuing to the year 2004; the drought periods in 2012 and 2015 were comparably long with the comparable onset and termination dates.

Drought parameters for the periods with the most massive deficit volume were further analysed for each river basin and evaluated year. The theoretical Weibull and GEV were used to calculate return periods of drought characteristics. Data calculated for the evaluated years were compared with the 1981–2010 reference period.

The return periods calculated for the minimum discharge, drought duration, deficit volume and intensity values were analysed regionally and also locally for each of the basins. The results of the regional evaluation are given in Fig. 7. Boxes refer to upper quartile, median and lower quartile of the return period; dots represent the maximum range of outliers. According to [10], return period of about 2–10 years represents mild drought conditions, 10–50 years moderate drought conditions and more than 100 years extreme drought conditions.

Drought conditions according to the minimum discharge values and the drought intensity were mild in Slovakia in all evaluated years; the lowest values of the return period were calculated for the 2015 drought, and comparable values were reached for the 2003 and 2012 droughts. On the other hand, the 2003 drought was moderately strong according to drought duration; 2012 and 2015 droughts were mild. The same is valid for the deficit volume. Again, the 2003 drought was moderate; 2012 and 2015 droughts were mild.

However, there were outliers in all evaluated parameters in almost all evaluated years. The highest return period over 100 years was calculated for minimum discharge in the Torysa River basin during the 2012 drought, representing the extreme drought conditions. The return period over 60 years reached drought duration in the Hron River basin in 2003, and the return period over 50 years was estimated for the maximum deficit volume in the Kysuca River in 2015. The estimated return periods of evaluated drought parameters reached higher values for 2003 and 2012 than those estimated for the 2015 drought. These values were also higher than the values estimated for the reference period, especially in the Myjava, Žitava, Váh and Torysa River basins. Exceptional was the situation in the Kysuca River basin, where the highest return periods were calculated for all four drought parameters for the year 2015.



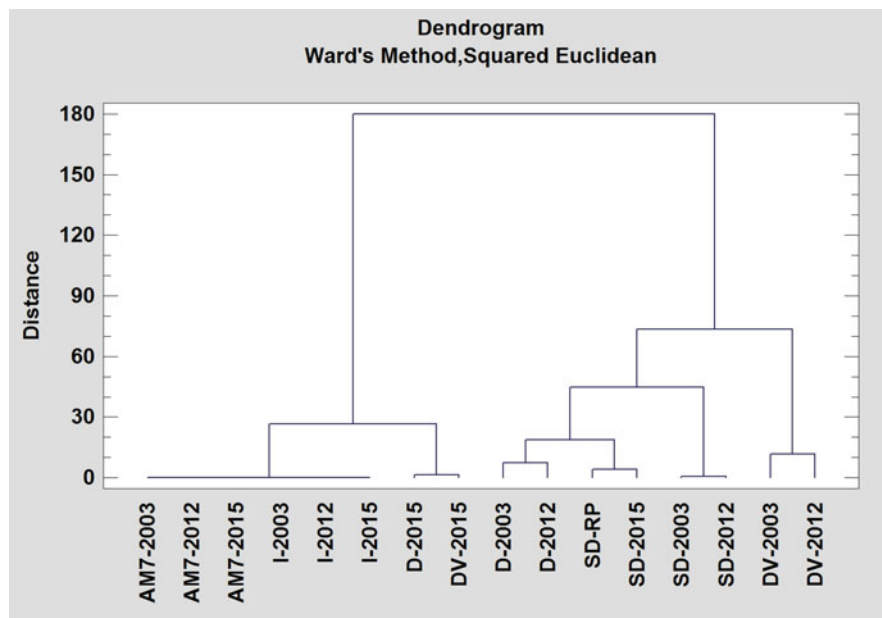
**Fig. 7** Box plots of the drought parameters in all evaluated river basins in 2003, 2012 and 2015

### 3.2.1 Interrelations Among Drought Parameters in Evaluated River Basins

The cluster analysis was used to find interrelationships among the calculated drought parameters. Besides the other already mentioned parameters, the starting dates of the drought periods in respective years and in the reference period were also used in the cluster analysis. Clustering of the drought parameters showed that there is a close relationship between minimum values (AM7-2003, AM7-2012, AM7-2015) and drought intensities (I-2003, I-2012 and I-2015) in all evaluated years as shown in Fig. 8.

The pairwise relation was confirmed between the drought duration (D-2003, D-2012), drought starting dates (SD-2003, SD-2012) and deficit volumes





**Fig. 8** Results of drought parameter clustering

(DV-2003, DV-2012) of the years 2003 and 2012. The relationship between the drought starting date in the reference period (SD-RP) and in 2015 drought (SD-2015) was also confirmed.

## 4 Discussion

The years 2003, 2012 and 2015 belong to the warmest years of the twenty-first century with the occurrence of meteorological and hydrological droughts on the Pan-European scale. The study of meteorological data showed that the initial climatic conditions over Europe were quite similar in all three dry years (2003, 2012 and 2015). There was a positive 500-hPa geopotential height anomaly in the upper-level atmospheric circulation over continental Europe, especially over the Central and Eastern Europe [11, 12]. As confirmed by WMO Report [13], the year 2015 was the second, the year 2012 the ninth and the year 2003 the tenth to twelfth warmest year within the observation period 1880–2016.

The evaluation of the meteorological drought on the Slovak territory [13] using the SPI and SPEI indexes showed that the manifestation of the meteorological drought was different in various parts of Slovakia. The influence of climatic conditions expressed by precipitation and potential evapotranspiration on drought parameters is notable but more pronounced since the year 2000. The more extreme values



of the standardized precipitation and evapotranspiration index (SPEI) in comparison with the standardized precipitation index (SPI) were estimated for the ongoing period since the half of the 1990s of the last century. The increase of potential evapotranspiration due to the increasing air temperatures is the reason for such development. This was confirmed mainly in the Oravica, Poprad, Torysa and Topľa River basins.

Study of interrelationships between the meteorological and hydrological droughts in the Slovak territory [4] showed that there is a quite good correlation between the meteorological and hydrological drought occurrence in more than half of the evaluated river basins. The closest correlations were obtained for the Myjava, Váh, Oravica, Kysuca, Nitra, Hron, Ipeľ and Topľa basins, where the meteorological drought was followed by the hydrological one. However, the hydrological drought parameters did not follow the meteorological drought onset or intensity in Žitava, Rimava, Poprad and Torysa River basins. The hydrological drought intensity in the Žitava, Rimava and Poprad River basins in 2003 was the lowest among the evaluated years, despite the most pronounced low SPI values. The reason was in quite wet preceding years which created conditions for balancing the lack of precipitation in 2003. The intensity of hydrological drought was in better compliance with the SPEI index values in the case of the Žitava and Rimava River basins than with the SPI values.

It is worth to mention that a high variability in drought manifestation even within small distances was confirmed for the territory of Slovakia. This was shown by a detailed comparison of drought parameters done for two southern, Ipeľ and Rimava, and two eastern, Torysa and Topľa, Slovakian river basins [14]. The results showed that the Ipeľ River basin with the smallest basin area, lowest altitude and highest air temperature suffered from the 2012 drought which was in a good compliance with the meteorological drought occurrence expressed by the SPEI12 index calculated for the Bolkovce meteorological station. The situation in the adjacent Rimava River basin was different despite meteorological drought parameters very similar to those of the Ipeľ River basin. The most pronounced drought period occurred in the Rimava Basin in 2003, similarly to the eastern Slovakian basins of Torysa and Topľa. However, return periods of drought duration and deficit volume and also the deficit volume intensity estimated for the Rimava River discharges were much lower than those calculated for the Torysa and Topľa basins.

The possible reason for such development is the high variability in climatic, geomorphological and geological conditions of Slovakia, which have their influence on wetness preconditions in respective river basins.

## 5 Conclusions

Hydrological drought occurs quite frequently in Slovakia since the 1980s of the last century. Three drought events with the Pan-European character occurred in Slovakia already in the twenty-first century. The influence of climatic conditions expressed by

precipitation and potential evapotranspiration on drought parameters is notable but more pronounced since the year 2000. The more extreme values of the standardized precipitation and evapotranspiration index (SPEI) in comparison with the standardized precipitation index (SPI) were estimated for the ongoing period since the half of the 1990s of the last century.

The evaluation of the 2003, 2012 and 2015 droughts showed that despite of generally similar weather conditions in all three evaluated years, the response of the twelve assessed river basins differed significantly. The research confirmed that the mild drought hit Slovakia according to the minimum discharge values and the drought intensity in all three evaluated years. The 2003 drought was moderately strong according to drought duration and deficit volume; 2012 and 2015 droughts were mild.

The assessment of interrelationships among evaluated drought parameters showed that the 2003 and 2012 droughts were more similar to each other than to 2015. The 2015 drought showed similarities with the average drought parameters of the reference period 1981–2010. However, there were exceptions from this development, as confirmed in the case of the Kysuca River discharges where all analysed drought parameters reached the highest return periods just in the year 2015.

The high variability in drought manifestation even within small distances was confirmed for the territory of Slovakia. Variable climatic conditions (air temperature and precipitation totals which are altitude-dependent) and geomorphological and geological conditions are the possible reasons for such development, together with the wetness preconditions in the respective river basin.

## 6 Recommendations

It is supposed that because of the climate change, the extreme hydrological events are going to be more pronounced and more frequent in the future also on the territory of Slovakia.

The country is quite well prepared for flood protection, as it results from the existing European and also Slovak legislation, where the flood directive of the European Community [15] and the Flood Act [16] are applied.

The Ministry of Environment of the Slovak Republic worked out the document: Strategy and adaptation on unfavourable climate change impacts. At present, the revision of the document is going on. The reason was in not satisfactorily addressing the drought issue.

Another document addressing the drought issue is the Action plan on drought impact mitigation measures which was prepared at the Ministry of Environment of the Slovak Republic by the group of experts in the second half of the year 2017. Nowadays the process of its discussion is going on at the level of the applicable ministries. The action plan should be prepared for the approval by the Slovak government in the near future.

However, there is still no legislation on drought impact mitigation and protection existing within the Slovak legislative space. Therefore, after approval of the Action plan, the respective legislative measures should be prepared and approved in order to move from the crisis management, as documented by measures taken during the 2015 drought, to drought risk reduction policy. More attention should be paid to prepare the long-term prevention and mitigation measures in all involved economy sectors (water management, forestry, agriculture, social sectors and others). Development and implementation of drought management plans of Slovakia in the context of the EU Water Framework Directive are inevitable. The drought issue should be included also in the next revised version of the Water Plan of the Slovak Republic.

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