Hydrological Drought Occurrence in Slovakia

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Contents

Abstract The chapter presents the problem of drought and describes its classification and methods of assessing this risk. The aim of this chapter is to identify statistically significant trends in streamflow characteristics of low water content in the Eastern Slovakia, which are used in the evaluation of hydrological drought. In this thesis is presented a new methodology for evaluating hydrological drought based on statistical analysis of observed minimal flows at selected 63 gauging stations in Eastern Slovakia for a 32-year period. Mann-Kendall statistical test identifies the frequency of minimal flow trends: in individual gauging stations, in river basins (Poprad, Hornád, Bodva, Bodrog to throughout Eastern Slovakia), and also in groups of gauging stations with the same physicogeographical parameters. Size of the flow trends is identified by directives of the trend lines. The procedure is also applied in assessing the impact of human activities and the impact of physicogeographical factors for the emergence of hydrological drought.

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Obtained results from the statistically significant trends in the flows are established prediction of hydrological drought risk in each month of the hydrological year in Eastern Slovakia.

Keywords Hydrological drought, Minimal streamflows, Statistical tests, Trend analysis

1 Introduction

In principle, the concept of drought is a deficiency of water in the atmosphere, soil, and plants. Depending on where it shows a lack of water by the World Meteorological Organization (WMO) [1] classifies four basic types of drought, including meteorological, hydrological, agricultural, and socioeconomic droughts [2]. The drought has a devastating impact on fauna and flora, human society, and all sectors of national economy; for this, it is recognized as an environmental disaster. Its effects have been observed on all continents, and over the past decade, the frequency of drought increases [3].

Hydrological drought is a phenomenon which rises with the existence of occurrence of no-precipitation period coupled with extreme temperatures. The genesis of hydrological drought also affects the morphological conditions of origin, climatic factors, geological and hydrogeological conditions, and anthropogenic activities. This type of drought is defined by a long-term decrease in levels of surface water bodies (e.g., rivers, lakes, reservoirs, and others) and drops in groundwater levels [4]. Low water content is proof of this type of drought [5]. For the mathematical-statistical evaluation of low water content are used the flow and no-flow characteristics [6].

A distinction is made between streamflow droughts and low flows (minimal flows). The main feature of a drought is said to be the deficit of water for some specific purpose. Low flows are typically experienced during a drought, but they feature only one element of the drought, i.e., the drought magnitude. Low flow studies are described as being analyses aimed at understanding the physical development of flows at a point along a river at a short-term (e.g., daily). Hydrological drought analyses in terms of streamflow deficits are said to be studies over a season or more extended time periods and in a regional context. A streamflow drought event definition quantitatively defines whether the flow can be regarded as being in a drought situation or not and gives the duration of a drought, whereas low flow indices characterize specific features of the low flow range [7, 8].

The primary objective of the chapter is to identify minimal streamflow trends in the selected 63 gauging stations in Eastern Slovakia in the time interval 1975–2010. The Mann-Kendall nonparametric test has been used to detect trends in hydrological time series. Statistically significant trends have been determined from the trend lines, and the prediction of hydrological drought risk in each month of the hydrological year for the whole territory of Eastern Slovakia has been made [8].

Slovakia is a rich country in water resources. Both the surface and the groundwater resources ensure the present and also the prospective needs of the country. However, they are distributed unequally over the Slovak territory. The distribution depends on natural conditions – mostly on geomorphologic, geological, hydrogeological, and climatic ones.

2 Study Area

The study area is situated at the eastern part of Slovakia (Fig. 1). It includes two major river basins – Bodrog river basin and Hornád river basin. Bodrog River is 15.2 km long at Slovak Republic but its basin area is 7,272 km^2. The territory of Bodrog basin is located in two orographic subassemblies, which are the Carpathians and Pannonian Basin. The morphological type of the relief is predominantly plane in the southern part and hilly in the northern part. Bodrog river valley has varied climatic conditions. Precipitations are highly differentiated. The highest annual totals are mainly at east border mountains and Vihorlat where rainfall totals are about of 1,000 mm. The decrease of total precipitation is quite intense direct to the south – annual totals fall to below 800 mm. Lowland part of the Michalovce – Lastomír and Medzibodrožie – belongs to among the driest in the eastern region (550 mm rainfall per year). Hornád river basin area is 4,414 km^2. Annual precipitation is 700 mm in Hornád river basin. The morphological type of terrain in Hornád river valley is dominated by rolling hills, highlands, and lower highlands. The southern sub-basin is part of a plane and Slovak Kras and is formed by moderately higher rugged highlands. Well-drained rocks with high permeability are only in Spiš and Gemer areas and in Slovak Kras near Košice.

In this territory, 63 gauging stations are located. List of gauging stations is shown in Tables 1, 2, 3, and 4, where the stations affected by human activity are highlighted in gray.

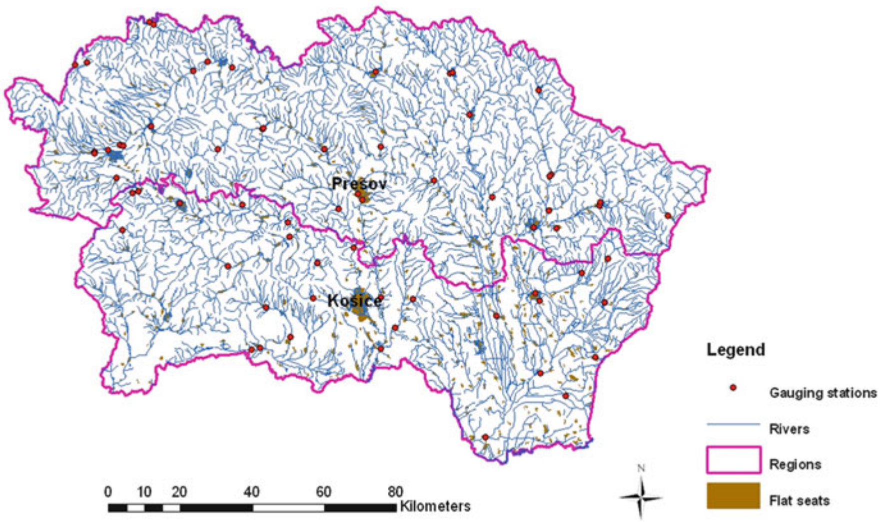

Fig. 1 A spatial distribution of river stations

Table 1 Basic statistical characteristics in river stations in Poprad basin

No	River station	Period			Kurtosis	Skewness	Median	Number of extreme values
		From	To	Total				
1	Ždiar–Lysá Poľana	1972	2010	39	1.554026	2.579875	1.235	16
2	Ždiar–Podspády	1961	2010	50	1.385817	2.07331	0.76	16
3	Červený Kláštor–Kúpele	1968	2010	43	1.89943	6.041278	0.41	17
4	Červený Kláštor	1968	2010	43	0.931166	0.816089	13.8	4
5	Svit	1966	2010	45	1.35799	1.653051	0.579	26
6	Svit	1963	2010	49	1.769929	3.811689	0.237	41
7	Poprad–Veľká	1963	2010	49	1.507696	4.297559	0.46	19
8	Poprad–Matejovce	1962	2010	49	1.131653	1.919848	0.279	16
9	Kežmarok	1972	2010	39	2.000563	5.511457	0.36	25
10	Nižné Ružbachy	1974	2010	37	1.248576	1.67138	5.899	17
11	Hniezdne	1972	2010	39	1.436049	2.549134	0.124	17
12	Chmeľnica	1931	2010	80	1.598901	3.609744	7.11	34

The affected hydrometric stations are considered as a station where the hydrological regime altered the flow by the interference of human activities (by water works, by excessive water abstraction, etc.).

3 Material and Methods

The first step in the evaluation was to obtain values of the minimal monthly flow for selected hydrometric stations. Hydrological data were provided by the Slovak Hydrometeorological Institute, Regional Centre Košice. Hydrological data files obtained were processed and statistically analyzed with the following sequence:

1. Creating a database and determining the fundamental characteristics of statistical series
2. Modifying existing files with respect to further processing
3. Testing the statistical files

   The methodology of the evaluation can be seen from Fig. 2.

Essential datasets were created by collecting and organizing the values of minimal streamflows to the statistical files. One set of values is for one gauging station. Each station was assigned by the statistical characteristics, namely, mean, median, skewness,

Table 2 Basic statistical characteristics in river stations in Hornád basin

No	Station	Period			Kurtosis	Skewness	Median	Number of extreme values
		From	To	Total				
13	Hranovnica	1965	2010	45	2.044337	6.020411	0.3315	27
14	Hrabušice	1967	2010	44	2.88779	15.51134	0.774	19
15	Hrabušice–Podlesok	1972	2010	39	1.204042	2.990362	0.248	11
16	Spišská Nová Ves	1972	2010	39	2.068367	7.152126	1.317	14
17	Spišské Vlachy	1975	2010	36	1.954649	6.447947	0.28	18
18	Margecany	1972	2010	39	2.361353	9.367487	3.5995	26
19	Stratená	1954	2010	57	1.929821	4.994504	0.479	35
20	Švedlár na Hrabliach	1931	2010	80	1.842699	3.956677	1.5535	66
21	Jaklovce	1931	2010	80	2.080526	5.453678	2.589	72
22	Košická Belá	1974	2010	37	2.060845	5.618473	0.087	23
23	Kysak	1929	2010	82	2.344298	7.271084	7.3	85
24	Nižné Repaše	1975	2010	36	2.351989	8.744696	0.0935	31
25	Brezovica	1973	2010	38	1.990774	5.837077	0.1475	20
26	Sabinov	1973	2010	38	1.742292	3.969851	1.18	20
27	Prešov	1970	2010	41	1.724631	4.083802	1.65	22
28	Demjata	1973	2010	38	1.238889	1.343055	0.3055	29
29	Prešov	1961	2010	50	2.052677	6.349703	0.6445	32
30	Košické Olšany	1931	2010	80	1.984643	6.990796	3.02	29
31	Svinica	1973	2010	38	2.124086	5.476892	0.06	40
32	Bohdanovce	1966	2010	45	2.383099	8.955003	0.3265	30
33	Ždaňa	1958	2010	53	2.364586	7.426313	11.915	54

Table 3 Basic statistical characteristics in river stations in Bodva basin

No	Station	Period			Kurtosis	Skewness	Median	Number of extreme values
		From	To	Total				
34	Nižný Medzev	1941	2010	70	2.162925	6.137853	0.251	64
35	Moldava nad Bodvou	1965	2010	46	2.146241	5.762377	0.341	41
36	Hýľov	1965	2010	46	3.727486	23.54098	0.1475	28
37	Turňa nad Bodvou	1966	2010	45	2.328922	7.631559	0.9375	45
38	Hosťovce	1968	2010	43	2.628787	9.080273	0.2025	43

Table 4 Basic statistical characteristics in river stations in Bodrog basin

No	Station	Period			Kurtosis	Skewness	Median	Number of extreme values
		From	To	Total				
39	Medzilaborce	1975	2010	36	1.969083	5.43406	0.223	23
40	Jabloň	1975	2010	36	1.590893	3.095441	0.2705	18
41	Kokošovce	1961	2010	50	7.232974	101.9174	1.062	33
42	Udavské	1975	2010	36	1.663648	4.150873	0.52	14
43	Snina	1957	2010	54	1.695406	3.443234	0.797	40
44	Snina	1975	2010	36	1.46199	2.463163	0.126	13
45	Kamenica nad Cirochou	1961	2010	50	2.923875	12.89779	0.26	43
46	Humenné	1967	2010	44	2.480386	13.64994	3.5825	20
47	Michalovce–Stráňany	1962	2010	49	1.927579	4.563265	2.4865	40
48	Jovsa	1970	2010	41	2.104789	6.216189	0.086	31
49	Michalovce–Meďov	1955	2010	56	1.172373	1.319246	5.25	16
50	Ulič	1972	2010	39	2.774549	11.53484	0.307	18
51	Lekárovce	1951	2010	60	1.905658	5.0883	7.543	30
52	Remetské Hámre	1955	2010	56	2.546627	9.075364	0.294	45
53	Sobrance	1970	2010	41	1.702476	3.742496	0.22	28
54	Ižkovce	1975	2010	36	2.220385	6.096453	20.545	34
55	Veľké Kapušany	1951	2010	60	2.086689	5.389429	11.59	55
56	Bardejov	1967	2010	44	1.681923	3.603626	1.1205	23
57	Hanušovce nad Topľou	1931	2010	80	2.116909	7.988851	2.9	38
58	Svidník	1962	2010	49	9.318237	149.7023	0.34	23
59	Svidník	1962	2010	49	2.138821	7.177429	0.405	21
60	Stropkov	1967	2010	44	4.074425	36.50911	1.245	22
61	Jasenovce	1957	2010	54	1.589772	2.876338	0.3	25
62	Horovce	1931	2010	80	3.032593	19.04556	7.79	37
63	Streda nad Bodrogom	1951	2010	60	2.599394	9.194828	43.285	56

kurtosis, and extremes. These characteristics were used in choosing the right modification files and in choosing a statistical test.

The calculated median was used in ranking stations and their hydrological data in the database and also in modification (1) of these files. Calculation of relative values was conducted for each gauging station by relation [9]:

$$y_i = x_i/\tilde{x} \tag{1}$$

where x_i the value of the minimum streamflow, $\tilde{x}$ median

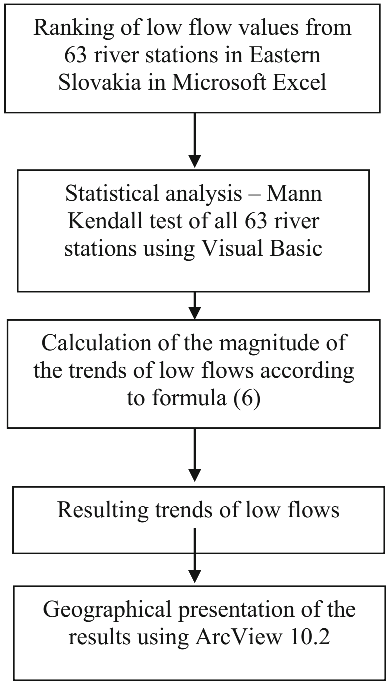

Fig. 2 Flowchart of the methodology

The median is the middle digit range of variation that is created from the values of minimal flows from one gauging stations arranged in ascending order for the entire period:

$$x_{(1)} < x_{(2)} < \ldots < x_{(n)} \tag{2}$$

Modification (1) was necessary because each gauging station had a different potential of water and in this case, it was not possible to establish one comprehensive set of statistics.

The skewness describes the form of distribution of the random variables and measures both the direction and the degree of asymmetry of the distribution of the random variables. Positive values (as measured in our case) cause the mean to be higher than the median. It follows from this fact that the majority of the values (in all studied data files) are lower than the mean.

The kurtosis measures the “peakedness” of the distribution of the random variables, which shows the potential occurrence of extreme (outlet) data. Mostly this coefficient is compared to the coefficient of kurtosis in the normal distribution, which equals 3. Using this statistical analysis, it was demonstrated that all entry data files contain more extreme (outlet) values. The graphs for all of the data files show log-normal distribution of low flow values with large positive coefficients for both skewness and kurtosis.

The existence of extreme values in the data file may be determined, e.g., using the box plot method.

For statistical tests were used relative streamflow values y_i as random variables Y.

Mann-Kendall test is used as a rule by which it is possible to decide whether the tested hypothesis H_0 is rejected or not rejected [9]. The test is based on the statistical value S. Comparing any two values y_i, y_j $(i > j)$, a random variable Y can be determined if $y_i > y_j$ and $y_i < y_j$. The number of pairs of the first type is denoted as P and the number of pairs of the second type as M. Then S is defined as [10, 11]

$$S = P - M \tag{3}$$

Mann-Kendall following statistics based on standard normal distribution (Z), where

$$\begin{array}{ll} Z = (S-1)/{\sigma_s}^{1/2} & \text{if } S > 0 \\ Z = 0 & \text{if } S = 0 \\ Z = (S+1)/{\sigma_s}^{1/2} & \text{if } S < 0 \end{array} \tag{4}$$

where the variance is defined as

$$\sigma_s = n(n-1)\cdot(2n+5)/18 \tag{5}$$

and n is a size of sample

Hypothesis H_0 no trend is accepted if the following applies: $Z < Z_{\alpha/2}$ or refused, if applies, that $Z > Z_{\alpha/2}$, then is accepted H_1-exist a statistically significant trend. The significance level is chosen as $\alpha = 0.05$, and $Z_{\alpha/2}$ is a value for normal distribution; in this case, $Z_{\alpha/2} = 1.645$. The sign of Z statistic indicates whether the trend is growing $(Z > 0)$ or decreasing $(Z < 0)$. Estimate of the magnitude of the trends obtained cannot be determined with this test, and therefore, the magnitude of the trends in the streamflow was calculated using relation (6) [12, 13].

For $x_2 \neq x_1$ applies

$$K = tg\varphi = D_{ij} = \left(y_j - y_i\right)/\left(x_j - x_i\right) \quad \text{for } i > j \tag{6}$$

where y_i is the relative value of the minimum monthly streamflow in year x_i.

All mathematical relations from (1) to (6) were programmed in Visual Basic in Microsoft Excel 2003. Using ArcView GIS 10.2 was created a graphical representation of analysis results.

4 Results

4.1 Descriptive Statistical Analysis

The first step in the evaluation was to obtain values of the minimal monthly flow for selected river stations. Hydrological data, provided by Slovak Hydrometeorological Institute, Regional Centre Košice, at monthly intervals during years 1975–2010 were used for the creation of essential datasets. Datasets were created by chronologically ranking the values of low flows to the statistical files. One set of values is for one river station in the mentioned 36-year period.

Essential statistical characteristics of the data files are presented in Tables 1, 2, 3, and 4. Stations affected by human activity are highlighted in dark color.

After the statistical analysis, each river station is assigned trends of low flow in each month.

4.2 Trends of Low Flows in River Stations

In analyzing the results, it is considered that there is a decreasing trend when normalized test statistics Z is negative and the obtained probability is higher than the adopted level of significance. Conversely, when the normalized test statistics Z is positive, and the obtained probability is higher than the adopted level of significance, it is considered that there is an increasing trend. If the obtained probability is less than the adopted level of significance, it is accepted that there is no trend.

Tables 5, 6, 7, and 8 present statistically significant trends in the months with the favorable development of water levels shown in double plus sign, prevailing water levels drop are shown in double minus sign.

The results of analysis of a possible trend shown in Tables 5, 6, 7, and 8 indicate that it is not possible to determine, with reasonable certainty, the existence of a trend in time series of low flows at evaluated river stations. There has been detecting a trend in 16 river stations which is 25% of all river stations. In ten river stations has appeared a decreasing trend (marked in tables by doubled minus $- -$) of low flows mainly in the smallest river basin – Bodva. In six cases from the all river stations have been found an increasing trend of low streamflows. It is interesting that, at 7 river stations (50%) from a total of 14 river stations located in parts of watercourses where there is an influence of man and its activities, a significant trend was noted. It is where hydraulics structures are situated. At four river stations (Švedlár na Hrabliach, Jaklovce, Brezovica, and Hosťovce) from mentioned seven stations influenced by human activities, this significant trend is decreasing. River stations Švedlár na Hrabliach and Jaklovce are located upstream of the sizeable Ružín dam. At the remaining seven stations, there is no trend, based on the results of the test.

4.3 Trends of Low Flows in River Basins

The next analysis was devoted to investigations of trends in river basins. River stations were grouped to sub-basins and ranked according to the increasing median. They create one statistical file within one sub-basin, which was created from values of low flows arranged according to (1). This statistical file was tested by Mann-Kendall nonparametric test, for the period 1975–2010. The magnitude of the statistically

Table 5 Statistically significant trends in river stations in river basin Poprad

No	Hydrological year											
	XI	XII	I	II	II	IV	V	VI	VII	VIII	IX	X
1	+	–	+	+	++	+	+	– –	–	– –	– –	–
2	–	–	–	–	+	+	+	–	–	– –	– –	–
3	++	+	+	+	+	+	+	++	++	+	+	+
4	+	+	+	++	+	–	–	–	–	–	–	+
5	–	–	–	+	+	+	+	–	–	– –	–	–
6	+	+	+	++	+	–	–	– –	– –	–	–	–
7	++	+	+	+	+	+	+	+	+	+	+	+
8	+	+	+	+	+	++	+	+	+	+	+	+
9	++	++	++	++	+	+	++	+	+	++	+	++
10	+	–	–	–	–	–	+	–	–	–	–	–
11	++	+	++	++	++	+	+	++	++	+	+	+
12	+	–	–	+	–	–	–	–	–	–	–	–

Table 6 Statistically significant trends in river stations in river basin Hornád

No	Hydrological year											
	XI	XII	I	II	II	IV	V	VI	VII	VIII	IX	X
13	++	++	+	+	+	+	+	+	+	++	++	++
14	+	+	+	+	–	–	– –	–	+	+	++	+
15	++	+	+	+	+	+	–	–	+	++	++	++
16	+	+	+	+	+	–	–	– –	–	+	+	+
17	++	++	++	++	+	+	+	++	++	++	++	++
18	+	–	–	–	–	–	– –	–	–	+	+	+
19	+	+	+	++	+	–	–	– –	+	+	+	+
20	+	+	+	+	+	+	–	–	–	+	+	++
21	–	–	–	–	–	– –	– –	– –	– –	–	–	–
22	++	+	+	+	+	+	+	+	+	+	+	++
23	–	–	–	–	–	–	–	–	–	+	–	–
24	++	++	++	++	+	+	+	++	++	++	+	++
25	+	+	– –	–	+	+	–	–	–	+	+	+
26	+	+	+	+	+	+	–	–	+	+	+	+
27	–	–	–	–	–	–	– –	– –	– –	–	–	–
28	++	+	+	–	–	–	–	– –	–	+	–	+
29	+	+	–	–	–	–	–	–	–	+	+	+
30	–	–	–	–	– –	–	– –	– –	– –	–	–	–
31	+	+	+	+	+	+	–	–	–	– –	–	+
32	+	+	+	+	–	–	–	–	–	–	–	+
33	–	–	–	–	–	–	–	– –	–	–	–	–

significant trend was calculated from Eq. (4) for each month of the hydrological year. Statistical analysis in river basin was done for all river stations and separately for river stations not influenced by human activity to compare the results and characterize the

Table 7 Statistically significant trends in river stations in river basin Bodva

No	Hydrological year											
	XI	XII	I	II	II	IV	V	VI	VII	VIII	IX	X
34	–	+	+	–	–	–	–	–	– –	–	–	–
35	–	+	+	–	–	–	– –	– –	–	–	–	–
36	+	++	+	+	+	–	–	–	–	–	+	++
37	–	–	–	–	–	–	– –	– –	–	–	–	–
38	–	–	–	–	–	– –	– –	– –	– –	–	–	– –

Table 8 Statistically significant trends in river stations in river basin Bodrog

No	Hydrological year											
	XI	XII	I	II	II	IV	V	VI	VII	VIII	IX	X
39	+	–	+	+	+	–	–	–	– –	–	–	+
40	+	+	+	++	+	+	+	+	+	–	–	+
41	–	–	–	–	–	–	–	– –	– –	– –	–	–
42	+	–	+	+	+	+	–	–	–	–	–	+
43	+	+	+	–	–	+	–	+	–	++	+	+
44	+	+	+	–	+	+	+	+	–	–	–	–
45	++	++	++	++	++	+	++	++	++	++	++	++
46	+	+	+	–	–	+	–	+	–	–	+	+
47	–	–	–	–	+	– –	– –	– –	– –	– –	–	– –
48	+	+	++	+	+	+	+	–	+	+	+	++
49	–	–	–	+	+	–	–	–	–	+	– –	– –
50	+	+	+	++	+	++	+	–	–	–	–	+
51	–	–	–	–	–	–	–	–	– –	– –	– –	–
52	+	–	+	+	+	–	–	–	–	–	–	–
53	+	+	+	+	+	+	+	+	+	+	+	+
54	–	+	–	+	+	+	–	– –	– –	–	– –	– –
55	–	–	–	–	–	–	– –	– –	– –	– –	– –	–
56	+	+	++	++	+	+	–	–	+	+	+	+
57	–	–	–	–	–	– –	– –	– –	– –	– –	– –	– –
58	+	–	+	+	+	++	+	+	–	+	+	+
59	+	–	+	+	+	+	+	–	–	–	–	–
60	–	–	–	–	–	–	– –	– –	– –	–	– –	– –
61	+	+	+	++	+	+	+	–	–	+	+	+
62	+	+	+	+	+	+	–	+	+	+	+	+
63	–	–	–	–	–	–	–	– –	– –	–	–	–

influence of human activities to the hydrological regime. The results are presented in Tables 12, 13, 14, and 15.

Influenced river station Červený Kláštor in Dunajec was not included in the second assessment (column: Non-influenced river stations). Influence of human activity was proved in March when the significant trend has occurred in non-influenced river stations.

It means that significant decreasing trends of low river flows are not occurring in March as a result of human activity in river basin Poprad. Based on Table 9, we can say that significant decreasing trends in low river flows are occurring in winter months – December and January. Vice versa significant increasing trend is occurring in May which is in coincidence with precipitation trend analysis.

Trends in river basin Hornád are depicted in Table 10.

River stations influenced by human activity in river basin Hornád are Švedlár and Jaklovce in Hnilec River; Margecany, Kysak, and Ždaňa in Hornád River; and Brezovica in Slavkovský potok. These river stations were not considered in trend detection within non-influenced river stations. The difference has occurred in August; the significant increasing trend of low flows is not occurring in non-influenced river stations. Based on Table 10, it is clear that significant decreasing trend is occurring in winter and spring seasons – from December to June.

Evaluation of trends of low flows during 1975–2010 in river basin Bodva is depicted in Table 11.

In Bodva river basin was proved the difference in trends of low flows between all river stations and by human activity non-influenced river stations (without river station Hosťovce in Turňa) in months January and May. There is a statistically significant decreasing trend of low flows during the whole year. In Table 11, a negative influence of hydrological regime of human activity is evident.

There is introduced the occurrence of trends of low flows in river basin Bodrog in Table 12.

The trend analysis in Bodrog river basin includes 25 river stations: 20 river station not influenced by human activity and 5 river stations influenced by human activity (Snina in Cirocha River, Michalovce and Ižkovce in Laborec River, Streda nad Bodrogom in Bodrog River, Horovce in Ondava River). The significant decreasing trend of low flows was proved in December, February, June, and July; in

Table 9 Statistically significant trends in river basin Poprad

	All river stations		Non-influenced river stations	
Months	Trend	Magnitude	Trend	Magnitude
IX – November	H_0 – not exist	−0.0016	H_0 – not exist	−0.00157
X – December	**H_1 – exist**	**−0.0078**	**H_1 – exist**	**−0.00835**
I – January	**H_1 – exist**	**−0.00635**	**H_1 – exist**	**−0.00735**
II – February	H_0 – not exist	0.002481	H_0 – not exist	0.00121
III – March	H_0 – not exist	−0.00756	**H_1 – exist**	**-0.00904**
IV – April	H_0 – not exist	0.001853	H_0 – not exist	0.002392
V – May	**H_1 – exist**	**0.013847**	**H_1 – exist**	**0.014733**
VI – June	H_0 – not exist	−0.00397	H_0 – not exist	−0.0047
VII – July	H_0 – not exist	0.000805	H_0 – not exist	0.000411
VIII – August	H_0 – not exist	0.002425	H_0 – not exist	0.002629
IX – September	H_0 – not exist	0.002781	H_0 – not exist	0.002534
X – October	H_0 – not exist	−0.00291	H_0 – not exist	−0.00298

Bold values: Significance level is 95%

Table 10 Statistically significant trends in river basin Hornád

Months	All river stations		Non-influenced river stations	
	Trend	Magnitude	Trend	Magnitude
IX – November	H_0 – not exist	−0.0116	H_0 – not exist	−0.01188
X – December	**H_1 – exist**	**−0.01897**	**H_1 – exist**	**−0.02119**
I – January	**H_1 – exist**	**−0.01417**	**H_1 – exist**	**−0.01461**
II – February	**H_1 – exist**	**−0.01463**	**H_1 – exist**	**−0.01525**
III – March	**H_1 – exist**	**−0.03008**	**H_1 – exist**	**−0.03076**
IV – April	**H_1 – exist**	**−0.01532**	**H_1 – exist**	**−0.01755**
V – May	**H_1 – exist**	**−0.01917**	**H_1 – exist**	**−0.02044**
VI – June	**H_1 – Exist**	**−0.01413**	**H_1 – exist**	**−0.0163**
VII – July	H_0 – not exist	−0.00455	H_0 – not exist	−0.00252
VIII – August	**H_1 – exist**	**0.011176**	H_0 – not exist	0.011107
IX – September	H_0 – not exist	0.003095	H_0 – not exist	0.002666
X – October	H_0 – not exist	0.000724	H_0 – not exist	0.000567

Bold values: Significance level is 95%

Table 11 Statistically significant trends in river basin Bodva

Months	All river stations		Non-influenced river stations	
	Trend	Magnitude	Trend	Magnitude
IX – November	**H_1 – exist**	**−0.03706**	**H_1 – exist**	**−0.03498**
X – December	**H_1 – exist**	**−0.03715**	**H_1 – exist**	**−0.03303**
I – January	**H_1 – exist**	**−0.02164**	H_0 – not exist	**−0.01926**
II – February	**H_1 – exist**	**−0.04673**	**H_1 – exist**	**−0.04173**
III – March	**H_1 – exist**	**−0.0535**	**H_1 – exist**	**−0.05171**
IV – April	**H_1 – exist**	**−0.05966**	**H_1 – Exist**	**−0.05091**
V – May	**H_1 – Exist**	**−0.04591**	H_0 – not exist	−0.03768
VI – June	**H_1 – exist**	**−0.01386**	**H_1 – exist**	**−0.01085**
VII – July	**H_1 – exist**	**−0.03503**	**H_1 – exist**	**−0.03329**
VIII – August	**H_1 – exist**	**−0.01144**	**H_1 – exist**	**−0.01219**
IX – September	**H_1 – exist**	**−0.01213**	**H_1 – exist**	**−0.01335**
X – October	**H_1 – exist**	**−0.01495**	**H_1 – exist**	**−0.01346**

Bold values: Significance level is 95%

other months, any statistically significant trend was not proved (Table 12). In this river basin is the course of flows the most stable.

4.4 *Trends of Low Flows in Eastern Slovakia*

The statistical file was created from the values of low streamflow in the gauging stations, monitored for a 36-year period and modified by relation (1). In this file were

Table 12 Statistically significant trends in river basin Bodrog

Months	All river stations		Non influenced river stations	
	Trend	Magnitude	Trend	Magnitude
IX – November	H_0 – not exist	−0.01314	H_0 – not exist	−0.01393
X – December	**H_1 – exist**	**−0.02115**	**H_1 – exist**	**−0.02388**
I – January	H_0 – not exist	−0.00869	H_0 – not exist	−0.0086
II – February	H_0 – not exist	−0.00552	**H_1 – exist**	**−0.00742**
III – March	H_0 – not exist	−0.0002	H_0 – not exist	−0.0028
IV – April	H_0 – not exist	0.009796	H_0 – not exist	0.00701
V – May	H_0 – Not exist	−0.00351	H_0 – not exist	−0.00555
VI – June	**H_1 – exist**	**−0.01136**	**H_1 – exist**	**−0.01382**
VII – July	**H_1 – exist**	**−0.00685**	**H_1 – exist**	**−0.00831**
VIII – August	H_0 – not exist	−0.00027	H_0 – not exist	−0.002
IX – September	H_0 – not exist	−0.00234	H_0 – Not exist	−0.00352
X – October	H_0 – not exist	−0.00356	H_0 – Not exist	−0.00313

Bold values: Significance level is 95%

included the 63 gauging stations (red color in Fig. 3). The second sets of statistics were created like the previous one but only from stations not affected by human activities (blue color in Fig. 3). Results of statistical analysis are recorded in the chart (Fig. 3) and in Table 13.

In both sets of statistic were detected significant statistical trends by Mann-Kendall test in these months: from December to July and October. All trends are decreasing. Low streamflow trends are slightly different in sizes. It was not proven the statistically significant impact of human activities for the hydrological regime of rivers.

Using ArcView GIS 10.2 was created the thematic map (Fig. 4) from the geographical map of Eastern Slovakia (Fig. 1) and were calculated relative magnitudes of the low streamflow trends in individual river stations. For each gauging station was assigned the streamflow histogram (Fig. 4).

In general, there was a statistically confirmed long-term decreasing trend of low streamflows in most of the monitored river stations in Eastern Slovakia.

4.5 *Trends Dependent to Geographical Parameters*

The next analysis was devoted to the evaluation of the interaction between the altitude of the river station and low flows in the river station. The results are documented in Table 14.

Statistically significant decreasing trends of low flows in river station with altitude up to 800 m asl. were proved in almost all the months of the hydrological year: November, April, August, and September. For river stations with altitude above 800 m were proved statistically significant trends from December till April and in June (Table 14).

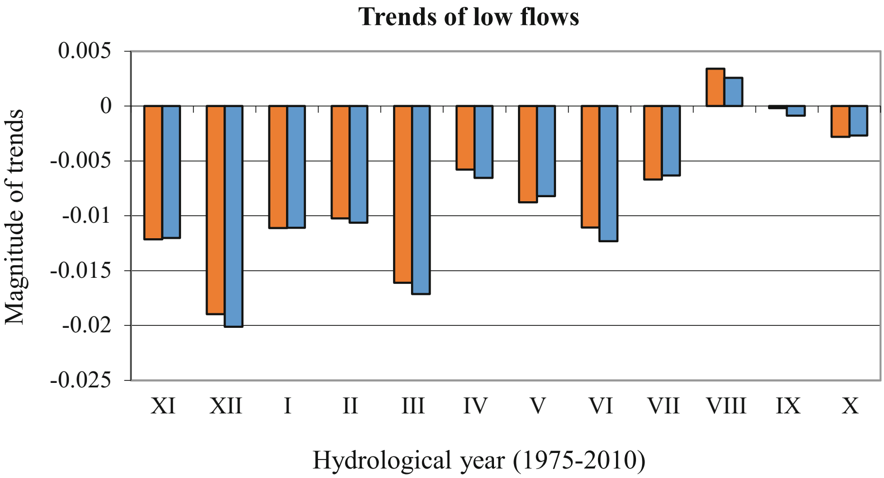

Fig. 3 Statistically significant trends throughout the territory of Eastern Slovakia

Table 13 Results of statistically significant trends

	All river stations		Non-influenced river stations	
Months	Trend	Magnitude	Trend	Magnitude
IX – November	H_0 – no exist	−0.01214	H_0 – no exist	−0.01203
X – December	**H_1 – exist**	**−0.01897**	**H_1 – exist**	**−0.02012**
I – January	**H_1 – exist**	**−0.01112**	**H_1 – exist**	**−0.01109**
II – February	**H_1 – Exist**	**−0.01014**	**H_1 – exist**	**−0.01063**
III – March	**H_1 – exist**	**−0.01610**	**H_1 – exist**	**−0.01714**
IV – April	**H_1 – exist**	**−0.00578**	**H_1 – exist**	**−0.00654**
V – May	**H_1 – exist**	**−0.00876**	**H_1 – exist**	**−0.00821**
VI – June	**H_1 – exist**	**−0.01106**	**H_1 – exist**	**-0.01230**
VII – July	**H_1 – exist**	**−0.00668**	**H_1 – exist**	**−0.00633**
VIII – August	H_0 – no exist	0.00340	H_0 – no exist	0.00257
IX – September	H_0 – no exist	−0.00018	H_0 – no exist	−0.00086
X – October	**H_1 – exist**	**−0.00280**	**H_1 – exist**	**−0.00268**

Bold values: Significance level is 95%

In the next analysis was investigated the interaction between low flows and the slope of the river basin. The results are documented in Table 15.

In the first group, formed from partial river basins with a slope lower than 15°, the low flow rate is expected to occur mainly in December, January, February, March, and in the summer months: May and June. For partial basins with a basin slope above 15°, the occurrence of the low water regime is predestined throughout the year except November, May, and August.

Physicogeographical factors in the river basin can suppress the influence of climatic factors, and therefore we also evaluated the natural hydrological flow regime depending

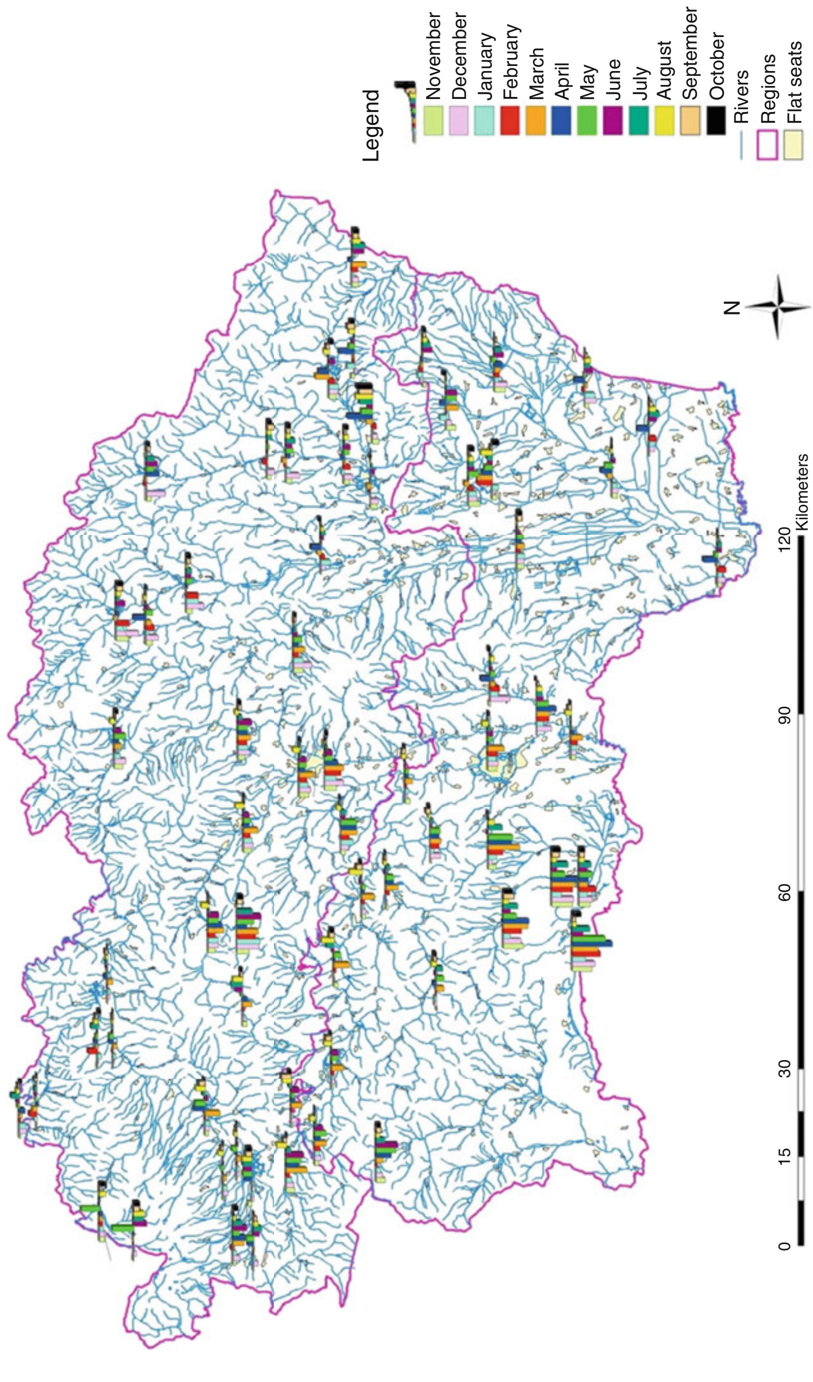

Fig. 4 Histograms from trends of low streamflow

Table 14 Results of the influence of the altitude to low flows

Months	Altitude up to 800 m asl.		Altitude up above 800 m asl.	
	Trend	Magnitude	Trend	Magnitude
IX – November	H_0 – no exist	−0.01533	H_0 – no exist	−0.00597
X – December	**H_1 – exist**	−0.02566	**H_1 – exist**	−0.01062
I – January	**H_1 – exist**	−0.01353	**H_1 – exist**	−0.00805
II – February	**H_1 – exist**	−0.01459	**H_1 – exist**	−0.00306
III – March	**H_1 – exist**	−0.01673	**H_1 – exist**	−0.01767
IV – April	H_0 – no exist	−0.00865	**H_1 – exist**	−0.00604
V – May	**H_1 – exist**	−0.01287	H_0 – no exist	0.002033
VI – June	**H_1 – exist**	−0.01153	**H_1 – exist**	−0.0126
VII – July	**H_1 – exist**	−0.0082	H_0 – no exist	−0.00209
VIII – August	H_0 – no exist	0.00078	H_0 – no exist	0.00646
IX – September	H_0 – no exist	−0.00287	H_0 – no exist	0.002704
X – October	**H_1 – exist**	−0.00384	H_0 – no exist	−0.00164

Bold values: Significance level is 95%

Table 15 Results of the influence of the slope of the river basin to low flows

Months	Basin slope up to 15°		Basin slope above 15°	
	Trend	Magnitude	Trend	Magnitude
IX – November	H_0 – no exist	−0.01239	H_0 – no exist	−0.01193
X – December	**H_1 – exist**	−0.02265	**H_1 – exist**	−0.01549
I – January	**H_1 – exist**	−0.01272	**H_1 – exist**	−0.00903
II – February	**H_1 – exist**	−0.0108	**H_1 – exist**	−0.01089
III – March	**H_1 – exist**	−0.01463	**H_1 – exist**	−0.02371
IV – April	H_0 – no exist	−0.00381	**H_1 – exist**	−0.01885
V – May	**H_1 – exist**	−0.00781	H_0 – no exist	−0.00852
VI – June	**H_1 – exist**	−0.00972	**H_1 – exist**	−0.01786
VII – July	H_0 – no exist	−0.00315	**H_1 – exist**	−0.01466
VIII – August	H_0 – no exist	0.005789	H_0 – no exist	−0.0061
IX – September	H_0 – no exist	0.000586	**H_1 – exist**	−0.00557
X – October	H_0 – no exist	−0.00157	**H_1 – exist**	−0.0074

Bold values: Significance level is 95%

on physicogeographical parameters by the regression analysis. We have determined the type of the regression function inductively, based on the empirical dependence of the evaluated values in the graph. We have evaluated the relative total amount of water in the river basin for the period 1975–2010 and the altitude/slope of the river basin. The grouping of points into a line or curve indicates that the relationship between the studied variables exists. The relationship is expressed by a coefficient of linear regression R. If R is less than ± 0.4 is an important relationship, R up to ± 0.7 means prognostic relation, and R up to ± 1 expresses a high degree of dependence, a functional relationship [5]. The evaluation of this analysis is shown in Figs. 5 and 6.

The linear regression dependence (Fig. 5) identifies that the increasing altitude increases the occurrence of low streamflows.

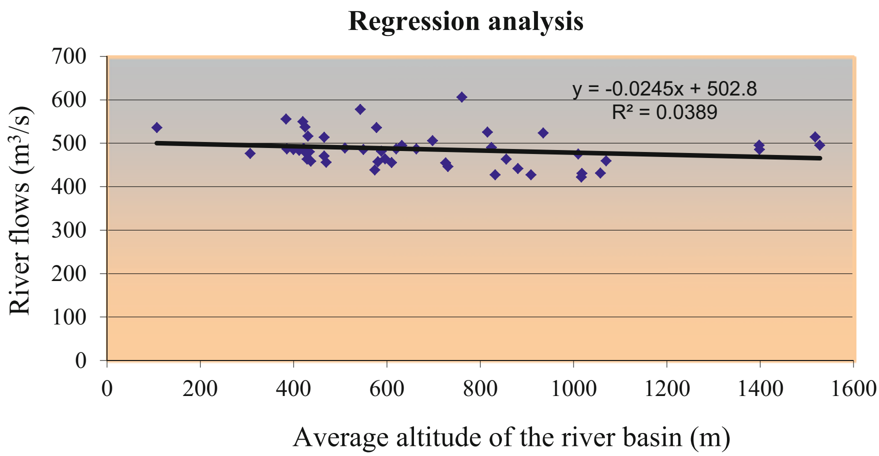

Fig. 5 Dependency of the altitude of the river basin and rate low streamflows

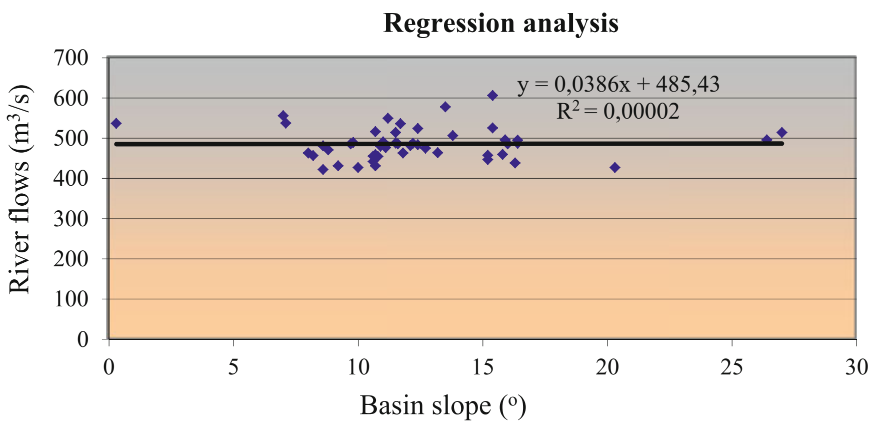

Fig. 6 Dependency of the slope of the river basin and rate low streamflows

Between the average slope of the basin and the relative amount of the streamflow, only a slight linear regression dependence is shown. With the increasing slope of the basin, the water quantity in the river stations increases only in a minimum.

It is important to note that in both cases (the dependency of the altitude and the slope of the river basin on the low flow), the regression analysis leads to a slight or almost no impact of the physicogeographical conditions of the basin on the low flow. The results were affected by taking into account (for simplicity) the total flow rate for the selected 36-year period. Unconstrained dependence can be obtained if only a proportionate amount of water per month of the evaluated period is taken as a variable and the regression analysis is performed for each month.

4.6 Spatial Analysis

The basis for the spatial analysis of hydrological drought analysis was the magnitude of the statistically significant flow trends obtained from the statistical analysis of the occurrence of trends in river stations. The spatial distribution map of the statistically significant trends for months during the year is shown in Fig. 7.

The spatial analysis was done for the period 1975–2010 and for each month separately by mapping the trend magnitude in the map of Eastern Slovakia. The maps were created using the kriging method in the ArcView GIS 10.2.

The results of the hydrological drought risk analysis confirm the more frequent occurrence of the low water season, especially in the locality of the Eastern Slovakia Lowlands.

A similar analysis can also be done for these parameters: temperatures, precipitation, and groundwater levels that significantly affect droughts. By covering all these maps, a comprehensive risk assessment of this phenomenon would arise.

5 Conclusion and Recommendations

Hydrological drought analyses in terms of streamflow deficits are said to be studies over a season or more extended time periods and in a regional context. A streamflow drought event definition quantitatively defines whether the flow can be regarded as being in a drought situation or not and gives the duration of a drought, whereas low flow indices characterize specific features of the low flow range.

The task of this chapter was to identify statistically significant trends in streamflow characteristics of low water content in Eastern Slovakia, which are used in the evaluation of hydrological drought. These data were obtained from the Slovak Hydrometeorological Institute, branch office Košice, at monthly intervals during the years 1975–2010. The methodology is based on statistical analysis of observed low streamflows at river stations. Mann-Kendall statistical test identifies the frequency of low streamflow trends. The hydrological drought is defined by a long-term decrease in levels of surface water bodies (e.g., rivers, lakes, reservoirs, and others) and drops in groundwater levels. Low water content is proof of this type of drought. Hydrological drought analyses in terms of streamflow deficits are said to be studies over a season or more extended time periods and in a regional context.

The main objective is to identify low streamflow trends in the selected 63-five river stations in Eastern Slovakia in the time interval from 1075 to 2010. The Mann-Kendall nonparametric test has been used to detect trends in hydrological time series. Some of streamflow records in rivers in Eastern Slovakia are affected by human activities, and another is without influence. Statistical tests can detect the existence of trends in hydrological time series. The purpose of the tests is to detect a statistically significant trend of decrease or increase of the low flow values. The nonparametric Mann-Kendall test has wide application in the testing of hydrometeorological characteristics. On the

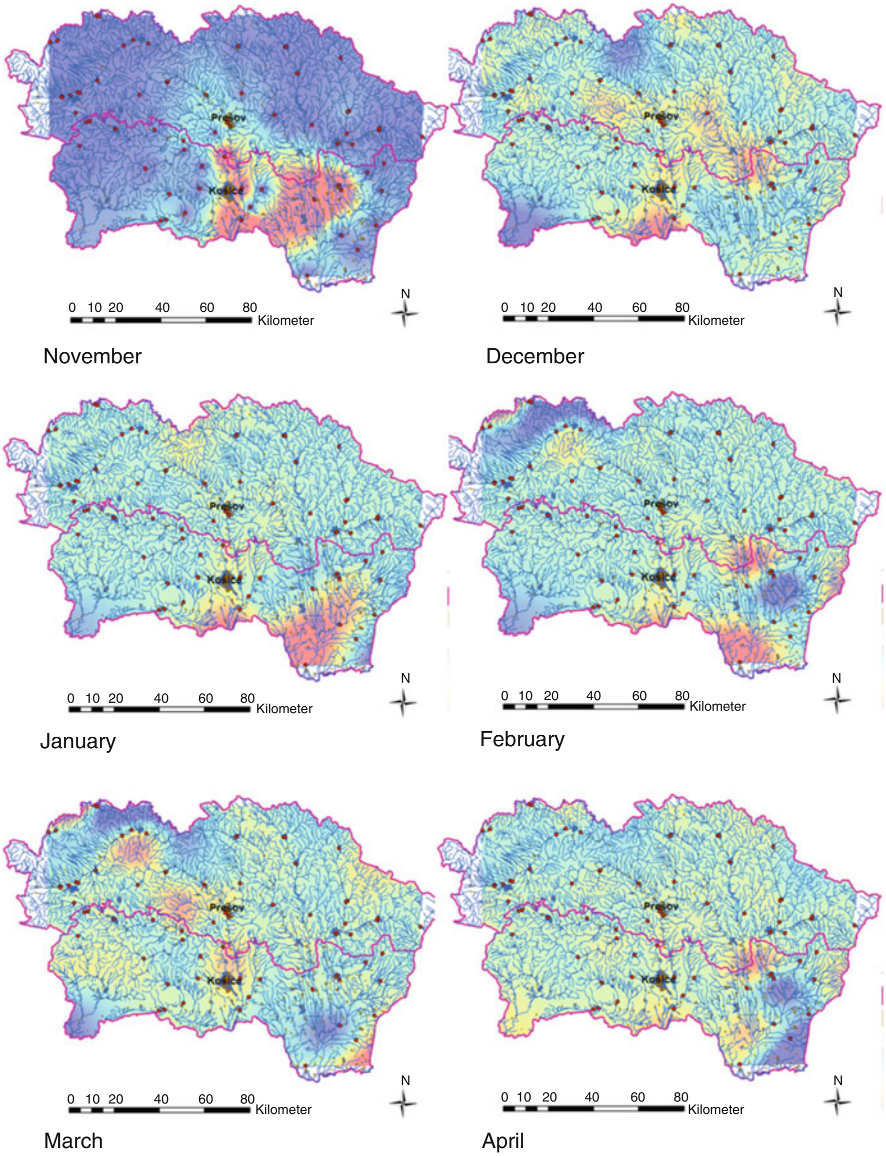

Fig. 7 Spatial distribution of the size of statistically significant trends in flows (*blue* color, wetter conditions; *red* color, drier conditions)

basis of the applied methodology, the existence of a trend in most of the evaluated river stations was not recorded. Only a small number of cases depict the decreasing trend in the time series of low flows. It was proven the slightly statistically significant impact of human activities for the hydrological regime of rivers.

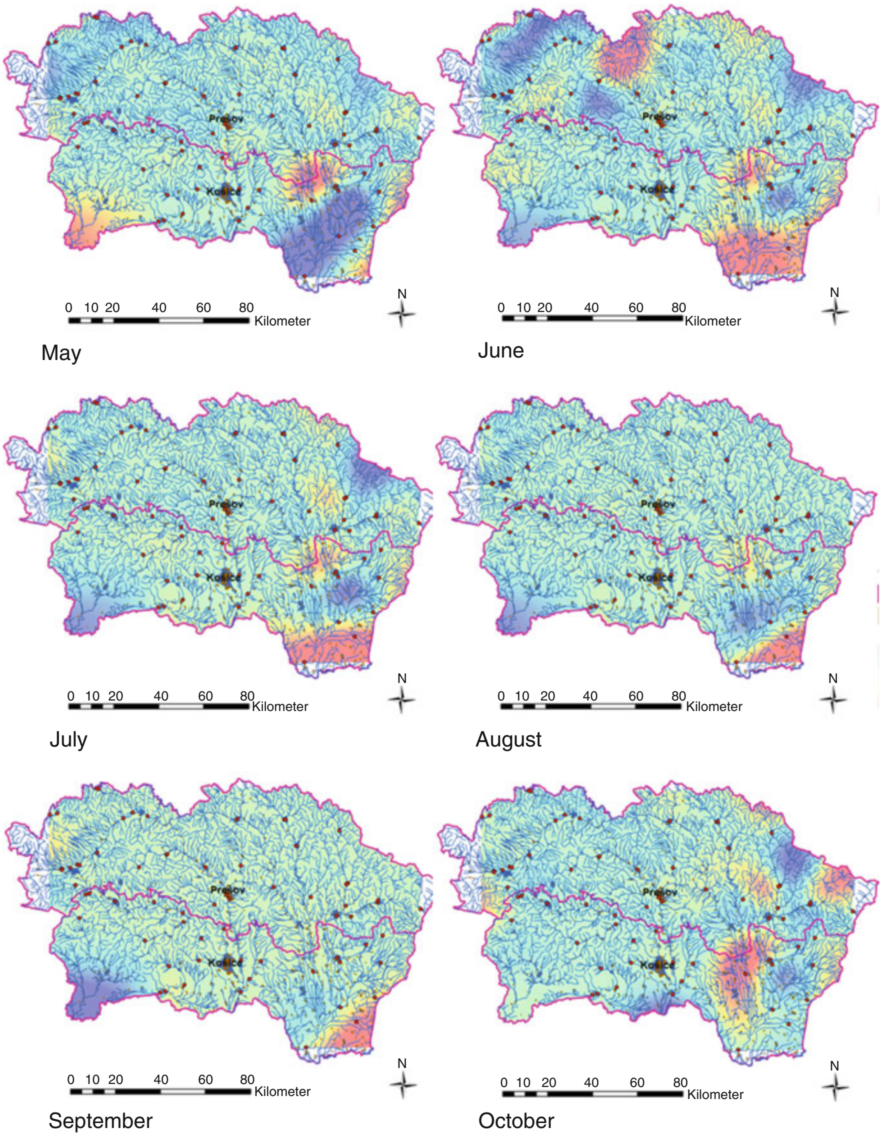

Fig. 7 (continued)

The results confirm the rising incidence trends of decreasing of low flows in the streams in Eastern Slovakia in river catchments Poprad, Hornád, Bodva, and Bodrog. Hydrological drought can be expected in almost summer months during the year – May, June, July, and August. In the complex vulnerability assessment of territory owing to drought, it is essential to take into account also the parameters as temperature, precipitation, and groundwater levels. Using ArcView GIS was created a graphical representation of hydrological drought risk regionalization in each month of the hydrological year.

Statistical tests can only indicate the significance of the observed test statistics and do not provide unequivocal findings. It is therefore essential to clearly understand the interpretation of the results and to corroborate findings with physical evidence of the causes, such as land use changes or river stations influenced by human activities. Changes in streamflow drought severity and frequency might occur as a result of changes in climate (mainly precipitation and temperature) and artificial influences in the catchment such as groundwater abstraction, irrigation, and urbanization [14]. Even so, low flow data are especially prone to artificial influences in a catchment, and the results presented in this paper may have been affected by this. The causes of a change in river flow behavior often do not have a simple explanation, and a further study would require a detailed analysis at the catchment scale, which is beyond the scope of this chapter. However, the spatial consistency in the results does indicate some systematic factors that can be evaluated at a qualitative, regional level.

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