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ANALYSIS OF TRENDS OF LOW FLOW IN RIVER STATIONS IN EASTERN SLOVAKIA

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Abstract

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The availability of using hypothesis test techniques to identify the long-term trends of hydrological time series is investigated in this study. The aim is to analyse trends of low flows at streams in eastern Slovakia, namely Poprad, Hornád, Bodva, Bodrog river basins. The article presents a methodology for prediction of hydrological drought based on statistical testing of low stream flows by non-parametric statistical test. The main objective is to identify low flow trends in the selected 63 river stations in eastern Slovakia. The stations with human impacts are also evaluated. The Mann-Kendall non-parametric test has been used to detect trends in hydrological time series. Statistically significant trends have been determined from the trend lines for the whole territory of eastern Slovakia. The results indicate that the observed changes in Slovakian river basins do not have a clearly defined trend.

low flow, river station, trend analysis, Mann-Kendall test

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 (2004) classifies four basic types of drought, including: meteorological, hydrological, agricultural and socio-economic droughts. (Mishra, Singh, 2010). 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. Hydrological drought is a phenomenon which rise with 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 (Pelikán, Šlezingr, 2011). This type of drought is defined by long-term decrease in levels of surface water bodies (e.g. rivers, lakes, reservoirs) and drops in groundwater levels (Demeterová, 2008).

During the past decades, many parametric and nonparametric techniques for the detection of long-term trends in time series were developed and applied (Hirsch *et al.,* 1991). The non-parametric Mann-Kendall statistical test has been effectively and the most used to assess the significance of trend in hydrological time series.

A number of recent studies have identified trends in streamflows. Despite several reports on recent droughts in Europe, the non-parametric Mann–Kendall test and a resampling test for trend detection in the paper (Hisdal *et al.*, 2001) was showed that it is not possible to conclude that drought conditions in general have become more severe or frequent. The period analysed and the selection of stations strongly influenced the regional pattern. It was also proved in the study (Stahl *et al.*, 2010) that investigates streamflow trends in a newly-assembled, consolidated dataset of near-natural streamflow records from 441 small catchments in 15 countries across Europe. It elucidated spatial patterns and regional variability of streamflows trends. Trends were calculated by the slopes of the Kendall-Theil robust line for standardized annual and monthly streamflow, as well as for summer low flow and low flow timing.

Burn and Elnur (2002) utilizes the Mann–Kendall non-parametric test to detect trends in hydrologic variables for Canadian catchments. There were found differences in the geographic location of significant trends.

Kapor (2000) analyzed the time series of hydrological data from 30 hydrological stations, which have a series of at least 50 years in water bodies belonging to the Danube river basin in the Republic of Serbia. The results indicate that the observed changes do not have a clearly defined trend:

The aim of this contribution is to demonstrate statistical analysis of low flows in rivers for the purpose of evaluating the long-term trend in the strength of stream flows in some catchment areas in the eastern part of Slovakia.

MATERIALS AND METHODS

Study area

Study area, as was mentioned, is situated in the eastern part of Slovakia (Fig. 1). In this territory 63 river stations are located (Tabs. I–IV). Evaluated stations are divided at stations affected by human activity and without human influence. The affected river stations (marked in the tables in grey) are considered as a station where the hydrological regime altered the flow by interference of human activities (by water works, by excessive water abstraction, etc.).

Data series of at least 36 years have been evaluated.

Basic statistical characteristics of the data files

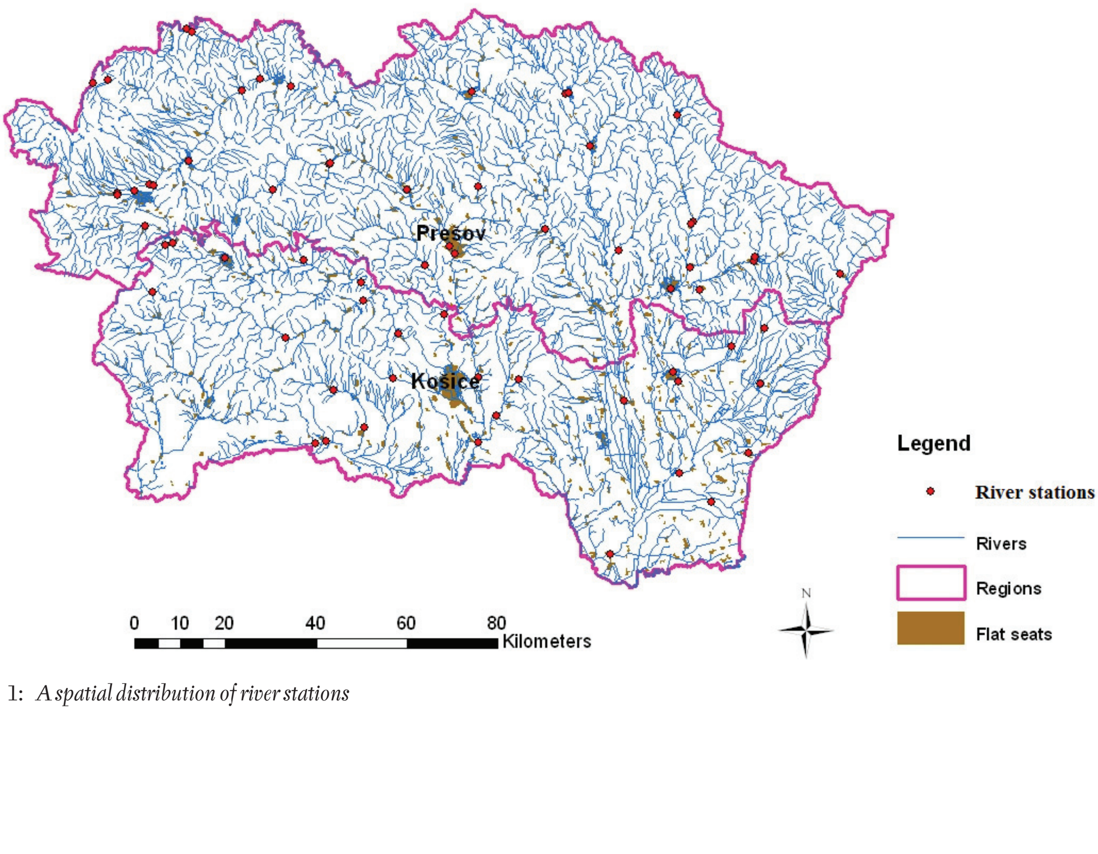
There are many statistical methods for data evaluation. The most of useful is the non-parametric Mann-Kendall test. This analysis was carried out for statistical data from 63 evaluated river stations. These data were obtained from the Slovak Hydrometeorological Institute, regional centre Košice, during the period marked in Tabs. II–V. Because the low flow data are not comparable for the individual stations, normally it is only possible to do the statistical analysis for each river station separately. In case it becomes necessary to evaluate the data from a group of stations, the problem of aggregation of data files must be dealt with, which is the aim of this paper.

First, it was necessary to find some basic characteristics of the entry statistical data files, above all mean, median, extreme values, kurtosis and skewness.

The mean is the average value of the data files. It is most useful value in statistical analysis generally.

The median is the middle value of the ordered statistical data file, e.g. it is the value which divides the (already ordered) data file into two parts exactly. The median is not affected by loading of the extreme values (in contrast to the mean) and is a more useful characteristic than the mean in statistical analysis of low flows.

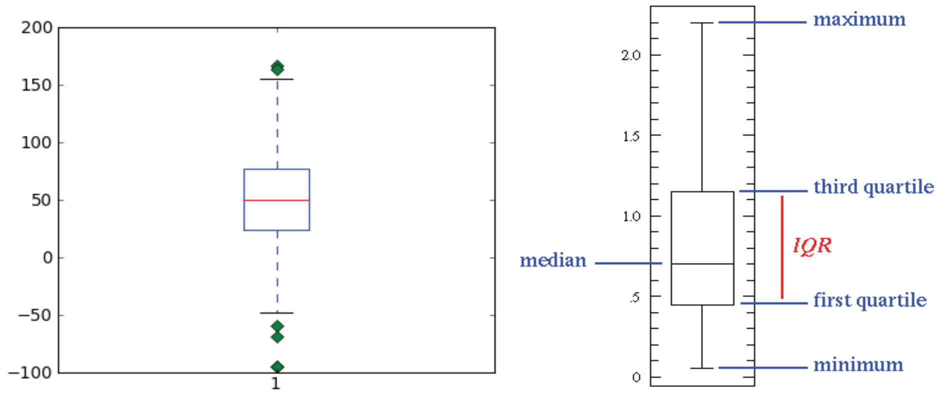
The existence of extreme values in the data file may be determined e.g. using the Box plot method. Another method known as the cutting mean leads to reduction of the original file, but without exact rules (Štipkala, 2009). The Box plot method is based on creating a so-called Box graph. This graph is the best possibility for geometrical visualisation of the distribution of random variables in some groups. These groups are created after ordering the data in the file between the extreme values, minimum and maximum. There are four groups created in this method. Each group has an identical number of data, and in mathematical statistic this is called a quartile. Tab. I shows a file divided using quartiles schematically.



1: *A spatial distribution of river stations*

I: *A quartile type of divided file*

Minimum is the smallest value. Lower quartile Q1	Median Q2 divides values into two equal parts		Maximum is the biggest value. Upper quartile Q3
	Median of the lower part	Median of the upper part	
25% of the data	25% of the data	25% of the data	25% of the data
	Interquartile range IQR, determined as the difference between Q1 and Q3		



2: *An example of a Box graph*

The Box graph describes the occurrence of extreme data (so-called "outlet" data). They are presented as rectangles in Fig. 2. Next, in Fig. 2 it is possible to see other important values, such as the median, quartiles (lower and upper) and the interquartile range (IQR). The maximum is represented by the 75th percentile + 1.5 × IQR, and the minimum by the 75th percentile – 1.5 × IQR. All data lying outside this interval are extreme (outlet).

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 greater 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 all of data files show Log-normal distribution of low flow values with large positive coefficients for both skewness and kurtosis.

Mann-Kendall test

A statistical hypothesis is an assumption about the distribution of a random variable generally. A statistical test of the hypothesis is a procedure which is used to find out whether we may "not reject" ("accept") the hypothesis, that is, act as though it is true, or whether we should "reject" it, that is, act as though it is false.

The Mann-Kendall test is a non-parametric statistical test. That means that we needn't make any assumptions about distribution of the random variable. This statistical test has a variety of applications for trend analysis (Kendall, 1975; Santos *et al.*, 2007). Its results are relevant as long as $10 \le n$ (n – range of the file). Only in this case can the Mann-Kendall statistic have a Normal distribution (Önöz, Bayazit, 2003). The data must be ordered chronologically in terms of one or more criteria. This test is based on the calculation of a special statistical value S. Comparing each of the couples y_i, y_j, $(i > j)$ of the random value Y, it is possible to determine if $y_i > y_j$ or $y_i < y_j$. Let's define the number of the first type as P and of the second type as M. Now S can be defined as (Önöz, Bayazit, 2003):

$$S = P - M. \quad (1)$$

The next Mann-Kendall statistic Z has a Normal distribution, where (Kendall, 1975):

$$\begin{aligned} Z &= (S-1)/\sigma_s^{1/2} && \text{if} \quad S > 0 \\ Z &= 0 && \text{if} \quad S = 0 \\ Z &= (S+1)/\sigma_s^{1/2} && \text{if} \quad S < 0. \end{aligned} \quad (2)$$

The deviation σ_s is defined as:

$$\sigma_s = n\,(n-1) \times (2n+5)\,/18, \quad (3)$$

where

n .... is the number of samples.

The hypothesis H0: no trend "not reject", if $Z < Z_{\alpha/2}$ or "reject" if $Z > Z_{\alpha/2}$. The value α is called the significance level; we choose α = 0.05. The calculation of probability of normalized Z test statistics is done using the application of the standard normal distribution, which is basically given by the following expression:

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}} . \qquad (4)$$

Moreover, the value of Z gives further information about any increasing or decreasing of the trend, but not its magnitude exactly (Önöz, Bayazit, 2003; Santos *et al.*, 2007).

All calculations, both of the basic characteristics of the entry data and of the testing of the samples were done using VisualBasic on the Microsoft Excel platform.

RESULTS AND DISCUSSION

Basic statistical characteristics of the data files are presented in following Tabs. II–V.

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 greater than the adopted level of significance. Conversely, when the normalized test statistics Z is positive and obtained probability is greater than the adopted level of significance, it is considered that there is a increasing trend. If the obtained probability is less than the adopted level of significance, it is accepted that there is no trend (Kapor *et al.*, 2011).

II: *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

III: *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

No.	Station	Period			Kurtosis	Skewness	Median	Number of extreme values
		from	to	total				
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

IV: *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

V: *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

The results of calculations of a possible existence of the trend using the Mann-Kendall test at river stations on the territory of eastern Slovakia in river basins Poprad, Hornád, Bodva, Bodrog are presented in Tabs. VI–IX (stations affected by human activities are marked in grey).

The results of analysis of a possible trend shown in Tabs. VI–IX indicate that it is not possible to determine with reasonable certainty, the existence of trend in time series of low flows at evaluated river stations.

There have been detecting trend in sixteen river stations which is 25% of all river stations. In ten river stations have appeared a decreasing trend (marked in Tables in Bold) of low flows mainly in the smallest river basin – Bodva. In six cases from the entire river stations have been found an increasing trend of low stream flows.

It is interesting that at seven river stations (50%) from a total of fourteen 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 large Ružín dam. At the remaining seven stations there is no trend, based on the results of the test.

On the basis of the methodology applied the existence of 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 slightly statistically

VI: *Results of the trend analysis in Poprad basin*

No.	Mann Kendall (S)	Normalized (Z)	Probability	Trend 95% significance
1	–71	0.846781	0.860592	no
2	62	0.52581	0.826238	no
3	106	1.098869	0.890911	no
4	127	1.318643	0.916361	no
5	162	1.574953	0.942275	no
6	–196	1.733168	0.955567	**decreasing**
7	253	2.239786	0.983758	increasing
8	193	1.655008	0.949276	no
9	93	1.112912	0.892592	no
10	34	0.431603	0.818223	no
11	188	2.262115	0.984554	increasing
12	–423	1.753268	0.957097	**decreasing**

VII: *Results of the trend analysis in Hornád basin*

No.	Mann Kendall (S)	Normalized (Z)	Probability	Trend 95% significance
13	–107	1.003624	0.879423	no
14	20	0.213407	0.80497	no
15	–7	0.072581	0.801003	no
16	47	0.556456	0.829096	no
17	78	1.048809	0.884886	no
18	107	1.282268	0.912309	no
19	–180	1.232209	0.906613	no
20	–886	3.676876	0.999769	**decreasing**
21	–624	2.588355	0.992998	**decreasing**
22	10	0.11771	0.801856	no
23	–243	0.969078	0.875243	no
24	98	1.321227	0.916645	no
25	–141	1.760067	0.957606	**decreasing**
26	–31	0.377157	0.814176	no
27	–66	0.730076	0.847156	no
28	–140	1.747495	0.956661	**decreasing**
29	–11	0.083649	0.801175	no
30	–36	0.145413	0.802577	no
31	15	0.176007	0.803545	no
32	–110	1.066273	0.886992	no
33	32	0.237792	0.80604	no

VIII: *Results of the trend analysis in Bodva basin*

No.	Mann Kendall (S)	Normalized (Z)	Probability	Trend 95% significance
34	–493	2.494272	0.991107	**decreasing**
35	–179	1.685331	0.951781	**decreasing**
36	–127	1.318643	0.916361	no
37	–90	0.870626	0.863418	no
38	–239	2.49077	0.991029	**decreasing**

IX: *Results of the trend analysis in Bodrog basin*

No.	Mann Kendall (S)	Normalized (Z)	Probability	Trend 95% significance
39	–106	1.430194	0.928249	no
40	–58	0.776391	0.852396	no
41	–51	0.418243	0.817188	no
42	–64	0.858116	0.861933	no
43	197	1.462239	0.931499	no
44	–16	0.204313	0.8046	no
45	147	1.221269	0.905351	no
46	–32	0.313542	0.810049	no
47	16	0.129298	0.802139	no
48	–46	0.505437	0.824403	no
49	572	4.035562	0.999942	increasing
50	–97	1.1613	0.898342	no
51	230	1.460546	0.931329	no
52	–284	2.000112	0.973004	**decreasing**
53	–126	1.403992	0.925535	no
54	–52	0.694666	0.843251	no
55	216	1.371255	0.922074	no
56	–40	0.394456	0.815412	no
57	64	0.261744	0.807197	no
58	40	0.336174	0.81144	no
59	–162	1.574953	0.942275	no
60	–82	0.819255	0.857359	no
61	466	3.469087	0.999514	increasing
62	773	3.207399	0.998836	increasing
63	332	2.111094	0.978511	increasing

significant impact of human activities for the hydrological regime of rivers.

Statistical tests can only indicate the significance of the observed test statistics and do not provide unequivocal findings. It is therefore important 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 (Hisdal *et al.*, 2001). 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 riverflow behaviour 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 paper. However, the spatial consistency in the results does indicate some systematic factors that can be evaluated at a qualitative, regional level.

SUMMARY

The paper presents the problem of drought and describes its classification and methods of assessing this risk. The goal of paper is the assessment of the extreme hydrological phenomena - drought, in the recent years, in the territory of eastern Slovakia. The task of this paper is to identify statistically significant trends in stream flow characteristics of low water content in eastern Slovakia, which are used in the evaluation of hydrological drought. Methodology for evaluating hydrological drought is based on statistical analysis of observed low stream flows at river stations. Mann-Kendall statistical test identifies the frequency of low stream flow trends. The hydrological drought is defined by long-term decrease in levels of surface water bodies (e.g. rivers, lakes, reservoirs and other) and drops in groundwater levels. Low water content is proof of this type of drought. Hydrological drought analyses in terms of stream flow deficits are said to be studies over a season or longer time periods and in a regional context.

The article presents a methodology for prediction of hydrological drought risk based on statistical testing of flow characteristics of low water content (annual stream flow) by non-parametric statistical test. The main objective is to identify low stream flow trends in the selected 63-five river stations in eastern Slovakia in the time interval till year 2010. The Mann-Kendall non-parametric test has been used to detect trends in hydrological time series. Some of stream flow records in rivers in eastern Slovakia are affected by human activities and another are 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. Non-parametric Mann-Kendall test doesn't make assumption on the probability distribution of random variable. It has wide application in testing of hydro-meteorological characteristics.

The results confirmed not significant rising incidence trends of decreasing of low flows in the streams in eastern Slovakia (in ten from all sixty-three river stations was found decreasing trend). In the complex vulnerability assessment of territory owing to drought is essential to take into account also the parameters as temperature, precipitation and groundwater levels.

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