Assessment of low flows occurrence in chosen river stations in Slovakia

MARTINA ZELEŇÁKOVÁ
Department of Environmental Engineering
Technical University of Košice
Vysokoškolská 4, 042 00 Košice
SLOVAKIA
martina.zelenakova@tuke.sk

PAVOL PURCZ
Department of Applied Mathematics
Technical University of Košice
Vysokoškolská 4, 042 00 Košice
SLOVAKIA
pavol.purcz@tuke.sk

TATIANA SOĽÁKOVÁ
Department of Environmental Engineering
Technical University of Košice
Vysokoškolská 4, 042 00 Košice
SLOVAKIA
tanik@post.sk

DOROTA SIMONOVÁ
Slovak Hydrometeorological Institute
Ďumbierská 26, 042 00 Košice
SLOVAKIA
dorota.simonova@shmu.sk

Abstract: - Hydrological drought is defined by long-term decrease in levels and flows of water bodies. The task of this paper is to analyze and identify statistical trends of low flows in streams in the eastern Slovakia. Methodology for evaluating hydrological drought is based on statistical analysis of observed low stream flows at chosen river stations – annual and seasonal. Mann-Kendall statistical test identifies the frequency of low stream flow trends in seasons. Obtained results from the statistical analysis of low stream flows can be the basement for hydrological drought risk assessment.

Key-Words: - Hydrological time series, eastern Slovakia, low flows, statistical analysis, trends, drought

1 Introduction

Changing climate and growing human water demand affect the intensity, duration and frequency of low flows and droughts and thus the water availability worldwide. Seasonal recurring low flows in rivers and sporadically occurring droughts are the most crucial limiting factors for the satisfaction of human and environmental water demands [1], [2]. Statistical analysis of hydrological and meteorological time series is an important and popular tool for better understanding the effects of climate variation [3], [4], [5]. It is performed with goal to know the trends in space and time distribution of rainfall which helps to reduce the impacts of droughts and floods [6], [7].

Many studies have given a great deal of attention to the potential impacts of climatic change and variability. Several of them are focused on low flows mainly local-scale and droughts and related indicators.

Over the past 40 years, Europe has been affected by a number of major droughts, most notably in 1976, 1989, 1991, and more recently in 2003 and 2005. The study [8] investigates streamflow trends in a newly-assembled, consolidated dataset of near-natural streamflow records from 441 small catchments in 15 countries across Europe. It was proved that the analyzed period and the selection of stations strongly influenced the regional pattern. The last study [9] presents that river flow droughts are projected to increase in frequency and severity in southern and south-eastern Europe, the United Kingdom, France, Benelux, and western parts of Germany over the coming decades.

Differences in the geographic location of significant trends were found in [10]. This study used the Mann–Kendall non-parametric test to detect trends in hydrologic variables for Canadian catchments. Douglas et al. [11] were evaluated trends in low flows in the US using also Kendall's trend test.

The Mann-Kendall test is example of non-parametric tests that are applied for the detection of trends in many studies and is widely used in hydrology science [3], [7], [12], [13], [14], [15], [16], [17], [18], [19], [20] etc. In this study non-parametric Mann-Kendall test is also used for the detection of the trend in a time series after the statistical analysis and assessment of low flow occurrence in chosen river stations in Slovakia.

Studies of water scarcity and drought occurrence are essential for decision makers in order to prevent an aggravation of water stress [1].

2 Material and methods

2.1 Study area

Study area is situated in the eastern part of Slovakia. In this territory 63 assessed river stations are located (Fig. 1). Some of evaluated stations are affected by human activity. The affected river stations 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.).

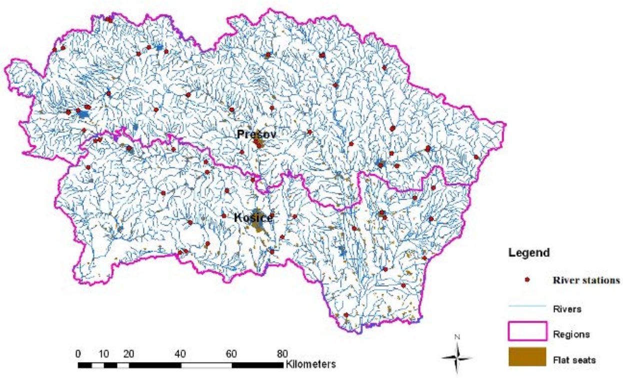

Fig. 1. A spatial distribution of river stations in eastern Slovakia

Hydrological data – monthly low flows in river stations in river basins – Hornád, Poprad, Bodrog and Bodva in eastern Slovakia in period 1975-2010 were provided by Slovak Hydrometeorological Institute Regional Centre Košice.

2.2 Statistical analysis

Hydrological time series were assessed by statistical methods as well as non-parametric Mann-Kendall test. Mann-Kendall test [21], [22] is statistics based on standard normal distribution. The significance level is chosen as $\alpha = 0.05$ and $Z_{\alpha/2}$ is the value of normal distribution function, in this case $Z_{\alpha/2} = 1.95996$. Hypothesis H0 - no trend is if ($Z < Z_{\alpha/2}$) and H1 - there is a trend if $Z > Z_{\alpha/2}$. Positive values of Z indicate increasing trends, while negative values of Z show decreasing trends.

The magnitude of the trend was determined using Sen`s estimator [23]. Sen's method assumes a linear trend in the time series. In this method, the slopes (β) of all data pairs are first calculated by median. A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

Some of the obtained results are presented in [7] and in the following.

3 Results and discussion

The results of statistical analysis of hydrological series of low flows in chosen river station in eastern Slovakia are discussed in the following. The results proved the statements published in [24] although the different methods were used. This study of analysis of water balance in drought year with a new flow limits was published in 2010 by Slovak Hydrometeorological Institute [24]. It deals with low water content in Slovak rivers till 2006. The results for river basins – Hornád, Poprad, Bodrog and Bodva in period 1975-2010 are presented below.

The longest range of flow in the Hornád river basin best demonstrated the fact that in evaluating of the occurrence of extreme hydrological characteristics must be given priority to an objective assessment of long-term hydrological series against subjective perception. Despite the use of water resources in river basins of Torysa and Slavkov stream in recent years, the incidence of low flows essentially binds to the first half of the observation period, respectively in 1974. In this year, the smallest monthly flow occurred in March. Absolute minimum flow occurred on 11th July 1968.

Minimum monthly flows in August, September and October were in 1947. In the other stations in Hornád river basin the absolutely minima flow occurred in different years, the predominant occurrence were in the summer and autumn months, especially in July. In gauging stations with shorter hydrological series the minimal flows occurred in the years 2002, 2003, 2006 and 2007.

In the vast majority of Poprad river basin streams rise in the High Tatras mountains. These streams have significant minimum flow in the winter months, so the occurrence of low flows occurs from November to March. The smallest average daily flow in Matejovce, Poprad river, gauging station with long low flow series, was experienced in the first half of March 1987, in Chmelnica, Poprad river in February of the same year. In addition in Ľubica river station in Kežmarok the smallest average daily flow occurred in October 1986. For all other streams in Poprad river basin is the occurrence of a minimum flow in the winter months.

For Bodrog river basin is the same finding, as to the method of assessing the extremes, such as in Hornád river basin. In gauging station with the longest hydrological series of low flows and no significant effect on the flow, in Hanusovce river station, Topla river, the lowest average daily flow occurred on 27th August 1947. Consequently, there are the occurrence of minimum monthly flows in Topla river in May and August in January and October 1948. In other gauges, the lowest average daily flow occurred in different years, and we find the three stations, in which the minimum occurred in the same year. The origin is clearly dominated by the occurrence of minima in summer-autumn period instead of occurrence during the winter.

Bodva river basin is strongly influenced by water use, and for this reason the absolute minima flow occurs in different months of the year, and in each gauging station of the catchment area is minimum occurred in another year. In station with the longest hydrological series the lowest average daily flow occurred on 20th December 2000.

The evaluation of low flows occurrence in chosen river stations in Slovakia in the presented paper was done for the time period from November to October. Data series for 36 years period from 1975 to 2010 in eastern Slovakia was considered for trend detection.

Course of low flows in chosen river basins are presented in Figures 1 to 4. Flows in streams in Hornad, Bodrog and Bodva river basins present decreasing trend in low flows. Flow in Poprad basin is slightly increasing.

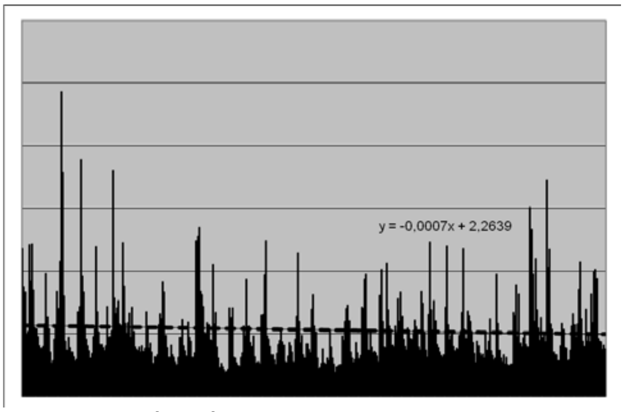

Fig. 1 Course of low flows in Hornad river basin

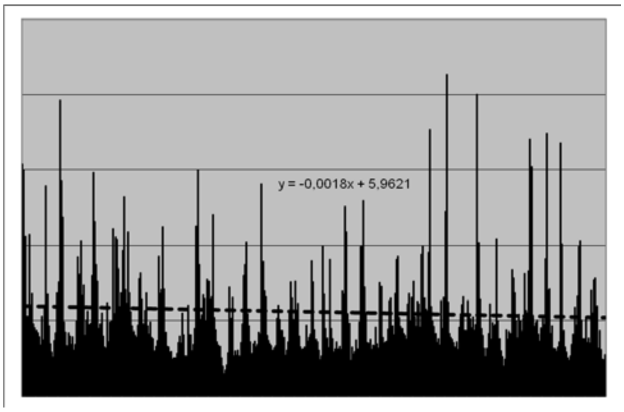

Fig. 2 Course of low flows in Bodrog river basin

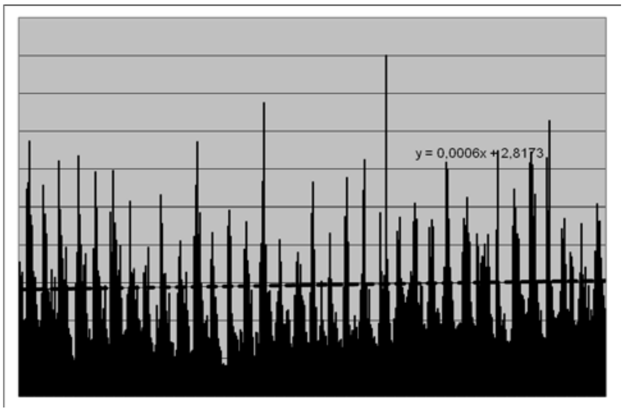

Fig. 3 Course of low flows in Poprad river basin

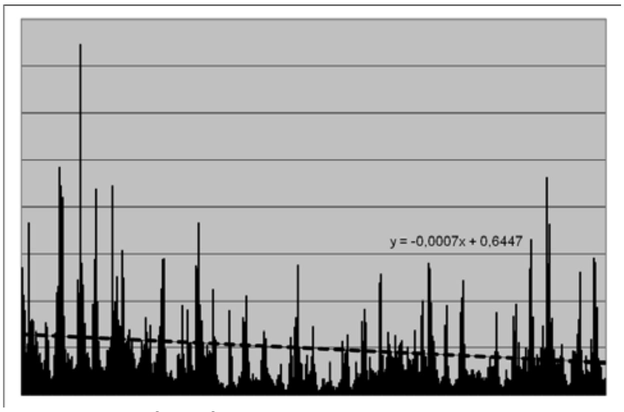

Fig. 4 Course of low flows in Bodva river basin

Statistical analyses of low flows in seasons are presented in Figures 5 to 8.

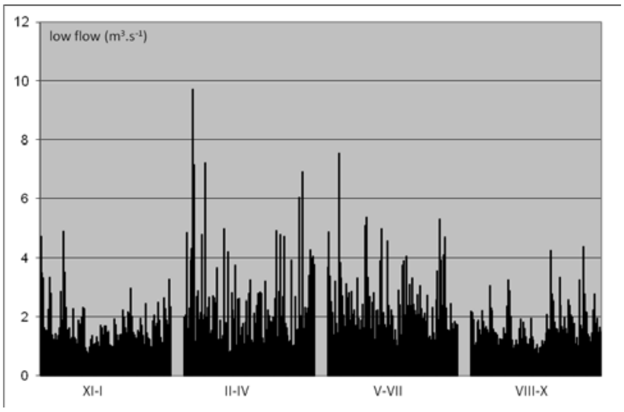

Fig. 5 Seasonal low flows in Hornad river basin

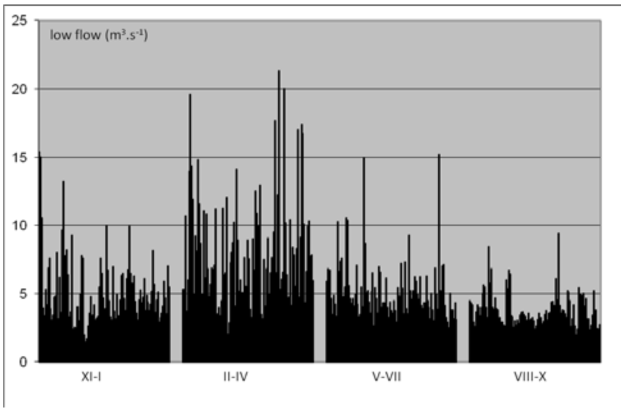

Fig. 6 Seasonal low flows in Bodrog river basin

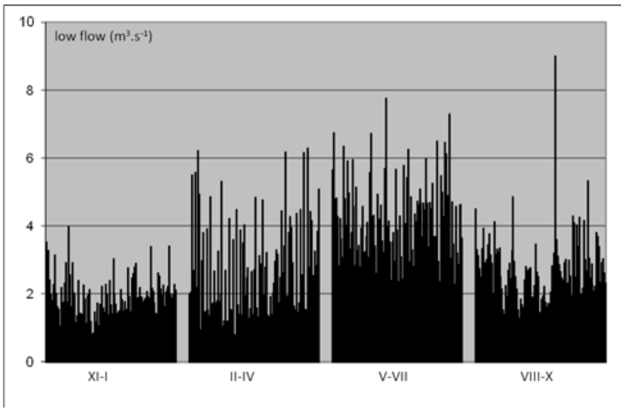

Fig. 7 Seasonal low flows in Poprad river basin

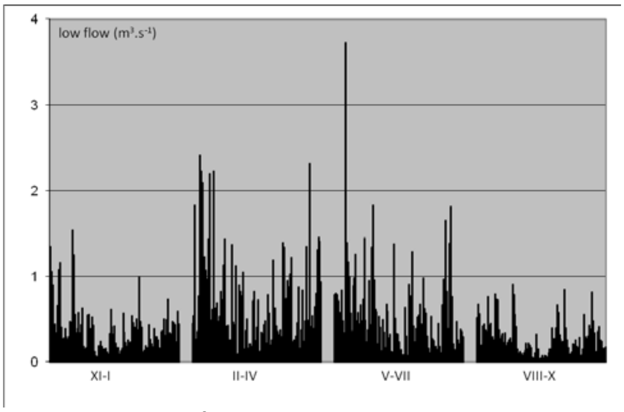

Fig. 8 Seasonal low flows in Bodva river basin

Hornad river basin (Figure 5) shows increased low flows mainly in spring and summer time. Decrease in low flows occurs in autumn and winter season.

Bodrog river basin (Figure 6) shows a little different course when the lowest value of the minimum flow rate is located between July and October.

Period of increased low flows in Poprad river basin (Figure 7) is most visible in the period from March to July. In autumn and winter months – from August to February is significant decrease in low flows in this mountainous area.

Bodva river basin (Figure 8) shows mostly stable values of low flows during seasons. Increased but also more unstable flow values we can observe especially from March to June. In this period were also observed individually extremely high values.

Low flow data were assessed also by statistical test in evaluated seasons. The trend was proved by nonparametric Mann Kendall test. Tables I.–IV. present number of statistical trends in river stations – decreasing, increasing or no trend in the season – XI-I (winter), II-IV (spring), V-VII (summer), VIII-X (autumn) during the hydrological year for river basins – 63 river stations in the eastern Slovakia.

Table I Number of trends in Hornad river basin

	XI-I	II-IV	V-VII	VIII-X
1	**0,002111**	**0,001568**	0,001345	**0,003175**
2	0,001575	-0,00028	-0,00183	**0,00304**
3	**0,001614**	**0,001373**	0,00036	**0,002224**
4	0,002393	0	-0,00358	**0,003592**
5	**0,002075**	**0,00203**	**0,002384**	**0,002636**
6	0,003702	-0,00453	-0,00939	0,009938
7	0,000643	**0,001714**	-0,00077	0,0011
8	**0,0055**	0,002687	-0,0027	**0,0045**
9	-0,00231	-0,00893	**-0,01982**	-0,0011
10	**0,000323**	**0,0006**	0,000313	**0,000273**
11	-0,00457	-0,00989	-0,01309	-0,00052
12	**0,000659**	**0,000885**	**0,000795**	**0,000655**
13	-6,3E-05	0,000722	-0,00051	0,0004
14	**0,005631**	0,005206	-0,00026	**0,004102**
15	-0,00025	-0,00498	**-0,01081**	-0,00239
16	**0,000889**	0,000313	-0,00119	0,00069
17	0,001361	0	-0,00088	0,002042
18	-0,00418	**-0,01921**	**-0,02286**	-0,00516
19	0,000222	**0,000746**	-6,7E-05	0
20	0,000857	0,000654	-0,00103	0,000529
21	-0,00922	-0,01979	**-0,03902**	0,001952

Table II Number of trends in Bodrog river basin

	XI-I	II-IV	V-VII	VIII-X
1	8,33E-05	0,000119	**-0,00086**	-1,4E-05
2	**0,001281**	**0,0025**	0,000158	-0,00014
3	-0,00029	-0,00088	**-0,0048**	**-0,00207**
4	0,001203	0,002232	-0,00096	-0,00019
5	0,001535	-0,00122	-0,00069	**0,002808**
6	0,000227	0,000239	7,94E-05	-2,7E-05
7	**0,003463**	**0,004955**	**0,003857**	**0,003438**
8	**0,014**	-0,00112	-0,001	0,005303
9	-0,0034	-0,01062	**-0,01911**	**-0,00901**
10	**0,000479**	**0,000879**	0,000149	**0,000317**
11	-0,01073	0,023365	-0,0125	-0,01308
12	0,001218	**0,003365**	1,56E-05	0,000182
13	-0,01984	-0,01281	**-0,03517**	**-0,01751**
14	0,000696	0,00022	-0,00052	-0,0004
15	0,000596	0,001367	0,00075	0,000328
16	-0,01103	0,026957	**-0,0371**	**-0,03973**
17	-0,01711	-0,07099	**-0,08631**	**-0,04052**
18	**0,006121**	**0,006674**	-0,00014	0,00224
19	-0,00558	-0,0117	**-0,02039**	**-0,01023**
20	0,000699	**0,003511**	0,000222	**0,000837**
21	0,0008	**0,003396**	-0,00036	8,82E-05
22	-0,00259	-0,00284	**-0,00627**	**-0,00278**
23	**0,001486**	**0,003328**	0,000293	**0,001**
24	**0,027557**	0,027391	0,013258	**0,029107**
25	-0,091	-0,15394	**-0,18797**	**-0,08537**

Table III Number of trends in Poprad river basin

	XI-I	II-IV	V-VII	VIII-X
1	0	**0,002237**	-0,00161	-0,00481
2	-0,00082	0,000333	-0,00036	**-0,00322**
3	**0,001593**	**0,002791**	**0,00255**	**0,001508**
4	0,02191	0,036875	-0,01192	0,0105
5	-0,00056	0,000842	-0,00043	**-0,00139**
6	5E-05	0,000235	**-0,00135**	-0,00039
7	0,000535	**0,001109**	**0,002073**	**0,00168**
8	0,000419	**0,001054**	**0,000891**	**0,000734**
9	**0,00219**	**0,003**	**0,0025**	**0,003241**
10	-0,0028	-0,00493	-0,01111	-0,00721
11	**0,001054**	**0,001877**	**0,000868**	**0,000554**
12	-0,00324	-0,00556	-0,01162	-0,00378

Table IV Number of trends in Bodva river basin

	XI-I	II-IV	V-VII	VIII-X
1	0,000473	-0,00011	-0,00092	-0,00035
2	0,000257	-0,00095	**-0,00285**	-0,00039
3	**0,000857**	0,000684	-0,00037	**0,000397**
4	-0,0017	-0,00373	**-0,0069**	-0,0023
5	-0,00031	-0,0007	**-0,00169**	-0,0005

It is clearly shown increasing trend (+) in low flows in almost all the river stations especially these situated in the north part of the country which is mountainous and in winter and spring season. Decreasing trend (-) is obvious in summer and autumn season, mostly in river stations situated in the plane areas and most of them are influenced by human activity (water extraction, dam constructions etc.). The results correspond with the trends of precipitation in the same area – eastern Slovakia, presented in [7].

The Mann–Kendall (MK) test [21], [22] is a rank-based nonparametric test for assessing the significance of a trend, and has been widely used in hydro-meteorological trend detection in many studies. In the Sen's method the slope of all the data points are calculated and their median value is the Sen's estimator of slope which determines magnitude of the trend.

4 Conclusion

The sustainable use of water is a priority question for regions and for agriculture and economic growth of the country in particular.

An important function in engineering hydrology is performed by trend analysis of low flows. In this study, statistical analysis and trends in low flow characteristics were analyzed for streams in eastern Slovakia. The task of this paper is to identify decreasing and increasing trends in stream flow characteristics of low water content, which could be used in the evaluation of hydrological drought. Methodology for evaluating hydrological drought is based on statistical analysis of observed low stream flows at gauging stations situated in different river basin. The evaluation has been done for seasons during the hydrological year in Slovakia. Mann-Kendall statistical test identifies the frequency of low stream flow trends.

Because the low flow data are not comparable for the individual stations, normally it is only possible to do the statistical analysis for gauging 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 was the aim of this paper. Results prove mainly increasing trend in low flows during the winter and spring season in the studied area and decreasing during the summer and autumn season.

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