RISCURI ŞI CATASTROFE, NR. XVII, VOL. 23, NR.2/2018

RECENT TRENDS IN THE LOW-FLOW VARIABILITY IN ROMANIA

I. TĂNASE[1], *Liliana ZAHARIA*[2]

ABSTRACT. – Recent trends in the low-flow variability in Romania
In the context of climate changes, knowing the low-flow trends is very important for establishing appropriate measures for water resources management, in order to ensure their sustainability. This paper focuses on Romanian rivers and aims to identify the recent trends (during the period 1980-2013) in the low-flow variability. The analysis is based on discharges data series (daily and monthly) recorded at 54 gauging stations, with a quasi-natural flow regime. The significance of trends for annual, monthly and seasonal low-flow in the analyzed period has been established using the nonparametric Mann-Kendall test.
The variability of the lowest annual values of the mean daily and monthly discharges showed positive trends at gauging stations located mainly in the Carpathian area, while negative trends were found in lowland regions (plains and tablelands). During the winter there were identified positive low-flow trends, while negative trends were found in summer and spring. Increases in the minimum monthly flow were particularly evident in February, March and December, and negative trends were identified especially in the summer (July, June and August) and the autumn months (September and October).

Key words: trend analysis, low-flow, natural regime, Mann-Kendall test, Romania.

1. INTRODUCTION

The report of the European Environment Agency states that the climate change in Europe leads to a radical alteration in the water cycle, resulting in an increase in summer droughts, floods during the winter periods and, implicitly, a greater variability in the annual water reserve (EEA, 2015). In the 21st century, drought is expected to intensify in some areas in Europe, Central and Northern America and Southern Africa (Seneviratne et al., 2012).

[1] National Institute of Hydrology and Water Management, Bucharest, Romania, e-mail: ileana.tanase@hidro.ro
[2] University of Bucharest, Faculty of Geography, Bucharest, Romania, e-mail: zaharialili@hotmail.com

Amplification of the drought phenomenon in the last decades has important impacts on low-flow and implicitly, on river water resources. The analysis of the low-flow and its trends is particularly useful for preparing actions aimed at reducing the negative effects of the water scarcity on social and economic activities, as well as on the ecosystems (Wilhite et al., 2014).

Low-flow may occur due to a reduced rainfall, high evapotranspiration or cold temperatures with freezing soils causing a delayed release of snow melt (Mauser et al., 2008). Lately, due to the climatic change, droughts tend to be longer lasting than floods in the same areas (Svensson et al., 2005). Accordingly, it is possible to occur severe low-flow conditions that can impose limitation regarding water resources, resulting in substantial financial loses. Therefore, low-flow analysis is an essential aspect of the water management and the reservoir storage design, determining minimum release policy and safe surface water withdrawals (Lee and Kil, 2007).

This paper focuses on Romania, aiming to investigate the trends in the variability of the rivers low-flow, in order to identify the possible impact of climate change on the low discharges and to give a scientific support for adapting the river management strategies to the identified trends.

The hydrological regime and implicitly the low-flow variability is strongly influenced by the climatic conditions in Romania, imposed by its geographic position, on one hand, and by the orography, on the other hand. As results of its location in Europe, Romania has a transition climate between temperate oceanic and continental with various regional influences (e.g. Mediterranean in the south-west and south, Baltic in the northern part, excessive continental in the east, marine in the south-east, etc.), reflected by the rivers flow regime. Romania's natural landscape is almost evenly distributed between mountains, hills and plains. A major role on the climate in Romania has the Carpathian mountain archwise chain (with the maximum altitude of 2544 m a.s.l.), occupying the central part of the country (fig. 1). The average annual temperature vary from 11°C in south and 8°C in north and the rainfall decreases from more than 1000 mm/year in Carpathians, to 400 – 500 mm and even less, in the plains. The annual precipitations also decrease from west to east by almost 300 mm (from 700 mm to less than 400 mm) (NAM, 2008). These variations are reflected by differences in the river flow regime.

Recent studies on climatic changes in Romania (e.g. Dumitrescu et al., 2014; Bojariu et al., 2015) showed for the period 1961-2013 warming tendencies annually, in spring, summer, and partially in winter. No significant trends in annual amount of precipitation were identified, but positive trends were founded for several stations in autumn (mostly in the central and western parts of Romania) and negative trends for some stations in the other seasons.

In Romania, the low-flow usually occurs in late summer when air temperatures and evaporation are high and precipitation is low, as well as in winter because of precipitation in the form of snow and freezing of the rivers. The streamflow trends are influenced by the recent climate changes (Bîrsan et al., 2012, 2014; Zaharia et al.

2018, etc.). For instance, Bîrsan et al. (2014) found predominantly upward trends in annual streamflow for low quantiles ($q_{0.1}$ to $q_{0.6}$), corresponding to low-flow and downward trends for upper quantiles (high flow). In Europe, some trends in low-flow were detected, as follows: decreasing trends in the northern half of Spain (Coch, Mediero, 2016) and some catchments from eastern UK (Hannaford, Marsh, 2006); not significant trends in eastern Slovakia (Zeleňáková et al., 2012).

The paper give new and original information which could be useful for improving the strategy on adaptation to climate change by appropriate measures to mitigate the effects of the water scarcity.

2. DATA AND METHODS

The study is based on the analysis of the flow data series (daily and monthly mean and minimum discharge) recorded at 54 gauging stations with a homogenous distribution, with a quasi-natural runoff regime (not influenced by major anthropogenic influences), during the period 1980-2013. The data series were provided by the National Institute of Hydrology and Water Management.

The stations were selected so that they cover all the country (fig. 1). The catchments corresponding to the gauging stations have variable areas (between 20-1500 km^2) and mean altitudes varying between 60-1600 m.

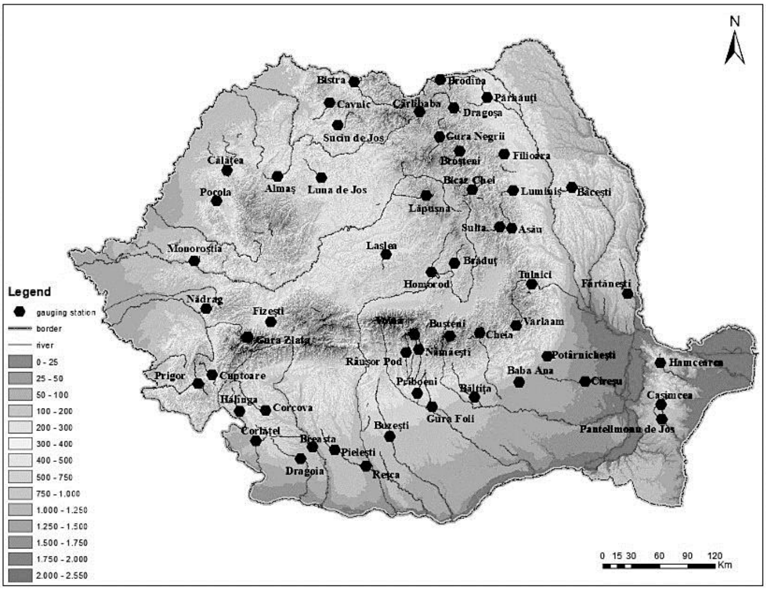

Fig. 1. The spatial distribution of the selected gauging stations

The trends and their significance were established using the nonparametric Mann-Kendall statistical test applied on daily, monthly and seasonal low flow, in the analyzed period.

The Mann-Kendall test is widely used to assess the significance of the trends in hydrological time series. It is a rank-based procedure, especially suitable for non-normally distributed data (Salas, 1993); the test is used for rendering the significance of a linear trend against the null hypothesis of "no trend". The statistic Z of the test enables us to compare the absolute value of Z to the standard normal cumulative distribution to detect a certain trend at a certain level of significance as follows: *** if the trend has 0.001 level of significance; ** if the trend has 0.01 level of significance; * if the trend has 0.05 level of significance; + if the trend has 0.1 level of significance and " " if the trend is insignificant (Mann, 1945; Kendall, 1975). Positive values of Z indicate upward trends, while negative values of Z indicate downward trends. The method enables the estimation of the magnitude of a trend. The identified trends were mapped using GIS (ArcGIS soft).

3. RESULTS AND DISCUTIONS

The analysis of trends in the variability of the annual minimum daily mean discharge showed the following results: 22% positive trends, mainly in Eastern Carpathians (fig. 2), 11% negative trends and no statistical significant trends for the most analyzed stations (67%).

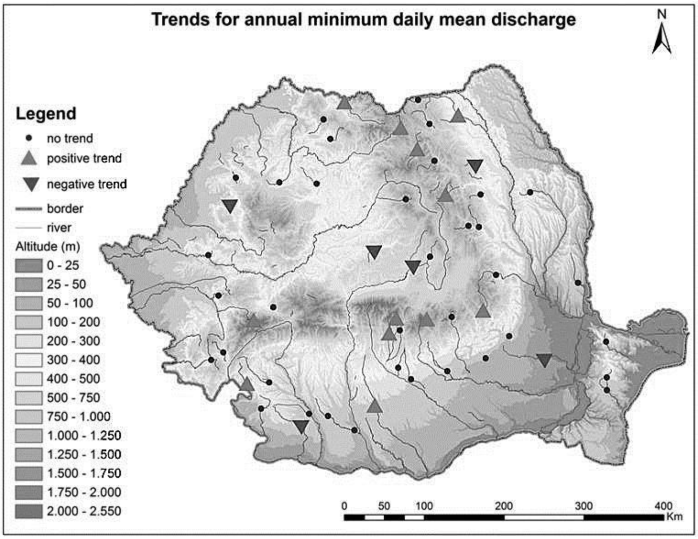

Fig. 2. Trends in the annual minimum daily mean discharge variability

As respects the variability of the annual minimum monthly discharge (instantaneous values), the Mann-Kendall test indicated: 22% positive trends (the most in Eastern Carpathians), 9% negative trends, while the most station (69%) had no trend (fig. 3). Concerning the variability of the annual minimum monthly mean discharge, the test detected 20% positive trends (mainly in Carpathian area), 17% negative trends (in eastern and southern parts of Romania) and 63% no significant trend (fig. 4).

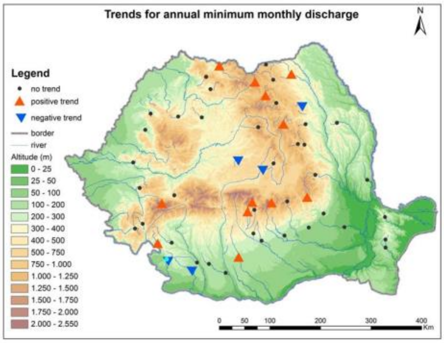

Fig. 3. Trends in the annual minimum monthly discharge variability

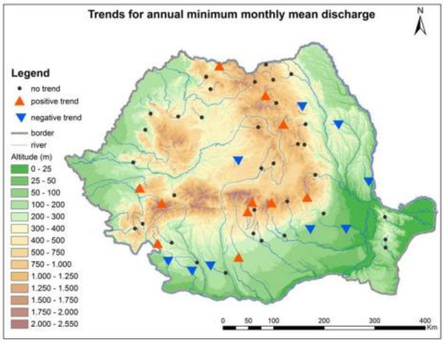

Fig. 4. Trends in the annual minimum monthly mean discharge variability

The analysis of the trends in the seasonal low-flow variability was performed using monthly mean flow data. In the winter period, the results showed positive trends in 20% of the cases (especially in Eastern Carpathians), negative trends in 13% of the cases, and no significant trend in 67% of the analysed gauging stations (fig. 5). During the spring, positive significant trends were identified in 9% of the cases, negative trends in 15% of the cases, and no trends in the most cases (76%) (fig. 6).

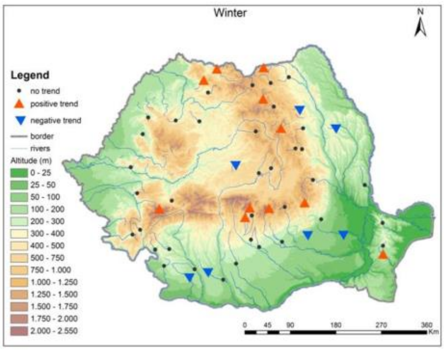

Fig. 5. Trends in the annual minimum monthly discharge variability during the winter

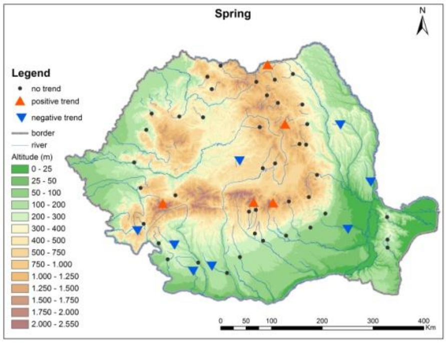

Fig. 6. Trends in the annual minimum monthly discharge variability during the spring

In the summer period, the results showed generally no trend (81% of the cases), positive trend in only 2% of the cases and negative trend in 17% of the cases (fig. 7). During the autumn, a relative balance was found between the positive and negative trends (11% and respectively 13% of the cases), but the most of the analyzed gauging stations (76%) had no trends (fig. 8).

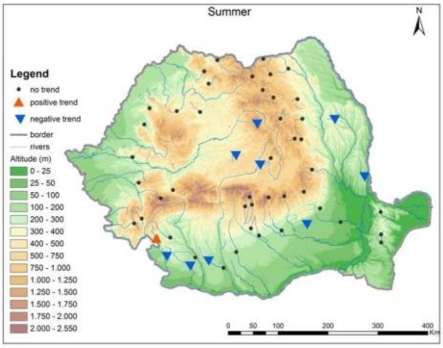

Fig. 7. Trends in the annual minimum monthly discharge variability during the summer

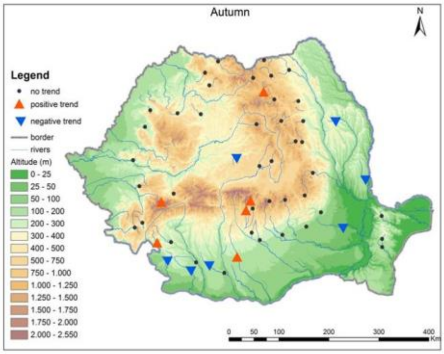

Fig. 8. Trends in the annual minimum monthly discharge variability during the autumn

In order to identify the months with the most significant trends, there were analyzed the values of the minimum flows considering the mean daily discharge every month for each hydrometric station. The Mann-Kendall test indicated increases in minimum monthly flow, particularly evident in winter months (mainly in February and December) and in March, probably reflecting seasonal shifts toward earlier spring melt and later autumn freeze-up, respectively (Table 1).

Table nr.1. Trends in the minimum monthly flow variability

No.	Gauging station	Month											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	Baba Ana												* ▼
2	Băcești				* ▼	+ ▼	** ▼	* ▼	* ▼	* ▼	** ▼		
3	Băile Homorod					** ▼		* ▼	* ▼	+ ▼	* ▼		
4	Bicaz Chei		+ ▲			+ ▼	* ▼						
5	Bistra		** ▲	+ ▲									
6	Brodina			* ▲									
7	Broşteni						+ ▼			+ ▼	* ▼		
8	Buşteni	* ▲	** ▲	** ▲									* ▲
9	Buzeşti	+ ▲	+ ▲				+ ▲	+ ▲	+ ▲	* ▲	** ▲	* ▲	** ▲
10	Cârlibaba		+ ▲	+ ▲		+ ▼		+ ▼					
11	Cavnic	* ▲	* ▲	+ ▲									
12	Corcova					+ ▼							
13	Corlaţel	** ▼		* ▼	+ ▼	** ▼	** ▼	*** ▼	*** ▼	*** ▼	** ▼	** ▼	* ▼
14	Cuptoare			* ▲		* ▼	+ ▼						

15	Dragoia	* ▼			* ▼	** ▼	** ▼	*** ▼	*** ▼	*** ▼	* ▼	+ ▼	
16	Fârţăneşti		* ▲								* ▼		
17	Filioara							+ ▼					
18	Gura Foii												* ▲
19	Gura Negri	* ▲	* ▲	+ ▲							+ ▲		* ▲
20	Gura Zlata	*** ▲	*** ▲	*** ▲	* ▲			+ ▲	+ ▲	* ▲	** ▲	** ▲	*** ▲
21	Halânga	+ ▲	+ ▲				** ▲	** ▲	*** ▲	*** ▲	*** ▲	*** ▲	** ▲
22	Hamcearca		* ▲					+ ▼					
23	Laslea	+ ▼		+ ▼	* ▼			** ▼	*** ▼	** ▼	** ▼	** ▼	+ ▼
24	Luminiş			* ▲									
25	Monoroştia		* ▲	* ▲									+ ▲
26	Nădrag	* ▲	* ▲	+ ▲								+ ▲	+ ▲
27	Parhăuti			** ▲								* ▲	* ▲
28	Pieleşti	+ ▼				* ▼	* ▼	* ▼	* ▼	* ▼	* ▼	* ▼	* ▼
29	Pocola							+ ▼	+ ▼	+ ▼			
30	Priboeni		* ▲										
31	Prigor					+ ▼		* ▼					
32	Râuşor Pod	** ▲	*** ▲	+ ▲							+ ▲	** ▲	** ▲
33	Resca		+ ▲			** ▲						* ▲	
34	Suciu de Jos							* ▼					
35	Sulta											* ▲	
36	Tulnici		+ ▲	+ ▲									
37	Varlaam		* ▲	** ▲								+ ▲	+ ▲
38	Voina	** ▲	** ▲	*** ▲		+ ▲					** ▲	*** ▲	** ▲

*Upward red triangle: positive trend. Downward blue triangle: negative trend. No sign: trend insignificant (no trend). ***: trend with 0.001 level of significance; **: trend with 0.01 level of significance; *: trend with 0.05 level of significance; +: trend with 0.1 level of significance.*

The most significant increases in minimum flow were found mainly in the mountainous area, at the stations: Gura Zlata, Gura Negri, Nădrag, Buzeşti, Voina, Râuşor Pod, Buşteni, Cavnic, Halânga, Varlaam etc. The most significant decreases of minimum flows were identified at the gauging stations located, in the most cases, at low altitudes (plain and plateaus): Laslea, Pieleşti, Pocola, Băceşti, Băile Homorod, Broşteni, Corlăţel, Dragoia.

Decreasing trends of the low-flow were identified especially in the summer months (July, June and August) followed by spring (May) and autumn months (September and October), due to the increase of the temperature, evaporation and number of drought events (fig. 9).

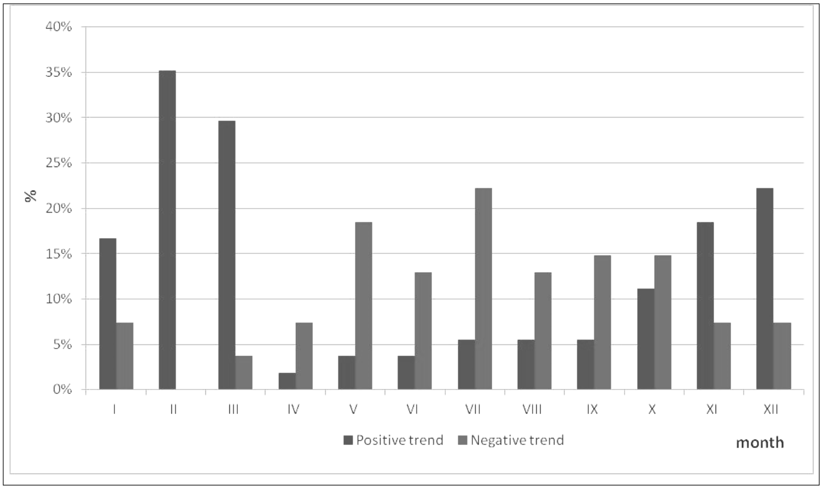

Fig. 9. The percentage of the gauging stations with positive and negative monthly trends in river low-flow

CONCLUSIONS

The paper investigated the trends of rivers low-flow in Romania, in the period 1980-2013, by analyzing the temporal variability of the discharge data series recorded at 54 gauging stations. The results revealed, in the case of the lowest annual values of the mean daily discharge, a positive trend at 22% of the analyzed stations and a negative trend at 11% of the stations. A relatively similar trend was identified for the minimum annual values of the monthly mean discharges (20% of the total cases upward trends and 17% downward trends). Generally, at annual scale, increasing trends are specific for the Carpathian area (mainly the Eastern Carpathians), and negative, for the plain regions (especially the Romanian plain).

At seasonal scale, the most important trends were detected to be positive during winter in 20% of the analyzed stations and negative during summer (in 17% of the cases) and spring (15%). The positive trends are observed mainly at the hydrometric stations located in high altitudes (in the Carpathians), while negative trends are manifested in lowland areas (plains and tablelands). Similar trends were also detected in Romania for the monthly average discharges, during the period 1961-2010, due to the climatic change which consisted in temperatures increases in winter and summer (Bîrsan et al., 2012, 2014).

Knowledge of the low-flow variability and its trends is crucial for the socio-economic sector because the low-flow is a limiting factor for the use of the water resources. The low-flow decreasing, especially in the summer, could generate important economic losses and affect the health and human welfare, as well as the aquatic ecosystems.

REFERENCES

1. Bîrsan, M.V., Zaharia, L., Chendeş, V., Brănescu, E. (2012), *Recent Trends In Streamflow In Romania (1976–2005*), Romanian Reports in Physics, Vol. 64, 1, 275–280*,* http://rrp.infim.ro/2012_64_1/art24Birsan.pdf.
2. Bîrsan, M.V., Zaharia, L., Chendeş, V., Brănescu, E. (2014), *Seasonal trends in Romanian streamflow*, Hydrological Processes 28: 4496-4505, DOI: 10.1002/hyp.9961.
3. Bojariu, R., Bîrsan, M.V., Cică, R., Velea, L., Burcea, S., Dumitrescu, A., Dascălu, S.I., Gothard, M., Dobrinescu, A., Cărbunaru, F., Marin, L. (2015), *Schimbările climatice – de la bazele fizice la riscuri și adaptare*, Printech, București 200 p.
4. Coch A., Mediero, L. (2016), *Trends in low flows in Spain in the period 1949–2009*, Hydrological Sciences Journal Volume 61, Issue 3.
5. Dumitrescu, A., Bojariu, R., Bîrsan, M.V., Marin, L., Manea, A. (2014), *Recent climatic changes in Romania from observational data (1961-2013)*, Theoretical and Applied Climatology, p 111–119.
6. EEA (2015), *Climate Change Impacts And Adaptation*, https://www.eea.europa.eu/soer-2015/europe/climate-change-impacts-and-adaptation
7. Hannaford, J., Marsh, T. (2006), *An assessment of trends in UK runoff and low flows using a network of undisturbed catchments*, International Journal of Climatology int. J. Climatol. 26: 1237–1253.
8. Kendall, M. G. (1975), *Rank Correlation Measures*, London, UK: Charles Griffin.
9. Kil, S.L., Kim, S.U. (2007), *Identification of uncertainty in low flow frequency analysis using Bayesian MCMC method*, Journal of Hydrological Process, 22(12), 1949–1964.
10. Mann, H. B. (1945), *Non-parametric tests against trend*, Econometrica, vol. 13, pp. 245-259.
11. Mauser, W., Marke, T., Stoeber, S. (2008), *Climate change and water resources: scenarios of 20 low-flow conditions in the Upper Danube River Basin*, IOP Conference Series: Earth and Environmental Science, 4(012027), 1–11.
12. NAM (National Administration of Meteorology), (2008), *Clima României*, Edit. Academiei Române, București 316p.
13. Salas, J. D. (1993), *Analysis and modeling of the hydrologic time series*, In Maidment DR (ed) Handbook of Hydrology, Mc Graw Hill, New York.
14. Seneviratne, S.I., Lüthi, D., Litschi, M., Schär, C. (2006a), *Land-atmosphere coupling and climate change in Europe*, Nature, 443(7108), 205-209.
15. Svensson, C., Kundzewicz, W. Z., Maurer, T. (2005), *Trend detection in river flow series: 2. Flood and low-flow index series*, Hydrological Sciences Journal, 50:5, -824, DOI: 10.1623/hysj.2005.50.5.811.
16. Wilhite, D. A., Sivakumar, M. V. K., Pulwarty, R. (2014), *Managing drought risk in a changing climate: The role of national drought policy*, Weather and Climate Extremes, 3, 4–13, doi:10.1016/j.wace.2014.01.002.
17. Zaharia, L., Perju, R., Ioana-Toroimac, G. (2018), *Climate changes and effects on river flow in the Romanian Carpathians*, vol. Air and Water Components of the Environment, Cluj- Napoca, Roprint, p. 211-218.
18. Zeleňáková, M., Purcz, P., Soľáková, T., Demeterová, B. (2012), *Analysis of trends of low flow in river stations in eastern Slovakia*, Acta univ. agric. et silvic. Mendel. Brun., LX, No. 5, pp. 265–274.