DOI: 10.31577/ahs-2021-0022.02.0023

**ACTA HYDROLOGICA SLOVACA**

**Volume 22, No. 2, 2021, 200 – 206**

# Extreme low flow change analysis on the Tysa River within Ukraine

Liudmyla GORBACHOVA*, Borys KHRYSTIUK

In the current conditions of a changing climate, which directly affects the variability of river runoff, it is very important to have the knowledge about the trends of its extreme flow. Extreme low flows, just like floods are causing a significant material damage. The Tysa River has the two periods with the low flow during year. In addition, some years are dry and such years can be observed for several years in a row. This research used the Indicators of Hydrologic Alteration method (IHA) for investigation of extreme low flow characteristics and their changes along the Tysa River within Ukraine. The research was carried out based on the observations of 4 gauging stations that are located along the Tysa River within Ukraine. The mean daily discharges were used from the beginning of observations until 2018 inclusive. It turned out that at the Tysa River – Vylok Village gauging station the low flow trends differ from the trends at other gauging stations that are located in the upper part of the Tysa River.

KEY WORDS: extreme low flow, IHA, Tysa River, statistical analysis

## Introduction

Knowledge of low flow trends is important for practice, especially for design, construction and operation of hydraulic structures on rivers, as well as for shipping, agriculture, etc. Extreme low flows, just like floods are causing a significant material damage. It should also be borne in mind that many scientists predict that in the warmer climate the droughts will become more common in the future. Longer periods of low flow and a decrease of discharge values, and for some rivers their complete disappearance are expected (Wimmer et al., 2015; Loboda and Bozhok, 2016; Chang et al., 2017; Ionita and Nagavciuc, 2020).

Usually, the assessment of trends and changes in river runoff is carried out on the basis of statistical approaches that allow to determine some quantitative indicators. So, to estimate the spatial and temporal homogeneity, stationarity of hydrological observation series, statistical tests are most often used (Kundzewicz and Robson, 2004; Blöschl et al., 2019). Also, the method of frequency analysis of time series is in great demand (Caruso, 2000; Onoz et al., 2019; Pekárová and Miklánek, 2019; Bačová Mitková and Halmová, 2020). Such approaches allow to operate with a certain set of information (statistical criteria, discharges of different probability, average value, variation and asymmetry coefficients). In the late 20th century, the method of Indicators of Hydrologic Alteration (IHA), which was developed in the United States, became widely used in the world (Richter et al., 1997; Gao et al., 2009; Halmová et al., 2011; Yu et al., 2017; Zhou et al., 2020). This approach allows to calculate quantitative statistical characteristics for runoff estimating of rivers, lakes and reservoirs and the degree of changes in their hydrological regime.

The research of low flow is an actual task for the Tysa River, which is characterized by low flow twice a year, namely in winter and summer-autumn. In the dry years that have been observed in the last few years, there are some problems with water supply to consumers in the region (Pochaievets and Obodovskiy, 2018). It should be noted that the study of the low flow of the Tysa river, as well as the Ukrainian Carpathians region, does not receive due attention due to the fact that, first of all, this area is the dangerous floods zone. For the upper part of the Tysa River the recent research of the low flow has been carried out in the papers by Gorbachova (2017) and Pochaievets (2020). However, this research focused on the study of long-term fluctuations and the definition of design characteristics.

The purpose of this research is to use the Indicators of Hydrologic Alteration approach to investigate extreme low flow characteristics and their changes along the Tysa River within Ukraine.

## Material and methods

### *The study area*

The Tysa River Basin is the largest sub-basin in the Danube River Basin with an area of 157 186 km$^2$.

The Tysa River also is the longest tributary of the Danube and the second largest by flow after the Sava River, its length is 966 km (Halmová et al., 2011). Five countries are sharing the Tysa Basin, namely Ukraine, Romania, Hungary, Slovakia and Serbia. In north-western Ukraine in the Carpathian Mountains the Tysa River rises. It is formed from the confluence of the Bila Tysa and Chorna Tysa Rivers (Fig. 1). At the same time, the source of the Tysa is taken to be the source of its longer tributary – the Chorna Tysa River. In Ukraine the Tysa River Basin area is 12 732 km$^2$, that is 2.1% of its territory. Moreover, share of the Tysa River Basin area in Ukraine is 8.1% (Makovinska, 2018). In the territory of Ukraine, there is the mountainous Upper part of the Tysa River Basin, namely mostly the right bank. The left tributaries of Upper part are located in Romania. The river at the upper part is a typical mountain river with a narrow valley, and it sometimes looks like a gorge with relatively steep slopes. The right bank tributaries of the Tysa River are located the southern slope of the Ukrainian Carpathians. The average altitudes of mountainous catchments are 800–1 200 m, and the average slopes are 200–400 m/km (Borsos and Sendzimir, 2018; Zabolotnia et al., 2019). In the Upper part river shows a high flow rate and low turbidity. Near Vylok village the multi-annual mean discharge is 202 m$^3$ s$^{-1}$ (1954–2018). The climate of the Upper Tysa in the Ukrainian Carpathians is reasonably continental. There are mild winters with thaws, a long, though unstable spring, a mild summer and warm autumn. The annual precipitation is between 1 750 mm in the mountains and 700 mm in the lowlands. The variability of the mean annual temperature is in the range of 3.0–8.5°C (Makovinska, 2018; Pochaievets, 2020).

The Tysa River Basin belongs to two hydrological regions, namely the Uzh-Borzhava and Carpathian regions according to hydrological regionalisation by the intra-annual distribution of the flow within Ukraine (Gorbachova, 2015).

Carpathian region covers the upper reaches of the Tysa River to the Rika River. There the snow-rain flood period lasts from March to July, the autumn period is characterised by floods, and winter is characterised by the smallest discharges in the year.

For the rivers of the Uzh-Borzhava region the lowest discharges are observed from August to October. Winters are characterised by intense floods in the cold period of the year.

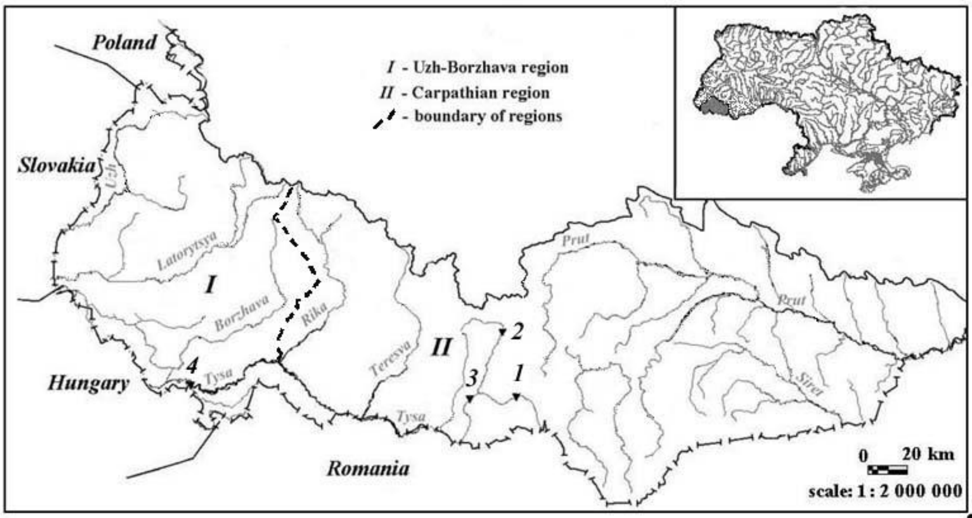



*Fig. 1. Scheme of the Tysa River Basin within Ukraine and location of the main gauging stations on its channel (numbering of posts corresponds to Table 1).*

**Table 1. List of the gauging stations on the Tysa River within Ukraine**

| № | Name of gauging station | Distance from the mouth [km] | Catchment area [km$^2$] | Latitude | Longitude | Altitude [m.a.s.l.] | Daily data [years] | $Q_a$ [m$^3$ s$^{-1}$] |
|---|---|---|---|---|---|---|---|---|
| 1 | Bila Tysa River – Luhy village | 15* | 189 | 48º 04′ N | 24º 56′ E | 652 | 1955–2018 | 5.13 |
| 2 | Chorna Tysa River – Yasynay village | 28* | 194 | 48º 16′ N | 24º 21′ E | 650 | 1956–2018 | 4.78 |
| 3 | Tysa River – Rakhiv town | 962 | 1070 | 48º 03′ N | 24º 12′ E | 430 | 1947–2018 | 25.4 |
| 4 | Tysa River – Vylok village | 808 | 9140 | 48º 06′ N | 22º 50′ E | 117 | 1954–2018 | 202 |

*Note:* * – to the confluence of the rivers Chorna Tysa and Bila Tysa; $Q_a$ – multi-annual mean discharge.

***Input data***

The research was carried out based on observations of 4 gauging stations that are located along the Tysa River within Ukraine (Table 1). In the upper Tysa River the low flow analysis was carried out by the observation series at the rivers Chorna Tysa and Bila Tysa. The mean daily discharges from the beginning of observations until 2018 inclusive were used. Observations series have almost the same duration, which makes a comparative analysis of the calculated statistical indicators more reliable.

***Methodology***

Indicators of Hydrologic Alteration was used to study the low flow of the Tysa River. In the IHA the daily levels and discharges of rivers, lakes and groundwater are used that allows to determine the statistic parameters of natural and disturbed hydrological regime of water bodies. According to this methodology, the river runoff is conditionally divided into five components:

- "Extreme low flows" – low flow, which is observed on rivers during droughts;
- "Low flows" – flow on river in the periods after spring floods, snow and rain floods, when the river is fed only by groundwater;
- "High-flow pulses" – flow on river during rainfalls in summer or thaw in winter, as well as for other reasons (reservoir releases, etc.); at the same time, the river does not overflow;
- "Small floods" – same as "High-flow pulses", but with the outflow of the river to the floodplain without catastrophic consequences;
- "Large floods" – extremely high floods, which are rare and cause catastrophic consequences.

To divide the arrays of daily discharges on 5 components, the values of the parameters recommended by the IHA were used, which were developed by The Nature Conservancy (2009). To calculate the river flow parameters of the Tysa River we used the IHA software, version 7.1.0.10.
This made it possible to separate from the total flow the extreme low flows, for which the IHA statistics were calculated.
The study calculated the following statistics:

- discharge thresholds for 5 flow components, [$m^3 s^{-1}$];
- mean values of the extreme low discharges (peaks) for each year, [$m^3 s^{-1}$];
- mean duration of the extreme low flows, [days];
- mean frequency of the extreme low flows, [number of cases/year];
- mean Julian dates of the extreme low discharges (peaks) for each year, [days].

Changes of extreme low flow characteristics along the river and over time were also analysed.

**Results and discussion**

At each gauging station the river flow was divided into five components: "Extreme low flows", "Low flows", "High-flow pulses", "Small floods", "Large floods" according to the discharge thresholds and the results are presented in Table 2. An example of such a distribution for the hydrological post of the Tysa River – Vylok village is shown in Fig. 2.
In the Upper part of the Tysa River all 5 flow components of the multi-annual mean and discharge thresholds are increasing in the direction from the headwaters to the Tysa River - Vylok village gauging station (Table 1, 2, 3; Fig. 3 *a*, *b*, *c*), that fully corresponds to the physical and geographical conditions of its formation. Further, the analysis of the calculated statistical parameters by IHA for the "Extreme low flows" component was carried out (Table 3).

**Table 2. Discharge thresholds at the gauging stations in the upper part of the Tysa River, [$m^3 s^{-1}$]**

| № | Name of gauging station | Large floods | Small floods | High-flow pulses | Low flows | Extreme low flows |
|---|---|---|---|---|---|---|
| 1 | Bila Tysa River – Luhy village | 39.5 | 24.2 | 6.43 | 3.68 | 1.54 |
| 2 | Chorna Tysa River – Yasynay village | 58.2 | 32.8 | 5.96 | 3.19 | 1.15 |
| 3 | Tysa River – Rakhiv town | 351 | 174 | 31.3 | 17.4 | 7.0 |
| 4 | Tysa River – Vylok village | 2480 | 1370 | 244 | 133 | 56 |

**Table 3. Statistical parameters of IHA for the "Extreme low flows" at the gauging stations in the upper part of the Tysa River**

| № | Name of gauging station | Mean values of peak discharge [$m^3 s^{-1}$] | Mean duration [days] | Mean frequency [number of cases/year] | Mean Julian dates peaks [days] |
|---|---|---|---|---|---|
| 1 | Bila Tysa River – Luhy village | 1.18 | 14 | 3.70 | 19 |
| 2 | Chorna Tysa River – Yasynay village | 0.89 | 12 | 3.57 | 29 |
| 3 | Tysa River – Rakhiv town | 5.66 | 9 | 4.82 | 30 |
| 4 | Tysa River – Vylok village | 46.4 | 11 | 3.65 | 302 |

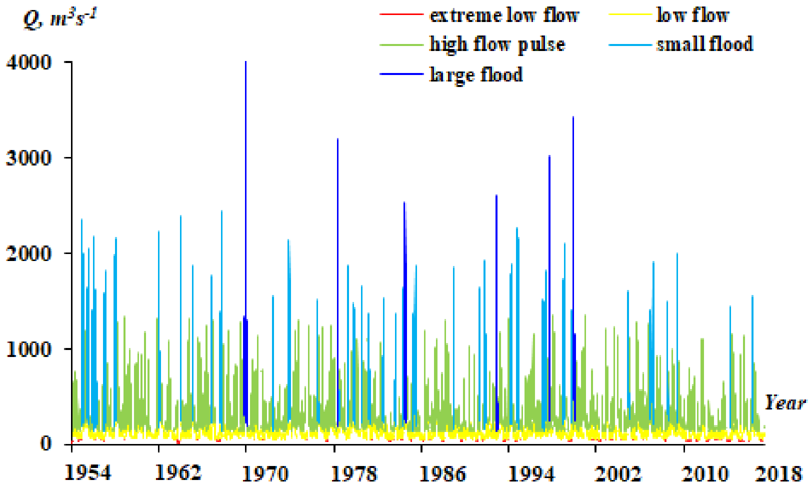



*Fig. 2. Separation of hydrographs into different flow types for gauging station of the Tysa River – Vylok village.*

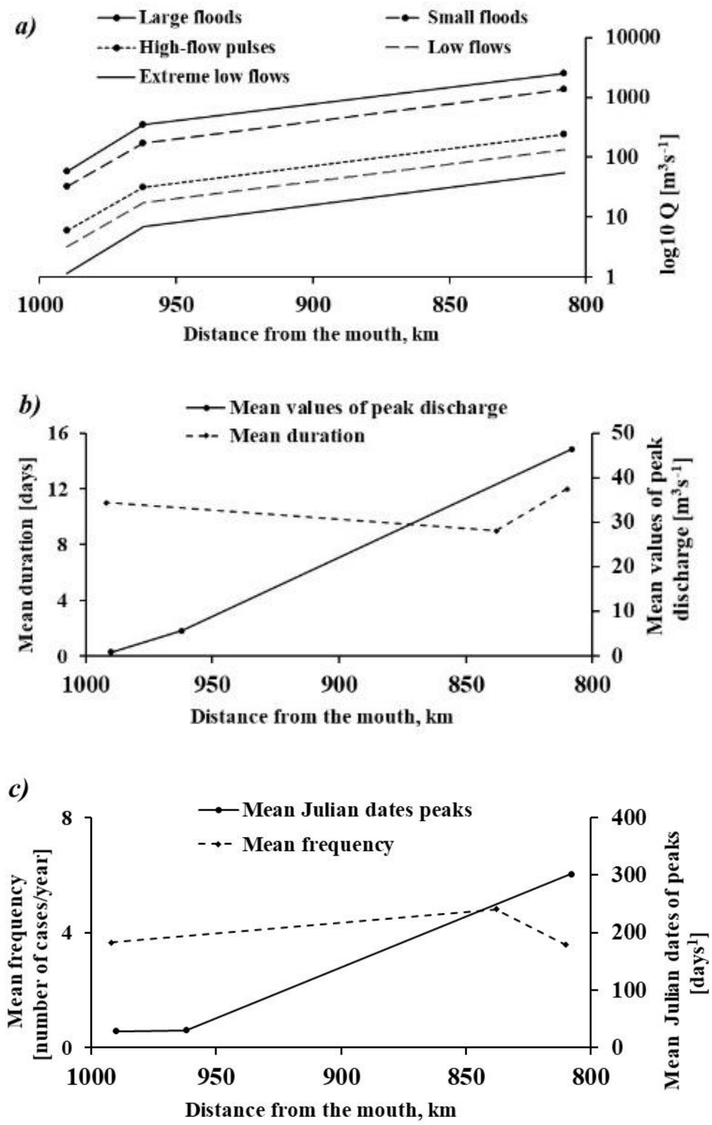
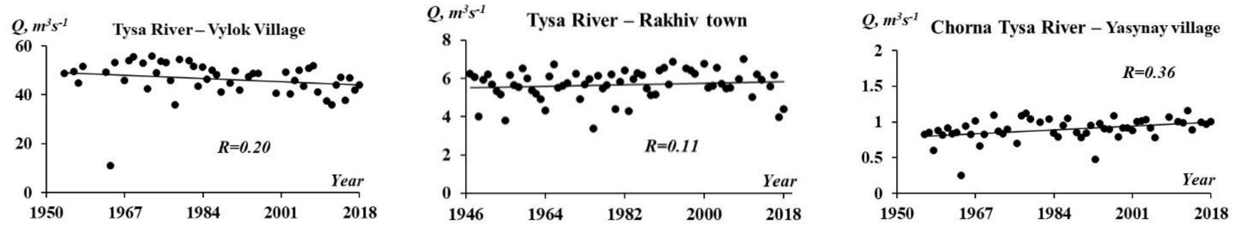


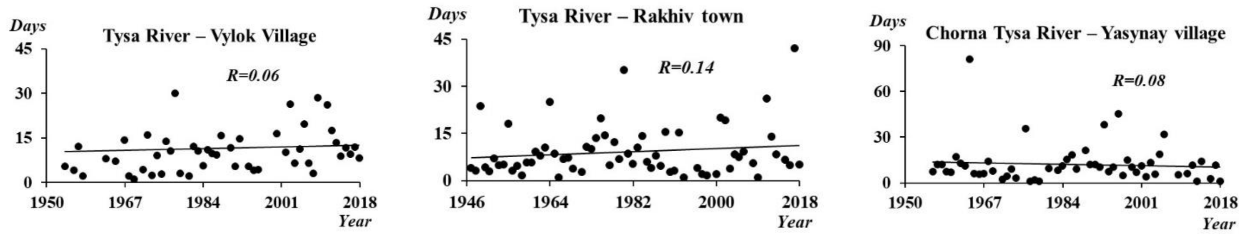

*Fig. 3. Discharge thresholds (a) and mean values of the peak discharges during for each year, mean duration (b) and mean frequency, mean Julian dates of peaks (c) of the extreme low flows at gauging stations in the upper part of the Tysa River.*

Mean duration of extreme low flows is in the range of 9 to 14 days. Gauging stations that are located on the headwaters have the greatest mean duration of the extreme low flows. Extreme low flows are observed in the mean 4 times a year. According to the mean Julian dates, the extreme low flow peaks are observed in January in the upper part of the Tysa River and in October for the Tysa River – Vylok village gauging station.

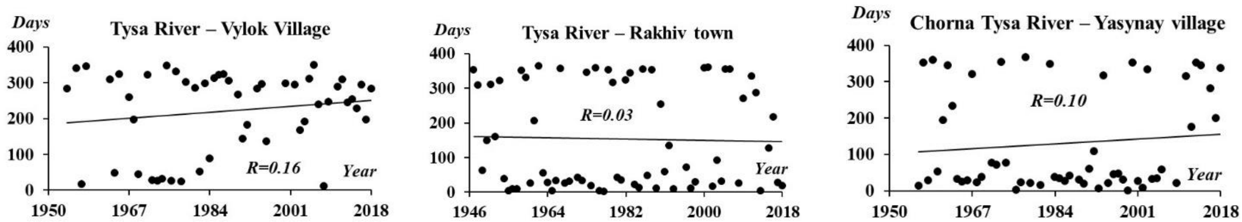
During the observations period, the mean values of the extreme low discharges (peaks) for each year have the tendency to increase in the upper part of the Tysa River and to decrease in the Tysa River – Vylok village gauging station (Fig. 4). However, only the Chorna Tysa River – Yasynay village gauging station has the significant trend. Mean duration and mean Julian dates of the extreme low discharges (peaks) for each year did not undergo significant changes for all gauging stations studied. At the same time, such a characteristic as the mean frequency of the extreme low flows has undergone significant changes over time. Wherein, on the Tysa River – Vylok village gauging station the mean frequency of the extreme low flows has the trends to increase. In all other gauging stations, this characteristic has the opposite tendency, i.e. it decreases.



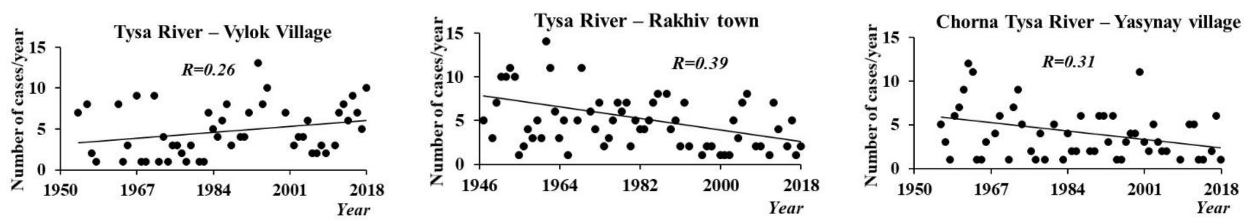

*mean values of the extreme low discharges (peaks) for each year*




*mean duration of the extreme low flows*




*mean Julian dates of the extreme low discharges (peaks) for each year*




*mean frequency of the extreme low flows*

*Fig. 4. Identification of trends in the characteristics of the extreme low flows in the upper part of the Tysa River.*

The Tysa River - Vylok village gauging station has the trends of extreme low flows which differ from the trends at other gauging stations that are located in the upper part of the Tysa River. This gauging station is the closing post in the upper part of the Tysa River. Its flow is formed under the influence of left and right tributaries, which are located both on the territory of Ukraine and on the territory of Romania. These are the mountain basins with the features of the surface watershed and climatic factors that are manifested in the uneven distribution of rainfall, temperature and evaporation. This is reflected in different runoff trends at such catchments (Gorbachova, 2017; Pochaievets, 2020). It is clear that the explanation of trends in extreme low flows on the Tysa River - Vylok village gauging station requires further research with additional observation data as along the river channel and its main tributaries.

## Conclusion

The application of the IHA method for the study of extreme low flows allows to obtain a new knowledge and expand the understanding about its statistical indicators. Dividing of hydrographs according to the calculated discharge thresholds into five components allowed to obtain the characteristics and periods of the extreme low flows in the upper part of the Tysa River. Analysis of extreme low flow characteristics showed that its mean duration is in the range of 9 to 14 days. Extreme low flow is observed in mean 4 times a year. Extreme low flow peaks are observed in January in the upper part of the Tysa River and in October for the Tysa River – Vylok village gauging station.

Analysis of the fluctuations of the extreme low flow characteristics showed that its mean peak values have the tend to increase over time in the upper part of the Tysa River except the Tysa River – Vylok village gauging station. At the same time, on this gauging station the mean frequency of the extreme low flows has the trends to increase. It is clear that in the future the continuation of such trends will cause the negative consequences for the population and the economy in the river basin. It should be noted that deeper understanding of the features of extreme low flows requires further research with using observation data along the river channel and its tributaries.

## References


Bačová Mitková, V., Halmová, D. (2020): Analysis of the runoff volumes of the wave belongs to maximum annual discharges. Acta Hydrologica Slovaca, Vol. 21, no. 2, 188–196. DOI: 10.31577/ahs-2020-0021.02.0023

Blöschl, G., Hall, J., Viglione, A., Perdigão, R. A. P, Parajka, J., Merz, B., Lun, D., Arheimer, B., Aronica, G. T., Bilibashi, A., Boháč, M., Bonacci, O., Borga, M., Čanjevac, I., Castellarin, A., Chirico, G. B., Claps, P., Frolova, N., Ganora, D., Gorbachova, L., Gül, A., Hannaford, J., Harrigan, Sh., Kireeva, M., Kiss, A., Kjeldsen, T. R., Kohnová, S., Koskela, J. J., Ledvinka, O., Macdonald, N., Mavrova-Guirguinova, M., Mediero, L., Merz, R., Molnar, P., Montanari, A., Murphy, C., Osuch, M., Ovcharuk, V., Radevski, I., Salinas, J. L., Sauquet, E., Šraj, M., Szolgay, J., Volpi, E., Wilson, D., Zaimi, K., Živković, N. (2019): Changing climate both increases and decreases European river floods. Nature, Vol. 573, no. 7772, 1-4. https://doi.org/10.1038/s41586-019-1495-6

Borsos, B., Sendzimir, J. (2018): The Tisza River: Managing a Lowland River in the Carpathian Basin. In: Schmutz, S., Sendzimir, J. (eds.) Riverine Ecosystem Management. Science for Governing Towards a Sustainable Future. Springer, Cham, 541-560. https://doi.org/10.1007/978-3-319-73250-3

Caruso, B. S. (2000): Evaluation of low-flow frequency analysis methods. Journal of Hydrology (New Zealand), Vol. 39, no. 1, 19–47. https://www.jstor.org/stable/43944831

Chang, J., Zhang, H., Wang, Y., Zhang, L. (2017): Impact of climate change on runoff and uncertainty analysis. Natural Hazards, Vol. 88, no. 2, 1113–1131. DOI: 10.1007/s11069-017-2909-0

Gao, Y., Vogel, R. M., Kroll, C. N., Poff, N. L. R., Olden, J. D. (2009): Development of Representative Indicators of Hydrologic Alteration. Journal of Hydrology, Vol. 374, no. 1, 136–147. https://doi.org/10.1016/j.jhydrol.2009.06.009

Gorbachova, L. (2015): Modern intra-annual distribution of water runoff in Ukraine’s river. Ukrainian Geographical Journal, no. 3, 16–23. doi.org/10.15407/ugz2015.03.016 (In Ukrainian with English summary).

Gorbachova, L. (2017): Spatio-temporal fluctuations of minimum flow in the Danube basin within Ukraine. Book of abstract of the XXVII Conference of the Danubian countries on Hydrological Forecasting and Hydrological Bases of Water Management, 26–28 September 2017, Golden Sands, Bulgaria, 26.

Halmová, D., Pekárová, P., Mészároš, I. (2011): Low flow change analysis in selected gauging stations on the Danube River. Acta Hydrologica Slovaca. Vol. 12, no. 2, 286–295. (In Slovak)

Ionita, M., Nagavciuc, V. (2020): Forecasting low fow conditions months in advance through teleconnection patterns, with a special focus on summer 2018. Scientific Reports, no. 10, 13258. https://doi.org/10.1038/s41598-020-70060-8

Kundzewicz, Z. W., Robson, A. J. (2004): Change detection in hydrological records – a review of the methodology. Hydrological Sciences Journal, Vol. 49, no. 1, 7–19. https://doi.org/10.1623/hysj.49.1.7.53993

Loboda, N. S., Bozhok, Y. V. (2016): Water resources of Ukraine in the XXI century under climate change scenarios (RCP4. 5 AND RCP8. 5). Ukrainian hydrometeorological journal, no. 17, 114–122. https://doi.org/10.31481/uhmj.17.2016.13

The Nature Conservancy Indicators of Hydrologic Alteration (2009): Version 7. User's Manual, 75 p. https://www.conservationgateway.org/Documents/IHAV7.pdf

Makovinska, J. (Ed.) (2018): Tisza River Basin Characterization Report on Surface Water. Interreg – Danube Transnational Programme, 30 p. http://www.interreg-danube.eu/approved-projects/jointisza

Onoz, B., Cetin, M., Yuce, M. I., Selek, B., Aksu, H., Burgan, H. I., Esit, M., Yildirim, I. and Karakus, E. U. (2019): Frequency analysis of low flows in intermittent and non-intermittent rivers from hydrological basins in Turkey. Water Supply, Vol. 19, no. 1, 30–39. https://doi.org/10.2166/ws.2018.051

Pekárová, P., Miklánek, P. (Eds.) (2019): Flood regime of rivers in the Danube River basin. Followup volume IX of the Regional Cooperation of the Danube Countries in IHP

UNESCO. IH SAS, Bratislava, 215 p. https://doi.org/10.31577/2019.9788089139460

Pochaievets, O., Obodovskiy, O. (2018): Assessment of the influence of the main hydrographic characteristics of the water catchments of the rivers of the Tisza basin (within Ukraine) on the formation of the minimum flow. Hydrology, hydrochemistry and hydroecology, no. 2(49), 6–15. (in Ukrainian with English abstract)

Pochaievets, O. (2020): Spatio-temporal dynamics of the minimum flow of the Tisza River basins within Ukraine. PhD thesis. The Taras Shevchenko National University of Kyiv, 139 p. (In Ukrainian with English summary)

Richter, B., Baumgartner, J., Wigington, R., Brau, D. (1997): How Much Water Does a River Need? Freshwater Biology, Vol. 37, no. 1, 231–249. https://doi.org/10.1046/j.1365-2427.1997.00153.x

Wimmer, F., Audsley, E., Malsy, M., Savin, C., Dunford, R., Harrison, Rüdi P. A., Schaldach, R., Flörke, M. (2015): Modelling the effects of cross-sectoral water allocation schemes in Europe. Climatic Change, Vol. 128, no. 3–4, 229–244. DOI: 10.1007/s10584-014-1161-9

Yu, C., Yin, X., Yang, Z., Dang, Z. (2017): Assessment of the degree of hydrological indicators alteration under climate change. In Proceedings of the 6th International Conference on Energy and Environmental Protection (ICEEP 2017). Advances in Engineering Research (AER), vol. 143, 210–216.

Zabolotnia, T., Gorbachova, L., Khrystyuk, B. (2019): Estimation of the long-term cyclical fluctuations of snow-rain floods in the Danube basin within Ukraine. Meteorology Hydrology and Water Management. Research and Operational Applications, Vol. 7, no. 2, 3–11. https://doi.org/10.26491/mhwm/99752

Zhou, X., Huang, X., Zhao, H., Ma, K. (2020): Development of a revised method for indicators of hydrologic alteration for analyzing the cumulative impacts of cascading reservoirs on flow regime. Hydrol. Earth Syst. Sci., Vol. 24, no. 8, 4091–4107. https://doi.org/10.5194/hess-24-4091-2020

Mgr. Liudmyla Gorbachova, Dr.Sc. (*corresponding author e-mail: gorbachova@uhmi.org.ua)
Ing. Borys Khrystiuk, PhD
Ukrainian Hydrometeorological Institute
37, Prospekt Nauky
03028, Kyiv
Ukraine