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Study of trends in the time series of maximum water discharges in the Tisza basin rivers within Ukraine

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Nowadays, due to global and local climate changes, according to leading experts, the likelihood of extreme natural phenomena increases. One of the dangerous natural phenomena with impacts on humans and the economy are floods. The Tisza River, which originates in Ukraine and flows further through Romania, Hungary, Slovakia, and Serbia, has repeatedly become a source of disasters for the population due to the devastating consequences of floods, which have been increasing in recent years. The purpose of this study is to analyze the long-term series of observations of the maximum water discharge on the rivers of the Tisza basin, within Ukraine. Using the methods of statistical analysis, tendencies in the time series of annual maximum water discharges were investigated, its temporal homogeneity was estimated also, as well as the significance of the trends. Using the method of residual mass curves, high-water and low-water periods were distinguished. We also obtained preliminary dependences of the maximum runoff modules on the catchment areas and their heights, which in the future can serve as a basis for the development of a regional calculation method for determining the maximum runoff of ungauged rivers in the region.

KEY WORDS: maximum water discharges, flood, trends

Introduction

The rivers of the Tisza basin are characterized by a flood regime and flow through the territory of Western Ukraine. Within this area, the mountain system of the Eastern Carpathians is located, which is subdivided into the Outer Eastern Carpathians (the Carpathian Rivers within the Dniester and Prut basin) and the Inner Eastern Carpathians (the Transcarpathian rivers – the Danube basin, namely the Tisza with tributaries). At the study territory, catastrophic floods are periodically observed, which lead to significant economic losses, and sometimes to human casualties. The floods of 1911, 1913, 1957, 1969, 1998, 2001, 2008, and 2020 can be classified as exceptionally high on the territory of the Ukrainian Carpathians (Margaryan et al., 2020). The issues of studying, statistical analysis, and calculations and forecasts of floods in the Tisza basin are relevant both for Ukraine and for neighboring countries through which the Tisza flows. The issue of assessment and management of flood risks in the Upper Tisza Basin in Hungary was considered in Szlávik (2000) and Linnerooth-Bayer et al. (2003) Janál and Kozel (2019) provides test results for the Fuzzy Flash Flood model. The model is implemented in the Czech Hydrometeorological Institute (CHMI) as an alternative tool for flash flood forecasting. In the publications of Blöschl et al. (2017, 2019) the Tisza basin was included in the analysis of flood trends in rivers in Europe. According to (Blöschl et al., 2017), there is a tendency for an increase in the influence of the Atlantic on the maximum runoff in winter, but the dates of annual maximums are still noted in the warm season. Thus, further study and systematization of data on the maximum runoff in the Tisza basin, taking into account the measurement data of recent years, is of scientific and practical interest.

Material and methods

The water gauge stations (WGS) on Transcarpathian Rivers have observation periods from 56 to 103 years, up to 2015 inclusive. According to the existing time series of observation of the maximum runoff in the territory of the Ukrainian Carpathians, the absolute values of the maximum water discharge at the rivers of Transcarpathia vary from 62.7 $m^3 s^{-1}$ (Studeny-Nizhniy Studeny, A= 25.4 km^2) to 1680 $m^3 s^{-1}$ (Uzh – Uzhgorod, A = 1970 km^2). Almost all considered Mountain Rivers of Transcarpathia belong to the category of small rivers; however, the length of the studied rivers in 90% of cases is more than 10 km. The catchments are characterized by slopes (from 8.1‰ to 41.1‰) and an average elevation from 300 to 1100 m. The Ukrainian Carpathians are densely covered with forests, therefore, the forest cover of catchments on the rivers of Transcarpathia from 18 to 77%, but there are almost no swamps and lakes in the studied catchments (table.1).

Table 1. **Initial information about catchments and observing period at the river of Tisza basin (within Ukraine)**

№	River - water gauge stations	Observation period	n, years	Length L [km]		The slope of the river I [$^0/_{00}$]		Catchment area, A [km^2]	The average elevation H_{av} [m]	Wetlands f_w [%]	Forest f_{fr} [%]	Plowing [%]	Lakes, f_l [%]
				from the source	from the farthest point of the river network	average	weighted average						
1	Tisa-Rakhiv	1947–2015	69	4	53	15.3	9.1	1070	1100	0	68	5	1
2	Teresva-Ust-Chorna	1947–1976 1978–2015	68	2	34	20	17.2	572	1100	0	77	<5	0
3	Rika-Mizhhirya	1946–2015	70	28	28	24.3	12.5	550	800	0	41	<5	0
4	Golyatynka-Maidan	1956–1994 1999–2015	56	18	18	23.4	23	86	790	0	40	<5	0
5	Pylypets-Pylypets	1956–2015	60	6.2	6.2	41.1	30	44.2	820	0	29	<5	0
6	Studeny-Nizhniy Studeny	1954–1994 1999–2015	58	7.5	7.5	31.6	22.7	25.4	800	0	18	<5	0
7	Borzhava-Dovge	1946–2015	70	37	37	35.9	12.6	408	620	0	71	10	0
8	Latorytsia-Pidpolozzia	1946–2015	70	24	24	17.7	12.3	324	720	0	50	5	0
9	Latorytsia-Svalyava	1961–2015	54	53	53	11.4	7.4	680	700	0	61	5	0
10	Latorytsia-Mukacheve	1946–2015	70	85	85	8.1	4.5	1360	570	0	63	5	0
11	Latorytsia-Chop	1956–2015	60	135	135	5.2	1.9	2870	310	<1	41	10	<1
12	Vicha-Nelipine	1957–2015	59	36	36	20	14.5	241	760	0	72	<5	0
13	Stara-Znyatseve	1952–2015	64	28	28	19.6	6	224	300	0	42	10	0
14	Uzh-Zhornava	1952–2015	64	28	28	19.6	12.3	286	670	0	45	<5	0
15	Uzh-Zaricheve	1946–2015	70	68	68	10.6	6.3	1280	560	0	54	5	0
16	Uzh-Uzhhorod	1946–2015	70	95	95	8.1	4.1	1970	530	0	57	15	0

To analyze the initial information, the method of mathematical and statistical analysis, spatial generalization, extrapolation, and correlation was used. To assess the statistical homogeneity of the initial information three criteria were used: F-test (Fisher criterion), Student's t-test, and Wilcoxon criterion (Manual, 1984). The assessment of cyclical fluctuations of maximal runoff is performed using the time series trends and residual mass curve (Manual, 1984; Guide, 1994). The current ordinates of residual mass curves from the time when a curve was plotted and by the end of the year may be found using the following equation:

$$\sum_{i=1}^{n}(Ki - 1) = f(t)\,, \qquad (1)$$

Where Ki = Qi/Qave are modular coefficients of the year; Qi and Qave are the discharge of the year and the average discharge for the *n* period.

For statistical processing was used the method of moments and maximum likelihood, practical application of these methods may be seen in Lukianets et al. (2019) and Gorbachova (2015).

Results and discussion

The database on the maximum annual water discharges in the Tisza River basin has been formed for the period from the beginning of regular observations until 2015 including (for 8 out of 16-time series – this is from 1946–1947; for 2 – from 1952; and for 6 – from 1956–1957). The data analysis confirms that the studied region is characterized by a floodwater regime, so the maximum values of runoff can be observed in any month of the year. However, floods are local and do not cover the entire territory at once. The absolute maximum water discharges in the long-term period were observed in 1957, 1966, 1968, 1980, 1998, and 2001, which can be classified as historical maximums (Fig. 1); the floods in 2008 and 2020 were also quite large, in terms of consequences and losses, however, the maximum water discharges in the considered catchments did not exceed the historical maximums.

For further research, the database of the dates of the observed maximum water discharges for each year of the existing series of observations for 16 watersheds was created, which are evenly distributed in the study area. As noted above, the maximum annual discharges at the rivers of the Tisza basin can be observed in any month of the year. For each time series, the observed dates were sorted by months, and the number of years of observation for each catchment was taken as 100%, and the percentage of maximal discharges cases was determined for the months (table 2). This percentage ranges in a fairly wide range from 0% to 26% of cases over a long period of observations. Then for each catchment 1–2 months were defined, in which the annual maximum water discharges were most often observed. For WGS Tisa-Rakhiv it is April and July, for WGS Pylypets-Pylypets it is July and November, for WGS Stara-Znyatseve it is January and March and for WGS Uzh-Zaricheve it is March and December, and for other catchments, it was only one leading month for each.

Thus, for the long-term observation period (from 54 to 70 years), the largest number of cases of annual maximum water discharges is observed in December – 44% (for 7 of 16 catchments), in March – 37.5% (for 6 of 16 catchments) and in July – 25% (for 4 of 16 catchments) (table.2). Since in some cases the maximum discharges were observed in two different months, the amount is not 100%.

This distribution can be explained by different types of

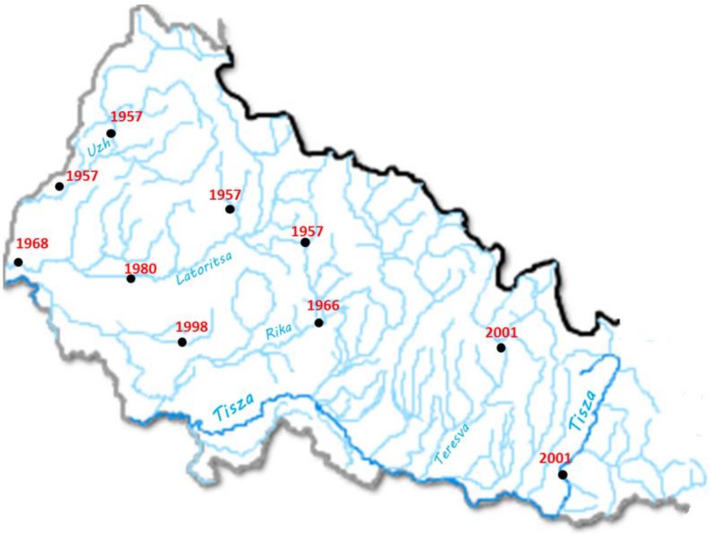


Fig. 1. The dates passed of absolute maximum water discharges (Q, m^3s^{-1}) at the river of Tisza basin (within Ukraine).

Table 2. Distribution of the observed maximum water discharges (*Q*, $m^3 s^{-1}$) by months over a multi-year period (as a percentage)

№	River- water gauge stations	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	Tisa-Rakhiv	6	7	**12**	**16**	6	4	**16**	1	7	6	7	**12**
2	Teresva-Ust-Chorna	4	1	**13**	15	10	7	**7**	1	6	6	9	**19**
3	Rika-Mizhhirya	7	4	**14**	6	7	7	**9**	3	3	7	16	**17**
4	Golyatynka-Maidan	5	5	**9**	5	5	11	**16**	9	2	7	11	**14**
5	Pylypets-Pylypets	7	5	**10**	0	2	5	**17**	7	3	15	**17**	**13**
6	Studeny-Nizhniy Studeny	3	3	**10**	5	12	19	**19**	12	2	5	3	**5**
7	Borzhava-Dovge	11	11	**17**	4	6	9	**1**	1	0	6	11	**21**
8	Latorytsia-Pidpolozzia	9	11	**19**	4	3	1	**9**	4	3	4	11	**21**
9	Latorytsia-Svalyava	7	6	**26**	4	6	2	**9**	2	4	9	9	**17**
10	Latorytsia-Mukacheve	10	11	**16**	9	4	1	**7**	1	3	7	13	**17**
11	Latorytsia-Chop	15	14	**24**	17	3	0	**1**	0	1	1	7	**15**
12	Vicha-Nelipine	8	5	**19**	5	3	8	**15**	3	0	7	10	**15**
13	Stara-Znyatseve	**22**	19	**22**	5	3	2	**3**	0	0	0	5	**20**
14	Uzh-Zhornava	8	6	**19**	6	5	5	**10**	5	5	6	11	**14**
15	Uzh-Zaricheve	10	14	**20**	9	4	1	**4**	1	3	4	7	**20**
16	Uzh-Uzhhorod	10	13	**20**	9	4	1	**4**	1	1	4	9	**23**

precipitation, which are observed in the cold and warm periods of the year over the territory of Transcarpathia. The Ukrainian Carpathians, of which Transcarpathia is a part, belong to the zone of sufficient moisture, where the amount of precipitation reaches the highest values in the territory of Ukraine. However, within this zone, we can distinguish mesoclimatic subregions, where the formation and frequency of precipitation significantly depend on local factors. Most precipitation (over 1400 mm) falls in the highest part of the Carpathian Mountains – in the east and northeast of the region. The amount of precipitation decreases in the south-western direction (up to 500–600 mm) – in the area of Chop and Berehove. Precipitation falls mainly in summer (over 60%), especially in June, and in the mountains – in July. In summer, there are showers and thunderstorms. Snow cover in the mountainous part of the region is established in mid-November, rises in early April, and its duration is up to 110 days (Nizhniy Studeny). The plain snow cover lasts from late December – to early January to early March near Berehove (51 days). In the plains, there are often winters without stable snow cover. During the year, Transcarpathia is dominated by air masses of temperate latitudes. On the plains, the south-western winds blow most often, in the foothills and mountains – mountain-valley, and above 1000 m the western air transfer prevails. In winter, northern winds penetrate the Carpathians along the depressions of river valleys. At the same time, cold air often descends from the mountains to the plain in the form of northern and northeastern winds.

Thus, the significant heterogeneity of the precipitation field, which is due to the heterogeneous conditions of precipitation, causes the formation of floods almost throughout the year. On the other hand, the factors of the underlying surface, in particular the catchment area, are also a factor in the formation of floods. Thus, local precipitation forms floods, mostly on small rivers. Long-lasting rainfall precipitation can already form floods on medium-sized rivers.

For example, in fig. 2, are represented 6 characteristic distributions of the dates of the observed maximum water discharge by months. For the catchment area of the Tisza River - WGS Rakhiv, which is located in the highlands and has an area of more than 1000 km^2, the predominance of floods in the warmer season is characteristic. On the other hand, if we consider the catchment area with approximately the same area, but already with an average elevation of 560 m (Uzh river – WGS Zaricheve), the distribution changes and the maximum discharge is observed in the winter-spring period.

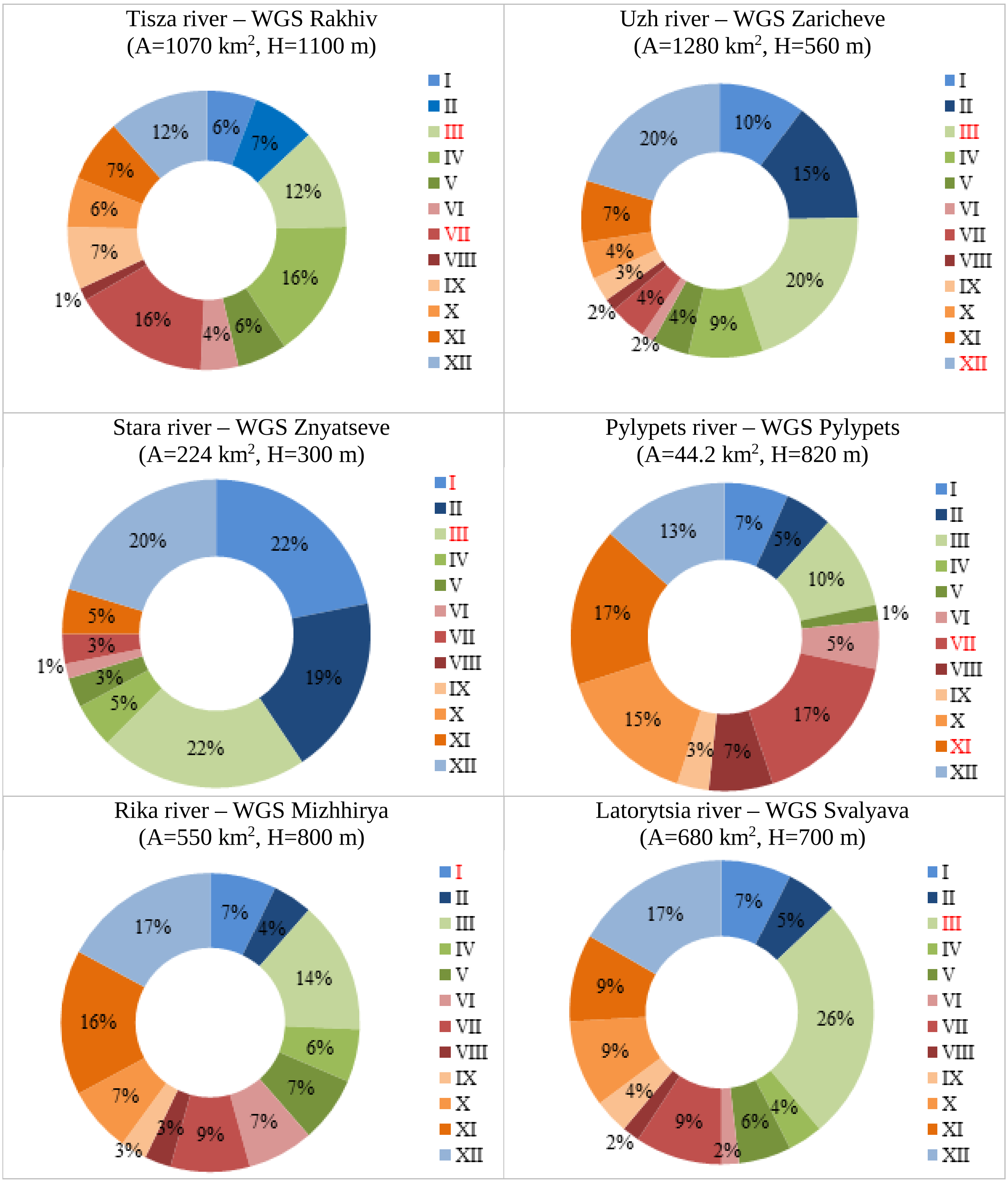
As the average catchment height decreases (Stara river – WGS Znyatseve, A=224 km^2, H = 300 m), the percentage occurrences of maximum in the winter-spring period is already more than 80%, so this is a river with a clear maximum during the spring flood. If we consider small catchments located in the high mountains, for example, Pylypets river – WGS Pylypets (A=44.2 km^2, H= 820 m), then here more than 60% of the maximum discharge occurs in the summer–autumn period. After analyzing all the constructed distributions of the observed maximum water discharges by months during the year, it should be noted that for each catchment there are 2–4 months, in which extremely high runoff values are most often observed. Generally, the studied region in different combinations are months such as November, December, January, February, March, and July.

The next stage of the study was the assessment of the statistical homogeneity of time series. Two parametric tests (Fisher's and Student's) and the nonparametric Wilcoxon test were used for the assessment. The results are listed in Table 3. The standard significance level for these criteria is 5% (Methodological recommendations, 2010). However, given that the observed maximum annual discharges are often close to a 1% probability of being exceeded, a 1% significance level was also used. As can be seen from Table 3, at the 5% significance level, – 50% (8 out of 16) time series turned out to be heterogeneous. At the 1% significance level, the results change significantly – only one of the 16 series (6%) turned out to be heterogeneous. The reasons for statistical heterogeneity can be different; however, the most common for hydrological time series is their insufficient length and the presence of trends caused by climate change and anthropogenic activity. In our case, the duration of observations at the WGS does not differ significantly and ranges from 54 to 70 years, while the heterogeneous Golyatynka-Maidan series has one of the shortest observation durations - 56 years. On the other hand, the Golyatynka-Maidan catchment also has one of the smallest catchment areas (A = 86 km^2). It is possible that the combination of these two factors led to the temporal heterogeneity of the series, but for the final conclusion, it is necessary to investigate possible trends for all catchments.

To study temporal trends in chronological series of maximum runoff, chronological graphs of annual maximum water discharge on the 16 WGS of the Tisza basin within Ukraine were constructed. The results of the estimation of linear trend signification are listed in Table 4. The estimation was based on the significance of the Pearson coefficient. . In case the value of R was more than double the root mean square error of the linear trend correlation coefficient ($2\sigma_R$), the trend was considered significant (Methodological recommendations, 2010). For the case when R was equal to 0.01, the trend was considered invariability. The trend analysis shows both an increase (3 cases or 19%) and decreases in runoff (12 cases or 75%), and in some cases – invariability (1 case or 6%) in fluctuations in the maximum annual water discharge. Thus, there is no definite regularity in the distribution of trends in maximal runoff in the Transcarpathian region. For 4 catchments, there is a statistically significant trend towards a decrease in runoff and, no one case statistically significant trend toward an increase. To illustrate various cases of trends, Fig. 3 shows examples for 6 river catchments of the study area.

The method of residual mass curves was used for further analysis. As shown in Fig. 4, on almost all rivers of the Tisza River basin, perennial fluctuations in maximum water flow are synchronous. Since 2001, there has been a long low-water phase, also at all the catchments considered; there are full water content cycles. As the low-water phase has been observed in recent decades, the onset of the next high-water phase on the rivers of the Tisza River Basin can be expected to exceed the maximum water discharges rather than now. That was confirmed in 2020, then Transcarpathia, once again, suffered from a flood, but currently, we have no officially published data to analyze that flood.

In Ukraine, as in other countries of the former Soviet Union, methods for determining the maximum flow of untrained rivers are developed separately for spring floods and rainfall floods. As the above analysis has shown, in modern conditions on the territory of Transcarpathia, the maximum water discharge is observed almost all year round. Therefore, it is of interest to obtain the calculated dependences for the annual maximums.


Tisza river – WGS Rakhiv
(A=1070 km^2, H=1100 m)

Uzh river – WGS Zaricheve
(A=1280 km^2, H=560 m)

Stara river – WGS Znyatseve
(A=224 km^2, H=300 m)

Pylypets river – WGS Pylypets
(A=44.2 km^2, H=820 m)

Rika river – WGS Mizhhirya
(A=550 km^2, H=800 m)

Latorytsia river – WGS Svalyava
(A=680 km^2, H=700 m)

Fig. 2. Distribution of the observed maximum water discharges (Q, m^3 s^{-1}) by months at the river of Tisza basin within Ukraine.

Table 3. **Estimates of statistical homogeneity of the initial information by three criteria: F-test (Fisher's test), Student's t-test, and Wilcoxon's test**

№	River – water gauge stations	Significance level 1%				Significance level 5%			
		Fisher criterion	Student's criterion	Wilcoxon criterion	Conclusion	Fisher criterion	Student's criterion	Wilcoxon criterion	Conclusion
1	Tisa-Rakhiv	Yes	Yes	Yes	homogeneous	Yes	Yes	Yes	homogeneous
2	Teresva-Ust-Chorna	No	Yes	Yes	homogeneous	Yes	Yes	No	***not homogeneous***
3	Rika-Mizhhirya	No	Yes	Yes	homogeneous	Yes	No	No	***not homogeneous***
4	Golyatynka-Maidan	Yes	No	No	***not homogeneous***	Yes	No	No	***not homogeneous***
5	Pylypets-Pylypets	Yes	Yes	No	homogeneous	Yes	No	No	***not homogeneous***
6	Studeny-Nizhniy Studeny	Yes	Yes	No	homogeneous	Yes	No	No	***not homogeneous***
7	Borzhava-Dovge	Yes	Yes	No	homogeneous	Yes	No	No	***not homogeneous***
8	Latorytsia-Pidpolozzia	Yes	Yes	Yes	homogeneous	Yes	Yes	Yes	homogeneous
9	Latorytsia-Svalyava	Yes	Yes	No	homogeneous	Yes	No	No	***not homogeneous***
10	Latorytsia-Mukacheve	Yes	Yes	Yes	homogeneous	Yes	Yes	Yes	homogeneous
11	Latorytsia-Chop	Yes	Yes	Yes	homogeneous	Yes	Yes	Yes	homogeneous
12	Vicha-Nelipine	No	Yes	Yes	homogeneous	No	Yes	Yes	homogeneous
13	Stara-Znyatseve	Yes	Yes	Yes	homogeneous	Yes	Yes	Yes	homogeneous
14	Uzh-Zhornava	Yes	Yes	Yes	homogeneous	Yes	No	No	***not homogeneous***
15	Uzh-Zaricheve	Yes	Yes	Yes	homogeneous	Yes	Yes	Yes	homogeneous
16	Uzh-Uzhhorod	Yes	Yes	Yes	homogeneous	No	No	No	***not homogeneous***

Table 4. **Assessment of the significance of linear trends at the rivers of Transcarpathia**

№	River – water gauge stations	n, years	Equation	R^2	R	σ_R	$2\sigma_R$	Conclusion	trend direction
1	Tisa-Rakhiv	69	y = 0.1127x + 88.785	0.0001	0.01	0.12	0.24	No	invariability
2	Teresva-Ust-Chorna	68	y = -0.0007x + 1.6981	0.0059	0.08	0.12	0.24	No	decrease
3	Rika-Mizhhirya	70	y = -1.5031x + 3251.7	0.0541	0.23	0.11	0.23	**Yes**	**decrease**
4	Golyatynka-Maidan	56	y = -0.6321x + 1302.3	0.1903	0.44	0.11	0.22	**Yes**	**decrease**
5	Pylypets-Pylypets	60	y = -0.214x + 457.87	0.0392	0.20	0.13	0.25	No	decrease
6	Studeny-Nizhniy Studeny	58	y = -0.2092x + 431.99	0.0956	0.31	0.12	0.24	**Yes**	**decrease**
7	Borzhava-Dovge	70	y = -0.909x + 1976.9	0.0448	0.21	0.11	0.23	No	decrease
8	Latorytsia-Pidpolozzia	70	y = -0.2914x + 757.71	0.0051	0.07	0.12	0.24	No	decrease
9	Latorytsia-Svalyava	54	y = -2.7846x + 5754.4	0.1089	0.33	0.12	0.24	**Yes**	**decrease**
10	Latorytsia-Mukacheve	70	y = 0.0004x + 1.1713	0.0014	0.04	0.12	0.24	No	increase
11	Latorytsia-Chop	60	y = 0.5347x - 805.95	0.0100	0.10	0.13	0.26	No	increase
12	Vicha-Nelipine	59	y = 0.1129x + 310.94	0.0013	0.04	0.13	0.26	No	increase
13	Stara-Znyatseve	64	y = -0.0617x + 151.38	0.0111	0.11	0.12	0.25	No	decrease
14	Uzh-Zhornava	64	y = -0.8209x + 1748	0.0982	0.31	0.11	0.23	**Yes**	**decrease**
15	Uzh-Zaricheve	70	y = -1.3613x + 3202.5	0.0128	0.11	0.12	0.24	No	decrease
16	Uzh-Uzhhorod	70	y = -5.4038x + 11334	0.0964	0.31	0.11	0.22	No	decrease

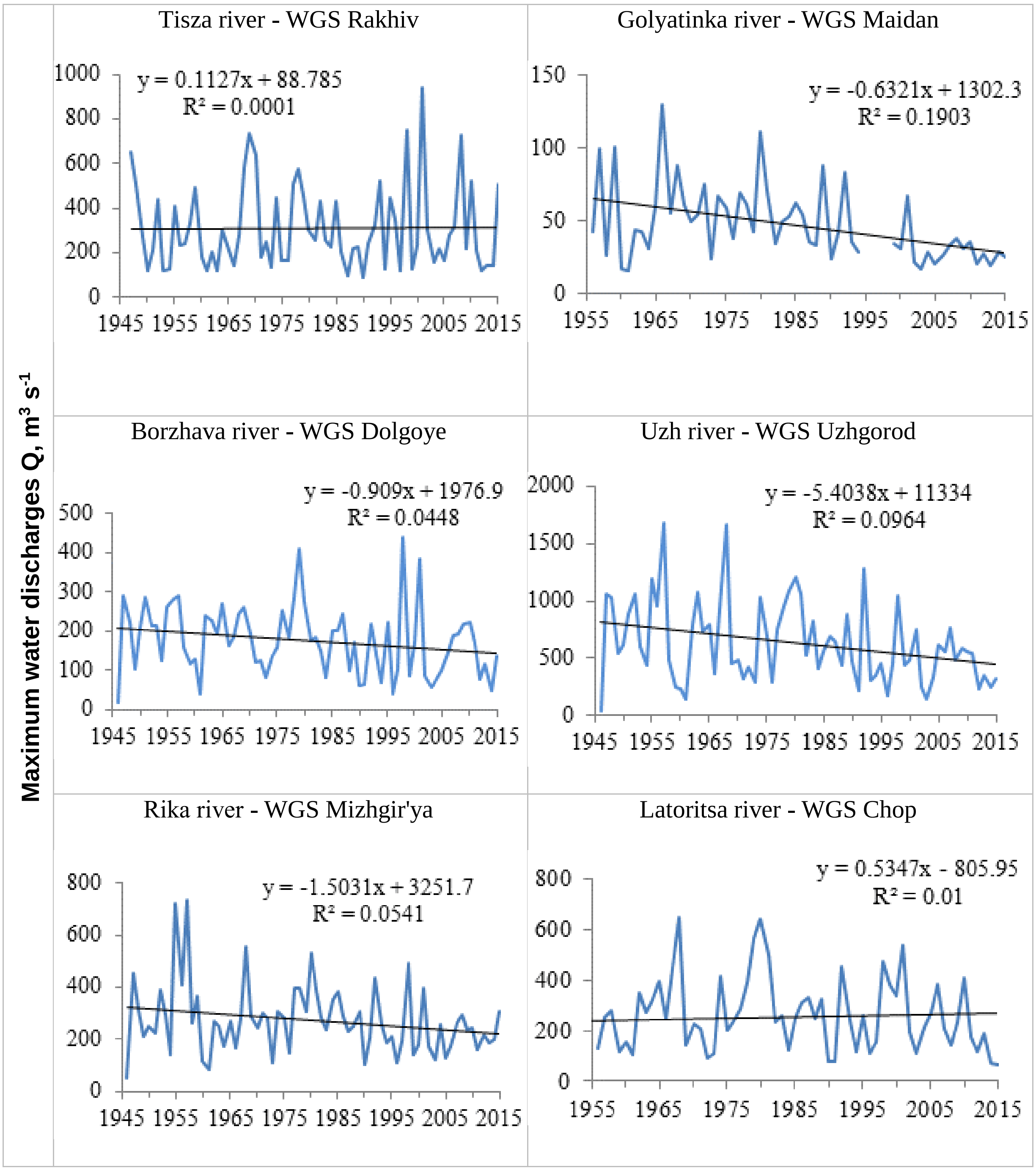


Fig. 3. The time series of maximum water discharges at the river of Tisza basin within Ukraine (Q, m^3 s^{-1}).

The final stage of the work was the study of the patterns of change in the maximum annual discharge from the factors of the underlying surface – the areas of catchments and their average elevations (Fig. 5). For the comparability of the discharges from watersheds of different sizes, when constructing the calculated dependencies, runoff modules were used, which are specific and allow comparing runoff values of different scales. Analyzing the obtained results, we can note that for the rivers under consideration there is a regular decrease in the absolute maximum runoff modules with an increase in the catchment areas. The reduction process can be described as an exponential function, which allows one to take into account the reduction deceleration in the area of large and small catchments (Fig. 5). On the other hand, taking into account that a mountainous region is being considered, the dependence of the investigated value on the average elevations of catchments was built – here there is a regular increase in the maximum runoff modules with an increase in the terrain elevation. In both cases, the dependencies are statistically significant, however, in the case of the average elevations; there is a significant deviation for the catchments with an average height above 1000 m.

Figure 6 shows that if we exclude catchments with an average elevation of more than 1000 m, the coefficient of the accuracy of the approximation increases significantly and will be 0.94. In this case, the obtained dependence can be used to calculate the annual maximum runoff modules for ungauged watersheds with an average elevation of less than 1000 m.

With regard to high-mountain catchments (with a height of more than 1000 m), there is not enough data to substantiate the calculated dependence and it is necessary to use data on neighboring basins. This task is for further research.

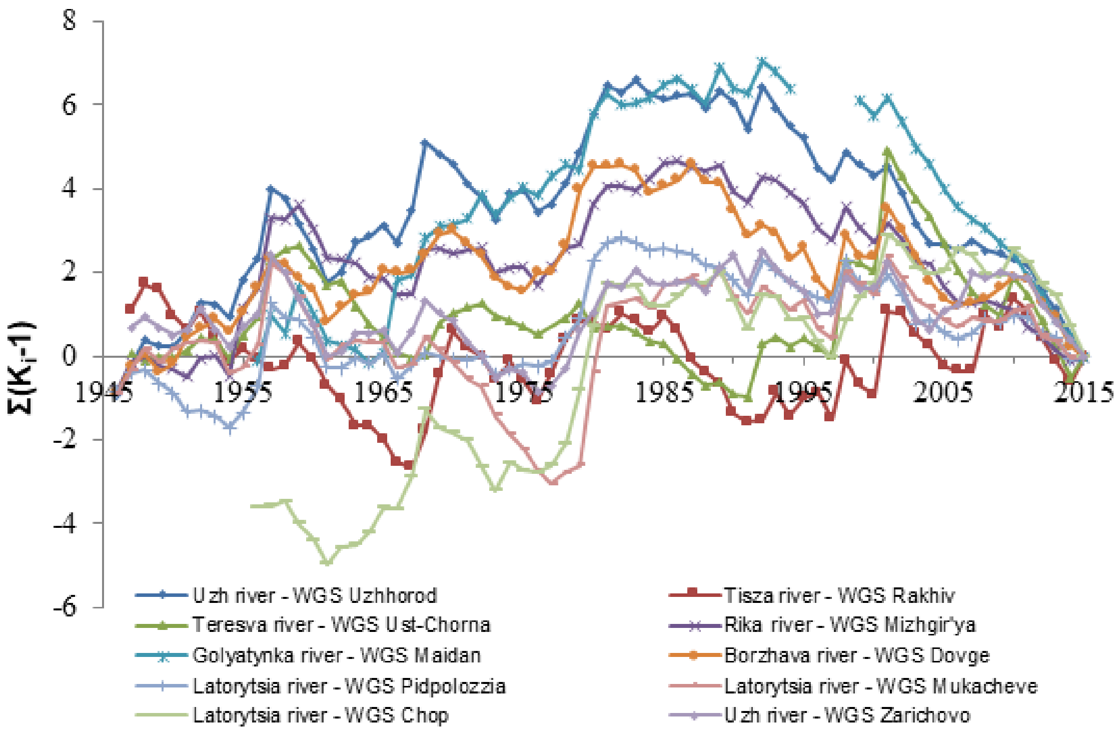


Fig. 4. The residual mass curves of maximum water discharge (Q, $m^3\ s^{-1}$) at the river of Tisza basin within Ukraine.

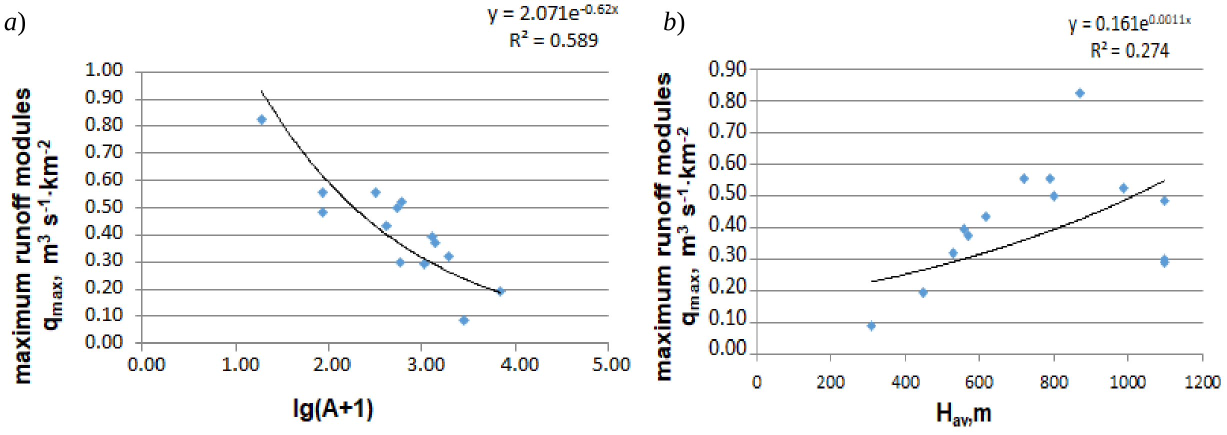


Fig. 5. Relationships of the value of maximum runoff modules ($q_{max}\ m^3\ s^{-1}\cdot km^{-2}$) a) on the area and b) an average elevation of catchments at the river of Tisza basin within Ukraine.

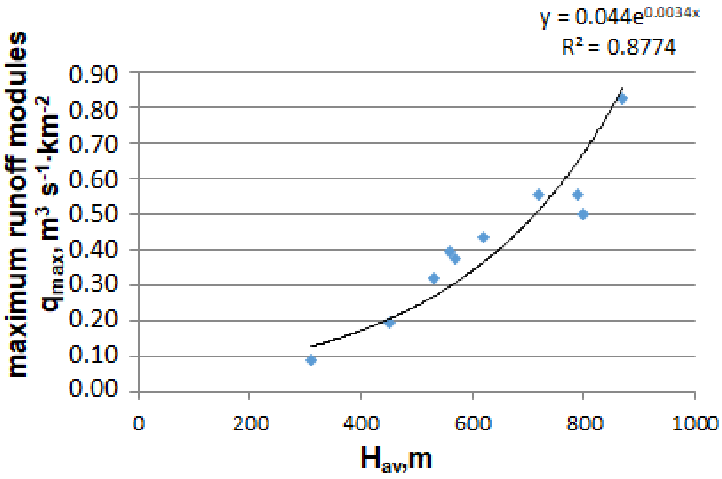


Fig. 6. Relationships of the value of maximum runoff modules (q_{max} $m^3s^{-1}km^{-2}$) on an average elevation of catchments less than 1000 m at the river of Tisza basin within Ukraine.

Conclusion

- Analysis of data on annual flow maximums showed that for the Tisza basin within Ukraine, now under climate change, floods were observed throughout the entire calendar year;
- For the long-term observation period (from 54 to 70 years), the largest number of cases of annual maximum water discharges is observed in December – 44%; in March – 37.5% and in July – 25%. Water resources engineers can use the results obtained, both for individual rivers and for the region as a whole, in planning water intakes from rivers, as well as in justifying the throughput of hydraulic structures.
- The study of the statistical homogeneity of time series shows that at the 1% significance level only one of the 16 series (6%) turned out to be heterogeneous. Time trends in the multiyear maximum water discharges also are not unambiguous. On the territory of Transcarpathia, for 4 catchments, there is a statistically significant trend towards a decrease in the runoff, and no one statistically significant trend cases to an increase.
- The novelty of the study consists in obtaining the calculated dependences of the maximum annual runoff modules on the underlying surface factors. This approach is new, in comparison with the existing similar ones separately for spring floods and rain floods.
- The study of the regularities of the distribution of the maximum annual runoff modules showed that there are statistically significant depen-dences on the catchment area and their average height. Such dependencies can be described by an exponential function. When plotting the dependence on the height no more than 1000 m, the coefficient of the accuracy of the approximation significantly increases, and the dependence can be recommended for practical use for determining the maximum discharge of ungauged rivers in Transcarpathia.

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