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Research Article

MAXIMUM FLOW OF RIVERS OF THE UKRAINIAN CARPATHIANS (IN THE UPPER DNIESTER) IN THE CLIMATE CHANGE CONDITIONS

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ABSTRACT

The complex nature of the flow of the Carpathian Mountains necessitates the identification of current trends in the changes in the maximum flow with different genesis (spring flood and rainwater floods). The studies were carried out over a period of the years (1961-2010) and various phases of water content. Statistically significant trends were identified by the Mann-Kendall test. It was found the statistically significant positive trends in air temperatures are generated during the summer season. The trend of maximum flow is offset in time from the calculated "winter" interval (1961-1981) to the calculated interval of "early snow melt flood" (1982-2010). Since 1989, a statistically significant increase in the maximum flow has been detected in the intervals of "late snow melt flood" and "spring floods". These shifts in time are due to changes in precipitation. The impact of rainfall on the generation of maximum flow is growing.

Keywords: Ukrainian Carpathians, climate change trends, trends in maximum flow of rivers, Mann-Kendall test.

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1. INTRODUCTION

The flow of the rivers is primarily a result of climatic factors. These changes affect the water resources of the territories. Most scientists consider modern changes of the Earth's climate to be the result of anthropogenic activity, which manifests itself in the form of greenhouse gas emissions into the atmosphere. The effects of anthropogenic influence can be predicted using mathematical modelling, depending on changes in the concentration of greenhouse gases in the atmosphere in the future [1, 2, 3]. There is an inverse relationship between climate change and Earth surface transformations. Due to the formation of inverse relationship, the response of the regional climate to the restructuring of the climate system for each geographic area or region may have its own characteristics. This circumstance makes it necessary to establish the existing trends in the regional climate changes and to identify their effects on the formation of water resources in certain areas.

A study of the changes of Ukrainian sluggish rivers flow characteristics with sustainable underground feeding showed that there is a decrease in maximum flow of spring snowmelt floods and the increase in the flow of summer-autumn low water. It was in studies revealing that the annual flow tends to decrease, especially in the southern part of the country [4], where the maximum possible evaporation from the land surface is much higher than the total amount of precipitation. The rise in air temperature during the warm period of the year provides an increase in evaporation from the land surface, which refers to the main discharge component of the water balance of catchments. If the growth of evaporation occurs against the background of statistically insignificant changes in precipitation, the water resources will decrease, and conversely, the growth of evaporation may be insensible with increasing precipitation. Climate change determines not only changes in Ukraine's water resources, but also their redistribution within a year (Kundzewicz et al., [5, 6]). Most of the sluggish rivers of Ukraine have mainly snow feeding, due to which the flow for the snowmelt flood forms the main part of the annual flow. The increase in air temperature during the cold period of the year and its transition from the area of negative air temperature to the positive area affects the depth of soil freezing, the accumulation of water reserves in the snow cover at the beginning of snowmelt, the duration of standing of the snow cover, the shift in the dates of the air temperature transition through 0ºC to earlier periods and so on. All these factors determine the volume, the length of the spring snowmelt flood and maximum discharge rate. The transition of air temperature from negative values to positive values in winter causes the formation of thaws, which contributes to the formation of winter floods and the reduction of water reserves in the snow cover and, accordingly, causes a decrease in the maximum flow of spring snowmelt flood. The loss of melt water to infiltration into underground aquifers contributes to an increase in the underground supply of rivers during the period of low-water.

In Ukrainian Carpathians, where the Dniester River originates, rain floods, formed almost every month, occupy the main place in the feeding of rivers. The rise in air temperatures of the cold period is evident in the plain, while in the mountains it is not so intense due to the influence of vertical zoning. The Ukrainian Carpathians are a zone of excessive and sufficient moisture, where precipitation is larger than the loss due to evaporation. Consequently, the reaction of the flashy rivers water resources to warming can significantly differ from the corresponding reaction of sluggish rivers. The conditions for the response of mountain catchments to climate change are more diverse due to vertical zonation in the distribution of climatic factors (precipitation and air temperatures), the presence of long-term snows, glaciers, and the like. Forecasts of changes in the annual average of multi-year flow of the rivers of Ukraine, were performed on a climate-flow model using climate scenarios (A1B, A2, RCP8.5 and RCP4.5), and showed, that by the middle of the 21st century the growth of water resources is expected on the territory of the Ukrainian Carpathians [7].

Flooding ("high" snowmelt floods, with flooding of areas observed) and floods can create an increased risk for people, the economy, as well as the environment [8]. In future possible climate changes, the frequency of their maxima occurrence is expected to increase [5, 9-12] and others showed in their works that a statistically significant increase in the number of intense precipitation and changes in the maximum flow series is characteristic of a significant number of regions that they have studied, but there are significant regional and subregional variations in the identified trends.

Therefore, most authors did not find any significant changes in the chronological course of maximum discharge. However, as stated by Robson and Chiew [13], "It is possible that changes are occurring but that we do not yet have sufficient data for it to be detectable".

Based on the results of studies on the effects of climate change on river flow characteristics of Ukraine conducted by N. Loboda [4], it is worth pointing out that it is necessary to conduct the identification of trends in flow fluctuations separately for flashy and sluggish rivers. Besides, it is necessary to consider the genetic nature of the formation of maximum flow (flooding or floods).

In this regard, studies of the specific features of climate change and the flow of rivers in mountainous and lowland areas are important for many countries in the world.

Relevance of the work is due to the need to identify the main trends of changes in the maximum flow of the Dniester River, as the main waterway that feeds the south-west of Ukraine and Moldova.

2. DESCRIPTION OF THE OBJECT AND THE RESEARCH METHODS

The Dniester River is the largest river in Moldova and Western Ukraine with a catchment area of 72,100 km^2, the length of the river reaches 1,380 km. Within Ukraine, there is 73.1% of the total catchment area of the Dniester River. The catchment area of the river consists of two unequal parts: mountainous and lowland. The mountainous part is located in the Ukrainian Carpathians (Fig. 1), where the average height of the catchment varies from 300m to 1200m. Through its catchment having a form stretching in the direction of the south-west-south-east, the river, originating in the Ukrainian Carpathians, crosses the forest, forest-steppe and steppe flat zones [14]. From the point of view of hydrological zoning, the mountainous area (the Ukrainian Carpathians) refers to a zone of high and high water content of rivers. Zone of sufficient water content occupies two-thirds of the flat territory occupies. The lower current is in the zone of insufficient water content (steppe).

Fig.1. The investigated part of the Dniester Basin

The water of the Dniester River and its tributaries is used to supply water to such large cities as Lviv, Chernivtsi, Ivano-Frankivsk, Ternopil, Kamianets-Podilskyi (Ukraine) and Chisinau, Bender, Tyraspol (Moldova). There is water intake of the Bilgorod-Dnistrovska irrigation system one kilometre from the Moldovan border on the River Dniester arm. After the merger of the two branches into one, the water flows to the Dniester water supply station, as well as to Mayak-Bilyayivska and Troitsko-Hradenytska irrigation systems. Dniester water supply station delivers water to the cities of Odessa, Shernomorsk, Bilgorod-Dnistrovsky and is of military-strategic importance.

The flow of the mountain tributaries mainly provides supply of the Dniester River. The characteristics of the natural hydrological regime of the main river may be achieved from observations data from the Dniester River section - Zalishchyky City, located above the Dniester reservoir. On the lower strips, the regulating effect of this reservoir transforms the hydrological regime of the Dniester.

Carpathian (flashy) rivers include the right-bank tributaries, in particular Bystrytsia of Nadvirna and Bystrytsia of Solotvyn, and some of the left-bank tributaries, including the Strvyazh River. Other left-bank tributaries of the Dniester relate to sluggish rivers. The main part of the Dniester River flow formation area is in the Ukrainian Carpathians.

A characteristic feature of the Dniester River is the flood regime, ensured by the peculiarities of the conditions for the formation of the flow of the mountain part of the catchment area. Rainfall floods occur during the warm season from April to October. The height of the floods depends on the amount of precipitation that fell during the rainy season. The maximum of the flood flow can be observed in any month of the warm period. It is the floods that pass on the flashy rivers that determine the regime of the main river levels: the highest rise of levels in the downstream of the Dniester River is observed when it is approached by the floodwater volume from the mountain part.

Spring snowmelt flood in the rivers of Carpathians can take place from mid-January to early June, most often in March. It consists of several waves and rain precipitation, which falls during the melting of snow and the decline of spring snowmelt flood, amplifies it. Depending on the climatic conditions, in one years the maximum flow of the spring flood prevails, in the second- the maximum flow of floods in the summer-autumn period, in the third- a continuous alternation of floods occurs in spring and in the summer-autumn period. Floods of a warm period on the rivers of Carpathians are formed by atmospheric precipitation if the amount of precipitation exceeds 20 mm per day. In very intense showers, during which more than 100 mm of precipitation falls, floods become catastrophic. The Carpathian tributaries of the Dniester provide almost 50% of the discharge of the Dniester River, although their catchments occupy only 17% of the total catchment area.

The left-bank tributaries of the Dniester River are a secondary source of feeding to the main river. The bulk of the flow of these rivers is formed during the spring snowmelt flood, when the snow accumulated in their catchments during the winter season melts. Snowmelt flood lasts from late February- early March to late April- early May. The flow of left-bank tributaries decreases to the south, where it is subject to significant water management changes in the form of flow regulation by artificial reservoirs. About 30% of the total flow of the Dniester River comes from the left-bank tributaries of the northern part of the catchment, which feed on powerful underground sources and only 20% the Dniester River receives from the middle and lower reaches, which account for 60% of the catchment area.

In the presented work studies of changes in the maximum flow of the rivers in the Dniester River catchment area, which took place at the beginning of the 21st century as a result of climate changes, were carried out according to data on the daily flow of the Dniester River tributaries and the left-bank tributaries of the upper Dniester River (the rivers Schyrets, Zolota Lypa, Seret, Smotrych). These rivers provide the bulk of the Dniester River flow. The gate of the Dniester River - Zalishchyky City, located above the Dniester reservoir (Table 1), was chosen to identify the patterns of flow fluctuations on the main river. The period of observations of the daily flow, used in this work, lasted from 1960 to 2010.

In order to take into account the features of the maximum flow formation in the intra-annual intervals, each year was divided into time intervals reflecting changes in the conditions for the formation of the maximum daily flow. The season with the most probable formation of maximum discharge because of melting snow (snow melt flooding, which lasts on average from 15/02 to 15/04) was divided into two: "early snow melt flooding", which is formed from 15/02 to 15/03, and "late snow melt flooding" that runs from 16/03 to 16/04. After 16/04 up to 31/05, melt water and rain precipitation, which fall out in the fall of the spring high water, predominantly take part in the formation of the flow maxima. This period was named the "spring flood". The period from 01/06 to 31/08 is considered as the period of passage of "summer rainfall floods", and from 01/09 to 30/11 - as the period of "autumn floods".

Table 1. Characteristics of the studied catchments

River (closing end)	Right-bank or left-bank tributary	Catchment area (km^2)	Average height of the catchment (m)	Average slope ($^{o}/_{oo}$)	Amount of woodland (%)
Tysmenytsa (Drohobych City)	Right-bank	250	390	20,9	36
Stryi (Verkhnje Syn'ovydne Village)	Right-bank	2400	760	4,7	48
Svicha (Zarichne Village)	Right-bank	1280	730	10,2	64
Bystrytsia of Solotvyn (Guta Village)	Right-bank	112	1100	44	90
Schyrets (Schyrets Village)	Left-bank	307	300	2,2	12
Zolota Lypa (Zadarìv Village)	Left-bank	1390			
Seret (Chortkiv City)	Left-bank	3170	350	0,9	11
Smotrych (Tsybulevka Village)	Left-bank	1790	300	1,3	8
Dniester (Zalishchyky City)	Main river	24600	-	-	-

Floods formed from 01/12 to 15/02 are "winter" floods. They are mostly caused by melting of snow during thaws. The ranks of the maximum per diem discharge were formed for each of the selected time segments. Daily maximum was determined within a year and within each of the selected period.

The main method of research is the method of revealing statistically significant trends using the Mann-Kendall test [15]. It uses non-parametric criteria to test the significance of the trend. Statistics S has the following form:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_i\right) \tag{1}$$

Where,

$$\operatorname{sgn}(x) = \begin{cases} 1 & if \;\; x > 0 \\ 0 & if \;\; x = 0 \\ -1 & if \;\; x < 0 \end{cases} \tag{2}$$

For n≥40, the statistic S is asymptotic, normally distributed with an average zero value and variance calculated by the following equation:

$$Var\left\{S\right\} = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)\right] \tag{3}$$

Where, t is the size of the associated group;

$\sum_t$ – the sum of all related groups in the data sampling. The standardized check statistics Z is calculated using the equation:

$$Z = \begin{cases} if \;\; S > 0, \dfrac{S-1}{\sqrt{Var(s)}} \\ if \;\; S = 0, 0 \\ if \;\; S < 0, \dfrac{S+1}{\sqrt{Var(S)}} \end{cases} \tag{4}$$

This characteristic Z obeys the law of the standard normal distribution with mean zero value and unit variance [15]. The significance level α of the Z statistic is determined using tables of the two-sided function of the normal integral distribution.

The concept of reliability values – P or "trend index" (Ti), which is calculated as Ti = (1-α) · 100% for a positive trend and Ti = - (1- a) · 100% for a negative, is used in many works (Kundzewicz et al. [8], and Pujol et al. [11]) for the trend estimation. The range of the Ti for bilateral tests is from -100% to +100%. Negative trends are indicated with negative values, whereas in contrast positive values indicate positive trends. The trends become more significant with higher absolute value of Ti.

The detection of trends in the maximum daily flow change in rivers was carried out for the entire period (1961-2010), and within the high-water (1961-1981) and low-water (1982-2010) phases of fluctuations in the annual flow maxima. The phases of flow fluctuations were distinguished by means of the differential integral curve of the maximum water discharge in the Dniester River - Zalishchyky City (fig. 2). The ordinates of this curve are the accumulated in time sums of deviations of the relative discharge values of the discharge from number one: $\sum(k_i-1)$, where n is the number of years of observations, $k_i=Q_i/Q_{aver}$. Q_i – is the maximum daily discharge for a year, Q_{aver} $Q_{aver.}$- mean maximum discharge value for the entire observation period, for a multi-year period it equals one: $k_{aver.} = 1$. The direction of the integral upward curve means a positive phase in the fluctuations in water content; the downward direction is the negative phase. The latter lasted from 1982 to 2007.

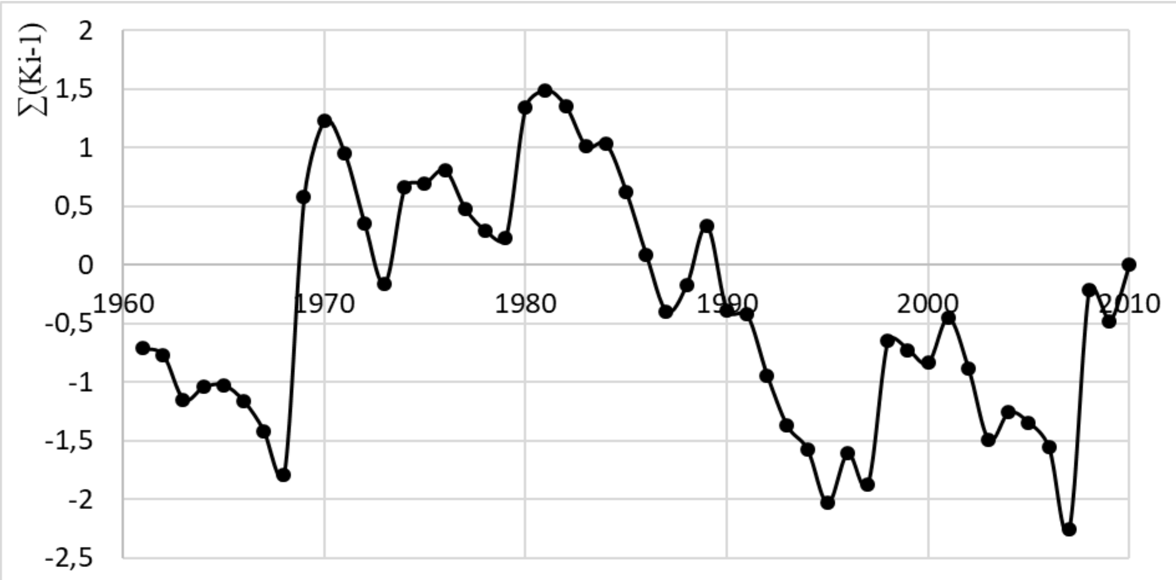

Fig.2. Differential integral curve of the maximum annual expenditures of the Dniester River - Zalishchyky City

The surge in the maximum flow rate, observed in 2008, 2009, and 2010 attributed to the low-water phase. The time interval from 1989 to 2010 forms a full cycle of water content highlighted in Figure 2 on the points of abscissa intersection by the curve. The year 1989 is a turning point for Ukraine: since this year, the rise in air temperatures has acquired statistical significance [16] on its plains.

Given that maximum daily discharge of the considered right-bank and left-bank tributaries of the Dniester River may have different genetic origins (snow or rain), then the distribution of the maximum expenditure frequency during the year was investigated for them. Fig. 3 shows an example of the maximum daily discharge repeatability for the designated intraspecific periods of the year for the right-bank (mountain) tributary - Svicha River and left-bank tributary - Zolota Lypa River. The greatest frequency of the daily flow maxima on the flashy Svicha River occurs during the summer flood period, on the sluggish Zolota Lypa River - during the late spring flood. These features of the intra-annual distribution of flow persist in the high-water and low-water periods.

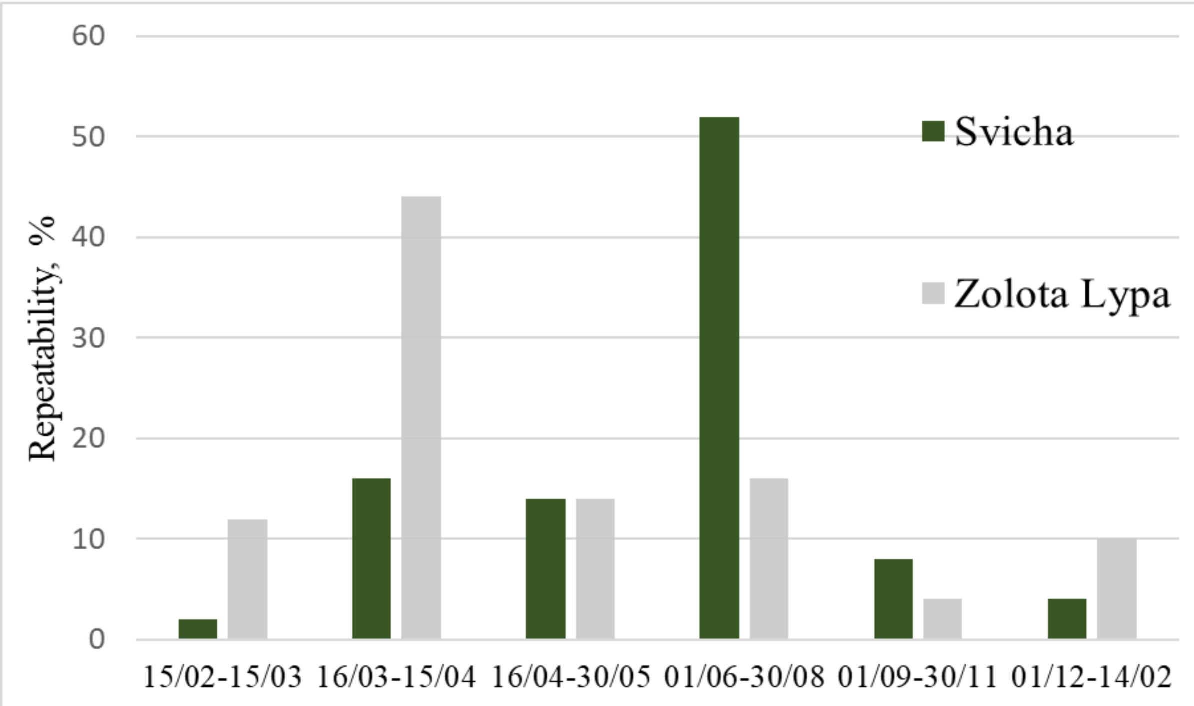

Fig.3. Repeatability of the maximum daily discharge in the corresponding periods of the year on the Svicha River (Zarichne Village), Zolota Lypa River (Village of Zadarìv), 1961-2010

3. RESULTS AND DISCUSSION

3.1 Results of researches

The calculated Ti for the entire period under review (1961-2010) showed that statistically significant trends in fluctuations in maximum daily flow are established only for individual rivers (Table 2). Calculations of Ti for mean monthly and annual air temperatures made it possible to reveal trends in their growth for the year and the warm period for both flashy and sluggish rivers. However, in the temperature fluctuations of the cold period, growth trends were found only in the flat territory (Ternopil weather station). Statistically significant precipitation growth was detected only at heights of 500 m (Slavske weather station) when considering the annual sums of precipitation, precipitation of the cold and warm periods (Fig. 4), and in May and September, considered separately.

Table 2. Trend indices for maximum daily discharge for 1961-2010 per year and allocated intra-annual segments

River (closing end)	For the year	Periods of the year					
		01/12-15/02	16/02-15/03	16/03-15/04	16/04-31/05	01/06-31/08	01/09-30/11
Tysmenytsa (Drohobych City)	**97**	18	27	10	**92**	78	**96**
Stryi (Verhnye Sinevidnoye Village)	54	0	-27	-51	-58	-16	27
Svicha (Zarichne Village)	-40	69	67	32	-38	54	88
Bystrytsia of Solotvyn (Guta Village)	-89	**96**	57	**94**	-73	-40	**98**
Schyrets (Schyrets Village)	82	**99**	-20	27	**99**	32	**99**
Zolota Lypa (Zadarìv Village)	-60	52	-37	-87	-31	-60	79
Seret (Chortkiv City)	**-98**	78	-35	**-92**	-60	10	73
Smotrych (Tsybulevka Village)	-64	**93**	-58	-89	24	0	**97**
Dniester (Zalishchyky City)	42	84	-30	-44	0	-23	74

Analysis of the high-water phase of flow oscillations (1961-1981) of the daily maxima fluctuations shows a stable tendency to increase the maximum daily flow (Table 3) in the winter period (01/12-15/02) and the period of autumn floods (1/09-30/11). Analysis of data on mean annual air temperatures made it possible to draw conclusions about the absence of positive trends in air temperature fluctuations, along with the tendencies of annual precipitation growth.

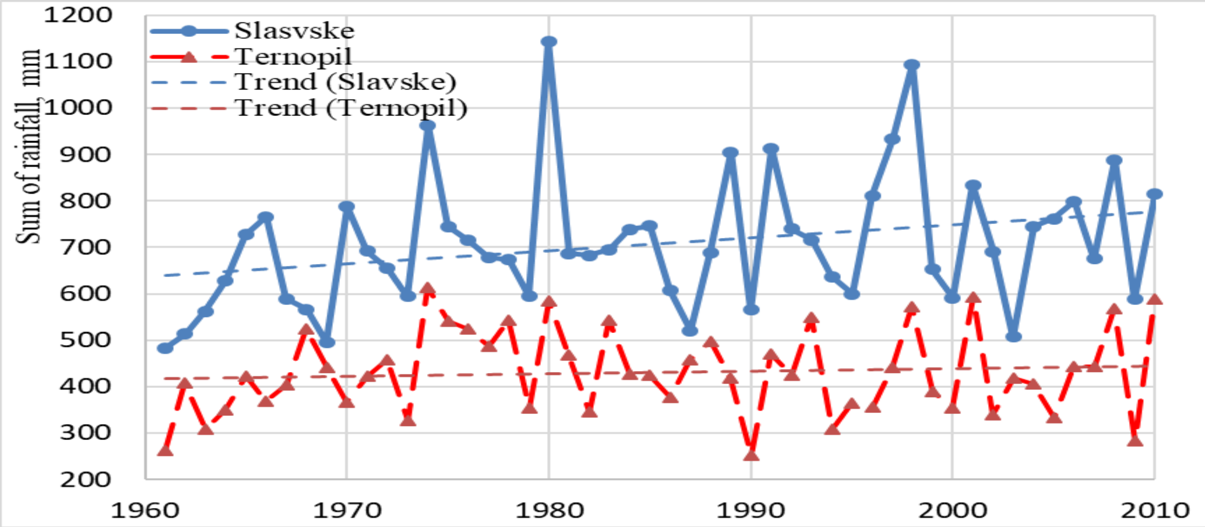

Fig.4. Fluctuations in the sums of precipitation in the warm period (April-October), 1961-2010. By meteorological stations of the city of Ternopil (left-bank area, altitude of 300 m) and Slavske City (the Ukrainian Carpathians, the height of 600 m)

The presence of positive trends in precipitation fluctuations in December, January and February has been discovered and is observed on all meteorological stations. It is conceivable that the increase in precipitation in the cold period against a background of lower air temperatures contributed to the accumulation of water reserves in the snow cover and slowed down their melting, especially in the mountains, where vertical zoning has a significant effect on the formation of the flow.

Table 3. Trend indices for the maximum daily discharge for 1961-1981, allocated by years and intra-annual segments

River (closing end)	For the year	Periods of the year					
		01/12-15/02	16/02-15/03	16/03-15/04	16/04-31/05	01/06-31/08	01/09-30/11
Tysmenytsa (Drohobych City)	27	**91**	17	0	87	74	**98**
Stryi (Verhnye Sinevidnoye Village)	-25	**92**	-56	56	36	86	70
Svicha (Zarichne Village)	32	**92**	-36	-64	74	86	85
Bystrytsia of Solotvyn (Guta Village)	**92**	**91**	-25	62	40	**99**	**95**
Schyrets (Schyrets Village)	28	**99**	0	0	**93**	88	**99**
Zolota Lypa (Zadarìv Village)	**93**	**99**	75	64	66	85	**99**
Seret (Chortkiv City)	38	**99**	36	10	54	72	**99**
Smotrych (Tsybulevka Village)	**98**	**99**	51	50	85	76	**99**
Dniester (Zalishchyky City)	81	**93**	52	-22	65	**98**	**91**

In the low-water phase of fluctuations (1982-2010), no statistically significant trends of the daily flow maxima in the winter period (01/12-15/02) have been established for any river (Table 4). Tendencies to increase the maximum flow shifted to early flooding (16/02-15/03). This is due to the trends to increase the amounts of precipitation in March (Table 5). The fluctuations of the mean annual air temperatures in the low-water phase can be characterized by growth tendencies, formed mainly in the summer months (June, July, and August).

Table 4. Trend indices for the maximum daily discharge for the years 1982-2010 for the corresponding periods of the year

River (closing end)	For the year	Periods of the year					
		01/12-15/02	16/02-15/03	16/03-15/04	16/04-31/05	01/06-31/08	01/09-30/11
Tysmenytsa (Drohobych City)	**96**	12	**95**	78	-40	86	60
Stryi (Verhnye Sinevidnoye Village)	41	36	45	-82	**-98**	-14	-50
Svicha (Zarichne Village)	**93**	52	**95**	73	-73	55	84
Bystrytsia of Solotvyn (Guta Village)	-61	73	**91**	**90**	-86	-55	80
Schyrets (Schyrets Village)	**99**	68	**99**	**98**	**99**	76	**99**
Zolota Lypa (Zadarìv Village)	0	-37	52	-28	40	-64	-23
Seret (Chortkiv City)	-40	54	**91**	-32	**96**	20	**92**
Smotrych (Tsybulevka Village)	84	85	**90**	0	86	62	**99**
Dniester (Zalishchyky City)	**91**	-26	**98**	64	-40	0	51

For the full cycle of fluctuations (from 1989 to 2010), the upward trend shifts during the late flood (16/03-15/04) and on sluggish rivers during spring floods (16/04-31/05) (Table 6). Analysis of Ti calculations results showed that a statistically significant trend in air temperature fluctuations was formed in April. There were no positive trends in air temperatures in the cold period established, even on the contrary, tendencies to decrease were observed (especially in January) (Table 7). In fluctuations in precipitation, statistically significant trends were identified in January and March for the plains only (Ternopil City).

Table 5. Indices of the trend of average monthly and annual temperatures and amount of precipitation for 1982-2010 (low-water phase of fluctuations in water content)

Months	Ternopil City		Slavske City	
	Temperature	Precipitation	Temperature	Precipitation
January	-49	58	-14	28
February	84	66	**93**	82
March	40	**99**	10	**90**
April	89	-63	81	-26
May	15	-72	56	-00
June	**99**	-81	**99**	-03
July	**99**	07	**99**	60
August	**99**	-63	**99**	00
September	-14	26	-31	-07
October	00	**94**	14	15
November	**99**	75	**98**	77
December	-12	10	10	51
Annual	**99**	68	**99**	**97**

Table 6. Trend indices for the maximum daily discharge for the years 1989-2010 allocated by years and intra-annual segments

River (closing end)	For the year	Periods of the year					
		01/12-15/02	16/02-15/03	16/03-15/04	16/04-31/05	01/06-31/08	01/09-30/11
Tysmenytsa (Drohobych City)	65	65	**98**	**92**	-8	69	-10
Stryi (Verhnye Sinevidnoye Village)	74	57	-42	10	**-92**	78	-87
Svicha (Zarichne Village)	**96**	**95**	73	**99**	-29	**92**	63

Bystrytsia of Solotvyn (Guta Village)	24	88	-39	**98**	-33	33	-62
Schyrets (Schyrets Village)	**91**	79	**98**	**97**	70	67	80
Zolota Lypa (Zadarìv Village)	61	-11	11	**96**	20	-71	-73
Seret (Chortkiv City)	39	44	67	84	**96**	-57	65
Smotrych (Tsybulevka Village)	**90**	**93**	80	82	**96**	73	**95**
Dniester (Zalishchyky City)	77	66	79	**96**	0	47	-40

Table 7. Indices of the trend of average monthly and annual temperatures and amount of precipitation for 1989-2010 (full cycle of fluctuations in water content)

Months	Ternopil City		Slavske City	
	Temperature	Precipitation	Temperature	Precipitation
January	**-93**	**98**	-61	83
February	-53	85	0	28
March	-71	**99**	-57	69
April	**90**	-71	**90**	-18
May	71	-72	88	0
June	**90**	0	**98**	57
July	**99**	51	**99**	18
August	**99**	-34	**99**	-03
September	74	0	72	-78
October	06	81	-11	-67
November	86	40	86	14
December	23	51	32	59
Annual	63	**91**	**92**	54

3.2 Discussion

Nicolas Pujol, Luc Neppel and Robert Sabatier, who studied the relationship between the formation of major floods in the French Mediterranean region and climatic changes [12], received similar results. It was in studies revealing that there was a shift in the occurrence of maximum flow values from March to April. The authors explain this fact by changes in the rainfall regime. They showed that, for the same reasons, monthly flow maxima in October increased in the central part of the study area.

These studies can serve as the basis for the assertion that, despite the regional peculiarities of shift of maximum flow values over seasons, they can have general values. These shifts are caused by a change in precipitation due to the climate change in Europe and world.

4. CONCLUSION

1. Estimates of the existence of statistically significant trends in air temperature, precipitation and maximum flow fluctuations were performed using the Mann-Kendall statistical test for various calculation periods, based on the analysis of the fluctuations in the annual maxima of the upper Dniester flow.

2. The Ti value was calculated for intra-annual intervals – their boundaries were designed in accordance with changes in conditions for the formation of maximum flow in the catchment area.

3. It is shown that the formation of trends towards the growth of maximum flow in the upper part of the Dniester River is first due to trends in precipitation growth.

4. Statistically significant trends in air temperature variations are observed in the summer months of June, July, and August. Since 1989, the trend towards an increase in air temperatures has become characteristic in April and May. For the cold period of the year (1989-2010), there have been trends indicating tendencies in decreasing air temperatures and precipitation growth found. This situation led to the formation of later snowmelt floods on the rivers of the upper Dniester.

5. As a result, it can be noted that in the upper part of the catchment of the Dniester River (up to the Zalishchyky City), precipitation is the main factor in the formation of maximum flow. The role of air temperatures is of secondary importance because of the statistically significant trends in their growth detected within the warm period. In the cold period, with conditions for the formation of snow-melt flood flow created, there are no positive trends in changes in air temperatures. The obtained results show that changes in the air temperatures of the cold period in the mountains do not yet have a significant effect on the water content of the Dniester River, in contrast to the flat rivers of Ukraine. This conclusion is very important for the Ukrainian water industry, where water deficit in conditions of global warming grows in a

significant part of the territory.

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