Environmental Research, Engineering and Management, 71(1), 36-46
Aplinkos tyrimai, inžinerija ir vadyba, 71(1), 36-46
crossref http://dx.doi.org/10.5755/j01.erem.71.1.10286
ISSN 1392-1649 (print)
ISSN 2029-2139 (online)

Spatial, Temporal and Forecast Evaluation of Rivers' Streamflow of the Drainage Basin of the Upper Tisa under the Conditions of Climate Change

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(received in March 2015; accepted in March 2015)

The drainage basin of the Upper Tisa is considered to be one of the most flood hazardous areas of the Ukrainian Carpathians. Climate changes in the past decade made a significant impact on the course of hydrological processes, including streamflow. The studies of the processes at global and regional levels are of great importance for grounding of flood protection operations as well as arrangement of measures for adaptation to climate change.

The study considers approaches to evaluation of changes of hydrologic balance elements of the investigated drainage basin in the period of the 20th century. A retrospective analysis of the changes is provided in order to find out relationship between the streamflow and the climate aspects which influence it. A statistical analysis of a series of long-term observations was performed in order to test their steadiness and homogeneity. Inter-row connections were determined between changes in precipitation regime, air temperature of the surface and streamflow in the modern period (1991–2012) compared to the period of the climatic norm (1961–1990). The closest interconnection between mentioned variables is observed for the warm period. For the cold period such dependencies are satisfactory. Consequently, an equation was derived for conversion of the expected influence of climate change on the streamflow.

Results of the regional model REMO-ESNAM5 were used to perform forecast evaluation of hydrological consequences of climate change. The projection of changes of climatic aspects for the drainage basin of the Upper Tisa for the time period 2021–2050 as well as A1B sustainable development scenario was created. The evaluation of possible changes of average, seasonal and annual streamflow in the basin is presented up to the middle of the 21st century. Annual redistribution is clearly registered. Forecast evaluations were performed of the maximum streamflow changes, floods frequency and their recurrence throughout the year.

Keywords: *forebay of the Upper Tisa, climatic changes, aqueous run-off, predictive assessments.*

1 Introduction

Over the past 1.5–2 decades, climate change and its effects are one of the main concerns of the global community. It is a measure of the extreme urgency of this problem that in October 2007 the Norwegian Nobel Committee awarded the Nobel Peace Prize to the Intergovernmental Panel on Climate Change (IPCC). Since all the conditions of human life – from its business and economic activities to mere survival – depend ultimately on the temperatures of land, water basins and air, the development of the methods of reliable prediction of climate trends is very relevant. Research of the impact of modern climate changes and assessment of future consequences of such changes on human activity and environment, including water resources, is equally important and urgent. It was attested by the 21st session of the Intergovernmental Council of the International Hydrological Programme of UNESCO, held in June 2014 at UNESCO Headquarters (Paris, France). The implementation of the eighth phase of this programme (for the period 2014–2021) entitled "Water Security: response to local, regional and global changes" was approved at such session.

The development of specific adaptation strategies is important for assessing the prospects of life of large population groups and requires an individual approach to each particular region with due regard to its natural and socio-economic characteristics. Climate changes significantly impact on many sectors of human activity and environment. The agriculture, housing and utilities sector, power industry, forestry and ecosystems, water, bioclimatic and recreational resources are the most vulnerable to climate changes in the studied basin of the Upper Tisa. In a natural aspect, climate changes impact on river water flow formation and its extreme manifestations. In particular, in the rivers of the Upper Tisa basin they are related to the formation of high and sometimes extraordinary floods.

2 Object, objective, methodical approaches of the research

2.1 Features of water regime of the Upper Tisa basin

Forebays of the Upper Tisa are abundant in Ukraine and refer to the one of the most flood hazard regions of the Ukrainian Carpathians (Fig. 1). The most part of the territory is located in the mountains and foot-hills. About 20% is located in the lowlands. The biggest depths of runoffs are observed on the mountain side, where the watersheds with significant depth of runoff occupy large areas. Over the past 50 years, the years 1955, 1980, 1998 and 2001 were exceptionally abundant, when water flows with runoffs over 800 mm exceeded the average values 1.5–2 times. And they covered 55–60% of the territory, reaching 1200–1800 mm.

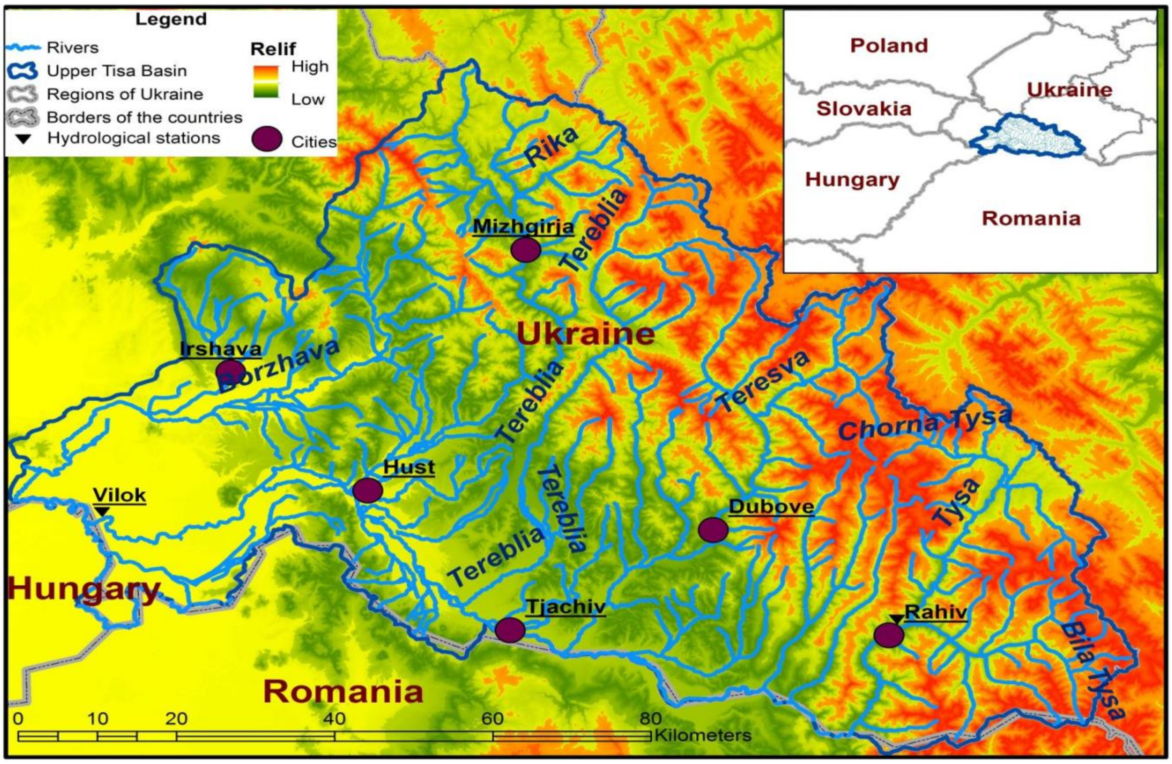

Figure 1. Catchment of the Upper Tisa within Ukraine.

In annual terms, high water content prevails in the cold season (November–April). On average, over the years it exceeds the runoff in the warm period 1.2–1.4 times. Only in 20% of cases, the water content of the warm period exceeds the water content of the cold one.

The floods of varying intensity are observed throughout the year in the basin of the Upper Tisa river and are repeated on average 3–8 times per year. About 20% more floods are formed during the cold period compared with the warm one. In 25–27% of years, the maximum annual water losses fall in March–April. This is due to either the formation of spring floods or snow-rain floods. In 12–15% of years, relatively high snow-rain floods occurred in the 20th century in spring during these two months. However, they were lower in terms of the maximum water losses and levels than in March 2001. During the period 1883–2012, the snow-rain floods, close to 2001, occurred in March 1888, 1914, 1920, 1922 and 1940. Heavy floods are also influenced by the rains. In the main areas of rainfall, on average 100–200 mm of rain fall. In case of forming the catastrophic rain floods, the precipitation during 2–3 days can reach 300–350 mm. It is 2–3 monthly rates for this basin. The highest rain floods were in 1927, 1941, 1947, 1969, 1998, and 2008 (Sosyedko & Luk'yanets, 2010).

2.2 The purpose of the study

In terms of the quantitative characteristics of water resources and water regime, and spatio-temporal dynamics and variability of the river's runoff, climatic factors play a decisive role. Climate changes include a set of vibrations of climatic characteristics of different scales, but above all, they are the changes of temperature and precipitation. In recent decades they have had significant impact on the course of long-term fluctuations in many hydrological processes and have been reflected in changes in the components of the water balance of territories and hydrological cycle. This affects snow cover, transpiration, ground water and so on. Annual redistribution of precipitation (changes in the structure and quantity) is displayed in fluctuations and regime of river run-off, the mode of round waters, groundwater supply, etc.

The purpose of this study is to evaluate current changes in the parameters of the climate system in the catchment area, identify their impact on changes in river water run-off in the area of the Upper Tisa and determine possible climate changes by the middle of the 21st century in this region and as a result reassess expected impacts of climate change on water run-off from the catchment area of the Upper Tisa.

2.3 Methodological approaches

The methods of water balance for a long period and the statistical relationship between meteorological factors and water runoff are applied to quantify the hydrologic effects of climate changes (Alexeevsky, 2012).

According to the water balance equation, the river water run-off is the difference between precipitations and evaporation from the surface of the river basin, which gives rise to assess changes in water run-off by the changes in thermal and moisture modes in practice. Such an assessment was implemented by finding statistical analytical expressions for the pair $(y = f(x))$ and multiple $(y = f(x_1, x_2)$ correlation. Statistical methods for analysis of hydrological data can be used only to homogeneous series, so prior to the statistical calculations the test of hypothesis of homogeneity of the average annual and maximum water losses was implemented. The nature of the changes in the modern period (1991–2012) in the mode of rainfall, surface air temperature and water run-off is set by comparing them with the base period 1961–1990 (period of climatic norm). For this purpose, the data of monitoring network stations and posts of the Hydrometeorological Service of Ukraine for the period of 1961–2012 are used.

The predicted assessments of possible climate changes in 2021–2050 were implemented according to the data of the regional climate model of REMO Max Planck Institute for Meteorology (Germany) based on the model of the general circulation of the atmosphere and ocean ECHAM5. This model best describes the climatic conditions of Ukraine (Krakovska, Palamarchuk, Shedemenko, Dyukel, & Hnatiuk, 2008; Palamarchuk, Krakovska, Shedemenko, Dyukel, & Hnatiuk, 2009). At the same time, the results of calculation obtained in the framework of the European project FP-6 ENSEMBLES for scenario SRES-A1B (balanced scenario for society development) were used with a resolution of 25 * 25 km.

3 Time homogeneity of water run-off characteristics in the basin of the Upper Tisa

Application of the traditional methods of statistical assessment of characteristics of random value ξ requires this value to be presented by sampling $x_1 \ldots x_N$, i.e. a set from N of its independent and homogeneous realisations. Independence means that the values $x_1 \ldots x_N$, randomly obtained in N experiments are independent in total. Homogeneity means that all N experiments were carried out in the same conditions, and values $x_1 \ldots x_N$ are subject to the same probability distribution function $F(x) = P(\xi(t) < x)$ (condition of homogeneity of series). The longer the sample, the more reliable assessment of the $F(x)$ and its partial characteristics, such as the expectation and variance. Mean square errors of already implemented assessments tend to 0 for $N \to \infty$, and the assessments tend to (in probability) the true values of characteristics ξ. And all realisations must be given with continuous time t of realisation $x_i(t)$, for which the process $\xi(t)$ is considered.

At most, the hydrologists are interested in certain hydrological characteristics over a particular period of time. These characteristics can only take one value per year, and the processes of their years-long fluctuations are represented only by one realisation for the period of observations. Therefore, there are random processes, for which receipt of statistical conclusions on single realisation is not only possible, but can even be implemented with satisfactory precision at sufficient length of such realisation. The first stage of data analysis should be testing of statistical hypotheses of independence and homogeneity. This is the most important issue in practical terms. Clarification of statistical homogeneity of populations is an important element for assessment of the reliability of statistical generalisations. One should feel strongly about the fact how an accepted theoretical scheme is consistent with the empirical material. It can be performed using non-parametric criteria that do not require knowledge of the law of distribution of probabilistic values of the process $\xi(t)$ and parametric criteria based usually on the assumption of normality of such distribution.

Statistical assessment of the homogeneity of a series of years-long fluctuations in river run-off in the basin of the Upper Tisa was carried out according to the observations of hydrological post Vylok in Tisa river (catchment area $F = 9{,}140$ km^2) for the period from 1961 to 2012 (Fig. 1). The flow of water through this dam site is an integral feature of hydrometeorological processes occurring in the studied area. The average and maximum annual water losses were used. Quantitative assessment of in-series homogeneity is performed by generalised standard parametric criteria (Table 1): by Student's test to check the significance of the mean values (statistics t) and Fisher's criterion to test the equality of variances (statistics F). With regard to nonparametric criteria, one of the most rigorous criteria is used – Mann-Whitney-Wilcoxon test (statistics of the number of inversions U) (Table 2).

Table 1. The results of test for time homogeneity of average annual and maximum water run-off in the basin of the Upper Tisa by parametric criteria for significance level 2α = 5%.

Homogeneity criteria	**Statistics value**		**Results of hypothesis test**
	empirical	**theoretical**	
Average annual water losses			
Student's, statistics t	0,11	1,68	$t_{emp} < t_{teor}$ homogenous
Fisher's, statistics F	1,42	2,01	$F_{emp} < F_{teor}$ homogenous
Maximum annual water losses			
Student's, statistics t	0,74	1,68	$t_{emp} < t_{teor}$ homogenous
Fisher's, statistics F	1,35	2,01	$F_{emp} < F_{teor}$ homogenous

Table 2. The results of test for time homogeneity of average annual and maximum water run-off in the basin of the Upper Tisa by non-parametric criteria of Mann-Whitney-Wilcoxon.

Theoretical critical values of statistics *U*		**Empirical quantity of inversions U_{emp}**	**Results of hypothesis test**
lower U_H	**upper U_B**		
Average annual water losses			
224	436	329	$U_H < U_{emp} < U_B$ homogenous
Maximum annual water losses			
224	436	376	$U_H < U_{emp} < U_B$ homogenous

To assess the homogeneity of the series of observations of average annual and maximum water run-off, the total integral curves are also built (Figures 2, 3). It is clearly demonstrated in the corresponding graphs that there are no breaking points. It is the evidence of homogeneity of series, i.e. absence of any major changes in the studied characteristics of water regime in the basin of the Upper Tisa.

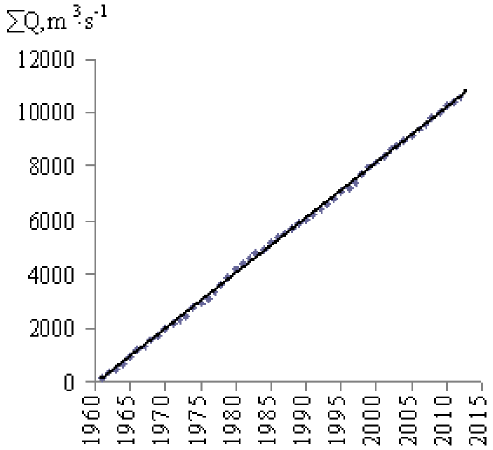

Figure 2. Total integral curve of average annual water losses of Tisa river – Vylok village.

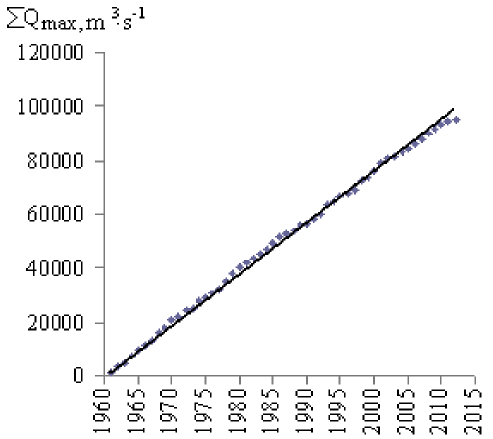

Figure 3. Total integral curve of maximum water losses of Tisa river – Vylok village.

4 Regional manifestations of the climate changes and their impact on the water run-off in the river basin of the Upper Tisa

4.1 Modern changes in air temperature, precipitations and water run-off in the basin of the Upper Tisa

The tendency towards an increase in the surface temperature is typical for the basin of the Upper Tisa in modern times compared to the base period of 1961–1990 (Fig. 4). It became higher in all seasons and for the year as a whole. The change in thermal regime is accompanied by changes in the moisture regime (Fig. 4B). The annual precipitations in the region have changed slightly, but their redistribution occurred between seasons and months (Table 3).

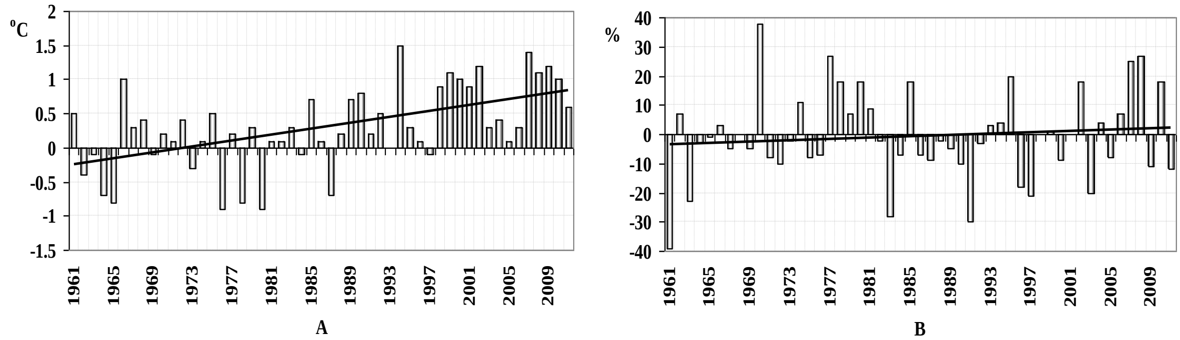

Figure 4. Anomalies of the average yearly air temperature (A) and the amount of precipitation (B) in the basin of the Upper Tisa compared to the climatic norm (1961–1990).

Table 3. Changes of the air temperature (ΔT, °C), amount of precipitation (ΔP, %) and run-off (ΔR, %) in the basin of the Upper Tisa in 1991–2012 compared to the climatic norm (1961–1990).

Periods (month, season, year)	Changes in 1991–2012 compared to the climatic norm (1961–1990)					
	Air temperature Δ*T*, °C			Amount of precipitation Δ*P*, %	Water run-off Δ*R*, %	
	Average	Maximum	Minimal		Average	Maximum
I	+1.7	+1.3	+2.2	+1	+20	-12
II	+0.4	+0.2	+0.6	+17	-9	-24
III	+0.8	0.0	+0.4	+13	+22	+16
IV	+0.5	+0.6	+0.2	+3	-1	+2
V	+0.7	+1.0	+0.4	-5	-10	-18
VI	+1.1	+1.4	+0.7	-19	-19	-27
VII	+1.5	+1.8	+1.3	+1	-17	-18
VIII	+1.6	+1.9	+1.3	-11	-23	-36
IX	0.0	-0.2	0.0	+30	-2	+8
X	+0.4	-0.3	+0.7	+32	+20	+52
XI	+0.6	+0.8	+0.3	+2	+27	+33
XII	+0.2	+0.1	0.0	+2	+12	0
Winter	**+0.8**	**+0.5**	**+1.0**	**+7**	**+8**	**-12**
Spring	**+0.5**	**+0.5**	**+0.3**	**+4**	**+4**	**0**
Summer	**+1.4**	**+1.7**	**+1.1**	**-10**	**-20**	**-27**
Autumn	**+0.4**	**+0.1**	**+0.4**	**+21**	**+15**	**+31**
Year	**+0.7**	**+0.7**	**+0.7**	**+6**	**+2**	**-2**

During the last two decades (1991–2012), the average annual temperature increased by 0.7°C compared to the climatic norm. Summer and winter seasons had the largest contribution to the change in annual air temperature in the region. Their average temperature increased by 1.4°C and 0.8°C respectively. The temperature in January (1.7°C), August (1.6°C) and July (1.5°C) increased most significantly. The average temperature of transition seasons (autumn and spring) also increased, but less than 0.4°C and 0.5°C. In the cold season there is a significant increase of the minimum temperature and an increase in maximum temperature in the warm period.

In 1991–2012, the annual precipitations increased by 6% compared to the climatic norm. There is a significant increase in precipitations in autumn by 21%, resulted in increase in moisture of the area during this period. At the same time, the maximum increase in precipitations is observed in September (30%) and October (32%). In summer, the amount of precipitations has decreased by 10%. June and August became the most rain-free periods. In these months, the deficit of precipitations over the past twenty years was 19% and 11% respectively. In winter, the change in precipitations is negligible, except February, when precipitations have increased by 17%.

Currently, the average annual run-off hardly changed; there is only a slight tendency to its increase (2%), but clear intra-annual flow distribution, well correlated with changes in temperature and moisture regime. In summer, the average water run-off of basin rivers decreased by 20%, in autumn it increased by 15%, and in winter and in spring it increased by 8% and 4% respectively. For two studied periods, the change in the values of the maximum monthly run-off mainly repeats intra-annual changes in average run-off. For the period of 1991–2012, the largest increase in maximum water run-off in the basin of the Upper Tisa was observed in autumn (31%), especially in October (52%) and November (33%). The maximum river run-off significantly declined in summer (27%). It notably decreased in June (27%) and August (36%).

4.2 Calculation equations for predictive estimation of changes in water run-off in the basin of the Upper Tisa

Assessment of modern hydrological consequences as a result of climate changes was based on the solution of water balance ratios in the form of statistical relationships between the meteorological factors and water run-off, with special emphasis on sensitivity of changes of the river water run-off *Rсер* to the changes in air temperature ΔT and precipitation *ΔP*. The relationship between changes in *ΔRaver*. and changes in maximum run-off ΔRmax. is also considered. When we considered the row dependences under one multiple correlation *Rser. = f (P, T)* and a pair of linear regressions *Rmax. = f(Rser.)*, the closest relationship was obtained for the warm season than the cold one (Table 4).

Table 4. Computational equations for predictive assessment of changes in water run-off in the Upper Tisa basin in 2021–2050 compared to the climatic norm (1961–1990).

Computational equations	**Relationship correlation factors**	**Possible factor error**	**Mean square error of calculated values**
Changes in average monthly water run-off for warm (*ΔRaver.w.p.*) and cold (*ΔRaver.c.p.*) periods of the year by dependence *ΔRaver. = f(ΔP, ΔT)*		multiple correlation $\varepsilon_{Rr} = \pm 0.674\ (1\text{-}R_r^2)\ (n^{0.5})^{-1}$	$E_{\Delta Raver} = \pm\sigma_{\Delta R} \cdot (1\text{-}R_r^2)^{0.5}$
ΔRaver.w.p. = 0.43*ΔP*-8.8*ΔT*+2.02	R_r= 0.88	±0.06	±6.4
ΔRaver.c.p. = -1.18*ΔP*+0.74*ΔT*+21.7	R_r= 0.65	±0.17	±9.7
Changes in maximum water run-off for warm (*ΔRmax.w.p.*) and cold (*ΔRmax.c.p.*) periods of the year by dependence *ΔRmax. = f(ΔRaver.)*		pair correlation $\varepsilon_r = \pm\ (1\text{-}r^2) \cdot ((n\text{-}1)^{0.5})^{-1}$	$E_{\Delta Rmax.} = \pm\sigma_{\Delta R\ max.} \cdot (1\text{-}r^2)^{0.5}$
ΔRmax.c.p. = 1.897*ΔRaver.w.p.*+6.275	r = 0.98	±0.01	±4.5
Δ Rmax.c.p. = 1.531*ΔRaver.c.p.*-21.861	r = 0.81	±0.15	±11.9

Possible errors of correlation factors and mean square errors of the calculated values are computed. Defined relationship correlation factor *ΔRaver.= f(ΔP, ΔT)* for the warm period, taking into account the probable error, is 0.88±0.06 and 0.65 ±0.17for the cold period.

The mean square error of values *ΔRaver.* calculated by the equation of the regression for the warm period is 6.4% and 9.7% for the cold period. Mean square errors of *ΔRmax*. for the warm period is 4.5% and for the cold period - 11.9% (Table 4). These errors limit the predicted assessments.

5 Projection of change in the parameters of the climate system and possible changes in the water regime of the Upper Tisa basin rivers to the middle of the 21st century

According to the projection of regional model REMO-ESNAM5, to the middle of the 21st century, for the period 2021–2050, one can expect an increase in air temperature throughout the year relatively to the period of climatic norm in the Upper Tisa basin. Thus, the average annual, maximum and minimum temperatures will increase by 1.1–1.2°C. The largest growth of extreme air temperatures is possible in autumn (1.3°C), mainly due to October (2.3–2.4°C) and winter (1.1–1.4°C), with the most significant change in February (2.1°C) and January (1.3°C). These changes will lead to the fact that the duration of winter and its severity will decline (Table 5).

Table 5. Projections of change in air temperature (ΔT, oC), amount of precipitation (ΔP, %) in the Upper Tisa basin in 2021–2050 compared to the climatic norm (1961–1990) and modern period (1991–2012).

Periods (month, season, year)	**Projections of changes in 2021–2050 compared to the climatic norm (1961–1990) based on the regional model REMO-ECHAM5**				**Projections of changes in 2021–2050 compared to the modern period (1991–2012)**	
	Air temperature, °C			**Amount of precipitation, %**	**Average air temperature, °C**	**Amount of precipitation, %**
	Average	**Maximum**	**Minimal**			
I	+1.3	+1.0	+1.3	-1.7	-0.4	-2
II	+2.1	+1.6	+2.1	+31.6	+1.7	+17
III	+1.3	+1.7	+1.5	+0.3	+0.7	-13
IV	+0.5	+0.4	+0.3	+1.4	0	-2
V	+0.3	+0.6	+0.8	+13.5	+0.1	+9
VI	+1.1	+1.1	+1.1	-2.1	0	+17
VII	+0.7	+0.6	+0.7	+11.1	-0.8	+9
VIII	+1.2	+1.2	+1.2	-10.9	-0.4	-1
IX	+1.2	+1.1	+1.2	+28.5	+1.2	-4
X	+2.3	+2.4	+2.3	-28.0	+1.9	-60
XI	+0.3	+0.4	+0.4	-4.1	-0.2	-7
XII	+0.4	+0.8	+0.4	+34.9	+0.2	+31

Periods (month, season, year)	Projections of changes in 2021–2050 compared to the climatic norm (1961–1990) based on the regional model REMO-ECHAM5				Projections of changes in 2021–2050 compared to the modern period (1991–2012)	
	Air temperature, °C			Amount of precipitation, %	Average air temperature, °C	Amount of precipitation, %
	Average	Maximum	Minimal			
Winter	+1.4	+1.1	+1.3	+22.8	+0.5	+15
Spring	+0.9	+0.9	+0.9	+6.2	+0.3	-2
Summer	+1.0	+1.0	+1.0	-0.1	-0.4	+8
Autumn	+1.3	+1.3	+1.3	-0.3	+1.0	-24
Year	+1.2	+1.1	+1.1	+6.3	+0.4	-0.5

As predicted, by the middle of the 21st century the moisture regime in the Upper Tisa basin will also change compared to the climatic norm. Although the yearly amount of precipitation will vary slightly (6.3%), but its significant heterogeneity will be observed throughout a year. Significant (22.8%) increase in precipitation can be in winter. At the same time, in December and February its amount may rise by one third compared to the climate norm. A significant increase in precipitations in September (28.5%) will be compensated by their substantial decrease in October, leading to the fact that, as a whole, the amount of precipitation will decrease in autumn. The amount of precipitation during the summer also will not change significantly, but its amount will increase in July and decrease in August. For experience of expected changes in climatic characteristics in 2021–2050 in comparison with the period of 1991–2012, the projections of changes are brought to the modern period (Table 5).

Using the computational equations presented in Table 4, the predicted assessments of the changes in average and maximum water run-off are calculated for the months, seasons and a year as a whole in the Upper Tisa basin in 2021–2050 compared to the climatic norm (1961–1990). Also, such assessments are performed for comparison to the modern period (Table 6).

Table 6. Predicted assessments of the changes in water run-off of the Upper Tisa basin in 2021–2050 compared to the climatic norm (1961–1990) and to the modern period (1991–2012).

Periods (month, season, year)	Predicted assessments of the changes in water run-off, %			
	compared to the climatic norm (1961–1990) by dependencies (Table 4)		*compared to the modern period* (1991–2012)	
	Average	Maximum	Average	Maximum
I	+24	+14	+4	+26
II	-17	-47	+2	-23
III	+22	+12	0	-4
IV	-2	+3	-1	+1
V	+0.8	+8	+9	+26
VI	-9	-10	0	+17
VII	+0.3	+7	+17	+25
VIII	-14	-20	+9	+16
IX	+3	+11	+5	+3
X	-30	-41	-50	-92
XI	+27	+19	0	+14
XII	-18	-49	-30	-49
Winter	**-4**	**-20**	**-8**	**-15**
Spring	**+7**	**+8**	**+3**	**+8**
Summer	**-8**	**-8**	**+9**	**+19**
Autumn	**0**	**-7**	**-15**	**-25**
Year	**-1**	**-9**	**-3**	**-3**

The following figures graphically illustrate the changes in the average monthly air temperature (ΔT, ^oC), amount of precipitation (ΔP, %) and water run-off (ΔR, %) in the modern period compared to the climatic norm (Figure 5); changes in the average monthly air temperature (ΔT, ^oC), amount of precipitation (ΔP, %) and predicted assessments of the changes in water run-off (ΔR, %) in 2021–2050 compared to the modern period (Figure 7).

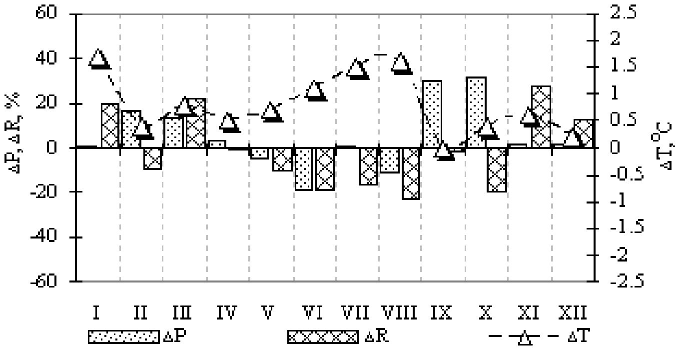

Figure 5. Changes in the average monthly air temperature (ΔT, °C), amount of precipitation (ΔP, %) and water run-off (ΔR, %) in 1991–2012 compared to the climatic norm (1961–1990). Projections of changes in the average monthly air temperature (ΔT, °C), amount of precipitation (ΔP, %) and predicted assessment of changes in water run-off (ΔR, %) in 2021–2050 compared to the climatic norm (Figure 6).

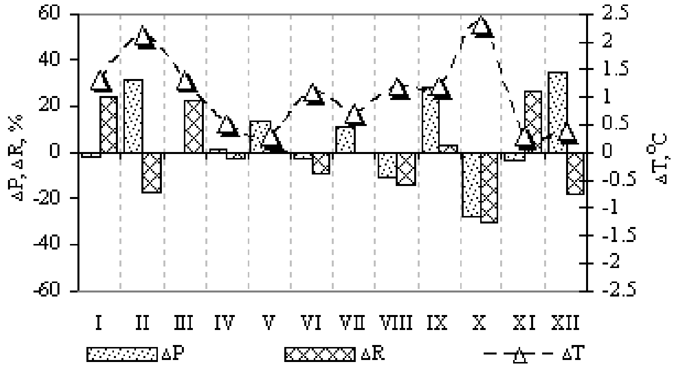

Figure 6. Projection of changes in the average monthly air temperature (ΔT, °C), amount of precipitation (ΔP, %) and water run-off (ΔR, %) in the Upper Tisa basin in 2021–2050 compared to the climatic norm (1961–1990).

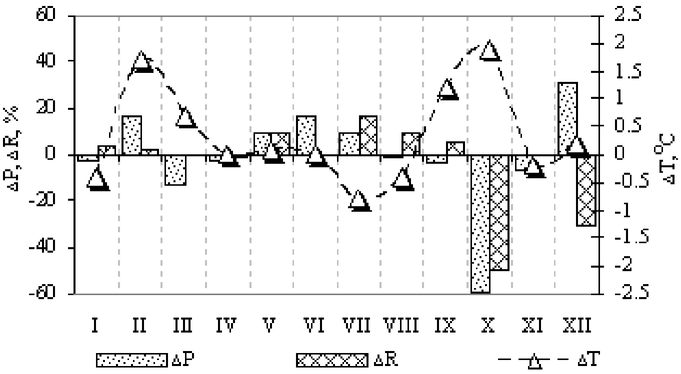

Figure 7. Changes in the average monthly air temperature (ΔT, °C), amount of precipitation (ΔP, %) and predicted assessments of the changes in water run-off (ΔR, %) in the Upper Tisa basin in 2021–2050 compared to the modern period (1991–2012).

Since the studied catchment area includes mountains and plains, the relationship of deviations of the changes in the average and maximum run-off in modern period is built in comparison with the period of climatic norm in the Upper Tisa river near Rakhov (water run-off from the mountains) and Vylok (water run-off from the territory of the Upper Tisa) (Figure 1). The absolute heights of these hydrological stations are 429.73 m and 115.15 m respectively. It was found that changes in water run-off are well correlated. For the average water run-off, the correlation factor is 0.87, for corresponding maximum water losses it is higher and amounts to 0.92. That is, until the middle of the 21st century, the character of changes in water run-off from the mountain will be identical to the Upper Tisa basin as a whole.

6 Comparison of results of research under the structure of years-long fluctuations in run-off in the rivers of the Carpathians

Given the mean square errors of calculated values (Table 4, 6), one should not expect for significant increase or decrease in the average annual and maximum run-off to the middle of the 21st century compared to the climatic norm and modern period. This thesis is confirmed by scientific papers earlier translated by the author of the article (Luk'yanets & Sosyedko, 1998; Luk'yanets, Sosyedko, & Balabukh, 2008). Investigation of the structure of years-long fluctuations in river run-off in the rivers of the Carpathians (autocorrelation and spectral analysis) demonstrated the presence of recurrence, regular alternation of periods (groups of years) of high and low water content (Figure 8).

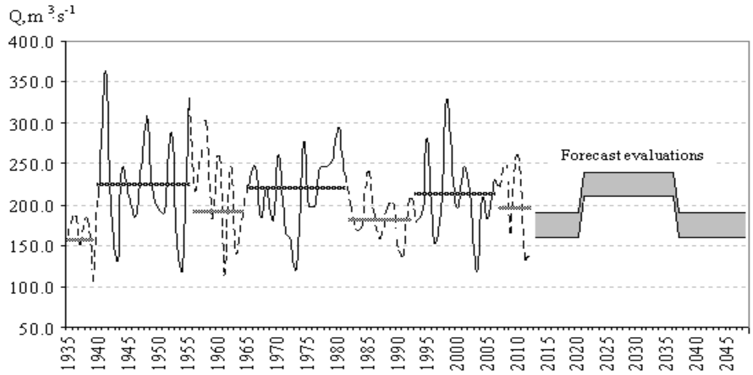

Figure 8. Chronological series of average annual water losses of Tisa river in Vylok village during the period of high and low water content and predicted assessments of the water run-off for the coming years.

These periods are relatively stable in terms of duration and magnitude of run-off. The duration of the periods of high water content is 16–17 years, low water content 9–13 years. The average duration of cycles is 26–29 years. Specific regimes of time variation of river run-off and frequency of significant floods are typical for various periods of water content. In the periods of low water content, the amount of precipitation and volume of river run-off by an average is less by 20–30% than the period of high water content. Floods are formed in the periods with abundance of water (for Tisa basin: 1912–1927, 1940–1955, 1965–1981, 1993–2006, etc.), often with devastating consequences with recurrence in 3–4 and 6–7 years. Significantly less quantity of floods is observed during the periods of low water content, and their recurrence is subtle or is not detected at all. The discovered patterns enable to assess the water content for the following periods. It is expected that in the first half of the 21st century, the period of high water content will be observed in 2020–2036.

7 Conclusions

Calculations demonstrate that the studied sequences of run-off characteristics in the Upper Tisa basin can be considered homogeneous random process, in which the average values and variances (within probable errors) are permanent, and correlation functions depend only on the difference of time arguments. Based on the given analysis of changes of average and maximum water content by the actual hydrometeorological data and projections of change in the parameters of the climate system in 2021–2050, the following conclusions can be made.

In modern times, there was significant intra-annual run-off redistribution. In relation to the climatic norm, the autumn season became abound in water, the summer period became dry. A slight increase in run-off was observed in spring and winter.

According to the predicted assessments of changes in water run-off in the Upper Tisa basin in 2021–2050 compared to the climatic norm (1961–1990), one should expect moderate changes in seasonal run-off. At the level of climatic norm there will be average water run-off in autumn and winter; the water content of autumn and summer is mutually compensated. It will increase (7%) in spring and reduce in summer (8%) compared with the period of 1961–1990.

Comparing changes in water run-off to the middle of the 21st century compared to the modern period, there are several other trends. In summer both the average and maximum water run-off will increase. These characteristics will significantly decrease in autumn.

Acknowledgements

The authors thank scientists-climatologists of the Ukrainian Hydrometeorological Institute for the support and the ability to receive data from the projections of changes in the parameters of the climate system up to the middle of the 21st century provided for in the course of study.

References

Alexeevsky, N. I. (Ed.) (2012). Regularities hydrological processes (pp. 289-332). Moscow: GEOS.

Krakovska, S., Palamarchuk, L., Shedemenko, I., Dyukel, G., & Hnatiuk, N. (2008). Data verification global climate center (CRU) and regional climate models (REMO) on surface air temperature forecast for the control period 1961-90. Scientific papers of UHMI, № 257 (pp. 42-60). Kyiv, Ukraine. Retrieved from: http://uhmi.org.ua/pub/np/257/Krakovska_et.pdf.

Luk'yanets, O. & Sosyedko, M. (1998). Die Abflussbewertung auf nächste Jahre in den Karpaten unter Berücksichtigung der mehrjaehrigen Abflusschwankungen. Sammelband der XIX. Konferenz der Donaulaender (pp. 393-401). Osijek, Kroatien.

Luk'yanets, O., Sosyedko, M., & Balabukh, V. (2008). Forecast's assessment of water content in Ukraine in the first half of XXIth century. Book of abstracts: *XXVI Conference of Danubian countries on the hydrological forecasting and hydrological bases of water management*, 2-4 June. (pp. 111-112). Bled, Slovenia.

Palamarchuk, L., Krakovska, S., Shedemenko, I., Dyukel, G., & Hnatiuk, N. (2009) Data verification global climate center (CRU) and regional climate models (REMO) on forecast rainfall fields in Ukraine for the control period 1961-1990. Scientific papers of UHMI, № 258 (pp. 69-84). Kyiv, Ukraine. Retrieved from: http://uhmi.org.ua/pub/np/258/Palamarchuk_et.pdf.

Sosyedko, M. & Luk'yanets, O. (2010). The Carpathians – flood danger region of Ukraine. Basin runoff forecasting system in Zakarpattya: Methodical and technological basis of its components (pp. 38-63). Kyiv, Ukraine.

Tisos aukštupio hidrografinio baseino srovės tėkmės vertinimas erdvės bei laiko požiūriu ir prognozės, kintant klimato sąlygoms

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Tisos aukštupio hidrografinis baseinas yra laikomas viena pavojingiausių Ukrainos Karpatų vietų, kurioje yra didelė potvynių rizika. Paskutiniojo dešimtmečio klimato pokyčiai padarė žymų poveikį hidrologiniams procesams, įskaitant upės vagos tėkmę. Globaliu ir regioniniu mastu vykstančių procesų tyrimai yra labai svarbūs grindžiant apsaugos nuo potvynių operacijas ir organizuojant priemones, kurių reikia imtis prisitaikant prie klimato kaitos.

Tyrime aptariami tiriamo hidrografinio baseino hidrologinio balanso elementų pokyčių vertinimo būdai XX amžiuje. Siekiant išsiaiškinti santykį tarp upės vagos tėkmės ir ją veikiančių su klimato kaita susijusių veiksnių, buvo pateikta retrospektyvi pokyčių analizė. Atlikta ilgalaikių stebėjimų statistinė analizė siekiant patikrinti jų pastovumą ir homogeniškumą. Nustatyta kritulių režimo, paviršiaus oro temperatūros ir tėkmės greičio pokyčių tarpusavio sąveika moderniajame periode (1991–2012 m.), palyginti su klimato normomis (1961–1990 m.). Didžiausia tarpusavio sąveika tarp minėtų kintamųjų stebima šiltuoju laikotarpiu. Šaltuoju laikotarpiu tokia priklausomybė yra pakankama. Atsižvelgiant į tai, išvesta formulė, kurią taikant apskaičiuojamas tikėtinas klimato kaitos poveikis upės vagos tėkmei.

Regioninio modelio REMO-ESNAM5 rezultatai buvo panaudoti siekiant nustatyti, kokios bus klimato kaitos hidrologinės pasekmės ateityje. Pateiktos Tisos aukštupio hidrografinio baseino klimato kaitos veiksnių prognozės 2021–2050 m. ir A1B darnaus vystymosi scenarijus. Vidutinės, sezoninės ir metinės upės vagos tėkmės galimų pokyčių baseine vertinimas pateiktas iki XXI a. vidurio. Metinis pasiskirstymas yra aiškiai užfiksuotas. Sudarytos maksimalių upės vagos tėkmės pokyčių, potvynių dažnumo ir jų pasikartojimų per metus prognozės.

Raktiniai žodžiai: *Tisos aukštupio rezervuaras, klimato kaita, vandens nuotėkis, prognozuojamasis vertinimas.*