Estimation of the Homogeneity of the Average Annual Runoff of the Rivers and Streams of the Zacarpatska Station

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Abstract

In the practice of the engineering and the hydrological calculations of one of the important hydrological characteristics is the average annual runoff, because at its basis the estimation of the water resources of any territory is carrying out. In the conditions of the global warming climate and its manifestation on the regional level the estimation of the homogeneity and stationarity of the observations data is the actual task. In the absence of the reliable information about the time and the resources that violate the homogeneity of the observations series, the statistical methods are the unique for such estimation.

This paper presents the estimation of the homogeneity of the average annual discharges in the water bodies of one of the existing water-balance stations in Ukraine namely of the Zacarpatska (ZWBS). The estimation of the homogeneity is carried out by methods: the total integral curve, the statistical criteria the Fisher and the Stjudent and of the statistical significance of the linear trends of the runoff long-term dynamics. The observations data in the mountain rivers and streams for the period from the beginning of observations (1957, 1958, 1959, 1960) to 2006 was researched. High and low hydrological cycles of rivers and streams are defined, too.

Keywords *climate change, small catchment, homogeneity, stationarity, average annual runoff*

Introduction

In the conditions of the global and regional climate change especially important have the knowledge about their direct impact on the rivers water regime because the water objects are the product of climate and landscape. In the last years in such flood danger region as the Ukrainian Carpathians is observing the increase of the quantity of the dangerous hydrological phenomena (1). That is why the research of the changes of the rivers water regime in this region is the actual task.

The research of small rivers allows getting the information about the conditions of the formation of the river runoff in the separate geographical zone, and they are the most sensitive to the anthropogenic and climatic changes (2, 3). So for research the small rivers and streams of the Zacarpatska water-balance station were chosen.

Before the statistical processing of the hydrological information need to know that the observations series consists from homogeneous and independent elements. It is known that on the formation conditions of the various characteristics of the river runoff is influencing: the change of the climatic characteristics (first of all, of the air temperature and precipitation); the change of the properties of the underlying surface; the water management and others. It is causing the disturbance in of the homogeneity of runoff formation process. In the result of the observations series can contain the inhomogeneity elements. It doesn’t allow the use of the methods intended for the homogeneous data.

In the hydrology the homogeneity (the accessory of all elements of the hydrological series and its selective statistical parameters (mean values, dispersion) to one totality) and the stationarity (the property of process does not change its characteristics over time) are the identical concepts. One of the central problems of the modern methods of the calculation of the hydrological characteristics is the estimation of the homogeneity and stationarity of the hydrological characteristics for the long-term period. The modern engineering and hydrological forecasts are based on the calculation of the hydrological characteristics of the past period. So any research of the runoff is starting with of the checking of the selected data on the homogeneity.

The main goal of this research consists in the estimation of the homogeneity and stationarity of the average annual runoff of the mountain rivers and streams within ZWBS. According the goal of the research the following problems were solved:

- in the separate years the observations data (the omission in the observations) were restored by method of regression on the variable;
- the homogeneity of the data of the average annual runoff was estimated by the total integral curve and by the statistical criteria the Fisher and the Stjudent;
- the estimation the stationarity of the long-term fluctuations of the average annual runoff was carried out;
- the cyclic fluctuations of the average annual runoff were analyzed.

Study Area

The Zakarpatska water-balance station is located in the upper part of the Rika River which is the right tributary of the Tusa River, with the closing gauge in the village Mizhgirya (F = 550 km2) (Fig. 1). It covers the main part of the Mizhgirya region of the Zakarpattya area (the western part of Ukraine) and occupies the southwest slopes of the East Carpathians within heights from 434 to 1598,9 m above sea level which are the chain of the mountains with the steep slopes that cuted the valleys of the rivers and streams. The river network is presented by the ten rivers (Rika, Rypynka, Lopushna, Golyatynka, Studenyy, Pylypets, etc.) by the length from 7,1 to 31,3 km and the large number (more than 500) of the streams by length from 2 to 3 km.

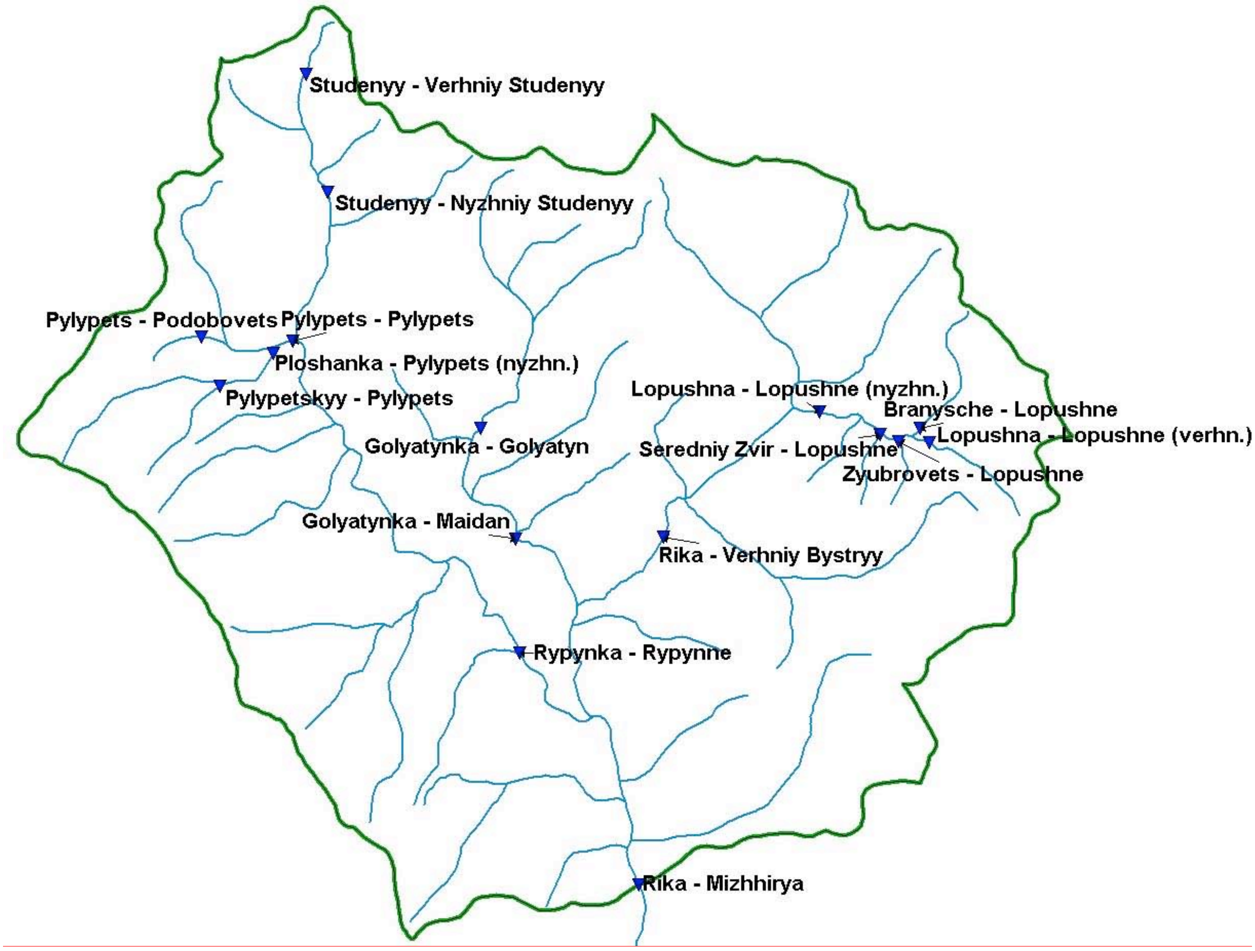

Figure 1. The scheme of the locating of points of hydrological observations within Zakarpatsca water-balance station

The total length of the river network exceeds 300 km. The density of the river network varies from 0,2 to 2,7 km/km^2. The catchment areas are changing in the greater limits - from 10-15 to 550 km^2. On the territory of the Zakarpatska water-balance station is falling the large quantity of the precipitation for year; the runoff process is very quickly. The maximum precipitation is falling by the summer, the minimum precipitation - in the March. On the rivers are frequently observing the floods which have the big height and intensity. By summer the floods are causing by rains, by winter and spring it usually is the mixed type. The floods of the snow alimentation on these rivers are observing in some cases. The coldest month is January with the average air temperature - 5,2 °C. The largest air temperatures are observing in July, with the average temperature 16 °C. The average maximum height of the snow cover is 30-40 cm. So, the Zakarpatska water-balance station is the very different area in the physics-geographical relation (the mountain region, the large cuting of the river valleys) and therefore the water regime of the rivers is the complicated and the actual for researching in the modern conditions of the global warming climate.

Within the limits of the Zakarpatsca station are 16 of the observation gauges which is located on 4 small and on 2 middle rivers, and on 5 streams. The characteristic of the observation gauges is showed in the table 1.

Table 1. The hydrological gauges within of the Zakarpatsca station

The name of the water watercourse	The name of the gauges	The average height of the catchment area, m	Catchment area, km^2
Rika River	Verhniy Bystryy village	920	165
	Mizhhirya village	800	550
Rypynka River	Rypynne village	780	203
Golyatynka River	Golyatyn village	800	59
	Maidan village	790	86
Pylypets River	Podobovets village	747	7,44
	Pylypets village	854	44,2
Pylypetskyy Stream	Pylypets village	1000	5,7
Ploshanka Stream	Pylypets village (nyzhn.)	983	19,9
Lopushna River	Lopushne (verhn.) village	925	13,2
	Lopushne (nyzhn.) village	897	37,3
Studenyy River	Verhniy Studenyy village	809	8
	Nyzhniy Studenyy village	800	25,4
Branysche Stream	Lopushne village	916	10,3
Zyubrovets Stream	Lopushne village	871	3,2
Seredniy Zvir Stream	Lopushne village	984	2,24

Methods

For some the rivers and streams in some years the discharge data were not observed. Thus, the omissions in the observations data were restored by method of the regression on the variable on the base of the data of the streams and analogues rivers according to (4).

This method consists in the calculating the regression equation by using the data of the analogues rivers. The restore of the data is carrying out provided that

$$R \geq 0{,}7; \quad n \geq 10; \quad k/\delta_k \geq 2 \tag{1}$$

were R – the correlation coefficient between the values of the discharges in the brought gauge and analogue gauge; n – the number of the joint years of the observations in the brought gauge and analogue gauge; k – the regression coefficient; δ_k – the average quadratic error of the regression coefficient.

The average quadratic error of the regression coefficient and the correlation coefficient is calculating on the formula

$$\sigma_k = \frac{\sigma}{\sigma_a}\sqrt{\frac{1-R}{n-1}}\,;\; R = \frac{\sum_{i=1}^{n} \Delta Q_a \Delta Q}{n\ \sigma\ \sigma_a} \tag{2}$$

were σ, σ_a – accordingly the average quadratic deviation of the discharge for joint period of the observations for brought gauge and analogue gauge; the values ΔQ, ΔQ_a accordingly is defining for brought gauge and the analogue gauge on the formulas

$$\Delta Q = Q_i - \overline{Q};\; \Delta Q_a = Q_{ia} - \overline{Q}_a \tag{3}$$

were $\overline{Q}$, $\overline{Q}_a$ – accordingly the average perennial value of the discharges for joint period of the observations for brought gauge and the gauge-analogue.

The regression coefficient is defining on the formula

$$k = r\ \sigma\ / \sigma_a \tag{4}$$

The analysis of the homogeneity of the restored and observations data is carried out by the statistical criteria the Fisher (for dispersions) and the Stjudent (for averages) with provision for interlinear and the in-row correlation. When it is impossible the use of the criteria the Fisher and the Stjudent then the analysis of the homogeneity was only carried out on the base of the total integral curve.

The estimation of the stationarity of the long-term fluctuations of the average annual runoff was carried out by an assessment of the statistical significance of the linear trends (5). In turn, the statistical significance of the trend is defined by the statistical significance of the correlation coefficient (R). The correlation coefficient of this dependence is estimating on the relation the random of quadratic error (σ_R):

$$R / \sigma_R \geq \beta \tag{5}$$

If as a result of the above-stated calculations it will appear that the trend significantly (at the given significance level) differs from zero, i.e. the double of standard deviation of the correlation coefficient is much less than of the correlation coefficient, it indicates no stationarity of the long-term fluctuations of the runoff, i.e. the inhomogeneity its in the time, and on the contrary, if $\sigma_R > R$ – the homogeneity of the runoff in the time. For 5 % of the significance level or for 95 % confidential limit $\beta=2$ (6).

The average quadratic error of the correlation coefficient for $n > 25$ is defined by the formula:

$$\sigma_R = \left(1 - R^2\right) / \sqrt{n-1} \tag{6}$$

To reveal the regularity of the cyclical fluctuations of the runoff on the mountain watercourses of the Zakarpatska station were used the difference integral curves for continuous periods of the observations.

Results

The results of the calculation on the equations (2-4) are presented in the Table 2. The carried out the calculations is corresponding to the condition (1) that allows using the restored data for next researches.

On the plots of the total integral curves of the average annual runoff which was built for all research rivers and streams of any significant points of the fracture of the directions of the curves were not found. It is shows the homogeneity of the series of observations, i.e. on the forming of the average annual runoff of the rivers and streams of the Zakarpatska water-balance station doesn’t have of the influence the anthropogenic factors and the manifestations of the global climate change. Examples of such curves are shown in Fig. 2 for some rivers and streams of the Zakarpatska station.

Table 2. Information about the restore of the observations data on the rivers and streams of the Zakarpatska water-balance station

№	The name of the gauge	The name of the gauge-analogue	Conditions			The years for which data were restored
			$n \geq 10$	$R \geq 0,7$	$k/\delta_k \geq 2$	
1.	Studenyy River – Nyzhniy Studenyy village	Studenyy River – Verhniy Studenyy village	41	0,91	371,6	1995-1998
2.	Seredniy Zvir Stream – Lopushne village	Branysche Stream – Lopushne village	46	0,82	237,1	1975-1981
3.	Zyubrovets Stream – Lopushne village	Branysche Stream – Lopushne village	45	0,88	319,3	1975-1978
4.	Golyatynka River – Maidan village	Pylypets River – Pylypets village	46	0,88	325,4	1995-1998
5.	Rypynka River – Rypynne village	Rika River – Mizhhirya village	38	0,95	529,7	1995-2006
6.	Rika River – Verhniy Bystryy village	Rika River – Mizhhirya village	46	0,93	452,2	1995-1998
7.	Golyatynka River – Golyatyn village	Rika River – Mizhhirya village	23	0,94	364,6	1980-2006

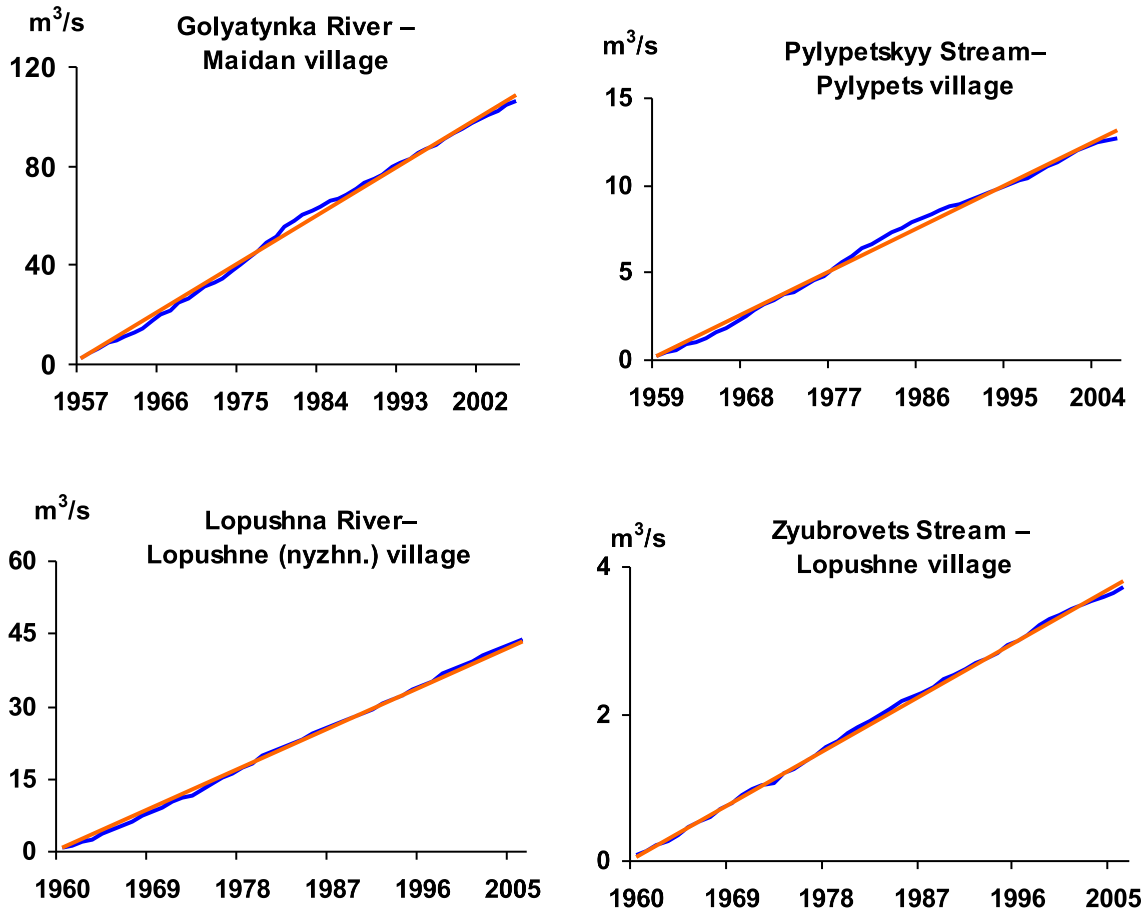

Figure 2. The total integral curves of the average annual discharges of the watercourses of the Zakarpatska station

The carried out the quantitative estimation of the homogeneity for the statistical criteria the Fisher and the Stjudent are showed that on 11 of observation gauges (from 16 gauges) the observations data have the interlinear and the in-row correlation simultaneously (Table 3). Hence the generalized criteria of the Fisher and the Stjudent are impossible to use because it is calculated for the data which have the interlinear or the in-row correlation only (7).

Table 3. The interlinear and the in-row correlation of the observation data of the average annual runoff of the rivers and streams of ZWBS

№	The name of the gauges	The correlation coefficient in the in-row	The correlation coefficient in the interlinear
1	Seredniy Zvir Stream – Lopushne village	0,1	0,2
2	Branysche Stream – Lopushne village	0,2	0,2
3	Lopushna River – Lopushne (verhn.) village	0,1	0,4
4	Pylypetskyy Stream – Pylypets village	0,4	0,1
5	Golyatynka River – Maidan village	0,1	0,1
6	Pylypets River – Pylypets village	0,3	0,2
7	Studenyy River – Nyzhniy Studenyy village	0,1	0,3
8	Ploshanka Stream – Pylypets village (nyzhn.)	0,3	0,1
9	Rika River – Verhniy Bystryy village	0,1	0,1
10	Studenyy River – Verhniy Studenyy village	0,2	0,0
11	Golyatynka River – Golyatyn village	0,0	0,0
12	Lopushna River – Lopushne (nyzhn.) village	0,0	0,2
13	Rypynka River – Rypynne village	0,0	0,2
14	Rika River – Mizhhirya village	0,0	0,1
15	Pylypets River – Podobovets village	0,0	0,1
16	Zyubrovets Stream – Lopushne village	0,0	0,1

For hydrological gauges the Lopushna River - Lopushne (nyzhn.) village, the Rypynka River - Rypynne village, the Rika River - Mizhhirya village, the Pylypets River - Podobovets village, the Zyubrovets Stream - Lopushne village (of the observations series have the interlinear correlation) the analysis of the homogeneity of the dispersions and averages values showed that they are homogeneous.
The observations data for the gauge the Studenyy River - Verhniy Studenyy village (has in-row correlation) are homogeneous for the Fisher criterion and non-homogeneous for the Student criterion. Also the homogeneous is of the observations series in the gauge the Golyatynka River - Golyatyn village which doesn't have of the interlinear and the in-row correlation (Table 4).

The long-term dynamics of the average annual discharge for the rivers and the streams of the ZWBS does not have the statistically significant of the trends at 5-% level of the significance except of the four gauges: the Branysche Stream - Lopushne village, the Studenyy River - Verhniy Studenyy village, the Ploshanka Stream - Pylypets village (nyzhn.), the Pylypets River - Pylypets village (Fig. 3).

The results of the calculation of linear trends are shown in the Table 5. The presence of the statistically significant trends indicates about the inhomogeneity of the observations data. However the view of the total integral curves for this data (Fig. 2) allows to assert that this observations series are homogeneous, and the statistical significant trends is caused by absence of the full hydrological cycle. So, the firsts the two gauges have the growing trends, and the others two - the falling trends. The first case it is the transition from low- to high-water phase of the hydrological cycle, and the second case – on the contrary (Fig. 4).

Table 4. Results of the check of the average annual runoff of the rivers and streams of the Zacarpatska station on the homogeneity for the statistical criteria the Fisher and the Stjudent

The name of the gauge	*t*	T_{cr}	*F*	F_{cr}	The results of the check	
					the Stjudent's	the Fisher's
Lopushna River – Lopushne (nyzhn.) village	0,01	1,80	1,71	2,22	homogeneous	homogeneous
Rypynka River – Rypynne village	0,38	1,80	1,85	2,22	homogeneous	homogeneous
Rika River – Mizhhirya village	0,51	1,94	1,70	2,27	homogeneous	homogeneous
Pylypets River – Podobovets village	1,68	2,01	1,39	2,27	homogeneous	homogeneous
Zyubrovets Stream – Lopushne village	1,14	2,01	1,33	2,27	homogeneous	homogeneous
Golyatynka River – Golyatyn village	0,47	2,01	1,75	2,27	homogeneous	homogeneous
Studenyy River – Verhniy Studenyy village	2,67	2,01	1,22	2,27	inhomogeneous	homogeneous

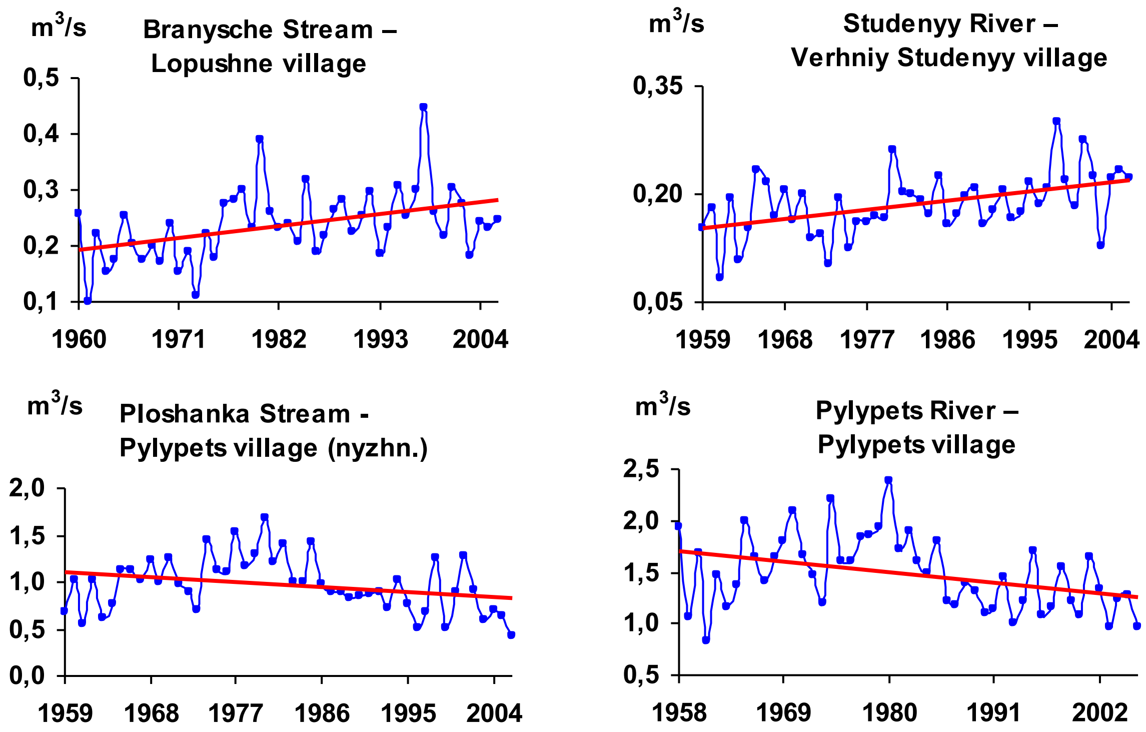

Figure 3. The long-term dynamics and linear trends of the average annual runoff of the rivers and streams of the Zacarpatska station

Hence, the statistically significant trends are in the observations series which does not have of one full hydrological cycle. The same results are received in the article (8) and for the plains rivers. So, the statistically significant trends are temporary and is causing by the dynamics of the cycles of the water flow.

Table 5. The estimation the statistical significance linear trends of the average annual discharges of the rivers and streams of the Zacarpatska station

The name of gauge	The observation period	The equation of the trend	R^2	R	σ_R	$2\sigma_R$	$3\sigma_R$	The result
Branysche Stream – Lopushne village	1960-2006	y=0,002x-3,66	0,182	0,426	0,121	0,241	0,362	"A"
Pylypets River – Pylypets village	1958-2006	y=-0,009x+19,8	0,139	0,373	0,124	0,249	0,373	"A"
Studenyy River – Verhniy Studenyy village	1958-2006	y=0,001x-2,57	0,209	0,457	0,115	0,231	0,346	"A"
Ploshanka Stream – Pylypets village (nyzhn.)	1959-2006	y=-0,006x+12,1	0,074	0,272	0,135	0,270	0,405	"A"
Golyatynka River – Golyatyn village	1957-2006	y=0,006x+9,97	0,049	0,221	0,136	0,272	0,407	"0"
Seredniy Zvir Stream – Lopushne village	1960-2006	y=-0,0003x+0,58	0,042	0,205	0,141	0,282	0,424	"0"
Lopushna River – Lopushne (verhn.) village	1960-2006	y=-0,001x+2,54	0,024	0,155	0,144	0,288	0,432	"0"
Pylypetskyy Stream – Pylypets village	1959-2006	y=-0,001x+2,31	0,042	0,205	0,140	0,280	0,419	"0"
Golyatynka River – Maidan village	1957-2006	y=-0,005x+12,5	0,018	0,133	0,140	0,281	0,421	"0"
Zyubrovets Stream – Lopushne village	1960-2006	y=-0,0002x+0,52	0,022	0,149	0,144	0,288	0,433	"0"
Lopushna River – Lopushne (nyzhn.) village	1960-2006	y=0,002x+3,37	0,020	0,144	0,144	0,289	0,433	"0"
Pylypets River – Podobovets village	1959-2006	y=-0,0006x+1,42	0,039	0,198	0,140	0,280	0,420	"0"
Studenyy River – Nyzhniy Studenyy village	1957-2006	y=-0,0008x+2,12	0,005	0,074	0,142	0,284	0,426	"0"
Rypynka River – Rypynne village	1957-2006	y=0,007x+8,21	0,007	0,081	0,142	0,284	0,426	"0"
Rika River – Mizhhirya village	1957-2006	y=0,047x-79,5	0,047	0,217	0,136	0,272	0,408	"0"
Rika River – Verhniy Bystryy village	1957-2006	y=-0,004x+12,8	0,004	0,060	0,142	0,285	0,427	"0"

"A" – the statistically significant trend, i.e. inhomogeneous
"0" - the statistically insignificant trend, i.e. homogeneous

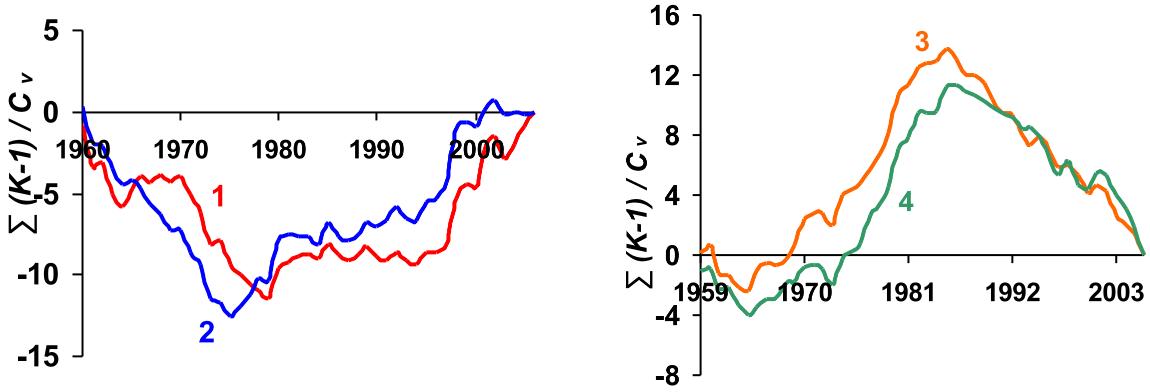

Figure 4. The difference integral curves of the fluctuations of the average annual discharges:
1 - Studenyy River - Verhniy Studenyy village; 2 - Branysche Stream - Lopushne village;
3 - Pylypets River - Pylypets village; 4 - Ploshanka Stream - Pylypets village (nyzhn.).

More evident representation about the character of the long-term fluctuations of the average annual runoff is showing the difference integral curves. Their analysis is showing that the observations on all rivers and streams of the Zacarpatska station have begun in the low water phase (at the end of the 1950 of the 20th century) (Fig. 4, 5).

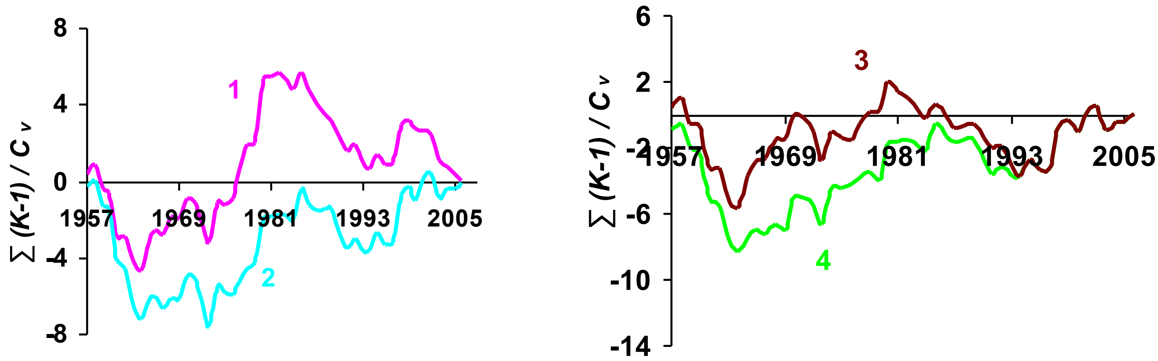

Figure 5. The difference integral curves of the fluctuations of the average annual discharges:
1 - Rika River – Mizhhirya village; 2 - Rika River – Verhniy Bystryy village;
3 - Rypynka River – Rypynne village; 4 - Golyatynka River – Golyatyn village.

The high water phase for the majority rivers and streams was starting since 1964, and for the others - from 1973 to 1979. The period of the low water phase on 10 gauge was starting since 1985, on the others - from 1980, 1982 and 1998. In the gauges the Studenyy River - Verhniy Studenyy village and the Branysche Stream - Lopushne village still continues the high water phase of the hydrological cycle (Fig. 4).

Conclusion

The carried out research showed that the observations data of the average annual runoff of the rivers and streams of the ZWBS are the homogeneous, because the analysis of the total integral curves didn't revealed of any significant points of the fracture of the curves directions, that indicate to absence of the influence of the anthropogenic factors and the manifestations of the global climate change.

The estimation of the stationarity of the perennial fluctuations of the average annual discharges of the rivers and streams of the Zacarpatska station have shown that on the 5 % significant level the majority of the observations data are the stationary. The statistically significant trends are in those observations series that doesn't have of the full hydrological cycle, i.e. the statistically significant trends are the temporary and by cyclic fluctuations of the runoff is causing. Therefore, on the rivers and streams of the Zacarpatska station the formation of the average annual runoff is the quasistationary.

The use of the quantitative generalized criteria of the Fisher and the Stjudent for the estimation of the homogeneity of the hydrological observations data is by limited and doubtful. First of all, the hydrological data can have the interlinear and the in-row correlation simultaneously, that is making the impossible the use of such criterions. Secondly, the generalized criteria can only use in the limited range. So, the generalized criterion of the Stjudent was developed for the data that have the asymmetry coefficient from 0 to 4 (5). Thirdly, at presence only of one full or almost complete hydrological cycle (for example, for gauge the Studenyy River - Verhniy Studenyy village) the use of the Fisher and Student criteria actually is the comparison of the dispersions and averages the low- and high-phases of the hydrological cycle that are not correctly. It also is characteristic of use of the non-parametric criterion of the Wilcoxon that detects the differences in the average values.

On the rivers and streams of the Zacarpatska water-balance station for the average annual runoff is observing the low period of the hydrological cycle except the gauges the Studenyy River - Verhniy Studenyy village and the Branysche Stream - Lopushne village where still is continuing the high period of the hydrological cycle.

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