УДК 519.2:330.007
DOI: https://doi.org/10.15407/ugz2021.04.030

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LONG-TERM FLUCTUATIONS IN THE ANNUAL RUNOFF OF RIVERS FLOWING INTO LAKE SEVAN UNDER THE CURRENT CLIMATE CHANGE*

The work identified, analyzed and assessed long-term fluctuations annual runoff of rivers flowing into Lake Sevan. As a starting point material used daily data of long-term actual instrumental observations of the annual runoff of rivers flowing into the lake, and also the air temperature and precipitation of the lake basin for the entire observation period (1927–2018). Analysis of the trend lines shows that in the lower river sections of the observed rivers (except for the rivers Vardenis and Bakhtak) are mainly observed the tendency of growth of average annual values of water consumption Such the pattern is also inherent in temporary changes in average annual temperatures and annual precipitation of the study area. It turned out that in the study area for the entire period of instrumental observations, the average annual air temperature increased by 0.5‒1.5 ° C or 10–30%, and precipitation increased by 80‒150 mm or 15-40%. Changes in river runoff reflect changes in precipitation. The values of the coefficient of variation (variability) of the river runoff of the studied territories vary widely - from 0.13‒0.23 (rivers with underground feeding) to 0.30‒0.40 (rivers with surface feeding), which due to different regimes of feeding the rivers of the basin, and the values of the coefficient asymmetry ‒ in the range from ‒0.85‒0.93. The paper discusses the issues of changing the cyclicity and synchronicity of the river drainage of the lake basin. It turned out that the change in runoff is characterized by cyclicity, and the synchronous change in the runoff is not clear.

Key words*: river runoff; air temperature; precipitation; trend; cyclicality; synchronicity; Lake Sevan basin.*

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БАГАТОЛІТНІ КОЛИВАННЯ РІЧНОГО СТОКУ РІЧОК, ЩО ВПАДАЮТЬ ДО ОЗЕРА СЕВАН В УМОВАХ СУЧАСНИХ ЗМІН КЛІМАТУ

У роботі виявлено, проаналізовано й оціненої багатолітні коливання річного стоку річок, що впадають до озера Севан. В якості вихідного матеріалу використано щоденні дані багатолітніх фактичних інструментальних спостережень за річним стоком річок, а також температури атмосферного повітря і опадів в районі басейну озера Севан за весь період спостережень (1927–2018 рр.). Аналіз ліній трендів показує, що в нижніх річкових створах річок, що впадають до озера Севан (за винятком річок Варденіс і Бахтак), спостерігається тенденція зростання середньорічних значень витрат води. Подібна закономірність притаманна також тимчасовим змінам середньої температури та річній кількості опадів на досліджуваній території. Було встановлено, що на досліджуваній території за весь період інструментальних спостережень середньорічні значення температури повітря підвищилися на 0,5–1,5 °C або на 10–30%, а атмосферні опади збільшились на 80–150 мм або на 15–40%. Зміни річного стоку відображають зміни кількості опадів. Значення коефіцієнта варіації стоку річок досліджуваної території доволі значно коливаються: від 0,13–0,23 (річки з підземним живленням) до 0,30–0,40 (річки з поверхневим живленням), що обумовлено різними режимами живлення річок басейну. Водночас значення коефіцієнта асиметрії коливаються в звичайних межах – від 0,85–0,93. У роботі дискутується питання щодо зміни циклічності та синхронності річкового стоку басейну озера Севан. Зокрема було з'ясовано, що зміни стоку характеризуються циклічністю, при чому синхронні зміни стоку не є чіткими.

Ключові слова: *річковий стік; температура повітря; атмосферні опади; тенденції; циклічність; синхронність; басейн озера Севан.*

Introduction

Like all natural phenomena, climatic conditions are also subject to periodic changes. The main indicator of climate change is river runoff, as it clearly expresses changes in air temperature and precipitation. Climate change, which began in the last century, will undoubtedly have an impact on the flow of rivers in Armenia. Lake Sevan is a strategic

*The work was supported by the Science Committee of RA, in the frames of the research project 21T-1E215 «Hydro-ecological assessment of winter low water period discharge characteristics of lake Sevan basin rivers».

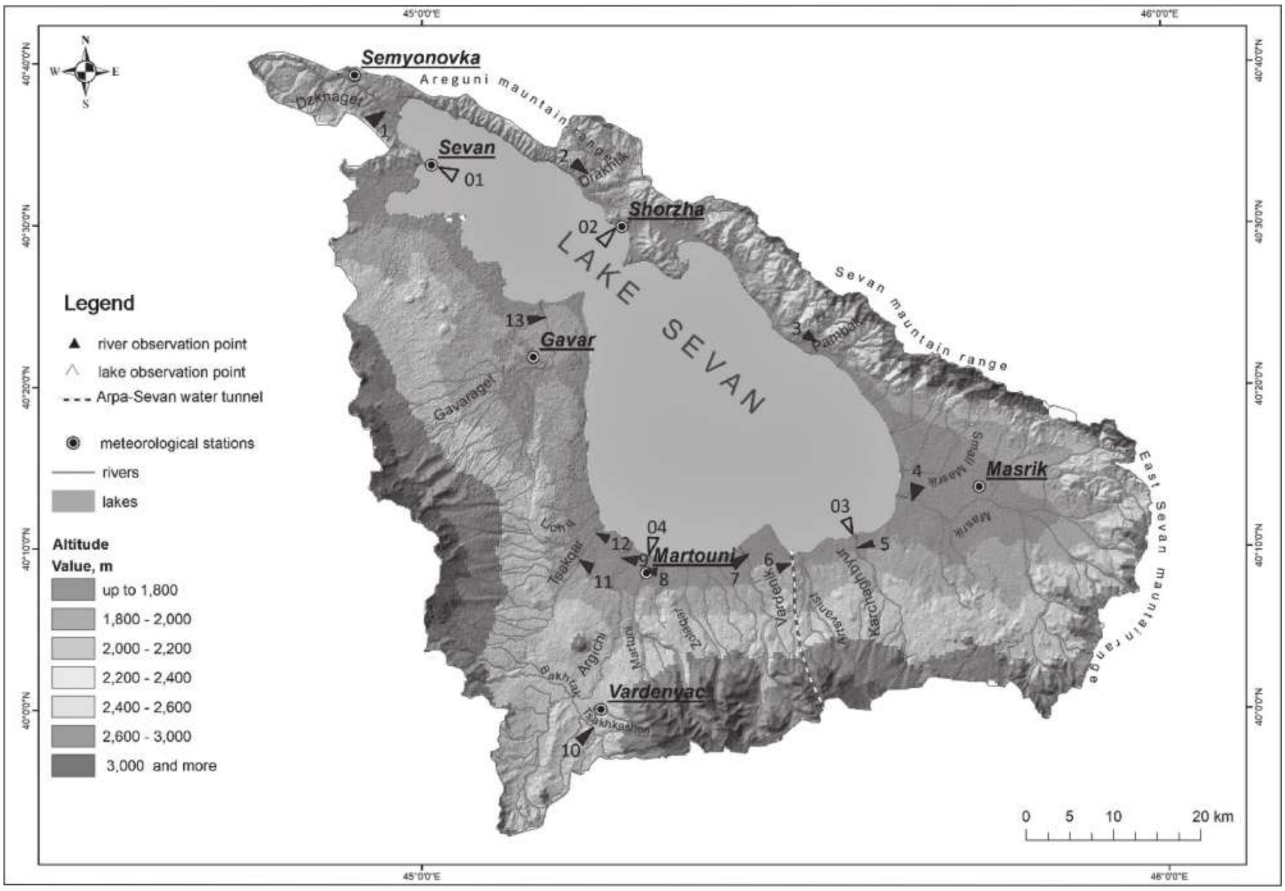

Fig. 1. Location of hydrometeorological observation points in within the basin of the lake Sevan

storage facility for fresh water in the Republic of Armenia, at the same time the lake basin is one of the richest and most unique areas of the Republic of Armenia on recreational resources. And the purpose of the work was investigate, analyze and evaluate the manifestations of change modern climate in the flow of rivers flowing into Lake Sevan.

For this purpose, the following tasks have been set and solved in the work:

– If possible, analyze the available relevant research work;

– Collect and process data of actual observations on river flow, flowing into the lake, air temperature and precipitation of the basin lakes;

– Briefly discuss and analyze the main physical and geographical factors of river flow formation in the study area;

– Analyze the patterns of spatial distribution annual river flow;

– Analyze and evaluate the current multi-year fluctuations in annual values of the average runoff of rivers flowing into Lake Sevan, average air temperature and amount of precipitation in the lake basin;

– Determine the issues of manifestation of cyclicity and synchronicity of the river drain.

Materials and research methods

To solve the set tasks, they served as a theoretical basis related research papers, reports, programs and projects. As a starting material, we used actual data of long-term observations of Armhydromet over temperature air, precipitation and water consumption (for the period from the day station opening until 2018). Long-term temperature fluctuations in operation air and precipitation are discussed separately for meteorological stations, and changes in water discharge - along river sections of rivers. Note that over time, both the number of observed rivers and the number of hydrological posts located on them, meteorological stations and posts. So, in the study area in 41 meteorological stations and posts operated in different years, 39 water measuring posts, and currently there are only 7 meteorological stations and 12 water measuring posts ***(Fig. 1).***

28 rivers and 2 large springs flow into Lake Sevan [1-3], 24 of them in different years water-measuring

observations were carried out. The pool is rich major sources. Most of the rivers in the basin have an insignificant the length and area of the drainage basin. There are 930 rivers in the basin up to 10 km long, of which only Argichi is 51 km long. Comparatively large rivers with a larger catchment area 100 km^2, the following: Masrik, Karchaghbyur, Vardenis, Argichi, Bakhtak, Gavaraget *(Table 1)*. Observations carried out in the respective river sections of these rivers, as well as the Dzknaget and Martuni rivers in this work in mainly used when discussing the manifestation of cyclicity and synchronicity of river runoff.

To change the quantitative and qualitative characteristics of water bodies the strongest impact is exerted by direct anthropogenic impact, and also a change in climatic conditions, especially manifested in the last decades [4-6]. Assessment of these changes in different parts of the world, including the territory of the Sevan basin, a number of works by various authors [5-11].

L.R. Vardanyan and others [12] estimated changes in the annual total runoff entering Lake Sevan under conditions of climate change and changes in seasonal and annual precipitation in the lake basin. So, for the period 1927–2014 annual total flow entering Lake Sevan increased by about 80 million cubic meters, and the amount of precipitation - by 40 mm. According to the research M.V. Shahinyan and B.G.Zakaryan [11] for the period 1927–1990 the total annual flow of water entering Lake Sevan, calculated on the basis of data from five rivers, decreased by 9 million cubic meters or by 1.2 %, and for the period 1961–1990 the stock has not changed. This work from previous works differs in that for the solution of questions in this work the results observations are discussed for each river separately, and more long series of observations. On the other hand, research should be continued, especially in the face of climate change.

The waters of the rivers flowing into the lake are used for drinking, household, irrigation, industrial, hydropower purposes, as well as for fish farm, for the purpose of watering. However, due to the extremely uneven spatial and intra-annual distribution of river runoff here there are significant difficulties with their use. Water consumption 2018 amounted to 30.8 million m^3, water withdrawal – 53.4 million m^3. Moreover surface water abstraction is an insignificant part of the total water intake (26 %).

During the period of irrigation for agricultural needs, it is used a significant part of the natural river flow. As shown by the V.O. Sargsyan field work [9], even on large rivers, water intakes in August account for 50–65 % of the monthly natural flow. But due to the lack of water intake data, only the results of actual observations.

Table 1

Main hydrometric characteristics of rivers and their catchments of the basin Sevan

River – point	Distance from the mouth, km	River length, km	River slope , ‰		Main characteristics of the catchment		
			River slope average from farthest point	WEighted average from the farthest point	Square, km^2	Average height, m	Average slope, ‰
R. Dzknaget – p. Tsovagyugh	1.0	22.0	34	30	82.6	2220	211
R. Drakhtik – p. Drakhtik	0.8	11.2	51	43	39.2	2270	246
R. Pambak – p. Pambak	1.8	10.0	104	92	20.4	2540	433
R. Masrik – p. Tsovak	2.8	45.0	27	16	673	2310	158
R. Karchaghbyur – p. Karchaghbyur	1.1	26.0	54	49	116	2650	174
R. Vardenis – p. Vardenik	4.1	28.0	48	44	117	2680	279
R. Martuni – p. Geghovit	7.2	27.0	60	46	84.5	2760	285
R. Argichi – p. Getashen	6.0	51.0	14	8	366	2470	144
R. Tsaghkashen – p. Vaghashen	2.3	–	–	–			
R. Lichk – p. Lichk	3.0	8.0	37	31	33.0	2060	87
R. Bakhtak – p. Tsakkar	6.0	30.0	47	42	144	2570	92.4
R. Gavaraget – p. Noratus	7.0	24.0	29	24	467	2430	133

For each hydrological station, a standard statistical analysis of long-term series of characteristic water discharges. 5 % was assigned the level of significance of the criteria.

The work uses mathematical and statistical, extrapolation, analytical, correlation methods.

Results and discussion

As a rule, the water regime of the rivers is determined by the geographic location basin, relief, average height of the basin, geological structure, soil and vegetation cover, nutritional conditions. Due to the influence of these factors, an uneven distribution is highlighted as a river the network of the Lake Sevan basin and the runoff.

Sevan basin, which is located between the Lesser Caucasus and the Armenian volcanic highlands, has a complex geological structure, different relief forms with variegated reworked forms. By features geological structure, the lake basin is divided into two parts: the northern and eastern (which belong to the folded-clumpy regions of Armenia) and southern and western (which form part of the Armenian volcanic highlands). In the southwestern part they are widespread strongly porous and permeable rocks with cracks, and in high mountain areas – chingils, which act as a regulator to feed rivers. Unlike from the southwestern part, the northeastern part of the basin stands out the absence of more or less large sources, the presence of many small tributaries, mudflows are characteristic. Almost all dropped here precipitation flows down the slope into streams or directly into the lake. Many of the rivers in the period of low water does not reach the lake.

Basin rivers lake Sevan are mainly fed with mixed water: melt water, rainfall and underground. Moreover, due to the sharp variety of geological features of hydrogeological conditions, sources of water supply of rivers in different the pool locations are very different. The feeding of the rivers originating from the Geghama and Vardenis mountains, which are of volcanic origin, predominantly underground (60-80 %), and the feeding of rivers originating from Areguni and Sevan mountain ranges, which have folded-clumpy origin, mainly occurs thawed and rainwater (60–70 %). Rivers with rain fed only, for with the exception of some that have a temporary runoff, they are absent. Catchment pools with favorable percolation conditions are characterized by predominantly underground food. Mainly underground power have the rivers Masrik, Karchaghbyur, Tsakkar, Gavaraget, exclusively underground – Lichk [13] .

In the study area, the river network is distinguished by an uneven distribution [8, 14], the average density is 0.77 km / km^2. Thick the Big Sevan basin is distinguished by the hydrographic network, in particular its southern and southwestern parts. Relatively all great rivers. The pool also has spacious areas where there is no surface runoff: for example, the section from Gavaraget to the head of the river Hrazdan (fig. 1). Young volcanic rocks are widespread here, which have strong cracks and are permeable to water, due to which precipitation almost completely percolates and does not convert to surface runoff.

Table 2.

The main characteristics of the annual water flow of the rivers flowing into Lake Sevan

River – point	Average annual water runoff, m^3/sec	Average annual water volume, mln m^3	Runoff module, l/sec•km^2	Runoff layer height, mm	Maximum runoff, m^3/sec	Minimum runoff, m^3/sec	Coefficient of variation,	Asymmetry coefficient,
R. Dzknaget – p. Tsovagyugh	1.09	34.3	13.2	416	2.14	0.41	0.33	0.72
R. Masrik – p. Tsovak	3.33	105	4.95	156	4.38	2.15	0.14	–0.02
R. Karchaghbyur – p. Karchaghbyur	1.06	33.3	9.14	287	1.52	0.37	0.23	–0.85
R. Vardenis – p. Vardenik	1.58	49.7	13.5	425	3.17	0.47	0.34	0.27
R. Martuni – p. Geghovit	1.68	53.1	19.9	628	3.20	0.82	0.29	0.94
R. Argichi – p. Getashen	5.46	172	14.9	471	11.2	2.81	0.26	0.87
R. Bakhtak – p. Tsakkar	0.65	20.4	4.51	142	1.30	0.11	0.39	0.48
R. Gavaraget – p. Noratus	3.50	110	7.49	236	4.82	2.77	0.13	0.93

Table 3.

Equations of linear trends and statistical characteristics of annual values of the river runoff of the basin of the lake Sevan (*T* – years)

River – point	Linear trend equation	Statistical characteristics			
		β (m³/sec /10 years)	ΔQ_{90}, °C	Autocorrelation,	Standard errors
R. Dzknget – p. Tsovagyugh	Q = 0.0007T+1.053	0.007	0.063	0.02	0.039
R. Masrik – p. Tsovak	Q = 0.111T+3.037	0.11	0.99	0.46	0.11
R. Karchaghbyur – p. Karchaghbyur	Q = 0.0084T+.0.774	0.084	0.76	0.72	0.077
R. Vardenis – p. Vardenik	Q = –0.0078T+1.816	–0.078	–0.70	0.44	0.11
R. Martuni – p. Geghovit	Q = 0.0037T+1.562	0.037	0.33	0.44	0.098
R. Argichi – p. Getashen	Q = 0.0078T+5.093	0.078	0.70	0.25	0.19
R. Bakhtak – p. Tsakkar	Q = –0.0005T+0.663	–0.005	–0.045	0.02	0.031
R. Gavaraget – p. Noratus	Q = 0.0008T+3.467	0.008	0.072	0.20	0.060

The annual values of the river runoff are also distinguished by the spatial uneven distribution. The rivers of the northeastern part of their basin water content is significantly inferior to the rivers of the southern and western parts (Masrik, Argichi, Gavaraget) (*table 2*).

The work considers the time course and trends of the annual river runoff the lake basin for the available observation periods (*table 3*, ***fig. 2***), i.e. conclusions about the main trend of the observed changes in the river drain.

Table 3 shows the equations of linear trends, statistical characteristics (trend coefficients β (m³/sec / 10 years), standard errors, etc.). As follows from the table 3, linear trend coefficient the largest in the r. Masrik – p. Tsovak settlement, which is β = 0.11 m³/sec / 10 years, which, in terms of 100 years, gives an increase in the annual river runoff by 1.1 m³/sec.

The values of the coefficient of variation C_v (variability) of the river runoff of the studied territories vary widely, due to the difference the feeding regime of the rivers of the basin. So, if for rivers with mainly underground power supply, the specified coefficient ranges between 0.13–0.23, then values of variation of the coefficient of small rivers mainly with surface feeding ranges from 0.30–0.40.

Asymmetry coefficient C_s of the maximum runoff of the study area fluctuates in even larger limits, from -0.85 to 0.93. Coefficient asymmetry is calculated by the equation

$$C_s = \frac{\sum_1^n (K_i - 1)^3}{nC_v^3},$$

where n – is the number of members of the series, K_i – is the modular coefficient, C_v – is the coefficient of variation.

As a result of the research, for most of the posts, statistically significant autocorrelation in fluctuations in annual runoff (significant autocorrelation coefficient r1 = 0.02–0.72). Overall high autocorrelation coefficient values indicate the presence cyclicality in runoff fluctuations, that is, a tendency for the grouping of years increased and decreased water content [6].

For clarity, fig. 2 shows the graphs of the time course of the annual river runoff, on which trend lines are plotted. In the pool, according to data from actual observations of annual river runoff predominantly show a growth trend. It turned out that in a number of long-term observations basin, there was mainly a tendency for an increase in the annual river drain. The only exceptions are the rivers Vardenis and Bakhtak that is the downward trend is observed for 17% of the rivers under discussion.

To assess the long-term fluctuations in the annual river runoff under conditions climate change in the work also discussed the dynamics of change air temperature and precipitation. Changes in air temperature and precipitation amounts are estimated for each meteorological station separately for the entire period of its validity.

Research results show that in the face of climate change, of all meteorological stations in the basin, only the trend towards an increase in average annual air temperatures (moreover, for the last decades – significantly) and annual precipitation. For the entire period observations the highest average annual air temperature were observed in 2010 (fig. 2). Long-term temperature fluctuations air and precipitation

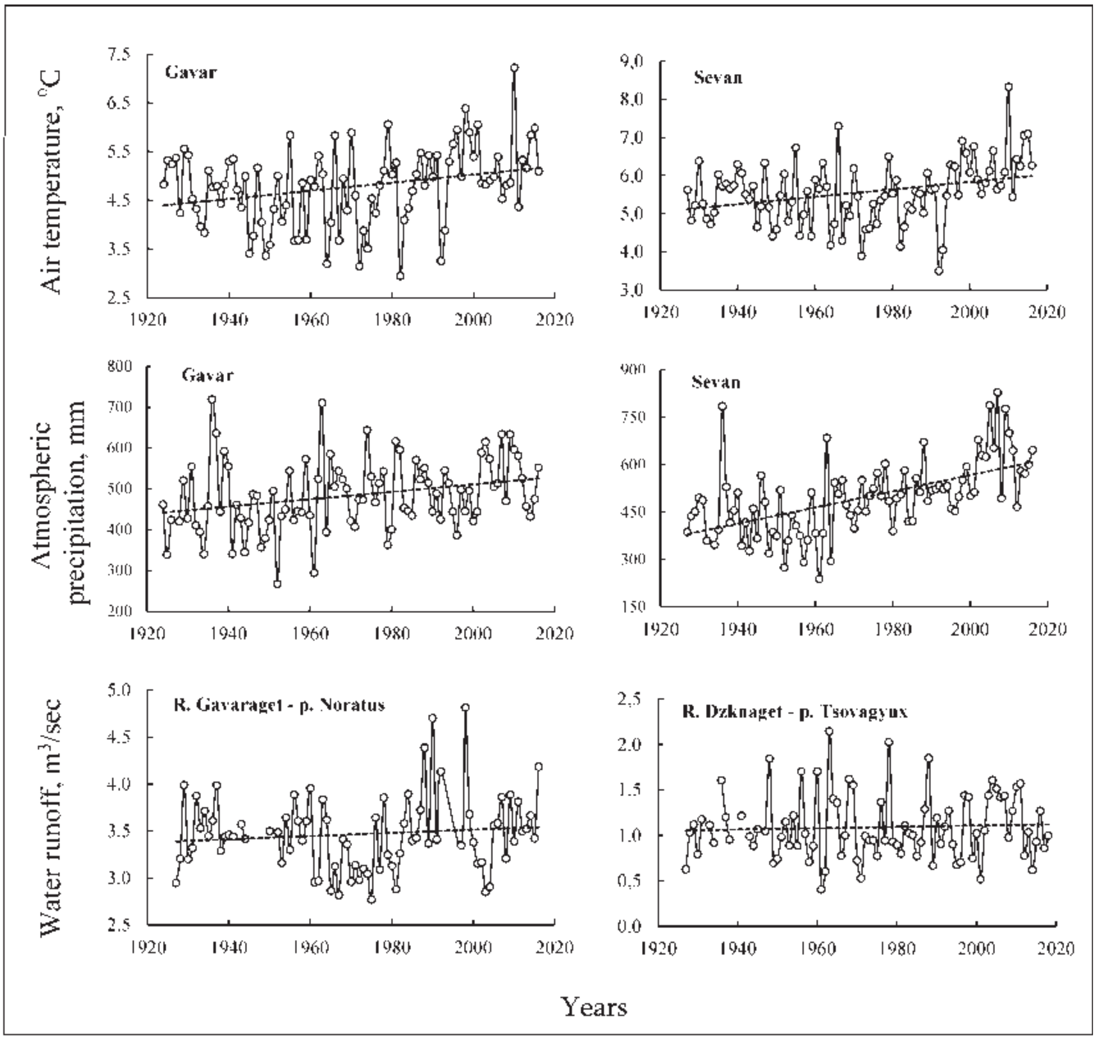

Fig. 2. Long-term fluctuations in the average annual water discharge of rivers, average annual air temperatures, annual precipitation

also have their manifestation in fluctuations in river flow study area.

It turned out that in the study area for the entire period of instrumental observations, the mean annual air temperature increased by 0.5–1.5 °C or by 10–30 %, and atmospheric precipitation – by 80–150 mm or by 15–40 %.

Note that the study area has a mixed continental climate with a well-defined ascending zip. On the formation of the climate the isolation of the basin and the presence of a lake have a great influence. In as a result, being bordered by mountains, the amount of precipitation in the basin relatively small. Winter is long, cold, forming stable snow cover. Summers are warm, the weather prevails with little cloudy. In January, the average monthly temperature ranges from –4.5 °C (Shorzha) to –8.5 ° C (Vardenyats), the absolute minimum reaches –38.1 °C (Masrik). Summers are cool and short, in July, the average monthly temperature is 14.0 °C to 17.1 °C (Shorzha), absolute the maximum reaches 35.2 °C (Masrik).

In the lake basin, precipitation is extremely unevenly distributed. [15]. In the northern and northwestern parts of the basin, significant rainfall than other parts. This is explained by the northern and especially the north-western part is more accessible for flow external air masses. Annual precipitation in the mirror zone and the coastal zone is 390-450 mm. Higher in the mountains the amount of precipitation increases, reaching 800-900 mm. Most precipitation falls in in the Dzknaget basin (635 mm – Tsovagyukh, 724 mm – Semenovka), and in the valley Masrik is relatively smaller (435 mm – Masrik).

The paper also discusses the issues of manifestation of cyclicity and synchronicity river runoff. For the manifestation of such periodic changes, it is necessary have a relatively large number of observations, where it will be more clearly the cyclicality and synchronicity of the studied phenomenon are expressed. The concept of cyclical fluctuations without the effect of displacement of the boundaries between phases of cycles of long and short duration, according to a number of researchers (V.G. Andreyanov and others) [14] provides the use of integral difference curves, or total curves of deviations from middle [16]. They can be expressed or in absolute terms, for example, in annual drain modules:

$$\sum_{1}^{i}(M_i - \bar{M}) = f(i) \quad , \qquad (1)$$

where M_i – is the runoff modulus of the i - th year, l/sec•km^2, M – is the average long-term runoff module (l/sec•km^2), $f(i)$ – area of the i - th river basin (km^2), or, in modular coefficients:

$$\sum_{1}(K_i - 1) = f(i) \quad , \qquad (2)$$

where K_i – is the modular coefficient.

On the difference integral curve, the deviation of the mean for any the time interval from the norm is characterized by the slope tangent to the horizontal line of the line connecting the start and end points of the interval, and is numerically determined by dividing the difference between the final ($I_к$) and the initial $I_н$ ordinates of the curve for the number of years of the interval n, i.e.

$$M_{\text{ср.}} - \bar{M} = \frac{I_{\text{к}} - I_{\text{н}}}{n}, \qquad (3)$$

$$K_{\text{ср.}} - 1 = \frac{K_{\text{к}} - K_{\text{н}}}{n}, \qquad (4)$$

In this case, the section of the integral curve with an upward slope and with a positive the value of the quantity M_{cp} - M or ($K_{\text{ср.}}$ – 1) corresponds to a high-water the phase of cyclical fluctuations of the runoff, and the section with a downward slope and with a negative value ($K_{\text{ср.}}$ – 1) corresponds to a low-water phase [16].

Relatively few works are devoted to the study of the cyclicity of the rivers of Armenia [15], and those are made on the basis of observations of a shorter series, which is not sufficient to determine the high-water and low-water runoff periods for the specified period of time, and also a full analysis has not been done cycle duration confirmation. In the collection of Surface Resources waters of the USSR, vol. 9, no. 2, l. 1973 shows the total curves of deviations from single modular coefficients of annual runoff along typical rivers. In the above-mentioned work, the curves are plotted according to observation data for 40-60 years period, which is not enough to identify certain periods of alternation high-water and low-water phases of runoff.

Cyclicity and synchronicity of runoff is determined for the average annual runoff main rivers flowing into the lake (Dzknaget, Masrik, Karchakhbyur, Vardenis, Martuni, Argichi, Bakhtak, Gavaraget), which have a long row observations.

To identify the cyclicality and synchronicity of the runoff, integral curves ***(fig. 3).*** Years are plotted on the abscissa, and the sum is plotted on the ordinate deviations from the average (K – 1). It can be seen that with a change in the flow for the observation period is traced a certain periodic change water content of rivers. For the construction of integral curves, modular runoff coefficients (K).

Figure 3 shows that, in the study area, the change in runoff a certain periodic change in the water content of rivers is characteristic, that is cyclicality. Moreover, it should be noted that the synchronous change in river runoff the basin is not clearly expressed and it was not possible to group the rivers by change in runoff. But nevertheless, the fact is clearly expressed that in some rivers correspond to one full cycle of 40–65 years, where low-water and high-water areas are separated, where periodic changes in runoff, which contain about 7–10 subcycles.

Findings

Under the conditions of climate change in the study area for the entire period observations increased the average annual air temperature, the annual the amount of atmospheric precipitation, as well as the average annual discharge of the rivers.

Increase in the amount of atmospheric precipitation and river runoff in the studied territories in the development of various spheres and sectors of the economy are assessed positively.

In the study area for the entire period of instrumental observations the mean annual air temperature increased by 0.5–1.5 ° C or by 10-30%, and atmospheric precipitation – by 80–150 mm or 15–40 %.

Values of the coefficient of variation (variability) of the river runoff of the studied territories due to the difference in the feeding regime of the rivers of the basin, range from 0.13–0.23 (rivers with underground feeding) to 0.30–0.40 (rivers with surface feeding), and the values of the coefficient asymmetry – within –0.85–0.93.

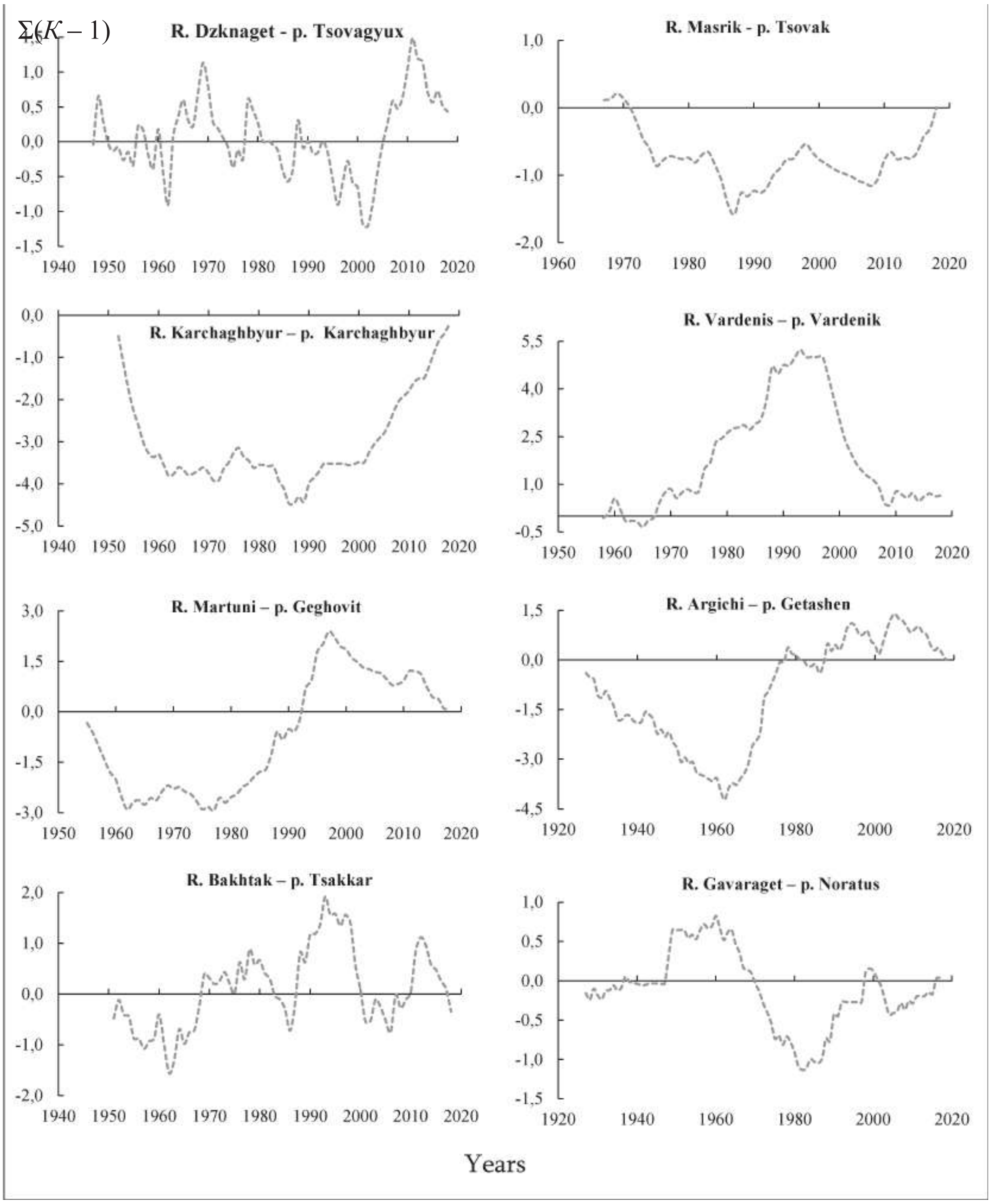

Fig. 3. Difference-integral curves of the annual runoff of the rivers of the Sevan basin

On the territory of the Sevan basin, the runoff change is characterized by a cyclical nature, moreover, the synchronous change in runoff is not clearly expressed.

One complete cycle corresponds to 40–65 years, where about 7–10 years of subcycles with periodic changes in runoff.

It is necessary to develop economic mechanisms for effective consumption and conservation of water resources, create a full-fledged base reliable data on water resources and climatic characteristics.

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The article received 02.08.2020