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Water resource sustainability management issues in the Sevan lake basin in the context of climate change

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Abstract

This work concerns water resource sustainability management issues in the Sevan lake basin in the context of climate change. The research used the data series (1930-2020) observed by the Hydrometeorology and Monitoring Center of RA, as well as short-term field studies conducted by us. The work mainly used the methods of analysis, synthesis, dispersion, and field research. As a result of human economic activity, many water bodies of the Earth have been transformed. In this regard, a classic example can be Lake Sevan, which has been considered an open-air laboratory for scientific research for nearly a century. It should be noted that the use of the centuries-old resources of Lake Sevan, the inefficient management of water resources, as well as the current and expected climate change, have caused irreversible losses to the ecosystem of the basin. The lake's ecosystem has been damaged and is undergoing eutrophication. In all studied rivers of the Lake Sevan basin, a definite downward trend in maximum runoff was observed and an increase in minimum runoff (except for two). This is likely due to global climate change and changes in peak river runoff. In other words, there is a tendency to equalize the wet and dry seasons. Studies show that in the context of climate change, a negative impact on the water resources of the lake is expected. In the worst-case scenario, river inflow of the Sevan basin will decrease by 34% (265 million m3) by 2100, and lake water evaporation will increase by 36.5% (292.6 million m3), compared to the base period (1961-1990). Consequently, the lake level is expected to drop by about 16 cm per year. In order to solve the problem, it is necessary to make legislative changes, improve the existing water legislation, as well as strengthen the institutional capacity and the water monitoring system.

Keywords: Lake Sevan, Climate change, Water balance, Water yield, Water resources management

Article Type: Research Article

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1. Introduction

Among the global problems caused by climate change, some relatively new and catastrophic phenomena are considered, the consequences of which harm the environment, water resources, and the sustainable development of society as a whole (IPCC, 2007; Jones et al., 2009; IPCC, 2022; Asgari et al., 2025). As a result of human economic activity, many of the Earth's water bodies have been transformed (Nabavi et al., 2025). A classic example of this is Lake Sevan, which has been considered an open-air laboratory for scientific research for nearly a century.

The impact of drought, climate change, and human activity is interconnected and reinforces each other, creating serious problems for lake ecosystems and water supply.

Drought, climate change, and human activity have a significant negative impact on the area and quantity of water in lakes, leading to a decrease in their volume and deterioration of water quality. Climate change, characterized by an increase in temperature and a change in the precipitation regime, accelerates the evaporation of water from lakes and also leads to the melting of glaciers, which affects water resources. Human activity, such as sewage disposal, agricultural use, and construction, also contributes to pollution and reduction of water volumes in lakes.

The idea of using the centuries-old water reserves of Lake Sevan (58 billion m^3) appeared at the beginning of the 20th century. At that time, Armenia was an agrarian developing country with no water supply necessary for irrigation in the Ararat Valley, and fuel and energy resources were lacking.

Because of Armenia's dry subtropical climate, potential evaporation considerably exceeds the amount of precipitation. Water is a scarce resource for agriculture. In particular, the Ararat valley, which is south of and 1000m lower than Lake Sevan, contains hundreds of thousands of hectares of arable land. But their annual precipitation is close to 300 mm, and potential evaporation is above 1000 mm. Meanwhile, millions of cubic meters of water were lost by evaporation from the lake. The original proposal (At the beginning of the 20th century) was to deepen the bed of the Hrazdan River and artificially increase the runoff. This would reduce the lake level by 55 m and increase the outflow of the Hrazdan river by 14-15 times, draining Big Sevan but using the water to irrigate 120,000 ha immediately downstream and in the Ararat valley. It would also allow the construction of a cascade of hydropower stations on the Hrazdan River (Gabrielian, 1980). Therefore, it was decided to use the water resources of the lake to develop the country's economy. Not until Soviet times was the project reconsidered. In 1931, after partial changes, the project was approved by the government, and construction started. As a result, the level of Lake Sevan dropped by about 20 meters, and its volume decreased to 32 billion m^3.

It should be noted that thousands of scientific articles have been published, and hundreds of theses defended both in Armenia and many other countries on the issue of Lake Sevan, in just the last seventy years. Only in the last 4-5 years has quite valuable research been conducted on the ecosystem of Lake Sevan. In particular, the following have been studied: the horizontal and vertical distribution of phytoplankton during the summer cyanoprokaryota bloom in Lake Sevan (Sakharova et al., 2020), anthropogenic Transformation of Lake Ecosystems and Existent Problems (Trahel Vardanyan et al., 2021), the condition of crayfish (Astacus leptodactylus*)* in the lake, affected by diseases, pollution, and poaching (Ghukasyan et al., 2023), modeling data of Lake Sevan for the period 2008–2017, including inflows, outflow, temperature, and model configuration (Shikhani et al., 2023), a public environmental alert calling for governmental restraint in approving excessive water releases from the lake (Sarkisyan, 2023), a detailed analysis of the current thermal and hydrodynamic structure of Lake Sevan (Poddubnyi et al., 2023), satellite-based detection of algal blooms in Lake Sevan, a large alpine lake (Asmaryan et al., 2024), water dynamics and morphometric parameters of the lake during the summer–autumn period, based on satellite data (Ginzburg et al., 2024), size–morphological structure and ecological strategies of prokaryotoplankton in Lake Sevan (Kuznetsova et al., 2024).

The mentioned works mainly concern the water ecology, water chemistry, and eutrophication of the lake. There have been very few scientific works on the management of lake water resources in the last 4-5 years (Vardanyan, 2023; Water-related data management…, 2021), and there are almost no articles on the issues of sustainable management in the context of climate change. In this regard, the presented research has important scientific and applied significance for Armenia and the region in general.

Many government decisions and programs have been adopted to save the lake (the latest one is the «2022-2027 Management Plan of the Sevan water Basin Management Area» (https://www.irtek.am/views/act.aspx?aid=119092)), and several international grant projects have been implemented.

Despite all this, the Sevan problem continues to be relevant, and we think it will remain a problem for a long time. It should be noted that the use of Lake Sevan's centuries-old resources, inefficient water resource management, and current and projected climate change have caused irreversible losses to the ecosystem of the basin.

Ensuring quality water at the right time and place to meet environmental, economic, and human needs requires effective water management. From this perspective, the management of Lake Sevan and its basin's water resources has not been effective, resulting in numerous problems. Considering these circumstances, along with present and anticipated climate changes in Armenia and the Lake Sevan basin, the outlook is not encouraging.

According to the Fourth National Communication on Climate Change of the Republic of Armenia (2020), during the last decades, there has been a significant increase in ambient air temperature in the country. Moreover, during the period of 1929-1996, average annual temperature has increased by 0.4 °C, during the period of 1929-2007 by 0.85 °C, during the period of 1929-2012 by 1.03 °C, and during the period of 1929-2016 by 1.23 °C.

Along with the increase in temperature, atmospheric precipitation has decreased significantly. Starting from 1935, comparison of estimated changes in the amount of precipitation over different periods shows that the decreasing trend in precipitation is maintained. Over the period of 1935-1996, the average annual precipitation decreased by 6 %, and during the period of 1935 to 2016, by about 9 %.

The main goal of the work is to analyze and assess the existing water resources management issues in the Sevan Lake basin, the dynamics of changes in water resources in the last hundred years, and the assessment of vulnerability in the context of the possible effects of climate change. Considering the economic, recreational, touristic, and ecosystem significance of Lake Sevan, the following problems have been posed, and possible solutions and mitigation methods have been provided:

- To present the current state of the lake and management issues
- To analyze and assess some hydrometric and hydrological parameters
- To analyze and assess the water balance of Lake Sevan in different years
- To study and assess the dynamics of changes in the mean annual water runoff of relatively large rivers flowing into Lake Sevan, trends of changes of absolute maximum and absolute minimum flows in the period from 1930 to 2020
- To study and assess the changes in the trend of atmospheric precipitation and air temperature in the basin of Lake Sevan
- The impact of potential climate change on the sustainable management of water resources in the Lake Sevan basin.

2. Materials and Methods

2.1. Study Area:

The field of scientific research of the article is diverse, which is due to the transformation and ineffective management of the water ecosystem. It includes the dynamics of changes in the main components of the aquatic ecosystem (climatic and hydrological), water balance parameters, and the impact of human economic activity in the context of changes of global and regional climate. The object of research is Lake Sevan (Fig.1). Lake Sevan is the largest freshwater lake in both Armenia and the Caucasus. The salinity of the lake water is only 600-700 mg/l (Gabrielian, 1980; Parparova, 1979; Vardanian, 2009). There are many theories about the origin of Lake Sevan (Gabrielian 1980; Paffenholtz, 1950; Sargsian, 1962, and others). However, the most probable is Sargsyan's theory (1962), according to which the lake has a tectonovolcanic origin. The lake is surrounded by 2500-3500 m high folded (Areguni and Sevan) and volcanic (Geghama and Vardenis) mountain ranges (Fig.1).

Lake Sevan is located in a dry subtropical climate zone, at an altitude of 1900 m above sea level. Due to the altitude, there is a temperate continental climate, and in the regions above 3000 meters spreads the snow climate type spreads. In the basin and Armenia in general, the duration of sunshine is very high (in Martuni, about 2800 hours). The average annual precipitation on the surface of the lake is 400 mm, and in the higher parts of the basin, it reaches up to 800 mm. The average annual air temperature in the lowlands is 6-7 °C, and in the high mountain regions it is -2-3 °C (Climate Bulletin of the Republic of Armenia, 2011).

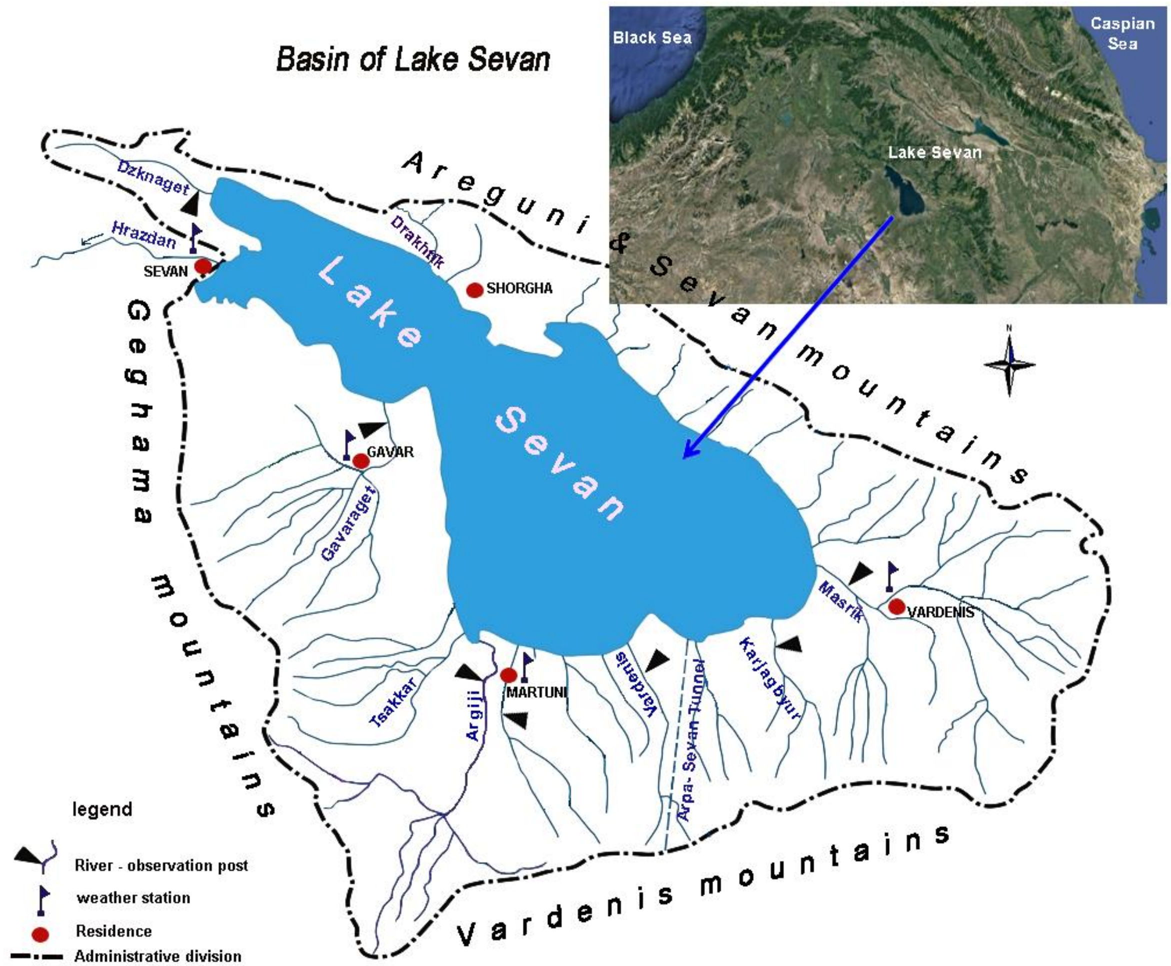

Figure 1. Geographical location of hydrometeorological observation points in the Lake Sevan basin used in the study

The basin of Lake Sevan has a fairly rich hydrographic network (Fig. 1). 28 rivers with different types of source (snowmelt, rain, and underground), with a length of 10 km or more, flow into the lake. Only one river, Hrazdan, originates from the lake, the flow of which is mainly used for irrigation and hydropower purposes, that is, it is completely regulated. Relatively large rivers of the Lake Sevan basin are: Argiji, Gavaraget, Masrik, and Vardenis, whose characteristics are given in Table 1.

Table 1. Some hydrometric and hydrological characteristics of relatively large rivers of the basin of Lake Sevan (Trahel Vardanyan et al., 2021)

River-observation post	River length, km	Size of watershed basin, km^2	Mean height of watershed, m	Years of observation	Mean annual water runoff, m^3/sec
Argiji-V. Getashen	51	384	2470	1930-2018	5.48
Gavaraget-Noratus	41	467	2430	1930-2018	3.52
Masrik - Tsovak	45	685	2310	1967-2018	3.31
Vardenis-Vardenik	24	116	2680	1958-2018	1.55
Karjagbyur - Karjagbyur	26	117	2650	1955-2018	1.08
Martuni-Geghovit	20	85	2760	1955-2018	1.68
Dzknaget-Tsovagyugh	21	85	2220	1930-2018	1.09

The first comprehensive scientific research on the water resources of Lake Sevan and its basin rivers began in the late 19th and early 20th centuries. During this period, the water and salt balances of Lake Sevan were drawn up, as well as hydrological observations began in the rivers of the basin (Markov, 1911; SJa, 1932; Davidov, 1938).

2.2. Methodology:

As starting data for the scientific research are the archival data of the Hydrometeorology and Monitoring Center state non-commercial organization (1930-2020, It should be noted that in the case of individual rivers or meteorological stations, the series of observations is not complete), as well as the data of the Water Resources Management Department of the Ministry of Environment, the Institute of Hydroecology and Fisheries, Yerevan State University and other departments. Scientific reports (Fourth National Communication on Climate Change of the Republic of Armenia, 2020; Climate Bulletin of the Republic of Armenia, 2011). Climatic and hydrological atlases of Armenia (Climatic Atlas of the Armenian SSR, 1975; Atlas of Natural Conditions…, 1990) were also used.

In order to explore the dynamics of the changes in the flow of the rivers entering the lake (1930-2018), the actual/existing flows were used instead of the natural flows of the rivers. The reason is that the volumes of water taken from the rivers for water use are not adjusted, and the existing recovery methods are not reliable (Vardanyan, 2006). The Vulnerability assessment of the annual river flow has not been carried out for each river flowing into Lake Sevan. Separately, since a multifactor correlation has not been established between the multiannual observation data of precipitation and air temperature at the meteorological stations for these river basins.

Multivariate correlations were used to determine the degree of vulnerability of lake water balance input components in the context of climate change. Using different known climate scenarios, the relationship between atmospheric precipitation, air temperature, and river flow, as well as between atmospheric precipitation, air temperature, and evaporation, was established.

This study's methodological approach consists of the following logical steps: the temporal statistical analysis, the spatial statistical analysis, and the identification of some hydrometeorological characteristics runoff of the rivers in the basin of Lake Sevan (Fig. 1).

The Mann-Kendall test (Mann, 1945) was used to analyze trends in hydrological and meteorological series. The MK test is a statistical test widely used to analyze trends in climatic and hydrological time series (Yue and Wang, 2004). There are two advantages of using this test: First, it is a nonparametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series (Stephens and Ellis, 2008). Any data reported as nondetects are included by assigning them a common value that is smaller than the smallest measured value in the data set (Kendall 1975). According to this test, the rejection of the null hypothesis H_0 assumes that there is a trend in the time series, while accepting H_0 indicates no trend detected, and the result is said to be statistically significant.

In order to remove serial correlation from the series, it was suggested to pre-whiten the series before applying the MK test (Von Storch and Navarra, 1999). The critical value of the lag-1 serial correlation coefficient (r1) for a given significance level depends on whether the test is one-tailed or two-tailed (a one-tailed test is used in the current report). The probability limits on the correlogram of an independent series for r can be computed by (Anderson, 1942; Salas et al., 1980). These methods can be reviewed in more detail in Vardanyan et al., 2021.

Basic principles and methods of spatial-temporal analysis were also used for processing initial data (general geographic, physical-geographic, hydrometeorological, socio-economic, hydro ecological), and the synthesis of relevant data and generalizations were used (Rusinov, 1970; Shelutko, 2007; Gagarina, 2012; Wikle et al., 2019).

In the study of hydrometeorological and hydrochemical information, we used empirical-statistical and genetic theoretical models, methods of mathematical statistical analysis, field expeditionary observations, processing techniques of specialized databases, geographic information systems, and other methods and techniques used in practice (Aliokhin, 1970; Rozhdestvensky and Chebotarev, 1974; Kendall, 1975; Shelutko, 1984; Trofimov and Igonin, 2001; Chichasov, 2013).

3. Results and Discussion

3.1. The problem of Lake Sevan

The Sevan problem arose from the late 19th to early 20th century and continues to be a problem to this day. However, it has had different meanings at different times. Taking into account the semi-desert conditions of the Ararat valley and the strong demand for water for irrigation of 120 thousand ha of land, as well as the huge volumes of Lake Sevan evaporation - 1210 million m^3 (Table 3), it was decided to deepen the Hrazdan River bed, to increase the discharge through the Hrazdan River by 14-15 times (the natural outflow was 50 million m^3 per year), and lower lake level by 55 m (Gabrielian, 1980; Musaelian, 1993; Vardanyan et al., 2007). In order to correctly visualize the Sevan problem, let's analyze several hydrological and hydrometric parameters of the lake and the water balance, which are given in Tables 2 and 3, respectively.

Table 2. Some hydrometric and hydrological parameters of Lake Sevan (Vardanian, 2023)

Indices	Unit of Measurement	In natural state (Davidov, 1938)	At the lowest level (2001) *	Present-day Condition*
A drop of the lake level	m	0.0	19,43	15,48
Height above sea level	m	1915.89	1896.46	1900.41
Watershed surface	km^2	3475	3649	3613
Lake surface	km^2	1416	1242	1278
Maximum depth	m	98.7	79.3	83.2
Water volume	km^3	58.5	32.8	38.3
* *According to the Hydrometeorology and Monitoring Center of RA*				

According to Davydov (1938), in its natural state, the height of Lake Sevan above sea level was 1915.89 m, the surface of the lake was 1416 km^2, and the water volume of the lake was 58.5 billion m^3 (Table 2). The water balance of Sevan was stable (Table 3). The largest component of the balance was evaporation, 1210 million m^3 per year, and the outflow through the Hrazdan River was only 50 million m^3.

Table 3. The water balance of Lake Sevan in different years (million m^3)

	Balance Component	In the natural state, Davidov V.K. (1927–1934)	Hydrometeorological Department of RA (1951–1970)	Hydrometeorological Department of RA (1981–2000)	Hydrometeorology and Monitoring Center of RA (2002–2009)*	2018	2021
Inflow	Precipitation	550	498	507	593	497	338
	River flow	720	749	777	735	725	557
	Arpa-Sevan flow	–	–	236	219	142	163
	Subsurface flow	50	78	80	94	94	94
	Total Inflow	1320	1325	1600	1641	1458	1152
Outflow	Evaporation	1210	1053	1102	1045	1203	1105
	Hrazdan River flow	50	1093	513	157	201	165
	Subsurface flow	60	24	10	14	14	14
	Total Outflow	1320	2170	1625	1216	1418	1284
	Inflow – Outflow	0	-845	-25	+425	+40	-132

*Ecology of Lake Sevan during the period of water level rise, the results of the Russian-Armenian biological expedition for hydrogeological survey of Lake Sevan (2010). (Armenia) (2005-2009). Publishing house, Science DNTs, Russia, 348.

The lake's water balance and level underwent the greatest change in the 1950s. The outflow of water through the Hrazdan River reached its historical maximum volume of 1.7-1.8 billion m^3, and the lake level dropped by 17-18 meters. The water balance of the lake continued to remain negative. The difference between water inflow and outflow was -845 mln. m^3 (Table 3).

It became clear that the decline in the level of Lake Sevan has had major consequences for the physical, chemical, and biological character of the lake and its surrounding region. At this stage, some irrigation, energy, and industrial problems were already partially solved. However, the government realized that it is necessary to make some changes in the water resources management plan of Lake Sevan. In particular, review the issue of further lowering the level.

In order to preserve the ecosystem of Lake Sevan and stabilize the water level, the government decided to design and build the Arpa-Sevan water tunnel (48 km), through which a part of the water of the Arpa River (250 million m^3 per year) would be transferred to Lake Sevan (Fig. 1). After the construction of the Arpa-Sevan tunnel (1982), the lake level gradually stabilized, which had a positive effect on the ecosystem.

However, the sustainability was interrupted by the economic and energy crisis in Armenia (Disintegration of the USSR, Karabakh war, economic blockade), and from 1992 on, large water releases from the Lake restarted (1.6-1.7 billion m^3). During this time, the level of the lake continued to decrease and in 2001 reached its historical minimum mark (1896.46 m), and the volume was only 32.8 km^3, instead of the previous 58.5 km^3 (Table 2)

In order to raise the water level of the lake, to restore and preserve the ecosystem, a number of large-scale measures were taken. In particular, in 2001, the Law of the Republic of Armenia on measures for restoration, conservation, reproduction, and use of the Lake Sevan ecosystem was adopted (https://www.arlis.am/DocumentView.aspx?docid=137373).

According to this law, in the field of raising the water level of Lake Sevan, it was planned to put into operation the Vorotan-Arpa hydro junction, whose construction was stopped in the 1990s, and to ensure the stable operation of the Arpa-Sevan water pipeline. As a result of the above and other actions, an annual increase in the level of Lake Sevan was expected to be about 21.6 cm. According to these calculations, during the 30

years planned by the complex program, the volume of Sevan water would increase by around 8.8 billion m^3, which is equivalent to a 6.5 m increase in the lake level (Vardanian, 2023).
However, as a result of inefficient management of the water basin, wrong calculations, and favorable climatic conditions in those years, instead of the planned 21.6 cm annual increase in the lake level, a double increase occurred. In just 6 years (2002-2007), the lake level rose by about 2.5 meters (Vardanian, 2023). As a result, a new issue emerged, namely, the coastal green zone (tree-shrub vegetation) and recent constructions are under water.
Based on this circumstance, in the following years, the sharp rise of the lake level was stopped, mainly by increasing the discharges through the Hrazdan River, so that it was possible to clear the coastal green zone and buildings. In addition, climatic conditions became more unfavorable (precipitation decreased, droughts increased). This process continues to this day. As a result, the lake became frequently covered with blue-green algae (Vardanian et al., 2021).
The bloom event in 2018 reached unprecedented levels and, therefore, stirred intense media attention (Gevorgyan et al., 2020). The lake continued to bloom in 2019-2022, too. Our studies have shown that raising the lake level is not enough. In order to effectively manage the water resources of the lake and develop the Ecosystem, it is necessary to ensure a stable level of the lake during the year.

3.2 The water resources of the rivers of Lake Sevan

The water resources of the rivers of the Lake Sevan basin have also undergone certain changes. The studies carried out in the relatively large rivers of the basin (Argiji, Gavaraget, Masrik, Karjagbyur, Vardenis) show that in the period from 1930 to 2020, almost all rivers (except for Vardenis) show an upward trend in flow (Fig. 2).

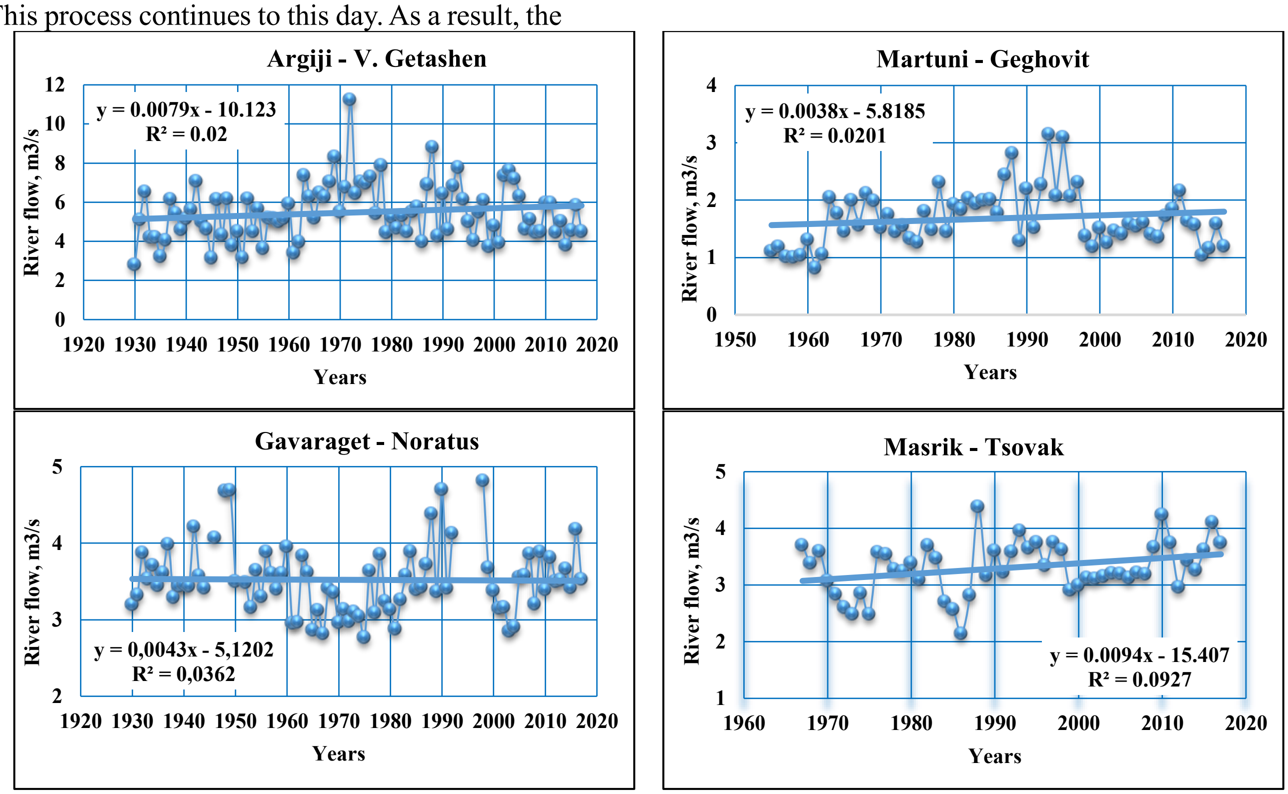

Figure 2. Trends of changes of river flow in the Sevan Basin (1930-2020)

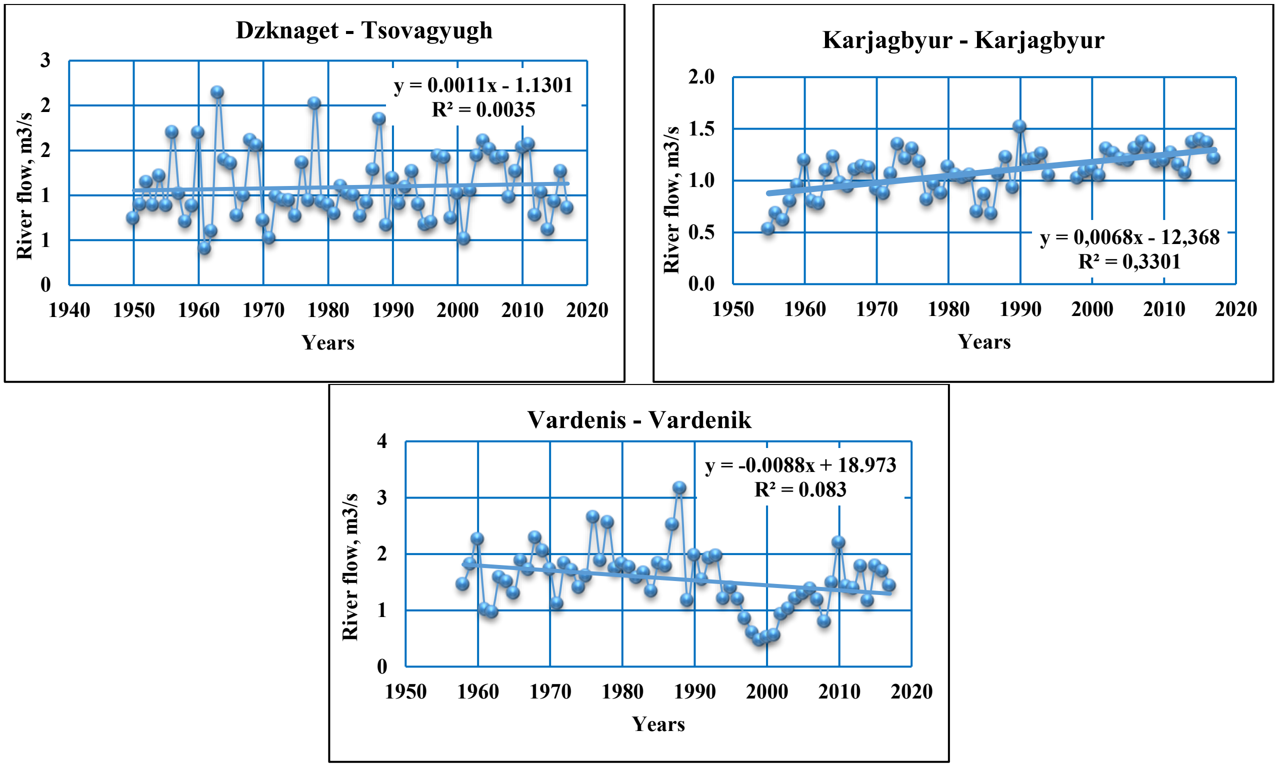

Figure 2. Cont. Trends of changes of river flow in the Sevan Basin (1930-2020)

When assessing the vulnerability of dynamics of the basin's river flow changes, it turns out that in five of the six studied rivers, a steady increase in river water flow is observed (Table 4). The maximum increase was observed in the Karjagbyur river: 0.20 m^3/s or 18.52 %, and the minimum in Gavaraget: 0.04 m^3/s or 1.14 %. A decreasing trend of the flow was observed only in the Vardenis river: -0.15 m^3/s or -9.68 %.

Table 4. The characteristics of the runoff of the major rivers of the Lake Sevan Basin

River-observation post	Trend line equation	Mean annual water runoff, m^3/sec	Change in Runoff	
			m^3 / s	%
Argiji-V. Getashen	y = 0.0079x - 10.12	5.48	0.27	4.93
Gavaraget-Noratus	y = 0,0043x - 5,12	3.52	0.04	1.14
Masrik - Tsovak	y = 0.0094x - 15.41	3.31	0.27	8.16
Vardenis-Vardenik	y = -0.0088x + 18.97	1.55	-0.15	-9.68
Karjagbyur - Karjagbyur	y = 0,0068x - 12,37	1.08	0.20	18.52
Martuni-Geghovit	y = 0.0038x - 5.82	1.68	0.12	7.14
Dzknaget-Tsovagyugh	y = 0.0011x - 1.13	1.09	0.04	3.67

If we compare with the dynamics of river flow changes in RA (Vardanian, 2006), we should note that the vulnerability of the dynamics of changes in the rivers of the Lake Sevan basin is relatively small, which can have a positive effect on the management of water resources of the basin and the sustainable development of the ecosystem. In order to assess the impact of climate change on river flow, the dynamics of atmospheric precipitation and air temperature changes in the Sevan basin were also observed in several meteorological stations (Fig. 3).

Air temperature, ^{0}C **Atmospheric precipitation, mm**

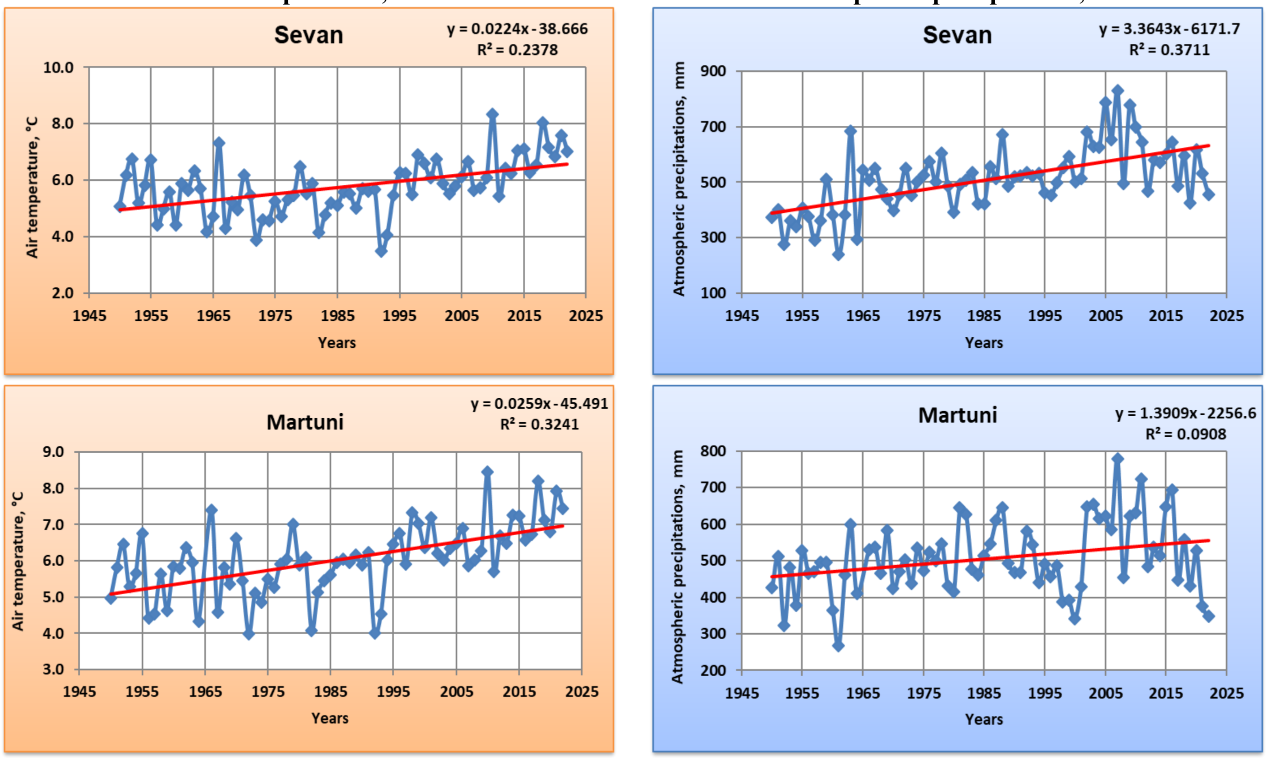

Figure 3. Trends of changes in atmospheric precipitation and air temperature in the Lake Sevan Basin

Air temperature, ^{0}C **Atmospheric precipitation, mm**

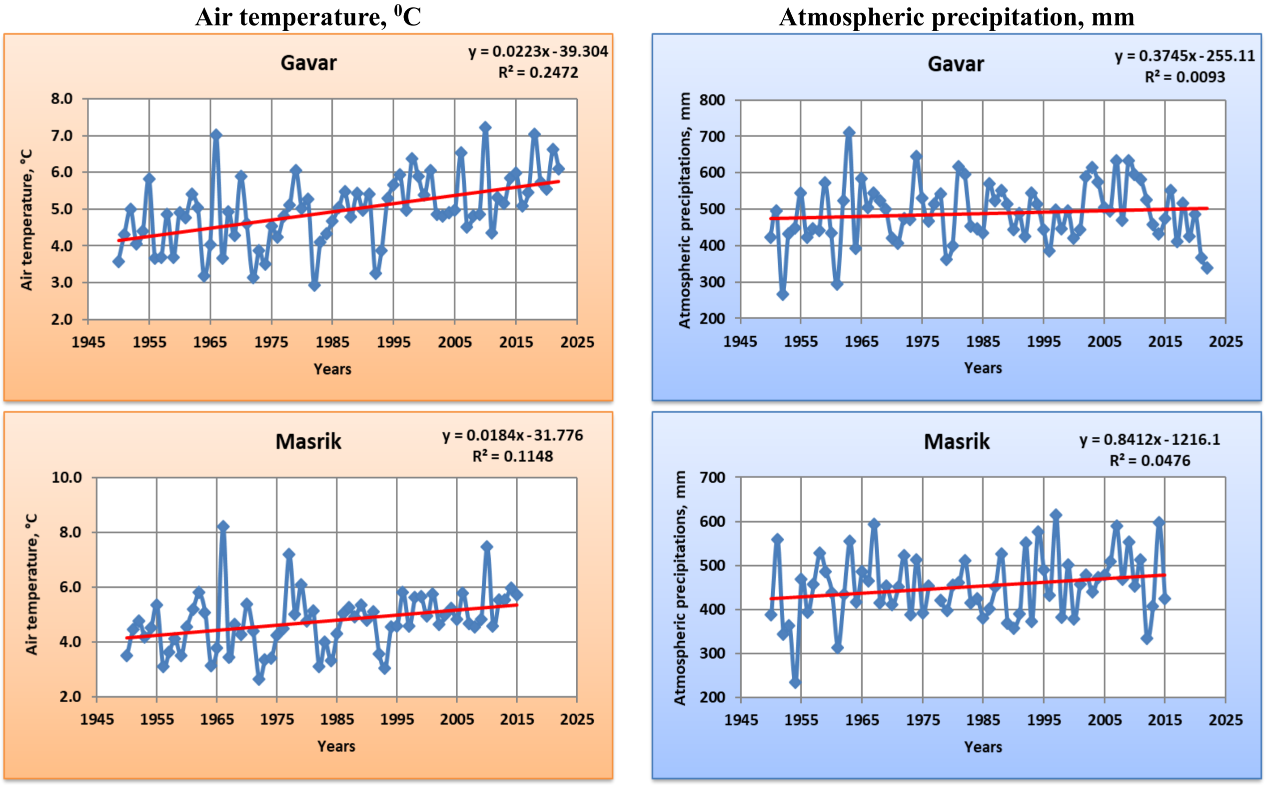

Figure 3. Cont. Trends of changes in atmospheric precipitation and air temperature in the Lake Sevan Basin

Air temperature, ^{0}C **Atmospheric precipitation, mm**

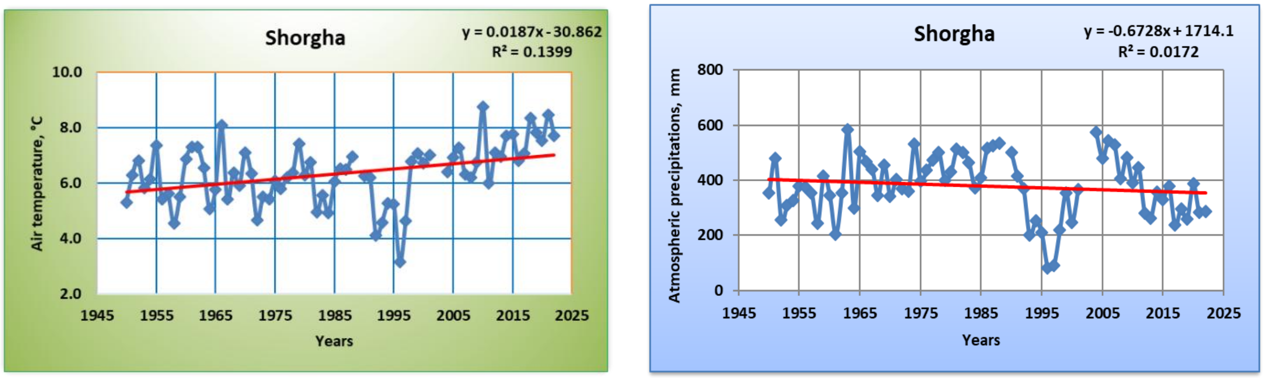

Figure 3. Cont Trends of changes in atmospheric precipitation and air temperature in the Lake Sevan Basin

As shown in the graphs, an increasing trend of atmospheric precipitation and air temperature was observed in almost all meteorological stations (the exception is Shorgha, where precipitation is decreasing, which needs further studies). Thus, this fact also confirms that the average annual flows of water in the rivers have increased. The dynamics of changes in the absolute maximum and minimum runoff of rivers of the relatively large rivers of the lake basin were also observed in parallel for the same period. Figure 4 shows the graphs of changes in absolute maximum and minimum river flows, and Table 5 and 6 summarize their trend line equations and flow vulnerability to the mean value, calculated in absolute values and percentages.

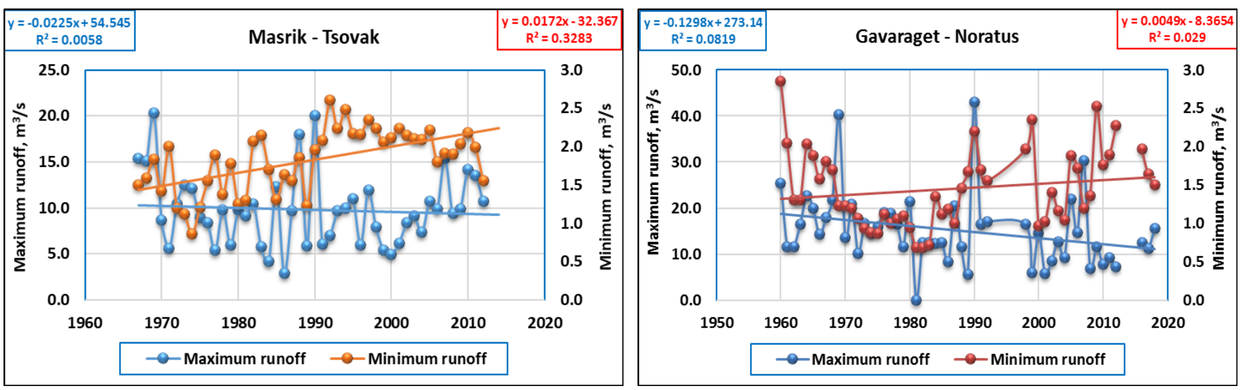

Figure 4. Trends of changes in absolute maximum and absolute minimum flows of relatively large rivers of the Lake Sevan Basin

It is clearly shown in the graphs that for all considered rivers, the maximum flow has a decreasing trend (Fig. 4). Argiji (55 %) and Karjagbyur (62.5 %) have the largest decrease values, and the smallest is Masrik, whose flow has decreased by 8.8 % (Table 5). This pattern is also characteristic of the entire territory of RA (Trahel Vardanyan et al., 2021)

Table 5. Changing dynamics of the absolute maximum runoff characteristics of rivers of relatively large rivers in the Lake Sevan Basin

N	River-Observation post	Trendline equation	Average value of the maximum runoff, m^3/s	Change in Runoff	
				m^3/s	%
1.	Argiji-V. Getashen	y = -1.0034x + 2054.3	54.9	-30.21	-55.0
2.	Gavaraget-Noratus	y = -0.1298x + 273.14	15.5	-4.51	-29.1
3.	Masrik - Tsovak	y = -0.0225x + 54.545	9.89	-0.87	-8.8
4.	Vardenis-Vardenik	y = -0.1427x + 294.58	11.24	-4.41	-39.2
5.	Karjagbyur-Karjagbyur	y = -0.0977x + 198.88	5.04	-3.15	-62.5

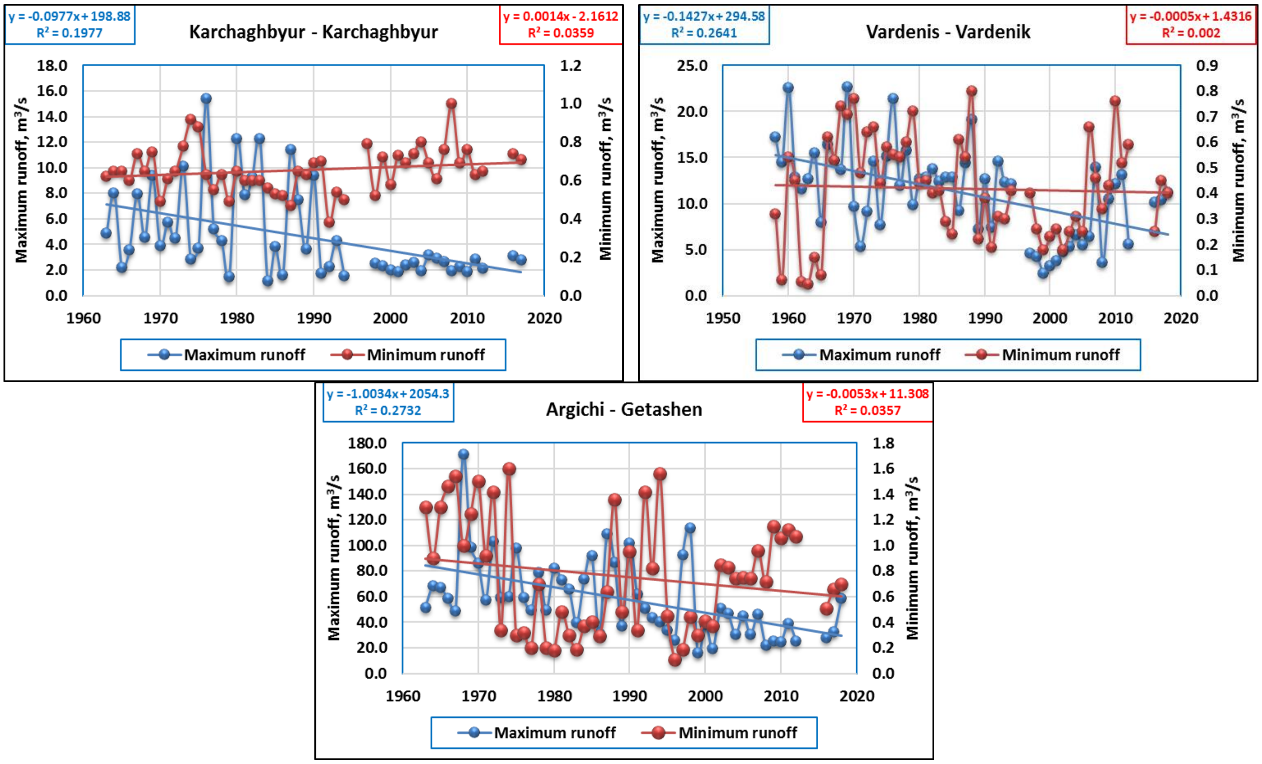

Figure 4. Cont. Trends of changes in absolute maximum and absolute minimum flows of relatively large rivers of the Lake Sevan Basin

In our opinion, the trend of mass reduction of maximum runoff in the studied rivers is mainly caused by global and regional climate changes. If we take into account the fact that in the same period in the territory of the RA, an increase in atmospheric air temperature was observed by 1.23°C compared to the average of 1961-1990, and precipitation decreased by 9% (Fourth National Communication on Climate Change of the Republic of Armenia, 2020), then in this context, it can be confidently confirmed, that the decreasing trend of the maximum runoff in Lake Sevan Basin rivers is caused only by climate change.

The process is explained as follows: the maximum runoff in RA rivers is formed in late spring - early summer, mainly from snowmelt. However, as the average air temperature rises, the snowmelt starts earlier and gradually extends until the beginning of summer, during which the accumulated snow gradually melts, and the snow remaining in the riverbanks at the end of spring does not pose a risk for the occurrence of floods. In other words, this process has also reduced the intensity of catastrophic floods and mitigated their potential dangers and loss volumes. Seasonal equalization does not mean that the frequency of floods and extreme runoff events will decrease under climate change. As studies show (Vardanyan et al., 2021; Asgari et al., 2025), their frequency is increasing.

Unlike maximum river runoff, the picture is different for minimum runoff. The graphs of changes in the absolute minimum runoff rivers are shown in Figure 4, and the equations of the trend lines and the vulnerability of the runoff to the average value, calculated in absolute values and percentages, are given in Table 6.

Table 6. Changing dynamics of the absolute minimum runoff characteristics of rivers of relatively large rivers in the Lake Sevan Basin

River-Observation post	Trendline equation	Average value of the minimum runoff, m^3/s	Change in Runoff	
			m^3/s	%
Argiji-V. Getashen	y = -0.0053x + 11.308	0.77	-0.17	-22.1
Gavaraget-Noratus	y = 0.0049x - 8.3654	1.5	0.11	7.3
Masrik - Tsovak	y = 0.0172x - 32.367	1.83	0.47	25.7
Vardenis-Vardenik	y = -0.0005x + 1.4316	0.42	-0.02	-4.8
Karjagbyur - Karjagbyur	y = 0.0014x - 2.1612	0.65	0.05	7.7

In this case, both an increasing and decreasing trends are noticeable. Both in the case of maximum and minimum flow, a decreasing trend was observed in the Argichi River; moreover, it is the maximum amount (55 and 22.1%, respectively), and the average annual flow has an increasing trend of 4.93% (Table 4).

This inconsistency is due to anthropogenic factors only; otherwise there would have been an increase in flow during the summer low water phase, as was the case in other rivers. If we also mention the fact that of the two seasons with little water in the RA rivers, the summer one is naturally more abundant (Vardanian, 2006), then the growth trend was inevitable.

We believe this is also due to global climate change and river peak runoff. As noted above, snowmelt in rivers is prolonged, reaching into early summer, contributing to increased volumes of summer runoff. In other words, there is a tendency to equalize the wet and dry seasons, that is, the maximum runoff decrease and the minimum runoff increase. Even though in summer the number of water intakes increases sharply. Thus, it can be concluded that changes in the maximum and minimum runoff of rivers in mountainous regions can serve as indicators of regional and global climate changes. In addition, in all cases, there are serious problems of integrated management of water basins.

3.3 The analysis of water and water economic balances of Lake Sevan

In the efficient management of water resources, the analysis of water and water economic balances is extremely important. In other words, it is the amount of water in the basin and the amount needed to ensure the sustainable development of the economy and to cope with the expected climate changes. As can be seen in Table 3, the input components of the water balance have undergone little change over the past hundred years. The only difference is the volume of additional water transported by the Arpa-Sevan tunnel, which is extremely important for stabilizing the lake level. As a result of the additional volume of water transferred, in 2018, the total volume of the input components of the water balance exceeded the volume observed in the natural state of the lake (1927-1934) by 138 million m^3.

Unlike the total volume of the input components of the water balance, the total volume of the output components has undergone significant changes due to the regulation of the flow of the Hrazdan River. In its natural state, the outflow from Sevan through the Hrazdan River was 50 million m^3; in 1960, it reached 1.7 billion m^3, while in 1981-2000 it was 513 million m^3, and now, according to the government's decision, it is up to 160 million m^3 each year.

Thus, after the artificial reduction of the Lake Sevan level, the annual difference between the inflow and outflow has almost always given a negative balance. In recent years, the outflow component has been considerably reduced, while steps are being taken to increase the inflow and create a positive balance (425 million m^3) and a rise in levels.

However, the volume of this additional water, which contributed to the gradual increase of the lake level, decreased in the following years, and already in 2021, the lake balance (Table 3) became negative (- 40 million m^3). This circumstance is explained by the fact that the recent years were not favorable in terms of climate: rainfall decreased, rivers became scarce, water demand increased, and additional water was released from the lake.

The Lake Sevan water balance assessment under the projected climate change scenarios was implemented through establishing a multifactor correlation between the annual inflow into the Lake and multi-annual observation data on atmospheric precipitation and air temperature at the meteorological stations of the basin.

The climate change scenarios show a negative impact on the conditions for life in the Lake, and the pessimistic (the worst) scenario (METRAS RCP 8.5) suggests a decrease in the total river inflow into the Lake Sevan by about 34% (265 million m^3) (Fig. 5) and increase of Lake surface evaporation rate by 36.5% (292.6 million m^3) by 2100 as compared to the baseline conditions (1961-1990). The Lake level will decrease by about 16 cm in a year (Fourth National Communication on Climate Change of the Republic of Armenia, 2020).

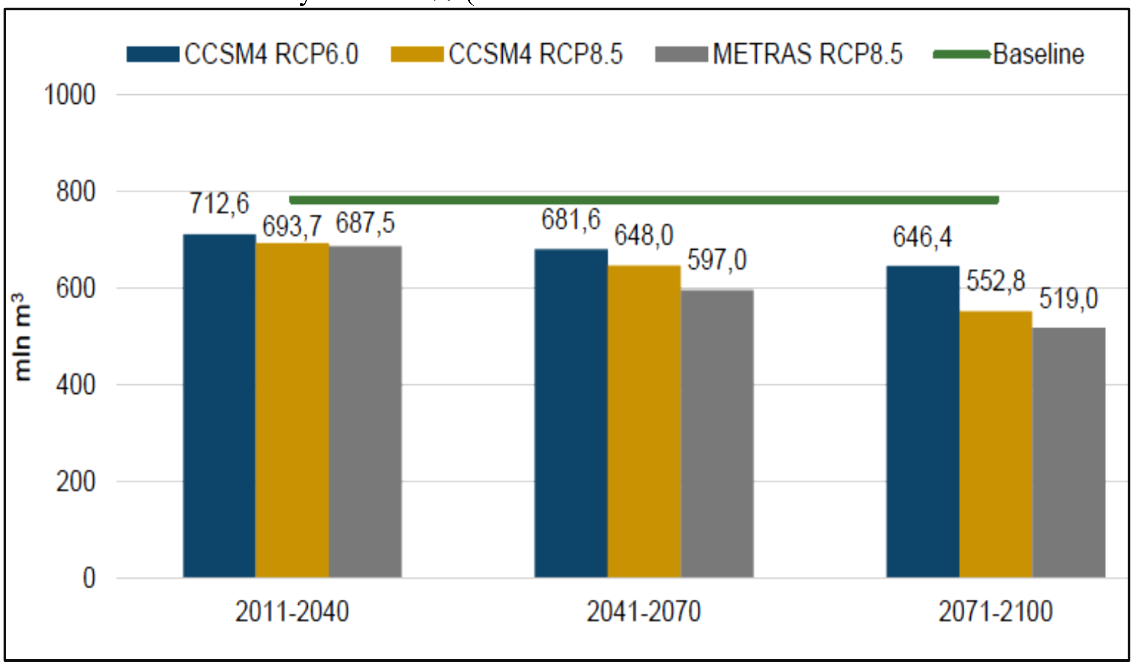

Figure 5. Vulnerability of the total annual river inflow into Lake Sevan (Fourth National Communication on Climate Change of the Republic of Armenia, 2020)

There is a highly stressed water-economic balance in the Sevan water basin management area. Water intake in the basin is carried out for drinking-domestic, irrigation, industry, hydropower, and fish farming purposes. According to water use permits, in 2022, as of January 1, the total volume of water intake was 134 million m^3 (2022-2027 Management plan of the Sevan water basin management area (https://www.irtek.am/views/act.aspx?aid=119092)).

However, there are many unauthorized water users. That is, a certain volume of water is not accounted for or considered as a loss. So, there is serious work to be done on water supply and demand. It is necessary to conduct monitoring of water use permits issued by the relevant department, which will enable determination the actual water demand. At the same time, improvement of water supply and irrigation networks is needed to reduce water losses. It is time for the state to define the priorities of the water use sectors in the basin and to implement the SCADA (Supervisory Control and Data Acquisition) system for the main water users, which will enable more efficient collection and processing of actual water use data.

Thus, in the context of global and regional climate change, a 34% decrease in river flow is expected in the Sevan water basin management area by the end of the 21st century, as a result of which a severe deficit of water resources will be observed. Considering this circumstance, we propose to diversify agriculture and industry in the effective and sustainable management of water resources. Develop ways to save water, in particular, introduce drip irrigation and differentiated water billing systems.

4. Conclusions

Assessment of the vulnerability of the dynamics of river flow changes in the Sevan basin shows that a steady increase in river water flow is observed in five of the six studied rivers. The maximum increase was observed in the Karjagbyur river: 0.20 m^3/s or 18.52 %, and the minimum in Gavaraget: 0.04 m^3/s or 1.14 %. A decreasing trend of the flow was observed only in the Vardenis river: -0.15 m^3/s or -9.68 %. We believe that this circumstance, in the context of global and regional climate changes, will have a positive effect on the management of water resources of the basin and the sustainable development of the ecosystem.

In all studied rivers, a definite downward trend in maximum runoff was observed and an increase in minimum runoff (except for two). We believe this is due to global climate change and peak river runoff. As noted above, snowmelt in rivers is prolonged, reaching into early summer, contributing to increased volumes of summer runoff. In other words, there is a tendency to equalize the wet and dry seasons, that is, the maximum runoff decrease and the minimum runoff increase.

Thus, it can be concluded that changes in the maximum and minimum runoff of rivers in mountainous regions can serve as indicators of regional and global climate changes. In addition, in all cases, there are serious problems of integrated management of water basins.

The climate change scenarios show a negative impact on the conditions for life in the Lake, and the pessimistic (the worst) scenario (METRAS RCP 8.5) suggests a decrease in the total river inflow into the Lake Sevan by about 34% (265 million m^3) and increase of Lake surface evaporation rate by 36.5% (292.6 million m^3) by 2100 as compared to the baseline conditions (1961-1990). The Lake level will decrease by about 16 cm in a year.

The research conducted and the results obtained can be used for the development of a long-term water resources management plan for Lake Sevan and its basin. They are also valuable for the development of agriculture in the basin, the development of ways for crops to adapt to climate change, as well as for irrigation and water supply. It is proposed to diversify agriculture and industry in the Sevan basin for effective and sustainable management of water resources. Develop ways to save water, in particular, introduce drip irrigation and differentiated water billing systems.

There is no single governing body in the region, as a result of which the ecological condition of Lake Sevan and its catchment continues to deteriorate. Therefore, in order to solve the problem, it is necessary to make legislative changes, improve the existing water legislation, as well as strengthen the institutional capacity and the water monitoring system.

It is necessary to monitor the water use permits issued by the relevant department, which will enable determination the actual water demand. At the same time, improvement of water supply and irrigation networks is needed to reduce water losses. It is time for the state to define the priorities of the water use sectors in the basin and to implement the SCADA (Supervisory Control and Data Acquisition) system for the main water users, which will enable more efficient collection and processing of actual water use data.

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All data generated or analyzed during this study are included in this published article.

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