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ABSTRACT

Thesis submitted for the degree of Doctor of Philosophy

ASSESSMENT OF THE IMPACT OF CLIMATE CHANGES IN THE RIVER FLOW OF THE GREAT CAUCASUS

Specialty: 5406.01 - Hydrology

Field of study: Geography

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The thesis was implemented at Hydrometeorology Research Institute, Department of National Hydrometeorology Department, the Ministry of Ecology and Natural Resources.

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GENERAL CHARACTERISTICS OF THE RESEARCH WORK

Relevance and degree of development of the topic. Recently, global climate change and its regional effects continue to have a negative impact on the sustainable economic development of most countries. Thus, abnormal atmospheric processes caused by climate change can lead to changes in hydrometeorological conditions and the resulting natural disasters, including floods, hurricanes, droughts, strong winds, continuous rains, forest fires, level fluctuations in water bodies, etc. caused an increase in incidents. This, in turn, increases human mortality worldwide and continues to have a negative impact on individual countries and the world economy as a whole. According to the World Meteorological Organization (WMO), the number of natural disasters caused by climate change has recently increased. 80-85% of such natural disasters in the world are related to hydrometeorological and the remaining to geophysical processes. Over the past 35 years, the economic damage caused by global hydrometeorological disasters has increased 74 times and amounted $ 995 billion[1].

At present, climate change in the Earth's atmosphere causes fluctuations in the seas and oceans, affecting the regime of water bodies on land, their water resources, and changes in the annual flow of rivers. All of the above mentioned, in addition to increasing people's demand for water, demand taking into account the effects of climate change on river flows to use river water more efficiently and optimally. In this regard, issues such as the assessment of river water resources, the preservation of ecosystems in river basins, adaptation to regional climate change are among the urgent issues that need to be addressed from a scientific and practical point of view.

The study of climate change on our planet, the factors that cause it and assessment of its effects, climate forecasting, reducing the negative impact of climate on the environment and the population are in the focus of world scientists, heads of state and international

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[1] Makhmudov, R.N. Regional climatic changes and regional runoff in Azerbaijan // Moscow: Gidrometeoizdat – 2016. No. 9, − p. 63-69.

organizations. As a result, the Framework Convention on Climate Change was signed under the control of the United Nations in Rio de Janeiro in 1992, and the Republic of Azerbaijan has joined to this convention since 1995.

It goes without saying that the fact that 8-9 of the existing climate types in the world being observed in our country in ine way or another causes to regional changes as a result of global climate change. This can be seen more clearly in the recent years with the rise in extreme temperatures, droughts, floods and mudslides, various local hurricanes, natural forest fires, sea level fluctuations, river water resources and regime changes in rivers. 2018 and 2021 were the hottest years in the world, and record temperatures were observed in our country, the number of continuous hot days above 35^0C was more than a month[2].

Taking into account that our country is one of the less secured countries in the world in terms of river water resources, then guided by the above, we can say that the study of the possible impact of climate change on river water resources, annual flow of rivers, their regime changes increases the urgency of scientific researches even more.

Objectives and tasks of the research. The main goal of the thesis is to study the impact of climate change on the flow of the Greater Caucasus Rivers within the territory of Azerbaijan, determine the regime and annual flow changes in territorial river flows and assess river flows for different climatic scenarios taking into account key climate indicators.

To achieve these goals in the study, the following tasks were considered expedient:

- Analysis of the formation characteristics of river flows taking into account climate change and detection of the principles of distribution of river flows in the area;
- determination of regional effects of climate change in the area;

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[2] Makhmudov, R.N. Regional climate change in Azerbaijan and its impact on hydrometeorological conditions // Baku: Journal of Geography and Natural Resources – 2021. No. 2(14), − p. 19-26

- study of the seasonal and annual distribution characteristics of the main climatic indicators and conducting their statistical analysis;

- conducting statistical analysis of river flows, revealing the impact of climate change on the river regime;

- Analysis of the characteristics of the vertical distribution of atmospheric precipitation in different scenarios of temperature increase;

- assessment of river flow in different scenarios of temperature change, depending on precipitation and temperature, suggesting analytical expressions;

- analysis of various models used in climate scenarios and the results obtained on the basis of these models.

Research methods. Geographical, hydrological similarity, mathematical statistics, water balance, empirical methods were used in the research.

The main provisions of the thesis.

1. Assessment of regional impacts of climate change in the area;
2. Assessment of the impact of climate change on river flow;
3. Time and space variability of hydrometeorological parameters;
4. Issues of application of suggested climate models for different climate scenarios.

Scientific innovation of the research:

- Genetic and statistical dynamics of key indicators of climate change were revealed;

- the impact of climate change on the regime characteristics of rivers and annual flow was determined;

- the dynamics of temperature and precipitation changes in altitude in different climatic scenarios and the degree of its impact on river flow were assessed;

- physical-geographical zoning was carried out in the study area depending on changes in temperature and precipitation;

- The principles of application of different models in different climatic scenarios are analyzed.

Theoretical and practical significance of the research. The results of the research can be used in scientific – research works, assessment of river water resources, water efficiency, the principles of adaptation of vegetation periods in the basin to climate change, as well as the development of methods for forecasting regional climate change.

Approbation and application. The results of the research were presented at the following conferences: Scientific-practical conference "Regional economic policy and development of cooperation", Baku, 2014 Azerbaijan; Collection of works on "Geography: theory, practice and innovation" Baku 2015, Scientific-practical conference "Modern problems of water use and its management in Azerbaijan" (Baku, 2015) Republican Scientific Conference "Modern problems of geography", (Sumgayit, 2019- cu il) “Russian Science in the Modern World” XXXVI International Scientific-Practical Conference, Penza, 2021).

Can be applied in the development of the principles of adaptation of the vegetation periods of the plants to climate change in the basin, in detection of genetic and static changes in the main indicators of the climate.

Name of the organization where the thesis is performed. The thesis was implemented at the Hydrometeorological Scientific Research Institute of the National Hydrometeorology Department of the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan.

Scope and structure of the thesis. The thesis consists of an introduction, 4 chapters and conclusions, and a list of used literature. The volume of the work is about 152 pages. The work consists of 3 pictures, 27 tables, 36 graphs, a list of 124 literature sources.

The introduction consists of 5 pages, Chapter I 29 pages, Chapter II 27 pages, Chapter III 28 pages, Chapter IV 46 pages, result 2 pages, bibliography 12 pages. It consists of 160,114 characters without tables, graphs, pictures and bibliography.

BRIEF DESCRIPTION OF THE THESIS

In the introductory part of the thesis, the urgency of the topic, goals and objectives of the research, scientific innovation, practical significance, etc. reflected.

The first chapter of the thesis is entitled **"Features of the formation of the flow in the rivers of the Greater Caucasus natural region".** In this chapter, the factors that create the flow, their effect on the river flow in the area and the nature of the formation of the flow in the area are studied. For this purpose, on the basis of the available literature, the orographic features of the area were analyzed, the factors influencing the formation of river flows in the area were studied and the distribution characteristics of the flow in the area were studied. This chapter confirms that the orography of the Greater Caucasus plays a special role in the formation of the climate, hydrographic network and river flow of the area.

The north-eastern slope of the Greater Caucasus is divided into four zones according to its hypsometric characteristics: high mountain belt; middle mountain belt; front mountain belt; plain belt[3].

In terms of genesis, the role of food sources in the distribution of river flow in any area is greater in terms of physical and geographical location, especially climatic conditions. Nutritional sources of rivers are of exceptional importance in the formation of the river system, its hydrographic network, the distribution of flow throughout the year, the changing nature of water balance elements. In general, the water reserves of rivers flowing through the Greater Caucasus are 5.52 km^3, which is 53.6% of the local water resources of the republic.[4]

The analysis of the upstream distribution of the flow shows that the flow gradient in the southern slope rivers is weaker than in the north-eastern slope rivers.

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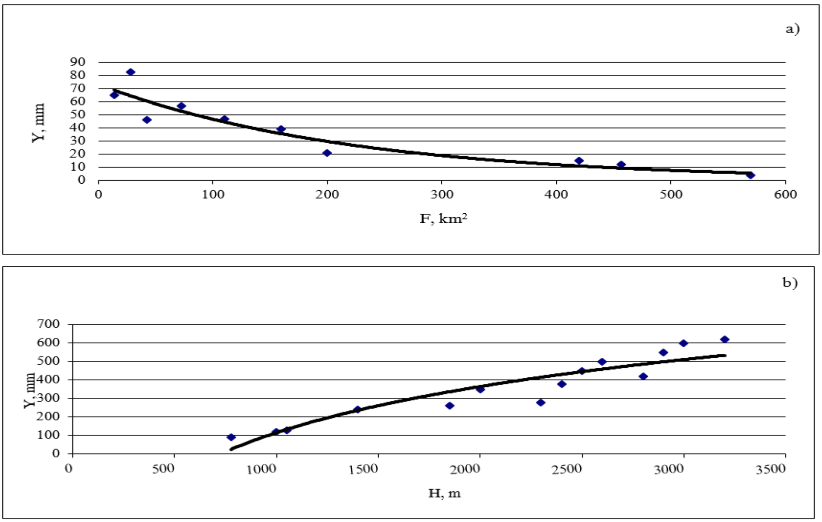
[3] Budagov, B.A. Geomorphology of the southern slope of the Greater Caucasus (within the borders of Azerbaijan SSR) / B.A. Budagov. – Baku: Elm publishing house, – 1969. – 178 p.

[4] Rustamov, S.T. Water resources of the Azerbaijan SSR. / S.T. Rustamov, R.M.Gashgay. – Baku: Elm, –1989. − 182 p.

The high correlation between the flow layer and the average height of the basin and the area of the basin corresponds to the law of vertical zoning of the flow and once again confirms that it is subject to this law. From this point of view, the dependence of Y = f (H) can be used to determine the flow layer of rivers without observational data. (Figure 1)

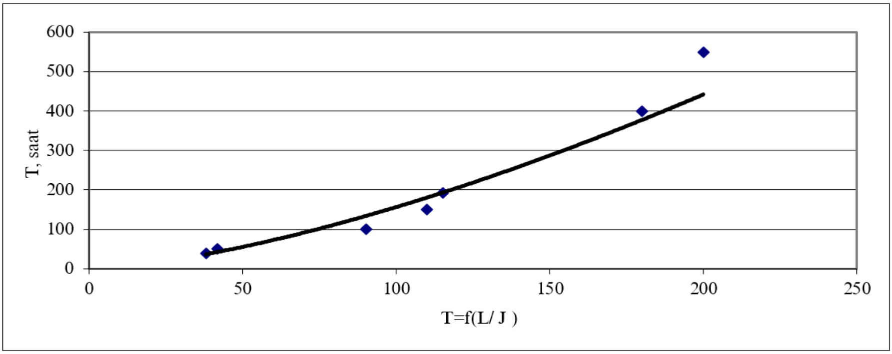
According to the height distribution and formation of the flow, the amount of flow coefficient (α) also increases with altitude for the northern and southern slope rivers of the Greater Caucasus, and the principle of $\alpha=f(\overline{H})$ also exists for the rivers of the area.

The annual flow modulus increases with altitude throughout the region. However, the relationship μ0 = f (H) is not so closely expressed and the correlation coefficient does not exceed 0.73. Trends in the variation coefficients of the annual flow at the main support points are analyzed by height, and the decrease in Cv by height occurs, which is due to the homogeneity of the flow formation in the upstream zone.



Graph 1. Dependence of the flow layer (Y, mm) on the area of the basin (a), (F, km^2) and average height (b), ($\overline{H}$,m)

The analysis of the observation information shows that maximum water consumption of rivers increases by an increase in the area of the basin (F) and here, the correlation Q_{max} = (F) finds its physical – genetic confirmation. In the graph 2, the dependence of duration of floods from rivers in the area on the length of river T (L, km) and the inclination (J, ‰) on the ratio $(L/\sqrt{J})$ are given.



Graph 2. Dependence of the duration of floods on the variable $(L/\sqrt{J})$.

In world practice, it is reflected in various sources that the duration of floods depends on the length and slope of rivers

In our study, this dependence refects itself in the form of $(L/\sqrt{J})$[5].

The second chapter of the thesis is entitled "Climate change and its regional effects". Here, modern climate change and its regional effects are studied. As a result of recent climate change on our planet, the number of natural disasters related to hydrometeorological processes, including floods, showers, hurricanes, droughts, forest fires has increased. Such natural disasters cause great damage both to the economies of individual countries and to the world economy as a whole.

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[5] Kuchment L.S. Mathematical modeling of river flow / L. Kuchment. – Leningrad: Hydrometeoizdat, – 1972. –270 p.

In this regard, to study the regional effects of global climate change, based on recent hydrometeorological observations and climate models, climate change forecasting methods in different scenarios should be improved and new ones should be developed. Accordingly, measures should be taken to adapt agricultural crops to the climate.

In recent years, the impact of global climate change on the regional aspect is fully manifested in the territory of our republic.

Thus, the studies of H. Rahimov, Y. Hadiyev, R. Mahmudov, H.Fatullayev and R.Verdiyev show that starting from 1980-1982, the main climatic indicators are temperature, precipitation, wind, etc. There are changes in the annual dynamics of the elements, and this change has become more characteristic since 1995. Repetition of various anomalous weather conditions, increase in the number of related natural disasters, including 1995, 1998, 2001, 2003, 2010-2015, 2018, 2021 being the warmest years during the entire observation period, the drought of 2000, the observation of the absolute maximum temperature in the territory of our republic (+ 46^0C in Ordubad, Julfa, + 44^0C in Kurdamir) are visual examples confirming these changes.

The number of floods in Sheki, Zagatala, Nakhchivan AR increased in a number of rivers of the republic in different years, including in 2010 historical maximum water consumption was exceeded (Damiraparan, Turyan, Girdman), in the Kura River, a sharp rise in the entire flow poses a great threat to the surrounding areas. All this is the result of climate change, abnormal atmospheric processes and weather conditions.

The formation of currents in any region, the formation of flood, turbulent, low-water hydrographs depends on the synoptic and meteorological conditions of the area, especially the distribution of precipitation and temperature.

Table 1

Differences between seasonal temperatures in 1970 – 1994 and 1995 – 2016

No.	Station	Heigh, (m)	Winter	Spring	Summer	Fall	Yearly
1	Shamakhi	802	-0,28	-1,17	+0,7	-0,9	-0,4
2	Zagatala	487	+1,3	-0,1	+1,1	+1,6	+1,0
3	Ismayilli	27	+0,79	+0,1	+0,7	+1,5	+0,7
4	Shaki	165	+0,72	-0,1	+2,6	+1,5	+0,1
5	Guba	93	+4,4	-0,5	+0,2	+0,6	+1,1
9	Shamkir	165 t	+0,72	-0,1	-2,6	+1,5	-0,1
10	Mingachevir	93	+4,4	-0,5	-0,2	+0,6	+1,1

Note: Table 1 shows the seasonal temperature difference between 1970-1994, 1995-2016 years. As can be seen from the data in the table, compared to previous years (1970-1994), the annual temperatures increased between 1995 - 2015 at all meteorological stations (Shamakhi (-0.4C) and Shamkir (-0.1C).

The maximum daily precipitation (X_{max}, mm) plays a special role in the formation of floods and their maximum water consumption (Q_{max}, m3 / sec). Daily rainfall of about 30 mm and more in Azerbaijan mainly causes floods[6].

In table 2, average perennial and absolute maximum values of daily maximum precipitation layer (X_{max}) are given for the area studied in comparison with other regions.

To study the effect of temperature and precipitation on annual and seasonal regimes, which are the main meteorological indicators of climate change in the Greater Caucasus natural region, a trend analysis of their observation periods covering 1961-2016 was conducted by seasons. The trend analysis of temperatures shows that the annual temperature trend continues in most regions.

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[6] Mammadov, M.A. Hydrological zoning of the territory of the Azerbaijan SSR according to the degree of flood mountain rivers: [in 3 volumes] / M.A. Mammadov. – Baku: Geological geography, − T3 – 1978. – c. 54–57.

Table 2.

Average perennial and absolute maximum values of precipitation layer

№	Stations	Absolute altitudes, m	Average perennial x_{max}, mm	Absolute maximum x_{max}, mm	Date
1	Astara	-23	96,6	294	01.11.1927
2	Nakhchivan	875	19,3	32	02.08.1892
3	Ordubad	928	10,3	63	27.08.1965
4	Julfa	736	24,1	67	
5	Shaki	639	19,3	128	16.07.1948
6	Zagatala	487	91,1	171	
7	Alibay	1745	89,1	188	
8	Bilasuvar	560	123,5	334	6.VIII.1955

Note: The analysis shows that the observed values of maximum daily precipitation for most weather stations in the country correspond to the calculated 1% guarantee of X_{max}.

As mentioned earlier, the annual and seasonal rainfall patterns don't reflect climate change. In the last 10 years, only in most cases, the increase in precipitation in spring is more than in other seasons. Accordingly, spring temperatures have declined over the past 10 years compared to previous years.

In the country, the highest increase in precipitation compared to the perennial norm was 124 mm in 2016, and the largest decrease (-101 mm) was observed in 2017[7]. Thus, after 2007, there was an increase and decrease in precipitation in all altitude ranges in different years, but as a rule, a decrease is observed only in the altitude range of 201-500 m. In general, there is a downward trend in precipitation during climate change.

Chapter III of the dissertation is entitled **"Statistical analysis of territorial river flows and climatic indicators".** This chapter is devoted to the statistical analysis of river flow and climate indicators in accordance with the purpose of the dissertation.

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[7] Mahmudov, R.N. Modern climate changes and dangerous hydrometeorological events / R.N. Mahmudov. – Baku: Ziya-Nurlan, – 2017. –231 p.

The study of river flows is based on genetic methods, analysis of physical-geographical factors, processes that form the flow in the basin, and the study of the dependence of the flow on individual hydromorphometric elements. However, systematic observations of the hydrometeorological conditions of the basin lead to the formation of hydrometeorological series, being considered a statistical indicator of the physical-geographical, as well as hydrometeorological conditions of any river basin.

Table 3 shows checking the homogeneity of the seasonal flow rows of rivers flowing from the study area according to the Wilcoxon criterion.

Statistical parameters of annual and seasonal flows of the north-eastern and southern slopes of the Greater Caucasus, as well as annual seasonal precipitation and annual seasonal temperatures were determined mainly by moments and the most realistic methods. The coefficient of variation of annual water consumption (Cv) of the studied area rivers varies between Talachay-Zagatala (Cv = 0.19) on the southern slope, 0.22 (Gudyal river, Khinalig) and 0.94 (Valvalachay, Tangaalti) on the north-eastern slope. The coefficient of asymmetry (Cs) varies between 2.52 (Karachay, Ryuk) and 5.3 (Valvalachay, Tangaalti). Variation and high-range variation of asymmetry coefficients, as seen in the large values, falls on the Valvalachay- Tangaalti settlement. The small value of Cv (Cv = 0.22) falls on Gudyalchayda-Khinalig settlement. The absolute height of this point is H = 2960 m. It seems that the influence of the height factor on the formation and variability of the flow is also reflected in the statistical parameters of the hydrological series.

The coefficients of variation of winter flows are between Cv = 0.22 (in Khinalig Gudyal river) and 0.86 (close to the hot-source), the coefficient of asymmetry is Cs = -0.44 (Khinalig Gudyal river) and 2.54 (in the Valvalachay- Tangaalti). The variable values of Cv and Cs for the winter season correspond to the variable values of the annual flow, and in both cases the minimum values of Cv fall to Gudyal river and the maximum values of Cs to Valvalacha, respectively.

Table 3

Parameters that meet the homogeneity of the seasonal flow of rivers according to the Wilcoxon criterion a.b- low crisis value; y.b - higher crisis value

№	River, settlement	P=1%			P=5%			Note
		$\upsilon_{a.в.}$	$\upsilon_{y.в.}$	υ	$\upsilon_{a.в.}$	$\upsilon_{y.в.}$	υ	
1.	Gusar river, Guzun	31,0	140,4	112	39,1	128	112	Meeting
2.	Gudyal river, Giriz	29,3	106,0	85,1	33,0	100	85,1	--
3.	Guru river Susay	42,6	151	136	50,0	142	136	--
4.	Valvala river, Tangaalti	23,6	118	77,1	42,0	106	771	--
5.	Derkchay, Derk	18,8	87,1	66,0	26,1	122	66,0	--
6.	Ayrichay, Bash – Dashagil	41,3	82,0	95,1	56,1	80	95,1	Not meeting
7.	Kurmukchay, Saribash	47,8	86,1	127	38,9	109	127	Not meeting
8	Balakan river, Balakan	32,6	156,0	122,1	46,0	113	122,1	Meeting
9.	Ayrichay – outfall	31,8	114	93,3	41,6	99,0	93,3	--
10.	Alijan river, Gayabashi	19,9	91,1	86,0	36,5	88,8	36,5	--
11.	Dmarchik - beggining	27,3	108	96,0	39,0	100	96,0	--
12.	Tala river, Zagatala	25,6	113	99,1	31,8	109	99,1	Meeting
13.	Goychay, Goychay	30,1	104,6	93,1	39,3	99,6	93,1	--
14.	Turyan river, Savalan	20,8	77,8	61,6	41,3	70,6	61,6	--

Note: As can be seen from Table 3, rows composed of perennial streams of rivers in most areas meet the homogeneity condition. Only these conditions are not paid for Ayrichay and Kurmuk rivers. This can be explained by the mixed presence of both rain and snow water in the flow of rivers, and sometimes, the increasing role of groundwater flows.

The coefficients of variation of summer flows vary between 0.31 (Garachay-Ryuk) and 0.95 (Chagachug-Rustov), and the asymmetry coefficient varies between 0.18 (Ryuk in Garachay) and 2.88 (Gudyalchay-Kupchal). The average Cv for summer is 0.53.

The variability of the coefficients for autumn flows varies between 0.21 (Gudyalchay-Khinalig) and 0.89 (Kharmidorchay-Khaltan), and Cs between 0.11 (Gusar river-Guzun) and 2.5 (Kunakhaysu-Saribash).

Table 4

Values of coefficients of variability (Cv) of water consumption, precipitation and perennial and seasonal rows of temperatures

Hydrometeorological elements	Yearly	For seasons			
		Spring	Summer	Fall	Winter
Water consumption	0,42	0,37	0,53	0,44	0,39
Rainfall	0,24	0,36	0,54	0,36	0,35
Temperature	0,11	0,20	0,11	0,11	0,55

Note: The coefficient of variation (Cv) of water consumption in the multi-seasonal and seasonal series of rivers in the specified region is 0.42, the coefficient of variation in precipitation is 0.24, and the temperature is 0.11. Statistical analysis of hydrometeorological elements shows that regional climate change manifests itself in statistical changes along with physical changes.

The values of Cs-/Cv for regions are given in table 5.

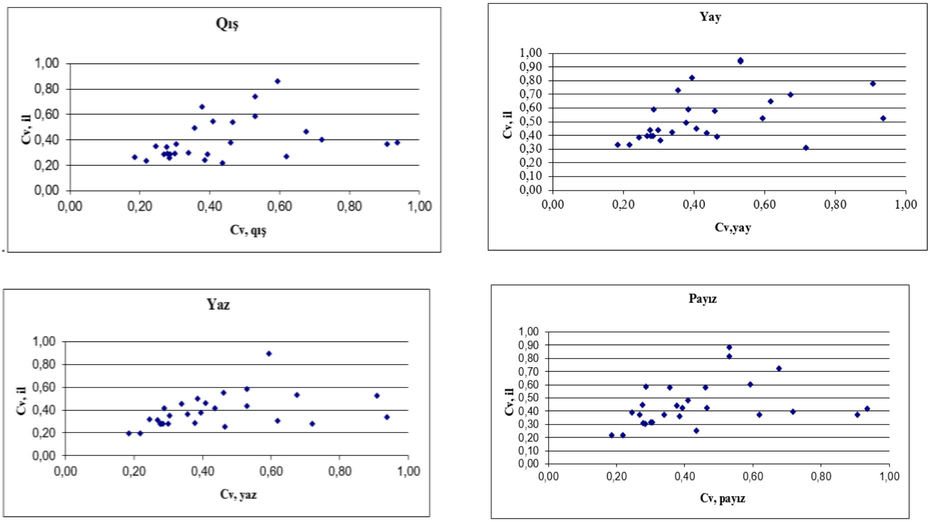
Table 5.

Cs/Cv ratio for regions

No. of regions	Name of regions	Winter	Spring	Summer	Fall	Yearly
1	Northeastern slope of the Greater Caucasus	2,5	2,5	2,0	2,15	2,3
2	Southern slope of the Greater Caucasus	2,0	2,0	2,0	2,0	2,0

Note: As shown in Table 5, the ratio of asymmetry (As) and variation (C_v) coefficients is given for the north-eastern and southern slopes of the Greater Caucasus. The annual value of this coefficient is 2.3 for the north-eastern slope and 2 for the southern slope.

The analysis of the graph of dependence of the variation coefficient of seasonal flows on the variation coefficient of yearly flow of the area rivers $Cv_{il} = f(Cv_{qis})$, $Cv_{il} = f(Cv_{yaz})$, $Cv_{il} = f(Cv_{yay})$, $Cv_{il} = f(Cv_{payiz})$ shows that there is increase tendency in weaker gradient between both Cv in all cases. (graph 3) That's, the dynamic of change in seasonal flows coincides with the dynamic of change in yearly flow.



Graph 3. Graph of correlation between variation coefficients of yearly flow (Cv_{il}) and variation coefficients of seasonal flows (Cv_f), $Cv_i = f(Cv_f)$.

Global climate change affects the environment on a regional scale, including water bodies, their water resources, regime, annual flow. According to the World Meteorological Organization and research conducted by scientists [Fukui H.], it is shown that changes are observed in the regime of rivers and their annual flow in the world's largest rivers, especially in the rivers of the Northern Hemisphere - Mississippi, Danube, Volga, Amur, etc[8].

[8] Fukui, H. Climatic variability and agriculture in tropical moist regions in WMO // proceedings of the world climate conference, – Geneva: – 1979. – p.426-474.

Chapter IV of the dissertation is about the study of the impact of climate change on river flow, forming the core of the work. **This chapter is entitled "Climate Change and River Flow".**

The main factors influencing river flow are air temperature and precipitation in the river basin, which have a significant impact on the amount of evaporation from the river basin, soil, soil temperature, lack of moisture and humidity, as well as the distribution of these indicators throughout the year. As these elements play an important role in the formation of river flow, their dynamics of change is highly dependent on temperature fluctuations as the main factor influencing the flow in the basin.

The problem of scientifically validating climate change and the quantitative assessment of other parameters related to climate change, including changes in water resources and river flows, has long been the subject of discussion among researchers.

Currently, the existing methods for studying the impact of climate change on river flow are conventionally divided into two groups:

1) deterministic methods;

2) stochastic methods.

In addition to the methods mentioned above, there are methods based on a mixture of these two methods, which involve the application of both deterministic and stochastic methods.

The assessment of climate change according to stochastic methods is based on the logic that precipitation, temperature and evaporation are the main climate-forming factors, and the study of the tendencies of these climate-changing factors over many periods allows the flow to change over many years. The existing statistical methods are mainly based on the analysis of the ups and downs of the flow and current-generating factors over a long period of time. These methods provide a basis for determining the changing trends of flow by determining the main directions of flow trends in rivers with a natural regime. In some cases, it is possible to study the main flow changes as a result of the assessment of the main changes in the relationship between these two elements based on precipitation-flow models. In addition, researchers such as Fyodorov S.B., Fukui H have also used numerical correlation between flow and precipitation and temperature to assess from numerical point of view the flow variation based on possible precipitation and temperature changes.

In general, basic estimates based on stochastic methods imply the application of the following dependencies:

Here, Y - river flow; T - time unit (years reviewed); - X

$$\left.\begin{array}{l} Y = f(T) \\ Y = f(X) \\ Y = f(X,t) \\ Y = f(X,Z) \\ Y = f(X-Z) \end{array}\right\}$$

atmospheric precipitation falling into the river basin; Z - total evaporation in the river basin; t - the air temperature in the river basin.

Existing deterministic methods for assessing climate change have been developed by the world's leading institutions. These methods are mainly based on the modeling of a large water cycle in the ocean-atmosphere-land-ocean direction.

One of the most widely used of these methods is the GISS model. The main purpose of the GISS model is to forecast atmospheric and climate change in the 21st century. This model uses global climate data, terrestrial and ocean processes, as well as combined data from satellite data.

Currently, various institutions around the world are working on regional models that can cover as many regions as possible. Many experts believe that in the future it is possible to achieve that regional models cover most regions, and then combine them in order to more accurately calculate the impact of climate change.

The assessment of the impact of regional climate change on the hydrometeorological conditions of Azerbaijan and the regime of rivers and water resources was first carried out by R.N. Mahmudov, H.Y. Fatullayev, and R.H. Verdiyev.

To determine the impact of climate change on precipitation on the northeastern and southern slopes of the Greater Caucasus, a double correlation was established between air temperature and the average perennial precipitation. Statistical analysis of the relations revealed that the three districts in the area were more clearly separated, and according to the results of the analysis carried out during the establishment of relations, the area was divided into three districts:

- North-eastern slope of the Greater Caucasus;
- South-western slope of the Greater Caucasus;
- The south-eastern slope of the Greater Caucasus.

The impact of climate change on the water content of local rivers is determined by the decrease in atmospheric precipitation, the main balance components of river flow, and the increase in evaporation from the river basins. For this reason, the following relationship between the average values of river flow and the average values of atmospheric precipitation has been established

$$Y = f(X)$$

and these relationships show that river flow varies depending on precipitation. These relations cover all three separate districts. The analytical expression of the above mentioned connection for the north-eastern slope of the Greater Caucasus is as follows:

$$Y = 0.101X^{0.44}(r = 0.72)$$

The analytical expression for the other two areas on the southern slope is as follows:

For the south-eastern slope of the Greater Caucasus:

$$Y = 0.19X^{0.39}(r = 0.91)$$

For the south-western slope of the Greater Caucasus:

$$Y = 0.091X^{0.46}(r = 0.81)$$

The first region covers the basins of all rivers up to the Ata River, including the Gusar River. The average values of atmospheric precipitation in this area have a monotonous increase depending on the altitude, and the average gradient is 50 mm per 100 m. The dependence of the average value of atmospheric precipitation for this area on the air temperature is as follows:

$$X = 37.3(13.6 - T)^{1.28}$$

For the other two districts, these dependencies are expressed as follows:

For the south-eastern slopes of the Greater Caucasus

$$X = 236.5(13.9 - T)^{0.92}$$

For the south-western slopes of the Greater Caucasus

$$X = 223.4(14.5 - T)^{0.33}$$

According to the last $X = f(T)$ relationships, For altitude ranges of 400-4400 m, it is possible to calculate the value of the average perennial precipitation in the Greater Caucasus for any value of the average air temperature. The accuracy of the relationships obtained is confirmed by comparing them with the values obtained for their dependencies.

$$X = f(H)$$

In table 6, the comparison of the values calculated as for the correlations $X = f(T)$ and $X = f(H)$ are given:

Table 6

Comparison of values calculated for different correlations of the atmospheric rainfalls in the territory of the Great Caucasus

A, m	**Air temperature, 0C**	$X = f(T)$ **mm,**	$X = f(H)$ **mm,**	ΔX **mm**
1000	12	356	364	8
1500	9,5	665	671	5
2000	7,0	736	731	5
2500	4,5	904	924	20
3000	2,0	1350	1375	25

Note: In Table 6, if the calculated value of X-atmospheric precipitation at temperature at 1000 m at 12^0C is 356 mm, the calculated value of atmospheric precipitation at altitude is 364 mm. This difference is 8 mm.

Two different methods have been used to assess the impact of climate change on flows.

In the first method, double regression relations between precipitation and temperature, precipitation and flow were found, in the second method, total correlation relations between temperature, precipitation and flow $Y = f(X,T)$ were found, and based on this, the total regression equations were obtained.

It goes without saying that, precipitation also changes depending on changes in temperature and evaporation at different altitude ranges. Such variations for different temperature scenarios are given in Table 7.

The correlation $Y = f(X,T)$ is expressed as follows for all three regions allocated in the Greater Caucasus:

For northern – eastern slopes of the Greater Caucasus:

$$y = 0.26x - 6.9t + 62 (R = 0.79)$$

Southern – eastern slopes of the Greater Caucasus:

$$y = 0.19x - 16.7t + 57 (R = 0.81)$$

Southern – western slopes of the Greater Caucasus:

$$y = 0.31x - 14.1t + 33 (R = 0.81)$$

Table 7

Changes in precipitation in different altitude temperature scenarios

A, m	**T^0C**	X, mm	$\Delta T = +1$	$\Delta X, mm$	$\Delta T = +$	$\Delta X, mm$	$\Delta T = +$	$\Delta X, mm$
600- 1000	13. 0	210	147	- 63	88	- 122	36	- 174
1000- 1500	10.75	360	287	- 73	228	- 143	162	- 198
1500- 2000	8.2 5	543	458	- 85	385	- 158	333	- 210
2000- 2500	5.7 5	393	334	- 59	266	- 127	293	- 100
2500- 3000	3.2 5	377	267	- 110	287	- 90	337	- 40
Higher than 3000	0.7 5	195	165	- 30	132	- 63	145	- 50
Average	6.9 6	346	276	- 70	229	- 117	217	- 129

These dependencies allow us to calculate the average values of the flow according to the average values of temperature and atmospheric precipitation in the regions allocated for the entire territory of the Greater Caucasus.

Assessment of the impact of climate change on the water content of the rivers of the southern slope of the Greater Caucasus has allowed to obtain new principles. Estimates of relationships $Y = f(X,T)$ for these principles can reduce river water content by up to 10% for each temperature scenario. However, the decrease in river water content may be different for different regions. Thus, the decrease in annual flow will be greater for rivers flowing from the south-eastern slope of the Greater Caucasus than from the north-eastern slope rivers. According to this pattern, the impact of climate change will be more pronounced in arid regions than in humid regions. For example, in the Turyan River, one of the largest rivers in the area, the response to climate change may be 3-5% higher than in the Gudyal River. This difference increases for subsequent scenarios and reaches 5-10%. The same effect can be applied to the Girdiman River.

Table 8

Changes in the average perennial module $Y = f(X,T)$ of some area rivers in different temperature scenarios

Rivers	M_0, *l/sec km²*	$\Delta T = +1^0$,	$\Delta T = +2^0$,	$\Delta T = +3^0$
Gusar river, Guzun	18,8	17,6	16,3	15,1
Gudayl river, Giriz	17,5	15,6	14,2	13,3
Kharmidorchay-Khaltan	7,18	6,91	5,51	4,91
Valvalachay, Tangaalti	8,78	7,35	6,41	5,25
Ganikh river, Ayrichay	9,16	8,1	7,11	6,09
Balakan river, Balakan	24	22,8	21,92	20,8
Tala river, Zagatala	28,1	27,2	26,41	25,33
Daəmiraparan river, Gabala	31,9	30,5	29,02	28,31

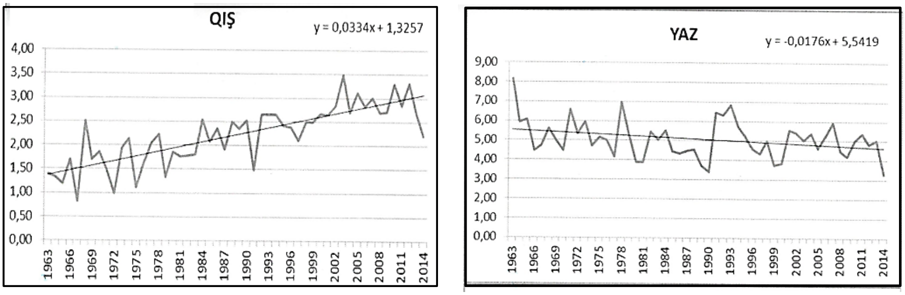
Note: As can be seen from Table 8, due to an increase in temperature of 1^0C, the Greater Caucasus region is expected to lose an average of 10% of its water resources and, accordingly, the water content of the area's rivers.

In other regions, the decreasing tendency in water resources differs sharply from the north-eastern and southern slopes of the

Greater Caucasus. For example, as a result of 1^0C warming, the water content of Katekh and Balakan rivers and adjacent rivers may decrease by an average of 9-12%, by 2^0C warming by 25-35%, and by 3^0C warming by 25-35%. The expected decrease is weaker than the southern sloping rivers of the Greater Caucasus due to the high humidity in these areas.

Multiple observational data (water consumption, precipitation and temperature data) were widely used to study the impact of climate change on the flow of rivers in the study area and its annual regime. This information mainly covers the observation periods from 1961-63 to 2006-2015.

Average monthly prices of water consumption were calculated by seasons and multi-chronological flow charts of water consumption for this season were compiled (Graph 4).



Graph 4. Chronological course graphs of seasonal flows of territorial rivers, Tala river, Zagatala

For example, in Zagatala settlement of the Tala River, if the flow layer in winter was 0.8 mm in 1963, 1.5 mm in 1990, and 2.5 mm in 2014, the flow in summer was 8 mm, 3, 5 mm, 3 mm.

In the Garachay-Ryuk, Chkhodurmaz-outfall, Ayrichay-beggining, Balakanchay-Balakan, Ayrichay-Bash-Dashagil, Kharmidorchay-Khaltan, Gudyalchay-Guzun rivers, there is an increase in winter and autumn flows, and a decrease in other seasons. In the Valvala River-Nohurduzu, Gudyal River-Khinalig, Tala River-Zagatala rivers, as a rule, the growth trend continues in winter flows.

CONCLUSION AND SUGGESTIONS

1. Taking into account the regional effects of modern climate change, the formation of currents in the study area, as well as the recurrence and duration of floods were studied. Observational data covering the years 1970-2015 show an increasing trend in the recurrence of floods in the area over the years.

2. Trend analysis of the main climatic indicators - precipitation and temperature shows that the temperature increase has been observed in the whole territory of the republic in recent years. In the highlands, the temperature rise gradient is greater. The average temperature rise is + 0.90C.

3. Seasonal analysis of temperatures shows that the increase in winter is higher than in other seasons. The anomaly of the last decade (1995-2015), which differs from the annual temperature and precipitation, shows that despite the increase in annual temperatures in all cases, (most meteorological stations and stations) temperature rise is not observed only in the spring, on the contrary, in some cases negative anomalies are observed. There is no regularity in the increase or decrease of precipitation.

4. Statistical analysis of temperature and precipitation shows that the coefficient of variation of winter temperature series is higher than in other seasons (Cv = 0.55). Seasonal and annual precipitation in the area does not change much in Cv, taking values between Cv = 0.17 and Cv = 0.36. The highest value of the coefficient of variation for precipitation occurs in the summer (Cv = 0.54).

5. Statistical analysis of hydrometeorological elements shows that regional climate change manifests itself not only in physical changes, but also in statistical changes. These changes are more manifested in the annual and seasonal flow of rivers, as well as in the seasonal indicators of temperatures than in precipitation.

6. The impact of regional climate change on the regime of rivers in the study area was identified. Thus, in most rivers there is an increase in winter flows, a decrease in the duration of the spring-summer flood period and maximum water consumption.

7. To study the regularities of the formation of the flow upstream, taking into account climate change, the dynamics of the change of the flow in different intervals, double correlations were established between the air temperature and the average multilayer precipitation layer. As a result of the analysis of such correlations, the studied area is divided into three different regions: the north-eastern slope of the Greater Caucasus; 2. south-western slope of the Greater Caucasus; 3. South-eastern slope of the Greater Caucasus.

8. Analytical expressions were obtained for the assessment of precipitation and river flow, depending on temperature changes and altitude, separately for each of the three regions.

9. Analytical expressions for the calculation of flow modules based on the dependence of the area rivers Y = (X, T) for each region have been proposed, taking into account the increasing temperature scenarios (T = + 10C, T = + 20C, T = + 30C).

The following scientific works on the topic of the thesis were published:

1 Kazımova, S.E. The role of regional climate change in the emergence of expected hydrometeorological events and economic development // − Baku: Ecology and water management magazine, − 2014. №2, − pp. 57-59

2 Kazımova, S.E. Assessment of the impact of regional climate change on the flow of rivers in the Greater Caucasus // Proceedings of the International Scientific-Practical Conference on "Development of regional economic policy and cooperation" on the occasion of the 50th anniversary of the ACU, Baku: − november 22, − 2014. − pp. 325-332.

3 Kazımova, S.E. Collection of works on "Climate change and anthropogenic impact on rivers // − Baku: Geography: theory, practice and innovation, Baku State University, − 2015. − pp. 608-611.

4 Kazımova, S.E. Proceedings of the conference on "Scientific problems of hydrological zoning of the Greater Caucasus // Modern

problems of water use in Azerbaijan and its management, − Baku: − february 18-19, − 2015. − pp.109-111.

5 Kazimova, S.E. Impact of modern climatic changes on water resources of Azerbaijan Hydrometeorology and Ecology // − Almaty: Quarterly scientific and technical magazine, − 2016. № 2. − pp. 37-42.

6 Kazımova, S.E. Impact of modern climate change on water resources in Azerbaijan // − Baku: Magazine of Geography and Natural Resources, − 2018. №1, − pp.137-141

7 Kazımova, S.E. Mineral resources of Azerbaijan and its assessment // Modern problems of geography, Republican scientific conference, dedicated to the 70th anniversary of Sumgayit, − Sumgayit: − october 24-25, − 2019. − pp.89-92

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10 Kazimova, SE Features of the formation of the river flow of the natural region of the Greater Caucasus // Russian science in the modern world XXXVI International Scientific-Practical Conference, − Penza: − 2021. − pp. 54-57

11 Kazımova, S.E. Climate change and its regional effects // − Baku: Journal of Geography and Natural Resources, − 2021. № 1, − p. 149-156

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