REGIONAL CLIMATE CHANGES IN AZERBAIJAN AND ASSESSMENT OF THEIR IMPACT ON WATER RESOURCES WITH A NEW METHOD

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Abstract

The article is devoted to regional climate changes in the territory of Azerbaijan and the study of water resources of the Karabakh region. Based on the actual multi-year temperature and precipitation data, the dynamics of changes of the specified parameters for the years 2007-2022 compared to the multi-year norm were evaluated by regions and different altitude intervals. An increase of 1.2⁰C in the average multi-year temperatures across the republic, and a decrease of precipitation to 26 mm was determined.

The water resources of the rivers of the Karabakh region were assessed using the newly developed Complex Water Balance Method (CWBM). This method is based on the principle of estimating water resources, taking into account the complex flow-forming factors. For this purpose, satellite data, GIS and other multifunctional computing technology were used. In 1998, the water resources of the Karabakh region's rivers were 2.13 km^3, but in 2022 it was 1.80 km^3, or a decrease of 15.2% was observed.

Keywords: climate changes, temperature, precipitation, CWBM method, water balance, water resources

I. Introduction

Provision of water to the population and economy, purposeful and economical use of water resources have always been priority directions in water policy. The aggravation of water-related problems has made it necessary to pay more attention to this spher than before. Conducting relevant scientific research on water problems is considered one of the priority scientific researches, being one of the always relevant issues in hydrology. Because there is a big difference between the demand and supply of water in the Republic of Azerbaijan, where irrigation agriculture and the population's demand for water dominate. In recent times, due to the influence of global climate changes, there have been changes in the world's water resources, especially in surface and underground waters, in the annual flow and regime of rivers, which of course also manifests itself in the territorial rivers of Azerbaijan. Thus, in the annual flood and high flows period of the country's rivers, their maximum water consumption decreases, while in the winter low flows period flows, on the contrary, there is an increase. As a result of the reforms carried out in Azerbaijan, a strong socio-economic potential has been created in the country. However, the depletion of natural resources against the background of global climate change creates additional problems in the implementation of reforms. For this reason, scientific directions and methods should be determined so that research does not lag behind the general pace of development of reforms. Current conditions require the assessment of natural resources with more modern, sensitive and operational methods that can respond to any changes [1, 3, 9]. Our proposed CWBM method is one of these types of methods. CWBM was developed on the basis of the leading water balance methods available in the world, taking into account their synthesis and the specific characteristics of the nature of Azerbaijan [6, 8].

II. Materials and methods

Satellite images of territory, digital elevation model (DEM) and hydrometeorological observation data of different years were used as initial input data for conducting the research. The main source of climate data is the measurement-observation data of the Ministry of Natural Resources and Ecology of the Republic of Azerbaijan. To determine the types of landscape, land cover, and moisture levels, multispectral space images of the terrain from different periods were processed using normalized difference indices (NDI-Normalized Difference Indices). Considering the content of the research work, difference indices of vegetation (NDVI, SAVI), bare soil and bedlands (BSI), erosion (NDBal), soil salinization (NDSI), residential and build-up (NDBI), urban (UI) , water (NDWI), drought (NDDI) and moisture (NDMI) were preferred in the study. The elevation, slope and aspect values of the study area were determined using DEM, and the morphometric indicators of the rivers using the Hydrology, Surface and Density software of the ArcGIS program. To select similar data and get more reliable correlations between components, Modern Analogue method and Multiple linear regression equations were used.

III. Results and discussion

Since regional climate changes have a greater impact on the water balance elements and annual flow of rivers, in order to study the dynamics of temperature and precipitation changes in the territory of the country, their higher intervals than the multi-year norm and by regions were studied, and some results are given in tables 1, 2 and 3, respectively [4, 5].

Table 1: *Changes of temperatures in the territory of Azerbaijan in 2007-2022 at different height intervals relative to the multi-year norm (1961-1990), T°C*

Periods	Elevation intervals, m					By the republic
	≤ 0	1-200	201-500	501-1000	> 1000	
Multi-annual norm, 1961 -1990	14.6	14.3	13.3	11.9	7.8	12.3
Medium perennial, 2007-2022	15.5	15.7	14.5	12.9	9.2	13.5
Relatively increase to the perennial norm	+1.0	+1.4	+1.2	+1.0	+1.4	+1.2

As can be seen from Table 1, the temperature increase in the territory of the country compared to the multi-year norm is +1.2^{0}C in the period 2007-2022. The greatest increase in elevation intervals is at 1-200 m and >1000 m elevations (+1.4^{0}C). However, the high annual temperature increase for the period 2007-2021 was 2010 (+1.3^{0}C), 2012 (+1.3^{0}C), 2014 (+1.3^{0}C), 2015 (+1.5^{0}C) , 2018 (+1.8^{0}C), 2019 (+1.5^0 C) and 2021 (+2.1^{0}C). In general, the years 2018 and 2021 have gone down in history as the hottest years in the world during the entire observation period, and this has also shown itself in Azerbaijan.

Table 2: *Temperature changes in the years 2007-2022 compared to the 1961-1990 period in different regions of the Republic of Azerbaijan, T°C*

Periods	Regions						By the Republic
	Absheron-Kobustan	Lankaran-Astara	Greater Caucasus	Lesser Caucasus	Kur-Araz	Nakhchi-van AR	
Multi-annual norm, 1961 -1990	14.5	12.9	10.7	9.2	14.3	12.4	12.3
Medium perennial, 2007-2022	15.5	13.9	11.5	10.5	15..6	13..7	13..4
Relatively increase to the perennial norm	+1.0	+1.0	+0.8	+1..3	+1.3	+1.3	+1..2

As can be seen from Table 2, the largest temperature increase by region is in Kura-Araz and the Lesser Caucasus (+1.3^{0}C), in Nakhchivan AR, and the least in the Greater Caucasus is +0.8^{0}C. In 2018 and 2022, a sharp increase in temperature was observed in all regions. Thus, in 2018, +1.4^{0}C in Absheron-Kobustan, +1.7^{0}C in Lankaran-Astara, +1.1^{0}C in the Greater Caucasus, +1.6^{0}C in the Lesser Caucasus, 1.9^{0}C in Kur-Araz, +2.8^{0}C in Nakhchivan AR. But the air temperature has risen by +1.8^{0}degrees across the entire republic.

In 2021, the average annual temperature for the republic increased by 2.1^{0}C, in 2022 by 2.0^{0}C, and the largest increase occurred in the Lesser Caucasus by 2.5^{0}C.

This increase in regions reflects its regularity for the multi-year period (2007-2022). In the Nakhchivan region, which is distinguished by its warm continental climate, the temperature increase compared to the multi-year norm was observed at a record level: +2.8^{0}C. In precipitation (Table 3), a weak decrease was observed compared to the multi-year norm, and it is interesting that, although there was an increase or decrease in all altitude intervals during this period, only in the altitude interval of 200-500 m, a decrease in precipitation was recorded in all years. In 2014-2017, a decrease was observed in all height intervals, including precipitation across the country. In 2011 and 2016, a maximum increase in precipitation was observed at all altitudes (except 201-500 m altitude), including the republic.

The study of regional climate changes in Azerbaijan, including the evaluation of river water resources in the occupied Karabakh territory, where systematic hydrometeorological observations have not been carried out for nearly 30 years, is proposed as the main research goal in the article [2, 7, 10]. Thus, against the background of modern climate changes, the study of the water resources of the Karabakh territory, re-estimation and improvement of water demand are considered more important from the point of view of scientific-research directions.

Currently, water balance methods are preferred in estimating water resources [3, 6, 9]. New advanced methods are created by internal modification of leading hydrological models, called "base methods", or by their synthesis and hybridization. Based on the current trend, a new operational-interactive method–Complex Water Balance Method (CSBM) has been proposed to assess the water balance and water resources of regional rivers. With the new method, the research process is carried out entirely through satellite images and GIS technologies. The main scientific principle of CWBM is the assessment of water resources through runoff coefficients, which include the influence of complex factors that shape the river flow. It is known that the greater the participation of factors affecting the flow formation, the more accurate the results. The participation of complex flow-forming factors was taken into account in CWBM. Even for the first time, new predictors were added to the calculations, such as the vegetation density, slope degree, horizontal fragmentation of the territory, exposure of slopes, humidity level. Among the innovations of CWBM, the application of new and different scientific approaches such as acceptance of the soil-air-water environment as a single mechanism, Counter-approach technology and Analogue method are also included. As a result, it is possible to calculate water resources with high accuracy without space-time limitation and dependence on observational data.

Table 3: *Precipitation changes in different altitude ranges in Azerbaijan for the period 2007-2022, mm*

Years	Heights, m					By the republic territory
	≤ 0	1 - 200	201-500	501-1000	>1000	
Norm	334	327	478	534	639	476
2007	-21.0	-8.0	62.0	89.0	25.0	+16.0
2008	+5.9	-29.0	-171	147.0	+5.0	-31.0
2009	+38.0	+69.0	-7.0	+17.0	+11.0	+6.0
2010	+30.0	+69.0	-28.0	+232	-20.0	+51.0
2011	+178	+124	-19.0	+288	+143	+87
2012	+14,0	-29,0	-130	+94.0	+51,0	-23,0
2013	+29.0	- 44	- 186	+ 78.0	- 18.0	- 45.0
2014	-11.0	-60	-117	-11	-82.0	-70.5
2015	+10.0	+32.0	-55.0	+33.0	-31.0	-42.0
2016	+118	+108	-12	+151	+124	+110
2017	-40.3	-38.6	-260	-41.2	-125	-101
2018	+6	-32	-7	+172	+10	-21
2019	+34	+6.0	-22.0	+8.0	-95.0	-50.0
2020	+20.9	-63.5	-141	+55.7	-43.7	-51.2
2021	-119	-80	-90	49	-140	-134
2022	+16,0	-10	-80	+75	-25	-27
Changes from norms	+14.5	-7.5	-77.0	+67	-22.0	-26.5

Research in this type of methods covers 4 main principles: applicability, operativeness, interactivity and prognosticity. Applicability - characterizes the maximum practical orientation of scientific results. Operativeness - refers to the faster use of the results obtained in order for scientific research not to lag behind the pace of economic development. Interactivity - is the adequacy of research against variable factors, prognosticity - is the assessment of changes in terms of possible consequences that may occur in the future. In terms of ensuring flexibility and interactivity in hydrological research, the most important tool is obtaining the necessary information about the research area without physical contact. Expanding the use of satellite images of the area, giving preference to remote sensing and flexibility methods are presented as an important scientific necessity in modern approaches. On the other hand, since it takes a lot of time to restart measurement and monitoring works on climate and flow quantities, the obtained results can lead to delays from a practical point of view, and lose scientific-practical and economic importance. Therefore, the minimization of observations and experimental experiments is also an important factor in terms of flexibility and interactivity. Expanding the use of modern technologies in the process of research data processing and calculation is one of the aspects considered as the foundation of this process. In this type of scientific approaches, various calculation, comparison, probability and prioritization technologies are highlighted with GIS and other technical means.

Thus, the advantages of the new methods are the following important principles:

1. Conducting research through satellite images without physical contact;
2. Fast, interactive and accurate calculation mechanism;
3. Lack of dependence on observational data;

4. Not imposing time-space and size restrictions;
5. Consideration of the influence of complex factors;
6. The effect of each factor on the flow can be given separately and together in a quantitative expression;
7. In addition to climate factors, landscape and anthropogenic effects are calculated separately;
8. Multivariate prediction line through 3-stage (past, present, future) research;
9. Air, soil and water space are considered as a single environment.

Among the innovations that attract attention in the process of developing the CWBM, for the first time in the GIS environment, the selection of similar geo-spaces based on complex factors, several different interpolation methods and the application of Counter-approach technology, including the inclusion of scientific principles such as recovery of unknown factors.

The Analogue method, that is, the principle of finding similarities in terms of physical and geographical conditions between basins with data and those without observations, is one of the widely used methods in hydrology. The more similar conditions are between geo-spaces, the more successful it is to calculate river flow and water resources. Flow formation is a very complex process. Until now, due to the influence of several factors, the condition of flow formation and the assessment of water resources did not allow obtaining very accurate results. Long-term experiments conducted in river basins using basic methods have also shown that the more similar the physical-geographical conditions in which the flow is formed, the closer the flow coefficients are to each other. At present, scientific and technical achievements have created conditions for a more in-depth analysis of flow formation and precipitation-flow process. These results were obtained based on the data of numerous measuring stations with different natural conditions, as well as artificial experimental experiments carried out in the basins.

In the research process, the correction process of flow coefficients with CWBM was carried out according to the following algorithm:

1. Daily climate and flow data of hydrometeorological observation points located in river basins with different physical and geographical conditions are collected.
2. Data on other complex factors influencing flow in these river basins is obtained through satellite images.
3. Available hydrometeorological observation data and indicators of flow-forming factors are collected and processed together in the ArcGIS database.
4. Based on actual observation and space data, the regional representativeness of climate and flow data in river basins is investigated.
5. The specific physical and geographical conditions corresponding to the flow quantities are defined.
6. Possible situations involving the combined effect of complex climate, landscape and other factors are considered and different runoff coefficients are found for each situation.
7. Correspondence of runoff coefficients is determined, same (or close range) coefficients are grouped and corrected.
8. The applicability of the obtained coefficients to similar places without data is checked and the most reliable results are selected.

In the CWBM method, the influence of factors on the flow is evaluated both separately and together in a complex manner. Not only the factors themselves, but also their intraspecies diversity, different quantitative indicators are necessary when determining runoff coefficients. For example, the vegetation density, the degree of soil moisture, the population settlement level, different slope and height gradations, etc. runoff coefficients are also determined for indicators. Each different situation manifests itself as a new runoff coefficient. The multiplicity of runoff coefficients is due to the consideration of complex effects and each specific situation. In order to facilitate the use of the method, the runoff coefficients are given on the basis of more important and variable factors, which actually include the influence of other factors directly or indirectly.

The application of CWBM is suitable for areas with any physical-geographical conditions and where observations are not made, without time-space restrictions. The evaluation of the water resources of the Karabakh region, which is distinguished by its extreme conditions, through CWBM is the basis of the research work. Due to the fact that it is under occupation, measurement works and researches have not been carried out in the region for many years. However, the research process was carried out with high accuracy, since the advantages of the new method allowed to eliminate these and other shortcomings. The research period covers the years 1998-2022 (figure 1).

Figure 1: *Location of the study area*

The water balance elements and water resources of the Karabakh region for the years 1998-2022 were investigated with satellite images and multifunctional GIS processing. The results obtained using CWBM method are reflected in Table 4.

Table 4: *Comparison of changes in the water balance components and water resources for 1998-2022*

Components of the water balance	1998	2021
Atmospheric precipitation, mm	572	547
Air temperature, C°	8.28	8.51
Potential evaporation, mm	802	829
Factual evaporation, mm	415	423
Humidity coefficient,	0.71	0.66
Maximum soil water retention, mm	1163	1189
Initial abstraction, mm	313	331
Actual soil moisture, mm	196	217
Hydrologic losses, mm	495	478
Rational runoff coefficient	0.303	0.290
Total runoff, mm	158	143
Surface runoff, %	48.9	47.9
Baseflow, %	51.1	52.1
River discharge, m^3/sec	67.5	57.3
Water resources, km^3	2.13	1.80

During 1998-2022, the change of water resources of the administrative regions included in the Karabakh region and the role of climate and landscape changes in this process were also assessed separately (Table 5).

Table 5: *The role of climate and other factors in the change of water resources of the Karabakh region in 1998-2022*

Regions	Water resources changes		İmpact of factors			
			Role of climatic factors		Role of other factors	
	increase-decrease	%	increase-decrease	%	increase-decrease	%
Terter	⬆	+10.9	⬆	+1.15	⬆	+9.75
Agdam	⬇	–9.47	⬇	–14.6	⬆	+5.13
Fuzuli	⬇	–4.86	⬇	–9.54	⬆	+4.68
Xojavend	⬇	–26.7	⬇	–7.59	⬇	–19.1
Jebrayıl	⬇	–18.7	⬇	–9.05	⬇	–9.65
Shusha	⬇	–37.2	⬇	–6.82	⬇	–30.4
Khojali	⬇	–14.4	⬇	–1.11	⬇	–13.3
Kelbejer	⬇	–4.53	⬇	–3.02	⬇	-1.51
Lachin	⬇	–8.91	⬇	–6.04	⬇	–2.87
Kubadlı	⬆	+7.91	⬆	+4.37	⬆	+3.54
Zengilan	⓿	0.00	⬇	–9.33	⬆	+9.53
Karabag	⬇	–15.2	⬇	–9.54	⬇	–5.66

IV. Conclusions

1. A new hydrological method – CWBM (Complex Water Balance Method) was used to assess the water balance of the area and the water resources of the rivers. CWBM is an operative-interactive and highly accurate method. Through CWBM, the whole research process and assessment can be performed without physical contact with the area, time-space limitations, and dependence on observational data.

2. Water resources of the Karabakh region using of the CWBM, were estimated at 2.127 km^3 in 1998 and 1.804 km^3 in 2021. In total, over the specified period, water resources decreased by 15.2 %.

3. According to assessment, the average total runoff coefficient of the Karabakh rivers in the period up to 2022 was equal to 0.2625; that is, 73.75 % of precipitation did not participate in the runoff formation. The fraction of surface runoff was 47.9 %, and baseflow – 52.1 % in total feeding of regional rivers.

4. It was determined that out of this 9.54 % decrease in water resources in 1998-2022 accounts for climatic, and 5.66 % - for the role of human activities and other factors.

5. Serious regime variability is observed in the rivers of the research area. Thus, due to the influence of regional climate changes, the annual runoff decreases, and the runoff of the winter low-water period increases. Due to the decrease in the volume of flood and torrential flows, their maximum water discharge (Q_{max}, m^3/sec.) also decreases.

References

[1] Amir Aieb, et. al. (2022). A hybrid water balance machine learning model to estimate inter-annual rainfall-runoff. Sensors 22 (9). 3241.

[2] Gerald A. Meehl, et al. Climate Change: Chapter 10: Global Climate Projections. 2007, pp. 842.

[3] Junfang Liu., et.al. Water balance changes in response to climate change in the upper Hailar River Basin, China. Hydrology Research. 2020. 51 (5): 1023–1035.

[4] Makhmudov R.N. Regional climatic changes in Azerbaıjan and its impact on hydrometeorological condıtıons. Slovak international scientifıc journal. N-63, 2022 s.48-55. https://doi.zenodo.org/records/6535054

[5] Makhmudov R.N. Regional climate change and river runoff in Azerbaijan. Meteorology and Hydrology, No. 9, Moscow, 2016., pp. 63-69.

[6] Rza Makhmudov, Vugar Aliyev, Movlud Teymurov, Emil Gafarov. Assessment of the water balance of the territory and rivers water resources using a new operational-interactive method. // RT&A, Special Issue No 5 (75) Volume 18, November 2023, https://doi.org/10.24412/1932-2321-2023-575-500-509

[7] Mammadov R.M., Teymurov M.A. Assessment of water resources and risk of water losses due to climate changes and human activities. The Scientific Heritage Journal. Budapest, Hungary. 2019.

[8] Movlud A.Teymurov. The value of ınıtıal abstractıon and estımatıon of run-off formıng raınfall rate at a specıfıc geographıcal locatıon. Journal Science, Education and Innovation in the context of modern problems, Vol. 5; Issue 4, 2022. DOI:10.56334/sei/6.1.4.

[9] Rebeca Martinez, et.al. Influence of climate and land cover/use change on water balance: An approach to individual and combined effects. Journal Water: 2022, 14(15), 2304. DOI: 10.3390/w14152304

[10] Regional Climate Change Impacts Study for the South Caucasus Region.Tbilisi, Georgia. 2011, pp. 61.