

Manifestation and Forecast of Global Climate Change in Azerbaijan

Aruz Mikayilov¹✉  and Fatima Huseynova¹✉

¹School of Advanced Technologies and Innovation Engineering, Department of Ecology and Environmental Sciences, Western Caspian University, Baku, Azerbaijan.

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Abstract

In the modern era, climate change is considered one of the most serious ecological challenges on a global scale. This problem is even more relevant for Azerbaijan, a country highly dependent on energy resources and with an arid climate. Analysis of long-term meteorological observations shows that a continuous increase in the average annual temperature, a key climate indicator, is being recorded in Azerbaijan. Compared with the period from 1961 to 1990, the average annual temperature has increased by approximately 1.1–1.4°C in recent periods. The acceleration of this increase after the 2000s demonstrates the real regional impact of global warming processes occurring in the climate system. Statistical analyses show that from 1950–2025, the rate of increase in average annual temperature in Azerbaijan was approximately +0.2°C per decade. In recent decades, however, this figure has risen even more in some local regions (for example, in the Central Aran zones), reaching +0.3–0.35°C/10 years. Long-term observations (1950–2025) also confirm a significant imbalance in both the total amount of precipitation and its seasonal distribution. A nationwide decrease in the average annual precipitation of approximately 5% to 12% is observed. Projection matrices show that by 2050, the probability of an increase in average annual temperature in Azerbaijan in the range of a minimum of 1.5°C to a maximum of 2.5°C is very high. Against a backdrop of rising temperatures, a decrease in annual precipitation of 2% to 10%, a sharp intensification of moisture deficit to 15–20%, especially during the growing season (spring and summer months), and a 20–30% reduction in mountain snow reserves is predicted.

Keywords: climate change, annual temperature, drought events, projection indicators, water resources, soil degradation

1. Introduction

Global climate transformations are the sum of profound, statistically confirmed changes in the planet's meteorological system that span decades or longer. This process is primarily characterized by a distinct dynamic in the temperature regime, the geography of precipitation distribution, the circulation of air masses, and other important climate parameters. Based on modern academic theory, climate anomalies are a multifaceted and complex global geosystem phenomenon caused by the result of both natural variations and human-generated energy sources. The scientific evidence shows that the climate of the planet is created based on the interactions that exist between the giant geospheres, including the atmosphere, hydrosphere, lithosphere, biosphere, and cryosphere.

The continuous global cycle of matter and energy between these named spheres plays a crucial role in maintaining the climate balance. For this reason, it is incorrect to perceive the process of climate change as simply a warming of the weather; it also signifies a change in the internal structure of global ecosystems, their resilience limits, and the functional characteristics of biomes.

When explaining the scientific nature of the problem in question, special attention is first given to the concept of "global warming." This process is the sharp increase in the concentration of greenhouse gases (CO₂, CH₄, N₂O, etc.) generated by industrial emissions in the upper layers of the atmosphere, and the resulting disruption of the planet's thermal balance. According to the consensus of the international scientific community, the rapid warming recorded since the Industrial Revolution is a direct negative environmental product of industrialization activities (IPCC, 2023).

The main driving force behind the modern climate crisis is anthropogenic (human-caused) factors. This includes oil, this includes the mass burning of fossil fuels such as oil and coal, the increase in emissions released into the atmosphere from industrial smokestacks, the proliferation of internal combustion engine vehicles, agricultural activities, and deforestation. In particular, the traditional structure of the energy sector, based on hydrocarbon resources, has led to the atmospheric concentration of CO₂ exceeding critical limits. Numerous empirical studies prove that the global warming anomalies of recent decades are a direct result of human capital production activities.

In addition, uncontrolled urbanization, land-use change, and agro-industrial waste also indirectly stimulate this degradation. The destruction of the green cover nullifies the biosphere's natural carbon-absorbing capacity, and as a result, the global carbon balance is completely disrupted. At the same time, the regional "heat island effect" created by the expansion of megacities makes the local microclimate more aggressive.

Changes in climate conditions also significantly challenge natural biodiversity and ecosystem stability. Many plant and animal species are losing their habitat areas or becoming threatened with extinction since they are unable to adapt to new climatic conditions genetically and environmentally. Most importantly, highly sensitive marine ecosystems on our planet, such as coral reefs (which are considered to be the cradle of life for oceans), are being destroyed in large numbers because of acidification and warming (Məmmədov, 2019).

In the modern period, the climate change problem represents a complex eco-economic phenomenon for the whole world that has transboundary influence on all institutional and functional sectors of the economic system; these destructive influences can be seen clearly at regional and national levels, especially in the economy. The macroeconomic analysis shows that agriculture, management of water resources, the fuel and energy sector, health care, and the production-infrastructure sector demonstrate the highest vulnerability to climate anomalies. Such sectoral vulnerabilities produce the multiplier effect that directly influences the dynamics of GDP creation, investment attractiveness, and changes in the employment structure (Qasimov & Məmmədov, 2025). In the agriculture sector, the constant growth of annual average temperatures, decrease of regional precipitation, and increase of drought periods lead to serious agricultural productivity instability.

Soil moisture regime disruptions, deviations of vegetation phases from scientific calendar principles, as well as the random increase in the need for irrigation water use, negatively influence the development cycle of important crops (cotton, vine culture, and others). Moreover, an imbalance in traditional agricultural calendars, growing plant protection problems, and soil erosion accelerate the process of desertification of the lands.

Climate change is significantly affecting Azerbaijan's water resources by altering the annual and seasonal flow patterns of rivers, reducing snow reserves in high mountain regions, and increasing evaporation rates. One of the most pressing consequences is the critically low water levels in the Kura–Araz River Basin, which have led to growing shortages in both urban drinking water supplies and

irrigation for agriculture. These changes have made water resource management increasingly complex, particularly because Azerbaijan relies heavily on transboundary rivers. As a result, the country must adopt alternative water management strategies and modern irrigation technologies to ensure long-term water security and maintain a stable internal water balance. In addition, declining reservoir storage capacity presents both operational and structural challenges for effective water management.

Climate change also poses serious challenges for the energy sector. During increasingly frequent summer heatwaves, the widespread use of air conditioning and cooling systems drives up electricity demand, placing additional pressure on the national power grid. At the same time, reduced river flows limit hydropower generation, making energy production less reliable. Together, these factors increase risks to energy security and grid stability, highlighting the urgent need to expand renewable energy sources and strengthen the resilience of Azerbaijan's energy system (Azərbaycan Dövlət Su Ehtiyatları Agentliyi, 2024).

Heat waves and dust clouds in the atmosphere, especially in large urban agglomerations, cause serious consequences for human health in the healthcare and social sectors. Heat stress, the chronicization of cardiovascular and respiratory diseases, as well as the expansion of the ranges of tropical disease vectors, are recorded in medical statistics. The deterioration of air quality due to ecological imbalance is causing a regional increase in respiratory diseases and a rise in the financial burden on the healthcare system (ÜST & Azərbaycan Respublikası Səhiyyə Nazirliyi, 2023). In infrastructure systems, sudden and intense rainfall, floods, and inundation events accelerate the technical wear and tear of transport-logistics corridors and engineering utility lines, increasing material losses. In urbanized areas, the urban heat island effect, caused by the heat capacity of concrete and asphalt surfaces, results in temperatures being felt as higher in urban environments compared to rural areas. This situation requires the engineering-based redesign of green architecture and drainage systems in modern urban planning (Azərbaycan Respublikası Dövlət Şəhərsalma və Arxitektura Komitəsi, 2024). In general, the analysis demonstrates that there exists an interconnectedness between impacts of climate change in various sectors. Hence, the full-scale implementation of adaptation and mitigation strategies is essential for the sustainable development of the country's economy.

Consequences of climate change generate internal inequalities in the socio-economic development equilibrium of regions. Since rural and urban zones have different potentials of adaptation to climate change and access to financial sources, processes of socio-economic stratification are intensifying. Although regions that depend fully on agriculture are highly sensitive to drought and ecological dangers, high population density in cities puts pressure on infrastructure and energy supply. In order to solve this issue, regions need to reconsider their approaches to sustainable development in terms of ecological aspects (İbrahimov, 2025).

Finally, the above-mentioned universal influence of climate change generates new priorities in the country's economic policy. Adaptation of the national economy to climate change, the transition to green energy sources, decarbonization, and international standards for carbon are crucial for the economic programs of the state. This strategy is very important for the country in order to switch to a diversified development model, thus being able to free itself from hydrocarbon dependency.

Theoretical and statistical evidence suggests that climate change affects Azerbaijan's key sectors through complex, interconnected, and multifaceted processes. The continuous temperature rise, a decrease in total precipitation, and the intensification of sudden extreme weather events negatively affect both the current operations and strategic planning of the national economy. Considering the profound penetration of environmental factors into the macroeconomic and social systems through economic mechanisms, the scientific development of national adaptation strategies and the promotion of green technologies in the agricultural and industrial sectors are of special importance to the state. Achieving sustainable economic growth in the future, reducing climate-related risks, and implementing coordinated, integrated eco-economic policies across all sectors of the economy will be essential to addressing these challenges.

2. Materials and Methods

This study employed a combination of research methods, including statistical data analysis, meteorological data analysis, comparative analysis of data from different years, trend analysis, and a systematic review of relevant literature and reports. A systematic approach was adopted to provide a comprehensive understanding of climate variability and the mechanisms through which it affects different sectors. This approach enabled climate processes to be examined as interconnected components of a broader environmental system.

In addition, comparative analysis was used to assess Azerbaijan's climate indicators alongside regional and global climate trends, allowing both similarities and differences to be identified. Statistical methods were also applied to examine changes in temperature and precipitation over time and to evaluate their long-term trends.

The projection of future climate conditions was conducted based on model results from the RCP 4.5 (medium emission) and RCP 8.5 (high emission) scenarios presented by the IPCC. The combined application of these methods has enhanced the objectivity and practical significance of the results obtained.

3. Results and Discussion

A statistical analysis of the dynamics of climate indicators in Azerbaijan clearly shows the general trends of climate changes observed in the country's territory in recent decades. Based on long-term meteorological observations, a continuous increase in the average annual temperature, the primary climate indicator in Azerbaijan, is being recorded. Compared with the 1961–1990 period, the average annual temperature has increased by approximately 1.1–1.4°C in recent periods. The fact that this increase has accelerated more significantly after the 2000s demonstrates the real impact of global warming processes in the climate system at a regional level.

A seasonal analysis of temperature dynamics shows that the highest increase is recorded in the summer season, with this figure rising to approximately 1.5°C. In the winter season, however, the increase is relatively weaker, averaging around 0.8°C (Qasimov & Məmmədov, 2025). This trend leads to a noticeable extension of the warm period, a shift in the vegetation period, and a disruption of the natural rhythm of agricultural activities. At the same time, a 15–25% increase is observed in the number of days with temperatures above 30°C, which proves the intensification of regional heat waves.

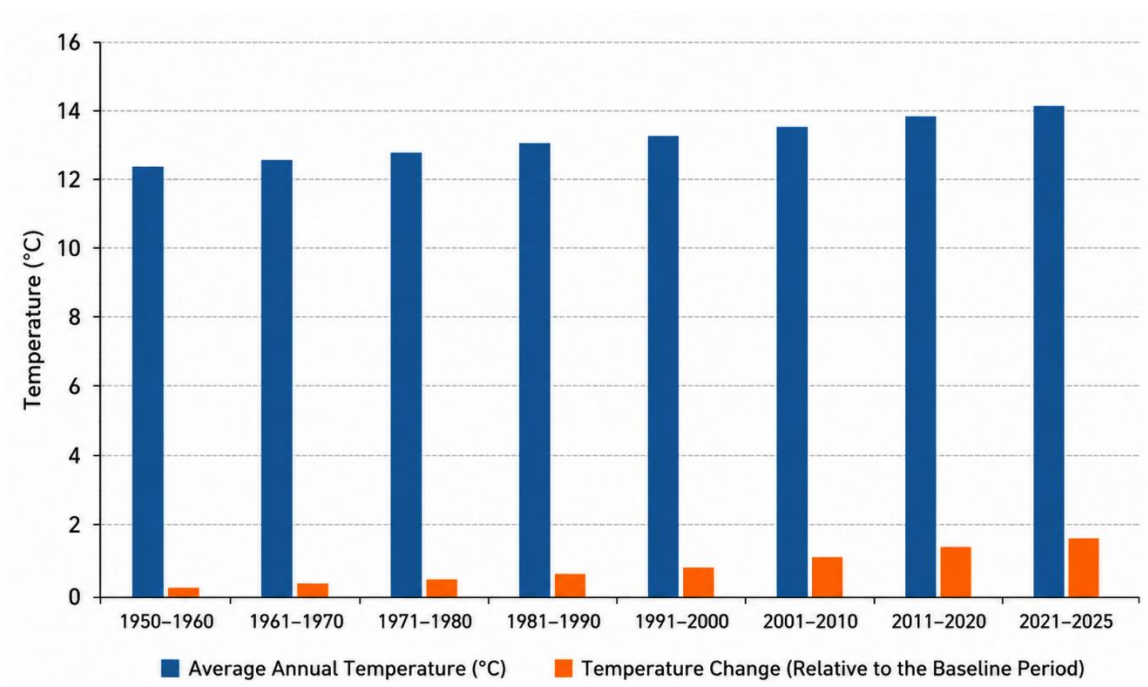


Figure 1. Dynamics of multi-year temperature in Azerbaijan (1950–2025).

Figure 1 shows that long-term meteorological observations in Azerbaijan indicate a clear and continuous increasing trend in the average annual temperature for the period 1950–2025 (İbrahimov, 2024). This is explained not only by large-scale global warming processes but also by the interaction of geographic and human-induced factors in the region.

Analysis of the observation periods chronologically shows several important stages:

From 1950 to 1970, the average annual temperature of the country remained rather constant, showing an average temperature from approximately 12.5 to 13.0°C. This time frame can be called the period of climate stability in the region. Since the end of the 1970s, a rather slow process of warming started becoming noticeable in the graphs.

The temperature increase is clearer in the 1980s and 1990s. During this period, the average annual temperature had already risen to approximately 13.0–13.3°C. The increase in temperature anomalies, particularly during the summer season, is considered the first serious signal of structural changes occurring in the climate system.

However, after the 2000s, the temperature increases in Azerbaijan became faster and more pronounced. According to statistical data, the average annual temperature has increased by approximately 0.6–0.8°C compared to the period from 1991 to 2010. This period is also characterized by an increase in the number of anomalously hot days and a rise in extreme high temperature events.

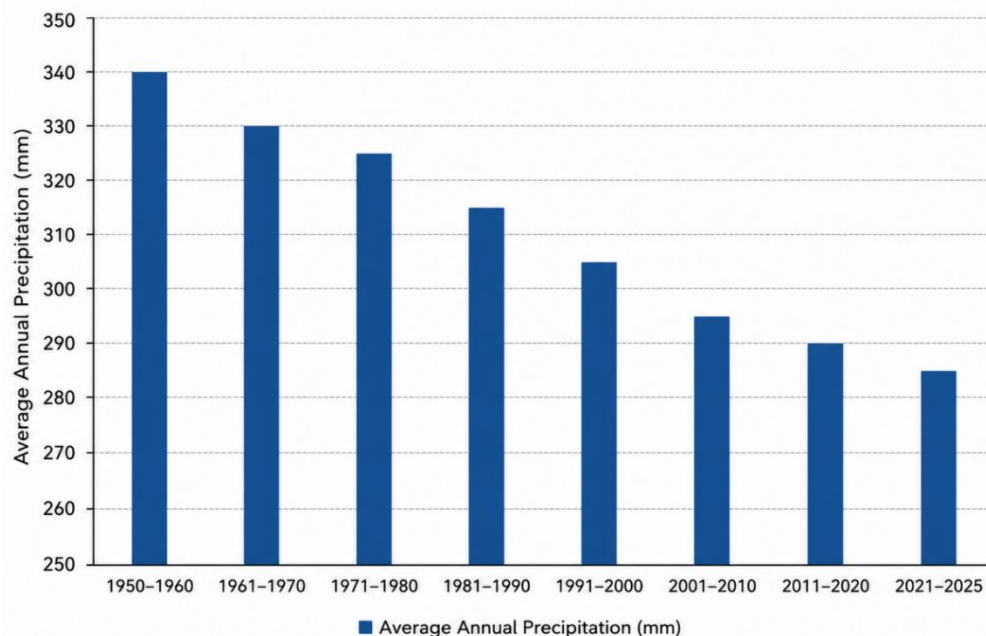


Figure 2. Dynamics of multi-year precipitation in Azerbaijan (1950–2025).

Since 2010, the regional impacts of climate change have reached a new peak. Over the last 15 years, the average annual temperature has increased by approximately 1.1–1.4°C compared to previous baseline periods. Record-high temperatures have been recorded in some years (especially in 2010 and 2020 and the years near them). This trend is accompanied by the intensification of dangerous heat waves and the extension of the natural vegetation period nationwide (Azərbaycan Respublikası Kənd Təsərrüfatı Nazirliyi / ATM, 2023; Quliyev, 2021). Regional analysis indicates that temperature increases are not distributed uniformly across Azerbaijan. Warming is more pronounced on the Absheron Peninsula and in the Kura–Araz Plain, largely due to the combined effects of urbanization and the urban heat island phenomenon. In contrast, mountainous regions have experienced a slower rate of warming, primarily because of the moderating influence of higher elevations (İbrahimov, 2024). These regional differences are driven by variations in microclimatic conditions, moisture availability, and topographic characteristics.

Statistical analyses show that during the 1950–2025 period, the rate of increase in average annual temperature in Azerbaijan was approximately +0.2°C per decade. In recent decades, however, this indicator has risen even more in some local regions (for example, in the central lowland zones), reaching a level of +0.3–0.35°C/10 years.

The statistical analysis of precipitation data in Figure 2, however, reveals a more unstable and fluctuating picture compared to temperature in Azerbaijan. Overall, a decrease in the average annual precipitation is observed across the country, ranging from approximately 5% to 12%, but this variation is sharply different depending on the region's geographical location. In the Absheron and Nakhchivan regions, the decrease in precipitation is pronounced and is estimated at approximately 10–12%, respectively. In the Ganja-Gazakh zone, this decrease is observed at a more moderate pace, while in the Lenkaran-Astara region, thanks to its humid climate type, relative stability and even an increase in specific years are recorded. These variations reaffirm the influence of complex topographical features on the country's climatic diversity.

One of the most sensitive indicators of climate change impacts in Azerbaijan is its precipitation regime. Long-term observations (from 1950 to 2025) prove that there is an obvious disproportionality between the amount of precipitation and its seasonal distribution. While there is a tendency towards a

general decline in the average annual amount of precipitation throughout the country, the dynamics differ during different time intervals:

In the period from 1950 to 1970, the precipitation regime was fairly stable with no sharp deviations in average annual amounts. In this phase, the annual distribution of precipitation was more even and fully conformed to the traditional seasonal rhythm. However, starting from the late 1970s, the variability of precipitation and the duration of drought periods gradually began to increase.

In the 1980s and 1990s, weak decreasing trends in precipitation amounts were recorded, and drought trends began to become more apparent, especially in semi-arid areas such as the Absheron Peninsula and the Kura-Araz Plain. During this period, a decrease of approximately 3–5% in the country's (Vəliyev, 2022) average annual precipitation was reflected in statistical reports.

Changes in the precipitation regime after the 2000s have become more critical. According to statistical analyses, the average annual precipitation across the country has decreased by approximately 5–10% compared to the 1990s. The most concerning aspect is the disruption of the seasonal pattern of precipitation: a relative increase in precipitation (mainly in the form of unstable rain) during the winter months, and a sharp decrease during the summer months, which are vital for agriculture (Qasimov, Ə. N., Məmmədov, 2025). This situation creates a serious imbalance in terms of the natural replenishment of water reserves.

Regional analysis shows that precipitation changes are not evenly distributed across the country. Although the Lankaran–Astara region has experienced relatively stable precipitation patterns, the Absheron Peninsula, the Nakhchivan Autonomous Republic, and the Kura–Araz Plain have seen a marked decline in precipitation, with drought conditions becoming increasingly frequent. In the country's high mountain regions, rising temperatures have reduced snow accumulation and accelerated snowmelt, leading to significant changes in river hydrology and seasonal precipitation patterns.

Overall, statistical analysis indicates that climate change in Azerbaijan has affected not only the total amount of precipitation but also its spatial and temporal distribution (Azərbaycan Respublikası Kənd Təsərrüfatı Nazirliyi / ATM, 2023). These shifts have made the integrated management of surface and groundwater resources more challenging while increasing climate-related risks for the agricultural sector.

4. Conclusion

A long-term analysis of meteorological data from across Azerbaijan shows a significant increase in extreme weather events. In recent years, the frequency of heatwaves has risen by approximately 30–40%, while widespread droughts have become nearly twice as common as in earlier historical periods. At the same time, heavy rainfall events, floods, and flash floods have increased by about 20–25%. These findings show that climate change is affecting not only average climate conditions but also the frequency and intensity of extreme weather events.

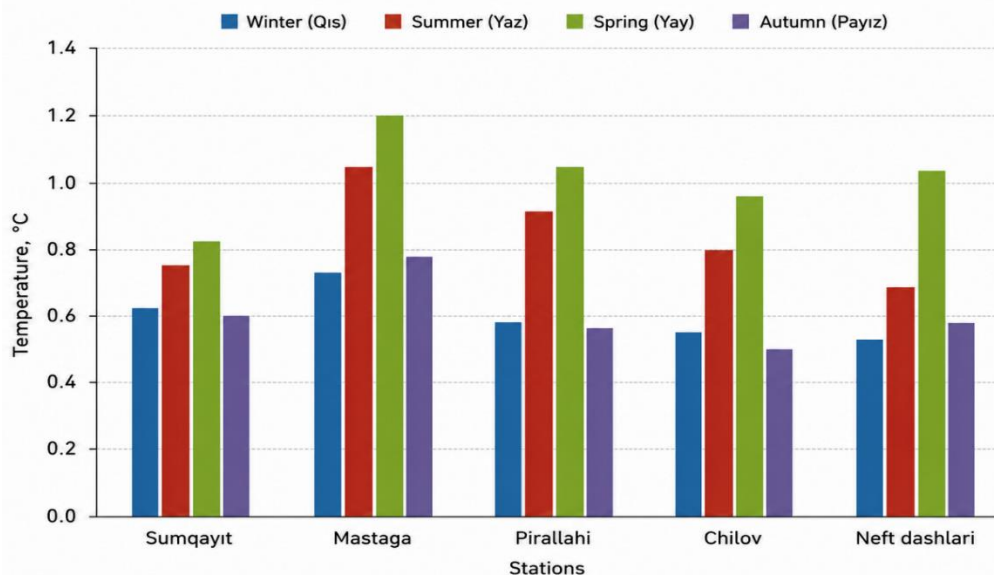


Figure 3. Seasonal Variations in Average Temperature in the Absheron Aquatorium, 1991–2020.

As for the frequency of drought and heat wave phenomena, the Kura-Araz Plain, the Absheron Peninsula, and the lowlands of Nakhchivan have proven to be more prone to these climatic conditions. Flash flooding due to heavy rains, on the other hand, is much more likely to happen in the mountainous and foothill regions, such as Sheki-Zagatala, Guba - Khachmaz, and Mountainous Shirvan. The presence of sharp regional variations in climatic conditions can be explained by the topography of the country and its hydrological conditions.

The presented Figure 3 shows the seasonal average temperature changes at five different stations in the Absheron aquatorium for the period 1991–2020. The highest temperature change was recorded at the Mashtaga station in the summer (approximately 1.2 °C). In the winter and fall, the temperature increase is lower and more stable compared to other seasons, ranging from 0.5 °C to 0.8 °C. Overall, temperature fluctuations are higher at stations closer to land (e.g., Mashtaga) compared to stations in the sea (e.g., Chilov and Neft Dashlari).

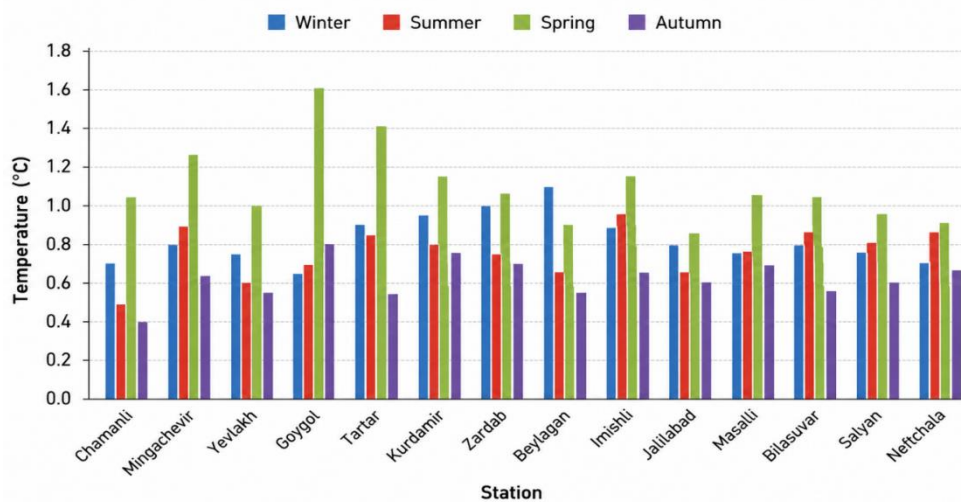


Figure 4. Seasonal average temperature changes in the Kur Intermontane Depression province from 1991 to 2020.

Table 1. Trends in the increase of extreme climate events in Azerbaijan (1950–2025)

Period	Drought events	Floods and inundations	Hot waves	General trend
1950–1960	Mild humidity (Caspian region—Kür-Araz → 10–12 years → 1–2 years of severe drought)	Average annual: 2–4 events (mainly on the southern slope of the Greater Caucasus)	Normal: 3–5 days per year (days with temperatures above 35°C)	Stable climate regime, minimal temperature anomalies ($\pm 0.1^{\circ}\text{C}$)
1961–1970	Stable (In arid zones, total soil moisture is nearly normal, <15%)	On average per year: 3–5 events (localized floods)	Stable: 4–6 days per year (characteristic for the Absheron and Kura-Araz regions)	Sustainable hydrometeorological period, minimal climate risks
1971–1980	Regional dynamics (the regional drought index in the Kura-Araz plain increased by 10%)	Average annually: 5–6 events (Activation in rivers of the Small Caucasus)	Slight increase: 6–8 days per year (in inland districts during summer months)	Regional temperature background rising by 0.2°C to 0.3°C
1981–1990	Moderate regional drought (15–20% decrease in precipitation during the growing season)	On average per year: 7–9 events (in mountainous and foothill zones)	Moderate intensity: 9–12 days per year (Change in the Caspian Sea's thermal regime)	Linear increasing trend in the frequency of climate anomalies
1991–2000	Severe aridification (Hydrological drought covering 25–30% of the country's territory)	On average per year: 12–15 events (Peak in the Talish Mountains and the Greater Caucasus)	High intensity: 14–18 days per year (beginning of the urban heat island effect)	Annual average temperature anomaly between $+0.5^{\circ}\text{C}$ and $+0.7^{\circ}\text{C}$ above normal
2001–2010	Persistent drought (15% reduction in water reserves, 40% expansion of arid zones)	An average of 18–24 events per year (regional floods in May–June)	Critical increase: 20–25 days per year (days of extreme heat stress)	Rapid change in temperature regime (0.9°C increase from the norm)
2011–2020	Extreme aridification (Synoptic drought phases in the Kura-Araz region and Nakhchivan doubled)	On average per year: 28–35 events (Highland River flood activity)	Aggressive trend: 28–32 days per year (record temperature indicators, $>40^{\circ}\text{C}$)	Sharpening of regional Climate risks (Increase from norm by $+1.4^{\circ}\text{C}$)
2021–2025	Decrease in water levels in the Kura River and land aridification	Sudden downpours and flood consequences	Record peak indicator: 35–42 days per year (anomalously long-term)	Maximum ecological and climate security risk (Stress on the national ecosystem)

The most notable feature in the presented graph (Figure 4) is the more pronounced rise in summer temperatures (by 1.4°C – 1.7°C) compared to other seasons at most stations (especially in Goygol and Tartar). While the winter anomaly at the Beylagan station exceeds the summer one, the overall trend indicates that the process of aridification and intensification of summer heat predominates in the region.

Analysis of Table 1 shows that over the last 70 years, the country has transitioned from a stable climate regime to a phase of sharp aridification and aggressive temperature increase. In the initial period, covering the 1950–1970s, the region was characterized by a mild, moderate, and stable climate, with temperature anomalies remaining at a minimal level (between $\pm 0.1^{\circ}\text{C}$ and $+0.3^{\circ}\text{C}$). During those decades, the number of hot days with temperatures above 35°C was a normal 3–6 days per year, while the annual average of flood and inundation events was low, ranging from 2 to 5 incidents.

Spatial analyses prove that changes in humidity are not evenly distributed across the country's geography. While the Lankaran-Astara zone has maintained a relatively stable precipitation regime, a more pronounced aridification of precipitation indicators is observed in the Absheron Peninsula, the Nakhchivan Autonomous Republic, and the Kura-Araz Plain. In high mountain zones, the direct impact of the thermal uplift causes a volume decrease and premature rapid melting of solid precipitation (snow cover and glaciated areas), leading to changes in the multiyear hydrological regime of rivers and the overall precipitation architecture.

According to the overall results of the statistical analyses, in Azerbaijan, precipitation is not only a quantitative indicator, but its configuration in time and space has also undergone a fundamental transformation. This situation has an integrated impact on surface and groundwater resources, management (YSMRI) strategies, complicating them and multiplying ecological risk factors in the agricultural sector. One of the most concerning statistical indicators in recent years is the significant increase in the frequency of extreme meteorological and climatic events. The frequency of severe heat waves has increased by approximately 30–40%, while macro-regional drought events have been recorded at nearly twice the rate compared to previous historical synoptic periods. In parallel, a 20–25% increase in the total number of destructive extreme rainfall, flood, and inundation events is also being recorded. These mathematical indicators prove that climate change is manifesting itself not only in linear average statistical figures but also directly in the intensity of catastrophic and anomalous extreme events (Əliyev, 2024).

In parallel with these processes, significant structural transformations are also occurring in moisture and evaporation indicators across the country. Based on multi-year measurement data from meteorological stations, the average relative humidity has decreased by 3–7%, particularly in arid and semi-arid regions, while annual potential evapotranspiration (evaporation potential) has increased by 10–18%. This downward trend has increased the risk of severe hydrological drought, disrupting the natural hydrological balance, reducing soil moisture availability, and lowering agricultural productivity (Kərimov, 2024).

The period from 2010 to 2025 was marked by even greater variability in precipitation patterns. Although some years experienced localized heavy rainfall events, the overall trend remained negative, with average annual precipitation across Azerbaijan declining by approximately 8–12% compared with earlier reference periods. At the same time, the frequency of anomalous regional precipitation events, i.e., short-term but extremely intense downpours, has increased, which bypasses infiltration into the soil and goes directly to surface runoff, sharply increasing the risks of floods and flash floods.

Overall, mathematical and statistical analyses demonstrate that the observed changes in Azerbaijan's climate indicators are not random but systematic, and are primarily accompanied by regional warming, a degradation in the distribution pattern of precipitation, and an increase in extreme events. These dangerous trends pose serious macroeconomic threats to the country's ecological balance, national water security, and the agro-industrial sector. Consequently, accelerating national adaptation programs for climate change and developing sustainable hydrometeorological monitoring systems with innovative methods emerge as a critical state necessity and strategic goal.

In the context of the consequences of global ecological transformations on a regional scale, Scientific forecast scenarios for the development of climate change in Azerbaijan through 2050 demonstrate that the imbalance in fundamental meteorological and hydrological indicators across the country will continue to increase and that ecological risks will systematically intensify (Azərbaycan Respublikası Ekologiya və Təbii Sərvətlər Nazirliyi, 2024).

According to the mathematical-statistical results of modern climate models applied at international and regional scales, the inevitable increase in temperature by the middle of the century, the destabilization of the precipitation regime with a sharp moisture deficit, and the intensification of destructive extreme natural events are the main macro-trends threatening the stability of the national economy. These changes

are not limited to disrupting regional ecological balance, but also directly place the state's long-term macroeconomic security architecture, demographic sustainability, and social infrastructure formation at risk. Forecast matrices from different Global Climate Models (GCMs) with various emission scenarios, particularly those containing different carbon concentrations, prove that the probability of a rise in average annual temperature in Azerbaijan by 2050 in the range of a minimum of 1.5°C to a maximum of 2.5°C is very high. The uneven distribution of the temperature increase dynamics across the seasons will manifest itself with more pronounced and anomalous thermal spikes, especially during the summer season, resulting in both the frequency and consecutive duration of massive heat waves becoming chronic. Such thermal stress will complicate the functioning of the biosphere and the overall urban environment, creating severe heat stress in the country's arid and semi-arid geographical zones, primarily in the vast Kura-Araz plain, the Absheron Peninsula, and the flatlands of the Nakhchivan Autonomous Republic.

The forecast indicators presented below (Table 2) show that by 2050, the average annual temperature across the country will increase by 1.3°C to 1.8°C under the RCP 4.5 scenario. The projections presented in Table 2.6 show that by 2050, the average annual temperature across the country will increase by 1.3°C to 1.8°C under the RCP 4.5 scenario, and by 2.0°C to 2.7°C under the RCP 8.5 scenario, with extreme temperatures exceeding 45°C in the lowland regions. Against a backdrop of rising temperatures, an annual precipitation decrease of 2% to 10% is projected, a sharp intensification of moisture drought by up to 15-20%, particularly during the growing season (spring and summer months), and a 20-30% reduction in mountain snow reserves. These climate changes will not only increase the risk of flash floods from short-term, intense downpours but will also cause a 15% to 25% reduction in the water reserves of transboundary and inland rivers, accelerating severe water stress, soil erosion, and desertification processes in the country. These negative trends stimulate large-scale land degradation, severely impacting the natural balance of semi-arid regional ecosystems, particularly the Kura-Araz Plain and the Absheron Peninsula. Under such conditions, the implementation of sustainable resource management strategies is inevitable for protecting the country's ecological security and adapting agriculture to climate change (Table 2).

The mathematical trajectory of the precipitation regime in the changing climate parameters -statistical projections also indicate that negative trends are dominant, suggesting a massive reduction of 5% to 20% in total nationwide precipitation by the middle of the century amid a moisture deficit.

This situation will not only fundamentally disrupt the natural moisture balance of soil but will also increase the evaporation and transpiration coefficient from open water surfaces, complicate the natural recovery process of surface water reserves, and maximize the risks of large-scale hydrometeorological drought. The most critical challenge projected in the sphere of water resources is the sharp decline in annual and seasonal flow volumes of rivers, as well as the rapid degradation of permanent snow cover and glaciers located in high-mountain ecosystems that feed the rivers, due to temperature anomalies. Such a negative transformation of the hydrological regime will create a strategic deficit in the drinking water supply of large urban agglomerations as well as in the irrigation systems of the agro-industrial complex, turning the existing resource shortage into a regional crisis against the backdrop of growing overall water demand.

From a geographical and regional perspective, it becomes clear that these ecological changes will not occur with the same intensity across the country but will vary depending on the characteristics of the terrain and microclimate. On the Absheron Peninsula, which has low-lying terrain, severe desertification, salinization, and degradation trends will come to the forefront in the Kura-Araz Plain and the flat parts of the economic regions; the high mountain zones of the Greater and Lesser Caucasus will experience a rise in the snow line to higher elevations and landscape transformation. In the relatively humid Lankaran-Astara zone, a serious structural imbalance will develop in the internal precipitation calendar and moisture regime. A cross-analysis of indicators and the modeled 10% to 25% risk of water loss proves

that the deepening of climate dependency in agricultural planning, water reservoir management, and the resilience of energy grids to peak loads will pose serious institutional and structural challenges.

Table 2. Projected climate change scenarios for Azerbaijan by 2050.

Indicator	Current Scientific Status (Base Period)	Official Projections for 2050 (with Scenario Difference)	Direction and Impact of Change
Average annual temperature	National historical norm ~11.5–12.5°C (in Baku ~14.5°C). An increase of 1.2°C has already been recorded over the last 30 years	RCP 4.5: an increase of +1.3°C to +1.8°C. RCP 8.5: an increase between +2.0°C and +2.7°C.	A continuous increase. The greatest increase is expected in the summer season
Summer temperatures and heat waves	The frequency and duration of heat waves (days of extreme temperatures) have increased.	An increase of 10–14 days in the number of heatwave days, with extreme temperatures exceeding 45°C in some lowland areas	A sharp increase. Increased risk of thermal stress for human health and agriculture.
Total precipitation for the next 30 years	Highly uneven by region (from 200 mm to 1400 mm)	A decrease in annual precipitation of 2% to 10% is projected (with a greater decrease in the Caspian Sea zones).	A moderate decrease. Moisture deficiency will be felt more acutely as temperature increases increase evaporation.
Seasonal distribution of precipitation	Seasonal variability is present.	A sharp decrease in precipitation by 15-20% in the spring and summer months, with a slight increase in some places during the winter.	Seasonal imbalance. In the summer, during the agricultural growing season, moisture drought will intensify.
Extreme events (Floods and torrents)	Increase in mountain stream floods resulting from local downpours.	Although the total amount of precipitation is decreasing, the frequency of short-term, intense downpours is increasing.	Increased risk. An increase in the frequency of flash floods and mudflows in mountainous and foothill regions.
Snow cover in mountainous areas	The retreat of glaciers and the snow line has accelerated in the Greater and Lesser Caucasus.	The retreat of the snow line to higher elevations, a 20-30% reduction in mountain snow reserves.	Rapid decline. Shifting of the spring flood period for rivers and disruption of the water regime.
Surface water reserves (River waters)	Over 70% of Azerbaijan's water reserves are received from outside the country (via the Kura and Aras rivers).	Risk of a 15% to 25% reduction in the water levels of the Kura and Aras rivers, as well as in inland rivers.	Severe water stress, due to both a decrease in flow in transboundary rivers and an increase in domestic water losses.
Soil and Ecosystem Stability	Salinization, erosion, and desertification processes are active.	Expansion of semi-arid and arid zones, acceleration of soil erosion.	Increased risk of degradation. Acceleration of desertification in the Kura-Araz and Absheron regions.

Author's contribution

The sole author is responsible for conceptualizing, collecting, and analyzing data, and writing and editing the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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