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TRENDS IN AIR TEMPERATURE AND PRECIPITATION IN THE MANGYSTAU REGION OVER THE PAST 50 YEARS

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Abstract: This article examines changes in air temperature and precipitation in the Mangystau region over the past 50 years (1974-2024). Using long-term meteorological data from the Climate and Weather database, an analysis of average annual and seasonal temperatures, as well as the annual precipitation distribution, is carried out. The results showed a steady warming trend: the average annual air temperature increased by more than 1.0 °C, with the most pronounced and stable increases observed in spring and summer. Winter and autumn temperatures also show a positive trend, accompanied by a decrease in the number of extremely cold periods. The early onset of the warm season and the increase in summer temperatures have an impact on phenological processes, accelerate evaporation and increase the heat load on ecosystems and populations. Precipitation analysis revealed high interannual and intra-decadal variability typical of arid territories: from extremely dry years with precipitation less than 70 mm to abnormally wet years exceeding 270 mm. The main contribution to the formation of the water balance is made by the cold period, while summer precipitation remains limited and relatively stable. The combination of warming and uneven precipitation distribution increases the aridity of the region and increases the vulnerability of natural and agricultural systems to climatic stress and extreme events. The results obtained emphasize the need to take into account both temperature and sedimentary dynamics when developing strategies for adaptation to climate change and management of water and natural resources in Mangystau.

Keywords: Long-term temperature trends, Air temperature, Precipitation variability, Arid climate, Seasonal trends, Mangystau region.

Introduction

To date, substantial evidence has been accumulated demonstrating climate change at both global and regional scales. It is enough to highlight the works of Arnell N.W., Zhao Q., Rawat A., Shaw T. A. and Li Z. [1,2,3,4,5]. Long-term changes in temperature conditions and precipitation have a significant impact on natural ecosystems, water resources, agriculture, and socio-economic development of territories. These issues are particularly relevant for arid and semiarid regions characterized by high sensitivity to climatic fluctuations and limited water resources [6].

Modern climate research indicates that there is a steady trend towards an increase in air temperature on a global and regional scale, as well as a transformation of the precipitation regime [7]. At the same time, the nature and intensity of climatic changes vary significantly depending on geographical location, geological conditions, and regional atmospheric circulation factors. For the Mangystau region, despite its natural and economic importance, detailed studies of the long-term dynamics of air temperature and precipitation still remain insufficiently systematized.

The analysis of climate data over the past 50 years makes it possible to identify long-term trends in air temperature and precipitation, assess interannual and seasonal variability, and identify the features of regional manifestations of modern climate processes. The use of long-term observation series is a prerequisite for separating natural climate variability from stable trends related to global climate change [8].

The aim of this study is to investigate the dynamics of air temperature and precipitation changes in the Mangystau region over the past 50 years. This research analyzes long-term time series of key climatic indicators, identifies trends in their variability, and examines the characteristics of their seasonal distribution. The findings can inform climate risk assessments, support the sustainable management of water resources, and guide the development of adaptation strategies to evolving climatic conditions in arid regions.

Materials and methods. In this study, the primary meteorological parameters for the Mangystau region were obtained from the "Climate and Weather" database [9], which is based on validated international SYNOP and METAR observational data. The database provides long-term records of air temperature, precipitation, and humidity for the Karaganda region beginning in 1933. The present analysis focuses on average annual air temperature and precipitation for the period 1974–2024, assessed using the linear trend method. This method enables a robust evaluation of the direction and magnitude of long-term changes in air temperature [10]. The computation of average annual trends in temperature and precipitation was performed using the arithmetic mean and the corresponding standard error of the mean.

Mangystau region is located in the southwestern part of the Republic of Kazakhstan, within the arid zone of the Caspian lowland (Fig. 1). In the north, the region borders Atyrau region, in the east - Aktobe region, in the southeast - the Republic of Uzbekistan, and in the west and southwest it is washed by the waters of the Caspian Sea. The total area of the region is about 165.6 thousand km^2 [11]. The territory of the region stretches for about 350 km from north to south and about 300 km from west to east.

The climate of the Mangystau region is characterized as sharply continental and arid. For most of the year, stable anticyclonal processes prevail in the region. In winter, climatic conditions are formed under the influence of the Siberian anticyclone, while in summer the influence of subtropical anticyclones dominates. As a result, the region is characterized by hot and dry summers and relatively mild, low-snow winters [12]. The territory of the region belongs to the zones of deserts and semi-deserts, where natural conditions create an increased vulnerability of landscapes to desertification, land degradation and water scarcity. Under these conditions, even minor changes in climatic parameters can lead to significant environmental and economic consequences [13].

Research results. In this work, changes in the average air temperature in the territory of the Mangystau region for the period 1974-2024, as well as its dynamics over decades are studied. The analysis of the average annual temperature regime of the region has been carried out in order to identify long-term trends in climate change. Special attention is paid to assessing the direction of air temperature changes and identifying possible cyclical fluctuations over the period under review.

To determine the changes in the average annual air temperature in the Mangystau region, a long-term series of average annual temperatures for 1974-2024 was analyzed. The study was performed using the linear trend method, which allows us to assess the nature of the increase or decrease in air temperature over time (Fig.1). The analysis showed the presence of a steady positive trend in the average annual air temperature.

During the period under review, there has been a gradual increase in the average annual temperature. In the 1970s and 1980s, average temperatures were mostly in the range of 11.0 - 12.0 °C, whereas since the 2000s they have consistently exceeded 12.5 °C, reaching values of the order of 13.5-14.0 °C in recent years. According to the linear trend, over the past 50 years, the Mangystau region has experienced a noticeable increase in the average annual air temperature, which indicates a general warming of the climatic conditions of the region.

There were no constantly recurring cycles in the dynamics of air temperature during the study period. At the same time, some years with increased annual average temperature values are recorded, which have become more frequent in recent decades. The maximum temperature values mainly occur after the year 2000, which indicates an increase in temperature anomalies and an increase in the thermal background.

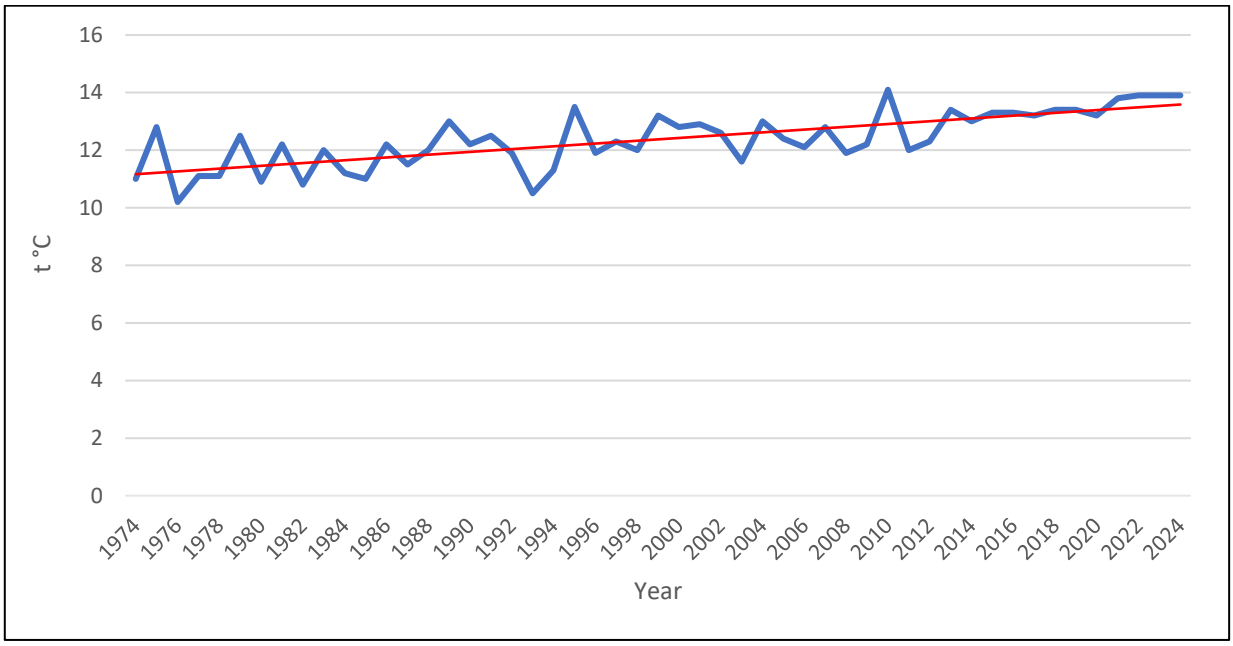

Figure 1. Dynamics of average air temperature for 1940-2020

The minimum values of the average annual temperature are typical mainly for the initial stage of observations (1970s-1980s). In subsequent years, the temperature values do not fall to the levels typical for the early period, which confirms the stability of the warming trend. Thus, the range of fluctuations in the average annual temperature is shifting towards higher values.

An analysis of the average annual air temperature in the Mangystau region over the past 20 years (2004-2024) revealed a steady upward trend in the presence of interannual variability (Fig.2). At the beginning of the period under review (2004-2009), the average annual temperature values were mainly in the range of 11.9-12.8 °C, reflecting a relatively cooler temperature background compared to subsequent years.

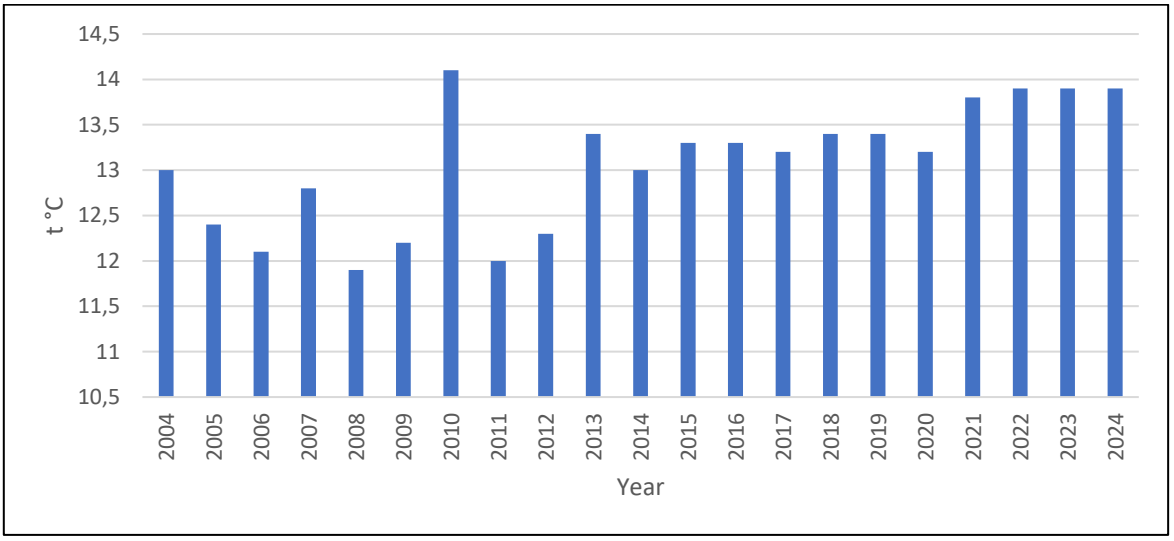

Figure 2. Fluctuations in the average air temperature between 2004 and 2024

Since 2010, there has been a noticeable increase in temperature indicators. Despite a short-term decrease in temperature in 2011-2012, since 2013 the average annual temperature has consistently exceeded 13.0 °C. In the period 2013-2020, the temperature values in most years ranged from 13.0–13.4 °C, which indicates the formation of a new, warmer climate regime.

The highest values of the average annual temperature were recorded in the last years of observations (2021-2024), when the temperature reached 13.8-13.9 °C. This indicates an increase in warming processes in the region and an increase in the frequency of warm years. It should be noted that the amplitude of interannual temperature fluctuations in the last two decades is relatively small, which indicates the stabilization of the temperature background at a higher level.

In general, during the period 2004-2024, the average annual air temperature in the Mangystau region increased by more than 1.0 °C. The dominance of the positive trend over short-term fluctuations confirms the presence of sustained regional warming, which can have a significant impact on the hydrological regime, water resources and the ecological state of arid ecosystems in the region.

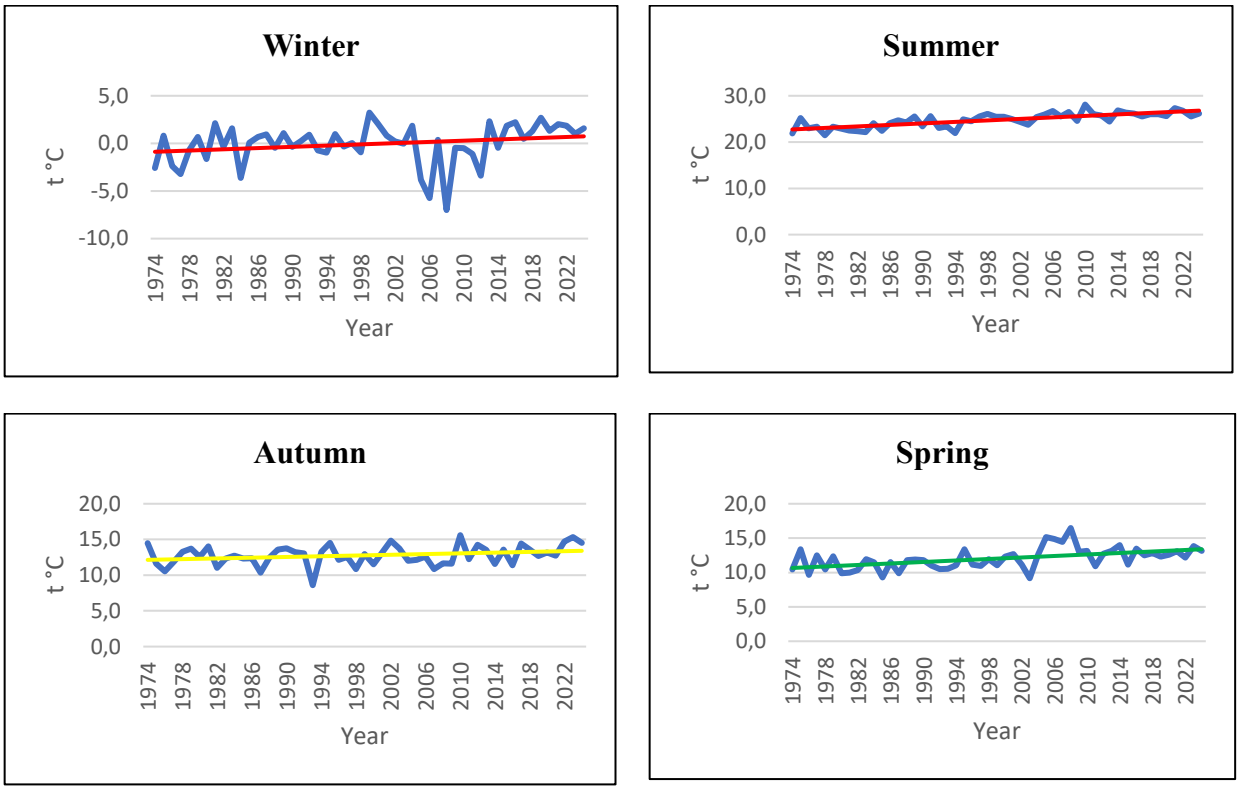

Figure 3. Seasonal change in average air temperature

For a more detailed assessment of seasonal characteristics of changes in the temperature regime, an analysis of average seasonal air temperatures was performed (Fig.3). This approach enabled the identification of seasons with the most pronounced and устойчивые warming trends. The seasonal aggregation of the data allowed for a comparative evaluation of the intensity and nature of temperature changes across different seasons.

An analysis of the long-term series of average air temperature in the Mangystau region for the period 1974-2024 revealed a steady warming trend in all seasons of the year, which indicates pronounced regional manifestations of modern climatic changes. The nature and intensity of temperature changes vary by season, but in general they form a single trend of increasing the temperature background.

A statistically consistent positive trend in winter mean air temperature has been identified. During the 1970s and 1980s, winter conditions were predominantly characterized by negative temperatures, with several years exhibiting extremely cold winters, when mean values reached approximately -7 °C, indicating pronounced interannual climate variability. Strong negative temperature anomalies were also recorded in the mid-2000s. Since the 2010s, the frequency of cold winters has markedly declined, accompanied by a systematic shift of mean temperatures toward near-zero and positive values. In recent years, winter mean temperatures have increasingly exceeded 0 °C,

reflecting a significant weakening of winter severity, likely associated with large-scale atmospheric circulation changes under ongoing global climate warming.

The spring season exhibits the most pronounced and persistent warming among all seasons. The linear trend indicates a steady increase in mean spring air temperature beginning in the 1970s. During the initial observation period, the average spring temperature was approximately 10–11 °C; however, since the early 2000s, a clear shift toward warmer spring conditions has been observed, with mean values reaching 14-16 °C in some years. Despite ongoing interannual variability, the identified trend suggests an earlier onset of the warm season, which may have substantial implications for regional phenological processes, water balance, and agro-climatic conditions.

The summer season also demonstrates a consistent increase in mean air temperature, with interannual variability being less pronounced than in winter. In the 1970s and 1980s average summer temperatures ranged from approximately 22 to 24 °C. Since the late 1990s a steady upward trend has been observed, and after 2010, mean summer temperatures have consistently exceeded 25-26 °C, reaching nearly 28 °C in some years. The observed increase in summer temperatures indicates heightened thermal stress, which has important implications for the assessment of drought risk, ecosystem degradation, and heat-related impacts on the population.

The analysis of the autumn season also revealed a steady trend towards an increase in the temperature background. At the beginning of the study period, the average autumn temperature was about 12.0 °C, with subsequent interannual fluctuations in the range of 10-15.5 °C. The coldest autumns were recorded in the mid-1990s whereas since the late 2000s, the frequency of warm autumns has been increasing with average temperatures above 13-14 °C, and in some years above 15 °C. Over the past 10-15 years, autumn temperatures have consistently exceeded the average annual values of the first decades of observations. In general, the increase in the average autumn temperature over a 50-year period is estimated at 1.0–1.5 °C.

Thus, the results indicate a comprehensive and sustained warming of the climate in the Mangystau region across all seasons. The most pronounced changes are observed in spring and summer, when temperature increases are both most intense and consistent. Warming during the winter and autumn seasons is accompanied by a reduction in extremely cold events and an increased frequency of warm temperature anomalies. These changes have substantial implications for natural ecosystems, water resources, and agro-climatic conditions in the region, and should be carefully considered in the development of adaptation measures and sustainable regional planning strategies.

An analysis of the time series of annual precipitation for the period 1974-2024 indicates a high interannual variability of precipitation typical for arid and semi-arid territories of the Caspian region (Fig.4). Annual precipitation rates vary in a wide range: from 60-80 mm in the driest years to 250-280 mm in years with abnormally high humidity.

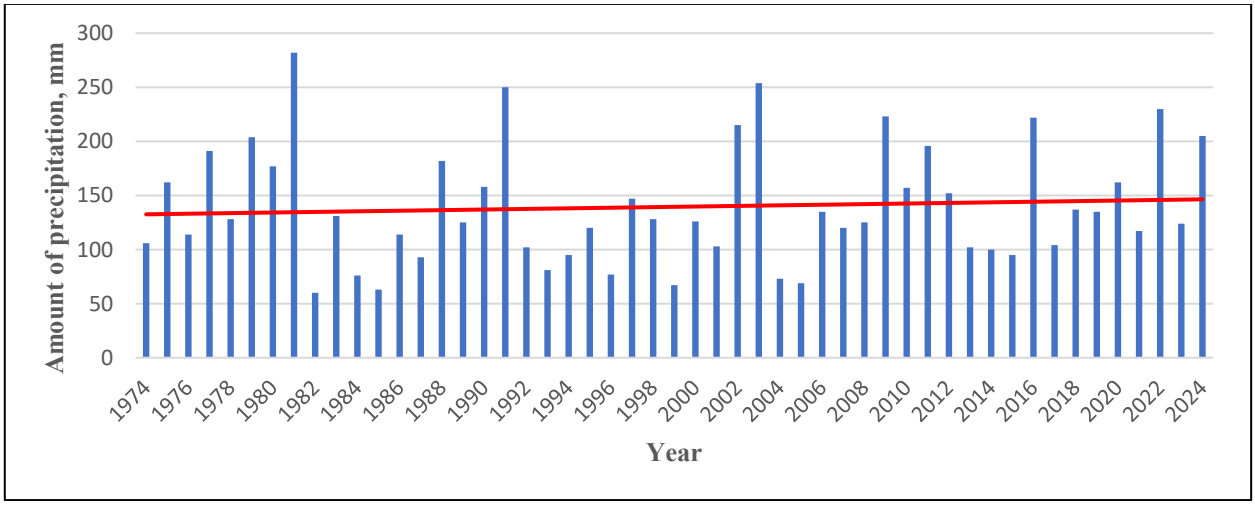

Figure 4. Dynamics of annual precipitation for the period 1974-2024

Analysis of annual precipitation in the Mangystau region reveals pronounced fluctuations over the 50-year period. Maximum precipitation values were recorded in the early 1980s, when the annual total exceeded 270 mm, substantially above the long-term regional average. In subsequent years, a sharp decline in precipitation occurred, including several extremely dry years with totals below 70 mm. Since the early 2000s, a slight tendency toward an increased frequency of years with higher precipitation has been observed; however, this trend does not display a consistent linear pattern. Despite several relatively wet years (2003, 2004, 2010, 2016, and 2022), the overall distribution of annual precipitation remains highly uneven, indicating that increases in rainfall are insufficient to compensate for the region's high evaporation rates, which continue to dominate the water balance.

Over the last 10–15 years, alternating dry and relatively wet years have been observed, with extreme values (both minimum and maximum) becoming more pronounced. This pattern suggests an intensification of extreme climatic events, including an increased likelihood of droughts and episodes of intense precipitation. Overall, the 50-year analysis does not reveal a clearly pronounced monotonic trend in annual precipitation. The primary characteristic of the precipitation regime in the Mangystau region remains high interannual and intra-decadal variability, which, when combined with the documented increase in air temperature, contributes to a progressive increase in regional aridity.

Based on the linear trend some differences were identified when considering the amount of seasonal precipitation in warm (April, May, June, July, August, and September) and cold (October, November, December, January, February, and March) periods (Figure 5). After analyzing the annual precipitation, the next stage of the study was to consider the seasonal structure of precipitation, which is of key importance for assessing the hydrological regime and climatic aridity of the Mangystau region.

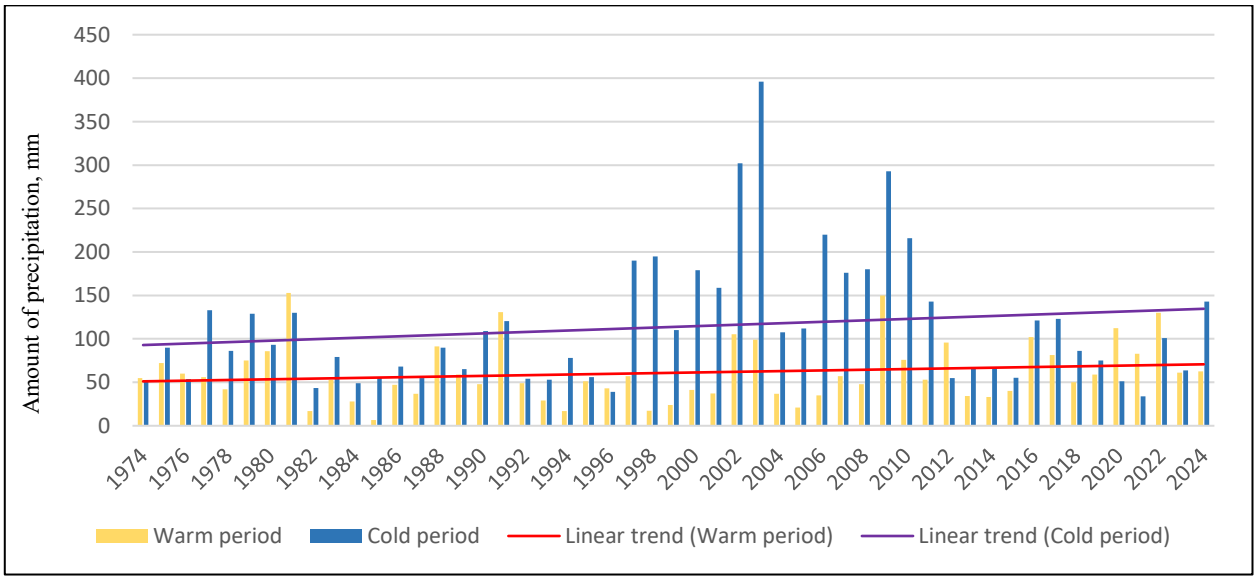

Figure 5. Dynamics of atmospheric precipitation in warm and cold periods

Analysis of long-term data for 1974-2024 shows that precipitation from the cold period steadily prevails over precipitation from the warm period throughout the time interval under consideration. The average precipitation values of the cold season in most years are 80-140 mm, while in the warm period they usually do not exceed 30-70 mm, reflecting the sharply continental and arid climate of the region.

The cold season is characterized by significantly higher interannual variability compared to the warm season. In some years (the early 2000s and 2010s), the precipitation amounts of the cold period exceeded 250-300 mm, and the maximum values reached about 400 mm, which indicates the presence of episodes of abnormal moisture and their dominant role in the formation of the annual water balance.

Precipitation during the warm period is characterized by relative stability and low absolute values. Even in the wettest years, their amount rarely exceeds 120-150 mm, and in dry periods it can decrease to 20-30 mm. This highlights the limited role of the warm season in replenishing water resources and the high dependence of natural ecosystems on precipitation during the cold period.

The linear trend of precipitation during the warm period shows a weak positive trend, while a more pronounced increase was detected for the cold period, indicating an increase in the contribution of autumn-winter and early spring precipitation to the overall annual balance. Despite this, the continuing unevenness of the seasonal precipitation distribution, combined with rising air temperatures, increases the aridity of the region's climate.

Discussion. Analysis of long-term temperature and precipitation data for the Mangystau region over 1974-2024 demonstrates significant climatic changes characterized by sustained warming and high variability in precipitation. The linear trend analysis indicates a steady increase in both annual and seasonal air temperatures, confirming a marked shift in the region’s thermal regime. Warming is observed across all seasons, with spring and summer showing the most pronounced and consistent temperature increases. Such seasonal asymmetry has important implications for phenological cycles, water balance, and agricultural productivity. Earlier onset of warm conditions in spring, combined with elevated summer temperatures, is likely to accelerate evapotranspiration, alter phenological events, and increase thermal stress on both ecosystems and human populations.

Winter and autumn also display positive temperature trends, although interannual variability remains more pronounced than in the warmer seasons. The reduction in extremely cold winters and the rise in warm anomalies reflect broader regional manifestations of global climate change and suggest modifications in large-scale atmospheric circulation patterns. The relative stabilization of temperatures at elevated levels in recent decades indicates the establishment of a new climatic norm, which may influence hydrological regimes and exacerbate water scarcity in this already arid region. Over 2004–2024, the mean annual temperature increased by more than 1.0 °C, further confirming the persistence of these warming trends.

Precipitation analysis shows a highly uneven distribution, typical of arid and semi-arid climates. The early 1980s recorded anomalously high rainfall, while several subsequent years were extremely dry, with annual totals below 70 mm. Since the early 2000s, the frequency of wetter years has slightly increased; however, this trend lacks a consistent linear pattern. High interannual and intra-decadal variability dominates the precipitation regime, highlighting the continuing prevalence of drought risk. Alternating dry and wet years, combined with pronounced extreme values, indicate an intensification of extreme climatic events, which could result in more frequent droughts or localized flooding.

Seasonal precipitation analysis emphasizes the dominance of cold-season rainfall in forming the regional water balance, whereas warm-season precipitation remains limited and relatively stable. Even with modest increases in autumn-winter and early spring rainfall, high evaporation rates and rising temperatures reduce the efficiency of these inputs in sustaining water resources. This combination of warming and uneven precipitation exacerbates the region’s aridity, increasing the vulnerability of natural and agricultural systems to climatic stress.

Overall, the observed trends indicate a progressive shift toward a warmer and more arid climate, consistent with global projections for arid regions. The concurrent warming and uneven precipitation highlight the need for integrated climate monitoring and adaptive water management strategies. These findings underscore the importance of considering both temperature and precipitation variability when planning sustainable development and climate adaptation measures in the Mangystau region. Continuous observation and modeling are essential for anticipating future climate impacts, improving resource management, and mitigating risks associated with increased aridity and extreme climatic events.

The results of this study align with regional and global research on climate change impacts in arid and semi-arid environments [14; 15; 16; 17; 18], confirming that increasing temperatures combined with irregular precipitation patterns pose a significant challenge for ecosystem stability and

water resource management. Therefore, adaptation strategies must prioritize seasonal and interannual variability to enhance resilience in both natural and socio-economic systems.

Conclusion. Thus, the analysis of long-term climatic data of the Mangystau region for the period 1974-2024 shows significant changes in both the temperature regime and precipitation distribution, which indicates a clear transition to a warmer and arid climate. Based on the results obtained, the following conclusions can be drawn:

1. Over the past 50 years, the average annual air temperature in the Mangystau region has increased by more than 1.0 °C, indicating a pronounced warming trend.

2. Seasonal analysis shows that the most significant and stable temperature increases are observed in spring and summer, while in winter and autumn there is also a positive trend, accompanied by a reduction in the number of extremely cold periods.

3. Warming has led to an earlier onset of the warm season, which can affect phenological cycles, accelerate evaporation, and increase heat stress on ecosystems and populations.

4. The annual precipitation in the region remains extremely variable: from extremely dry years with amounts below 70 mm to abnormally wet years with precipitation exceeding 270 mm. There has been no stable linear trend in annual precipitation over the 50-year period.

5. The precipitation of the cold period prevails in the formation of the regional water balance, while the warm season is characterized by limited and relatively stable precipitation, which emphasizes the importance of winter-spring precipitation for maintaining water resources.

6. The combination of rising temperatures and uneven precipitation increases the aridity of the region, increasing the vulnerability of natural ecosystems and agricultural systems to climatic stress and extreme events.

In general, the results indicate a complex warming of the climate of the Mangystau region against the background of high precipitation variability. These trends emphasize the need to take into account both temperature and precipitation dynamics when developing long-term measures for adaptation to climate change and sustainable management of natural resources. Continued observations and simulations are essential for predicting future climate impacts and effective regional planning.

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СОҢҒЫ 50 ЖЫЛДАҒЫ МАҢҒЫСТАУ ОБЛЫСЫНДАҒЫ АУА ТЕМПЕРАТУРАСЫ МЕН АТМОСФЕРАЛЫҚ ЖАУЫН-ШАШЫН ӨЗГЕРІСТЕРІНІҢ ҮРДІСТЕРІ

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Аңдатпа. Бұл мақалада Маңғыстау обылысының ауа температурасы мен атмосфералық жауын-шашынның соңғы 50 жылдағы (1974–2024 жж.) өзгерістері зерттеледі. «Климат және ауа райы» деректер базасынан алынған ұзақ мерзімді метеорологиялық мәліметтер негізінде орташа жылдық және орташа маусымдық температуралар, сондай-ақ жауын-шашынның жылдық таралуы талданды. Зерттеу нәтижелері тұрақты жылыну үрдісін көрсеттіп, орташа жылдық ауа температурасы 1,0 °С-тан астамға артқан, ал ең айқын және тұрақты өсім көктем және жаз мезгілдерінде байқалады. Қысқы және күзгі температуралар да

оң үрдіс көрсетіп, экстремалды суық кезеңдердің санының азаюымен қатар жүреді. Жылы маусымның ертерек басталуы мен жазғы температуралардың жоғарылауы фенологиялық үдерістерге әсер етіп, буланууды жеделдетеді және экожүйелер мен халыққа түсетін жылулық жүктемені арттырады.

Жауын-шашынға жүргізілген талдау аридті аумақтарға тән жылдар арасындағы және онжылдық ішіндегі жоғары өзгергіштікті анықтады. Атап айтқанда, жауын-шашын мөлшері 70 мм-ден төмен болатын өте құрғақ жылдардан бастап, 270 мм-ден асатын аномальды ылғалды жылдарға дейін ауытқуы анықталды. Су балансының қалыптасуына негізгі үлесті суық кезең қосады, ал жазғы жауын-шашын мөлшері шектеулі әрі салыстырмалы түрде тұрақты болып қалады. Жылыну мен жауын-шашынның біркелкі бөлінбеуінің үйлесуі өңірдің аридтілігін күшейтіп, табиғи және ауылшаруашылық жүйелердің климаттық стресс пен экстремалды құбылыстарға осалдылығын арттырады.

Алынған нәтижелер Маңғыстау өңірінде климаттың өзгеруіне бейімделу стратегияларын әзірлеу және су мен табиғи ресурстарды басқару барысында температуралық және жауын-шашындық динамиканы кешенді түрде ескерудің маңыздылығын көрсетеді.

Түйін сөздер: ұзақ мерзімді температуралық үрдістер; ауа температурасы; атмосфералық жауын-шашынның өзгергіштігі; аридті климат; маусымдық үрдістер; Маңғыстау облысы.

ТЕНДЕНЦИИ ИЗМЕНЕНИЯ ТЕМПЕРАТУРЫ ВОЗДУХА И АТМОСФЕРНЫХ ОСАДКОВ В МАНГИСТАУСКОЙ ОБЛАСТИ ЗА ПОСЛЕДНИЕ 50 ЛЕТ

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Аннотация. В данной статье исследуются изменения температуры воздуха и осадков в Мангистауской области за последние 50 лет (1974–2024 гг.). Используя долгосрочные метеорологические данные из базы «Климат и погода», проведен анализ среднегодовых и средне сезонных температур, а также годового распределения осадков. Результаты показали устойчивую тенденцию к потеплению: среднегодовая температура воздуха увеличилась более чем на 1,0 °C, при этом наиболее выраженные и стабильные повышения наблюдаются весной и летом. Зимние и осенние температуры также демонстрируют положительную тенденцию, сопровождающуюся уменьшением числа экстремально холодных периодов. Раннее наступление теплого сезона и повышение летних температур оказывают влияние на фенологические процессы, ускоряют испарение и повышают тепловую нагрузку на экосистемы и население.

Анализ осадков выявил высокую межгодовую и внутри декадную изменчивость, характерную для аридных территорий: от крайне засушливых лет с осадками менее 70 мм до аномально влажных годов с превышением 270 мм. Основной вклад в формирование водного баланса вносит холодный период, тогда как летние осадки остаются ограниченными и относительно стабильными. Сочетание потепления и неравномерного распределения осадков усиливает аридность региона и повышает уязвимость природных и сельскохозяйственных систем к климатическому стрессу и экстремальным явлениям.

Полученные результаты подчеркивают необходимость учета как температурной, так и осадочной динамики при разработке стратегий адаптации к климатическим изменениям и управлении водными и природными ресурсами в Мангистау.

Ключевые слова: долгосрочные температурные тенденции, температура воздуха, изменчивость атмосферных осадков, аридный климат, сезонные тенденции, Мангистауская область.