ОШ МАМЛЕКЕТТИК УНИВЕРСИТЕТИНИН ЖАРЧЫСЫ. АЙЫЛ ЧАРБА: АГРОНОМИЯ, ВЕТЕРИНАРИЯ ЖАНА ЗООТЕХНИЯ

ВЕСТНИК ОШСКОГО ГОСУДАРСТВЕННОГО УНИВЕРСИТЕТА. СЕЛЬСКОЕ ХОЗЯЙСТВО: АГРОНОМИЯ, ВЕТЕРИНАРИЯ И ЗООТЕХНИЯ

JOURNAL OF OSH STATE UNIVERSITY. AGRICULTURE: AGRONOMY, VETERINARY AND ZOOTECHNICS

e-ISSN: 1694-8696
№3(12)/2025, 1-19

VETERINARY

УДК: 551.583:631.1(575.3)
DOI: 10.52754/16948696_2025_3(12)_1

ECONOMY OF THE AGRICULTURAL SECTOR OF THE TALAS REGION OF THE KYRGYZ REPUBLIC UNDER THE INFLUENCE OF CLIMATIC FACTORS

КЛИМАТТЫК ФАКТОРЛОРДУН ТААСИРИ АСТЫНДА КЫРГЫЗ РЕСПУБЛИКАСЫНЫН ТАЛАС ОБЛАСТЫНЫН АЙЫЛ ЧАРБА ТАРМАГЫНЫН ЭКОНОМИКАСЫ

ЭКОНОМИКА АГРАРНОГО СЕКТОРА ТАЛАССКОЙ ОБЛАСТИ КЫРГЫЗСКОЙ РЕСПУБЛИКИ ПОД ВЛИЯНИЕМ КЛИМАТИЧЕСКИХ ФАКТОРОВ

Esenbek Belek uulu
Эсенбек Белек уулу
Эсенбек Белек уулу

Applicant, Kyrgyz National Agrarian University named after K.I. Skryabin 720005, 68 Mederov Str., Bishkek, Kyrgyz Republic
Изденүүчү, К.И. Скрябин атындагы Кыргыз улуттук агрардык университети 720005, Медеров көч., 68, Бишкек, Кыргыз Республикасы
Соискатель, Кыргызский национальный аграрный университет им. К.И. Скрябина 720005, ул. Медерова, 68, г. Бишкек, Кыргызская Республика
https://orcid.org/0000-0002-5590-1354

Ulan Chortombaev
Улан Чортомбаев
Улан Чортомбаев

Doctor of Economics, Professor, Kyrgyz National Agrarian University named after K.I. Skryabin 720005, 68 Mederov Str., Bishkek, Kyrgyz Republic
Э.и.д., профессор, К.И. Скрябин атындагы Кыргыз улуттук агрардык университети 720005, Медеров көч., 68, Бишкек, Кыргыз Республикасы
Д.э.н., профессор, Кыргызский национальный аграрный университет им. К.И. Скрябина 720005, ул. Медерова, 68, г. Бишкек, Кыргызская Республика
https://orcid.org/0000-0002-4718-1633

Maria Umarova
Мария Умарова
Мария Умарова

Doctor of Economics, Professor, Kyrgyz National Agrarian University named after K.I. Skryabin 720005, 68 Mederov Str., Bishkek, Kyrgyz Republic
Э.и.д., профессор, К.И. Скрябин атындагы Кыргыз улуттук агрардык университети 720005, Медеров көч., 68, Бишкек, Кыргыз Республикасы
Д.э.н., профессор, Кыргызский национальный аграрный университет им. К.И. Скрябина 720005, ул. Медерова, 68, г. Бишкек, Кыргызская Республика

https://orcid.org/0000-0002-4784-1937

Ainura Dyikanova
Айнура Дыйканова
Айнура Дыйканова

PhD in Physical and Mathematical Sciences, Associate Professor
Kyrgyz National Agrarian University
named after K.I. Skryabin 720005, 68 Mederov Str., Bishkek, Kyrgyz Republic
https://orcid.org/0000-0001-6054-7479
Ф.–м.и.к., доцент, К.И. Скрябин атындагы Кыргыз улуттук агрардык университети
720005, Медеров көч., 68, Бишкек, Кыргыз Республикасы
К.ф.-м.н., доцент, Кыргызский национальный аграрный университет
им. К.И. Скрябина 720005, ул. Медерова, 68, г. Бишкек, Кыргызская Республика

Tologon Kerimov
Тологон Керимов
Тологон Керимов

Master, Kyrgyz National Agrarian University
named after K.I. Skryabin 720005, 68 Mederov Str., Bishkek, Kyrgyz Republic
Магистр, К.И. Скрябин атындагы Кыргыз улуттук агрардык университети
720005, Медеров көч., 68, Бишкек, Кыргыз Республикасы
Магистр, Кыргызский национальный аграрный университет
им. К.И. Скрябина 720005, ул. Медерова, 68, г. Бишкек, Кыргызская Республика
https://orcid.org/0009-0000-5310-0644

ECONOMY OF THE AGRICULTURAL SECTOR OF THE TALAS REGION OF THE KYRGYZ REPUBLIC UNDER THE INFLUENCE OF CLIMATIC FACTORS

Abstract

The relevance of the study was conditioned by the increasing impact of climate change on the agricultural sector of the Talas region of the Kyrgyz Republic, where agriculture plays a key role in ensuring food security, employment, and rural development. The trends of rising temperatures, decreasing precipitation, degradation of pasture lands, and reduction of water resources directly affect the sustainability of agricultural production in the region, making the task of assessing climate risks particularly significant. The purpose of the study was to comprehensively assess climate change over the past decades and determine its impact on the agricultural economy of the Talas region. The methodological basis included statistical analysis of temperature, precipitation, humidity, wind conditions, and evaporation, processing of long-term data, and interpretation of satellite images that reveal spatial changes in landscapes and natural resources over a period of approximately 40 years. The results showed a steady increase in the mean yearly temperature by 1.4°C and a decrease in yearly precipitation by 9-10%. A decrease in the area of glaciers, a decrease in spring runoff, degradation of pastures, a decrease in soil moisture supply and deterioration of conditions for agriculture were noted. The analysis of crop yields indicated a decrease in productivity in the valley and foothill zones, which was accompanied by a decrease in livestock production efficiency. The identified spatial differences in climate change enabled the identification of the most vulnerable areas and the designation of zones of increased climate risk. The practical significance of the study was to develop recommendations for the modernisation of irrigation systems, the introduction of drought-resistant crop varieties, the adaptation of pasture management, and the creation of a regional climate monitoring system aimed at increasing the sustainability of the agricultural sector of the Talas region.

Keywords: climate change; agriculture; water balance; pastures; productivity; adaptation measures

Климаттык факторлордун таасири астында Кыргыз Республикасынын Талас областынын айыл чарба тармагынын экономикасы

Аннотация

Изилдөөнүн актуалдуулугу Кыргыз Республикасынын Талас облусунун агрардык секторуна климаттык өзгөрүүлөрдүн таасири күчөп бара жатканы менен шартталат. Бул аймакта айыл чарбасы азык-түлүк коопсуздугун камсыз кылууда, калкты жумуш менен камсыздоодо жана айыл аймактарын өнүктүрүүдө негизги роль ойнойт. Абанын температурасынын жогорулашы, жаан-чачындын азайышы, жайыт жерлеринин деградациясы жана суу ресурстарынын кыскарышы аймактагы агрардык өндүрүштүн туруктуулугуна түздөн-түз таасирин тийгизип, климаттык тобокелдиктерди баалоо маселесин өзгөчө маанилүү кылат. Изилдөөнүн максаты акыркы ондогон жылдардагы климаттык өзгөрүүлөрдү комплекстүү баалоо жана алардын Талас облусунун агрардык экономикасына тийгизген таасирин аныктоо болуп саналат. Методологиялык негиз климаттын негизги көрсөткүчтөрүн – абанын температурасы, жаан-чачындын көлөмү, абанын нымдуулугу, шамал режими жана буулануу деңгээлин –статистикалык талдоону, көп жылдык маалыматтарды иштетүүнү, ошондой эле болжол менен 40 жыл аралыгындагы ландшафттардын жана жаратылыш ресурстарынын мейкиндиктик өзгөрүүлөрүн аныктоого мүмкүндүк берген спутниктен алынган сүрөттөрдү

Экономика аграрного сектора Таласской области Кыргызской Республики под влиянием климатических факторов

Аннотация

Актуальность исследования обусловлена усиливающимся воздействием климатических изменений на аграрный сектор Таласской области Кыргызской Республики, где сельское хозяйство играет ключевую роль в обеспечении продовольственной безопасности, занятости населения и развитии сельских территорий. Тенденции роста температуры, снижения осадков, деградации пастбищных угодий и уменьшения водных ресурсов напрямую влияют на устойчивость агропроизводства региона, делая задачу оценки климатических рисков особенно значимой. Целью исследования являлась комплексная оценка климатических изменений за последние десятилетия и определение их последствий для аграрной экономики Таласской области. Методологическая база включала статистический анализ температуры, количества осадков, влажности, ветрового режима и испаряемости, обработку многолетних данных, а также интерпретацию спутниковых снимков, позволяющих выявить пространственные изменения ландшафтов и природных ресурсов за период около 40 лет. Полученные результаты показали устойчивый рост среднегодовой температуры на 1,4 °C и снижение годового количества осадков на 9-10 %. Отмечено сокращение площади ледников, уменьшение интерпретациялоону камтыды. Алынган жыйынтыктар орточо жылдык аба температурасынын 1,4 °Сге туруктуу жогорулаганын жана жылдык жаан-чачындын көлөмү 9-10 %га азайганын көрсөттү. Муздуктардын аянтынын кыскарышы, жазгы агын суунун азайышы, жайыт жерлеринин деградациясы, топурактын ным менен камсыз болуусунун төмөндөшү жана дыйканчылык үчүн шарттардын начарлашы белгиленди. Айыл чарба өсүмдүктөрүнүн түшүмдүүлүгүн талдоо өрөөн жана тоо этектериндеги зоналарда өндүрүмдүүлүктүн төмөндөшүн көрсөтүп, бул мал чарбачылыгынын натыйжалуулугунун азайышы менен коштолгон. Климаттык өзгөрүүлөрдүн мейкиндиктик айырмачылыктарын аныктоо эң жогорку деңгээлде алсыз аймактарды белгилөөгө жана климаттык тобокелдиктер күч алган зоналарды ажыратууга мүмкүндүк берди. Изилдөөнүн практикалык мааниси ирригациялык системаларды модернизациялоо, кургакчылыкка туруктуу айыл чарба өсүмдүктөрүнүн сортторун киргизүү, жайыт чарбасын адаптациялоо жана Талас облусунун агрардык секторунун туруктуулугун жогорулатууга багытталган регионалдык климаттык мониторинг системасын түзүү боюнча сунуштарды иштеп чыгууда турат

Ачкыч сөздөр: климаттын өзгөрүшү; айыл чарбасы; суу балансы; жайыттар; түшүмдүүлүк; адаптация чаралары

весеннего стока, деградацию пастбищ, снижение влагообеспеченности почв и ухудшение условий для земледелия. Анализ урожайности сельскохозяйственных культур свидетельствовал о сокращении продуктивности в долинных и предгорных зонах, что сопровождалось снижением эффективности животноводства. Выявленные пространственные различия климатических изменений позволили определить территории с наибольшей степенью уязвимости и обозначить зоны повышенных климатических рисков. Практическая значимость исследования состоит в разработке рекомендаций по модернизации ирригационных систем, внедрению засухоустойчивых сортов культур, адаптации пастбищного хозяйства и созданию региональной системы климатического мониторинга, направленной на повышение устойчивости аграрного сектора Таласской области

Ключевые слова: климатические изменения; сельское хозяйство; водный баланс; пастбища; урожайность; адаптационные меры

Introduction

Climate changes in recent decades have become more pronounced, having a significant impact on natural complexes, water resources, and socio-economic development of agricultural regions. Territories where the economy is heavily dependent on agriculture and the stability of natural and climatic conditions are particularly vulnerable. For the Talas region of the Kyrgyz Re-public, this problem is of paramount importance, since rising temperatures, reduced precipitation, land degradation and unstable water supply directly affect crop and livestock productivity. The deterioration of climate indicators leads to an increase in the risks of droughts, disruption of vegetation periods, and increased water management tensions, which makes the analysis of cli-mate trends and their impact on the agricultural sector an urgent scientific task.

According to Kyrgyzhydromet (n.d.), the number of extreme weather events has almost doubled between 1990 and 2020. Particularly frequent are: droughts in the southern and western regions of the country; mud-slides and landslides in mountainous areas (Naryn, Osh, Jalal-Abad regions); heavy rainfall and short-term floods in Chui and Issyk-Kul regions. In recent years, a wide range of studies have been devoted to climate change and its consequences in Central Asia, allowing for an assessment of the transformation of natural processes and the emerging threats to agriculture. Thus, according to G. Chi et al. (2020), changes in temperature and precipitation patterns are a key factor in reducing yields in Kyrgyzstan and associated regional economic losses. L. Liang et al. (2021) emphasised that areas with developed irrigated agriculture, including the Talas valley, show increased sensitivity to droughts, which reinforces the need to modernise water systems. L. Wu & H. Zheng (2023) showed that climate change has an impact not only on crop productivity, but also on the sustainability of livestock systems, especially in foothill areas.

An important contribution to the investigation of climate trends in Central Asia was made by K. Standal et al. (2023), who found that the temperature increase in Kyrgyzstan is faster than the global average, and a decrease in snow cover and a decrease in glaciers lead to a decrease in water resources during the warm season. The paper noted that temperature changes directly affect the water balance and require the development of adaptive mechanisms in the agricultural sector. Climate change requires adaptation not only of agricultural practices, but also of the entire system of natural resource management at the regional level. The researchers also focused on the social dimension of the problem, noting that climate risks increase migration processes and financial instability in rural households.

A comparative climate analysis on a regional scale was presented in the study by Z. Bolatova & S. Engindeniz (2020), who found that Central Asia is one of the most vulnerable areas in the world in terms of warming rates and precipitation deficits. These findings indicate an increase in aridisation and degradation of pastures in Kyrgyzstan, especially in areas with intensive agricultural land use. The researchers emphasised that a decrease in humidity and an increase in mean temperature have a direct impact on the economy of the agricultural sector, increasing irrigation costs and reducing production profitability. A number of contemporary studies indicate the need to use geoinformation technologies and digital climate models to obtain more accurate estimates of the spatial variability of climatic processes. In particular, studies by the WMO (n.d.) and Meteoblue (n.d.) demonstrated the effectiveness of using climate reconstructions to analyse long-term temperature and precipitation trends in regions with complex terrain, such as the Talas region.

A summary of the studies reviewed shows that cli-mate change in Central Asia is characterised by a steady increase in temperature, a decrease in precipitation, a reduction in water resources, and the degradation of pasture ecosystems. These processes are most intensively manifested in the agricultural regions of Kyrgyzstan, where economic stability directly depends on natural and climatic conditions. However, despite the significant number of studies, comprehensive research devoted specifically to the Talas region and based on a combination of meteorological data, climate models, and satellite observations is still limited. Considering the identified scientific gaps, the purpose of this study was to investigate the dynamics of climate change in the Talas region and determining their impact on the agricultural sector using advanced digital and geoinformation analysis methods.

Materials and Methods

The study was based on the integrated use of digital, statistical, and geoinformation methods to assess the long-term dynamics of climate change in the Talas region. The time frame of the analysis covered the period from 1979 to 2024, which provided representativeness and allowed comparing recent climate indicators with the data of the climatic norm. A long time series was a key condition for identifying trends in temperature, precipitation, humidity, and extreme events. The use of Google Earth (n.d.) satellite data was conditioned by its high availability, the regularity of image updates, and the ability to visually analyse natural processes in dynamics. The platform provided historical images of the area, which allowed exploring changes in glaciers, water bodies, vegetation, and the transformation of agricultural areas. This was especially important for the Talas region, as it is characterised by mosaic landscapes and a pronounced vertical gradient of climatic conditions. Historical images from the period 1980-2024 were used to qualitatively assess the dynamics of glaciers in Talas Ala-Too, changes in riverbeds and reservoir areas. All images were further refined using distance and area measurement tools built into Google Earth (n.d.). Meteorological data were obtained from two reliable sources: Kyrgyzhydromet (n.d.) – basic observations of temperature, humidity, wind speed, and precipitation recorded at stations in the Talas region; Meteoblue (n.d.) (ERA5T and NMM model) – reconstructed climatic series and climatic trends available for territories with limited ground-based observation network. The use of a combination of observational and model data allowed compensating for the lack of weather stations in high-altitude areas and increasing the reliability of the assessment of the spatial distribution of climatic parameters. Data processing included several analytical stages: calculation of yearly and monthly averages of temperature, precipitation, humidity, and wind speed; calculation of linear trends using the least squares method to identify long-term changes (temperature rise, precipitation decrease, etc.); analysis of extreme values – the number of frosts, days with strong winds, precipitation intensity; construction of climate diagrams and maps using Excel and Google Earth (n.d.).

To minimise errors, methods of smoothing time series and checking the consistency of data between sources were used. However, the study had limitations: the accuracy of satellite measurements depended on the quality of the images, and climate models produced errors in mountainous areas due to the difficult terrain. Thus, the combination of Google Earth (n.d.), Kyrgyzhydromet (n.d.) and Meteoblue (n.d.) data provided a comprehensive approach to assessing climate change in the Talas region and allowed analysing their impact on the natural and agricultural systems of the region.

Results and Discussion

Geographical and climatic factors contributing to Kyrgyzstan's vulnerability. Kyrgyzstan is located in the centre of the Eurasian continent, at the intersection of the Tien Shan and Pamir-Alai mountain ranges. More than 90% of the country's territory is mountainous, with a significant part located at altitudes from 1,500 to 4,000 metres above sea level. This location causes a variety of climatic zones: from dry steppes and semi-deserts in the west to humid alpine meadows and glaciers in the central and eastern regions. These changes entail the need to introduce climate monitoring systems, modernise irrigation networks, and transition to sustainable agriculture. Advanced analysis tools play an important role here, including the Meteoblue (n.d.) and Google Earth (n.d.) platforms, which allow modelling climate trends and assessing risks. The Talas region occupies the western part of Kyrgyzstan and is one of the smallest in terms of area, but one of the most distinctive regions of the country. Its territory is characterised by a combination of mountain ranges and an extensive intermountain valley, which forms unique natural and geographical conditions that determine the climate, economic activity, and distribution of the population.

In Figure 1, the city of Talas is located in the central part of the image, with clearly distinguishable urban development and street network. The territories adjacent to the city are actively used for agricultural purposes: fields with varying degrees of sowing and different colours of crops are visible. In the north and east there are areas, probably intended for pasture, with a lighter colour and uneven surface texture. Riverbeds and shallow bodies of water running through agricultural land are visible as dark, winding lines. The overall structure of the image reflects the anthropogenic impact on the landscape, with a clear contrast between urban areas and agricultural areas.

Figure 1. Satellite image of Talas city and adjacent agricultural territories

The climate of the Talas region is shaped by its geographical location, relief, and air circulation. The isolation of the Talas basin, surrounded by high mountains, creates specific microclimatic conditions that distinguish the region from neighbouring regions of Kyrgyzstan. The climate here is continental, with hot and dry summers, cold winters, and sharp diurnal and seasonal temperature fluctuations. These features are crucial for economic activity, vegetation distribution, and water resources (Chi et al., 2020).

General climatic characteristics. According to Kyrgyzhydromet (n.d.), the mean long-term air temperature in the Talas valley is +7...+9°C, which is slightly lower than in the low-lying areas of the Chui region, but higher than in the mountainous areas of Naryn or Issyk-Kul. The mean temperature in January varies from –6 to –10°C, and in July – from +22 to +25°C, sometimes reaching +35-38°C in especially hot years. The Talas region is one of the most continental regions of Kyrgyzstan, which is reflected in large temperature ranges. The difference between the coldest and warmest months reaches 30-35°C, and diurnal fluctuations in summer can be 10-15°C. The location of the valley between mountain ranges contributes to the accumulation of cold air in winter and intense warming in summer. Temperature inversions are not uncommon in winter, when cold air stagnates in the valley and milder weather is observed on the mountain slopes (Liang et al., 2021). Figure 2 shows an estimate of the mean yearly temperature for the larger Talas region.

The blue line in Figure 2 shows the linear trend of climate change. If the trend line rises from left to right, the temperature trend is positive, and it is getting warmer in Talas due to climate change. If it is horizontal, there is no clear trend; if the line goes down, it gets colder in Talas over time. The mean yearly precipitation is shown below (Fig. 3).

Mean yearly temperature (Synthetic Approximation)

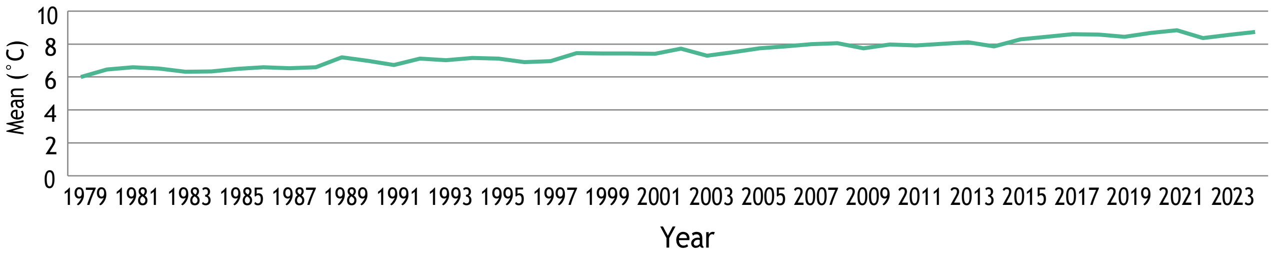


Figure 2. Yearly temperature change in Talas

Source: Meteoblue (n.d.)

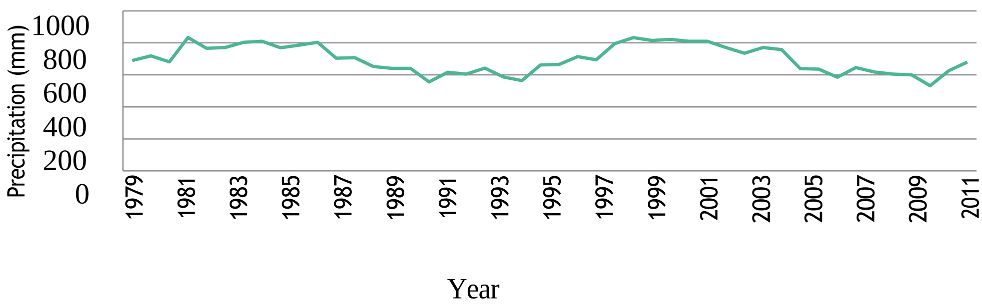


Figure 3. Mean yearly precipitation

Source: Meteoblue (n.d.)

Spring comes relatively late, in March and April. Temperatures rise rapidly, and in May daytime values reach +20...+25°C. Spring is short and windy, accompanied by active snowmelt and possible floods. Summers are warm and dry. The mean temperature in July is +23...+25°C, but on some days it rises to +38...+40°C. Precipitation is rare at this time, and the evaporation rate significantly exceeds the amount of precipitation. Autumn is relatively long and warm, especially in September. The temperature is gradually decreasing, the nights are getting cooler, and the first frosts are possible in October. Data from the Meteoblue (n.d.) weather platform show that over the past 30 years, the region has seen a steady trend of an increase in mean temperature of about 0.9 °C, especially noticeable in the winter months. This confirms the general trend of global warming observed throughout Central Asia (Zhunusova, 2017). Heavy rains are often accompanied by thunderstorms and hail, which can cause soil erosion and damage to farmland. Mudflows are possible in mountainous areas in summer, caused by heavy precipitation against the background of snowmelt. Figure 4 shows the mean monthly air temperature and precipitation in the city of Talas during the year.

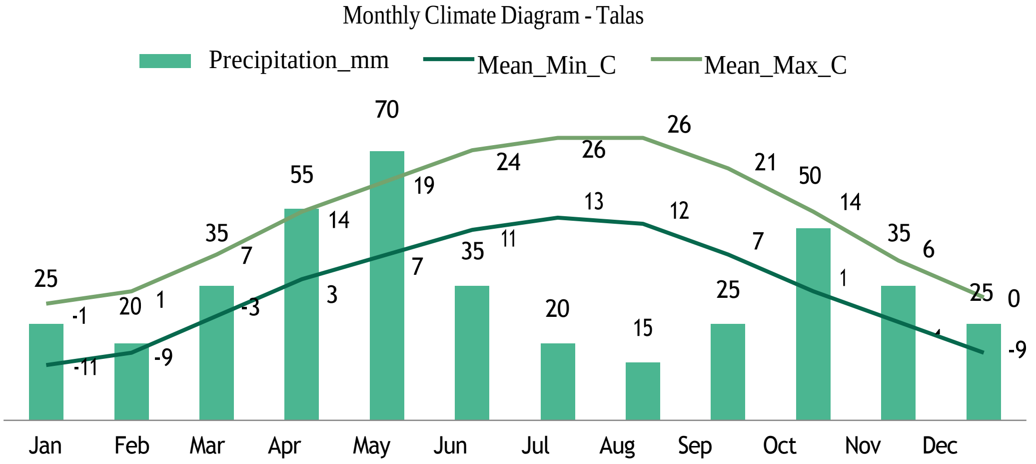


Figure 4. Mean monthly temperatures and precipitation in Talas

Source: Meteoblue (n.d.)

The "mean daily maximum" (solid grey line) shows the maximum temperature of the average day of each month for Talas. Similarly, the "mean daily minimum" (solid orange line) shows the average minimum temperature value. The hot days and cold nights (dotted red and blue lines) represent the average of the hottest day and coldest night of each month over the past 30 years. The default wind speed is not displayed. Figure 5 shows a climate calendar showing the distribution of precipitation and cloud cover by month throughout the year.

Figure 5 shows the monthly number of sunny, partly cloudy, cloudy, and rainy days. Days with less than 20% cloud cover are considered sunny, days with 20-80% cloud cover are partially cloudy, and days with more than 80% are cloudy. Figure 6 of the maximum temperatures for Talas shows how many days per month reach certain temperatures.

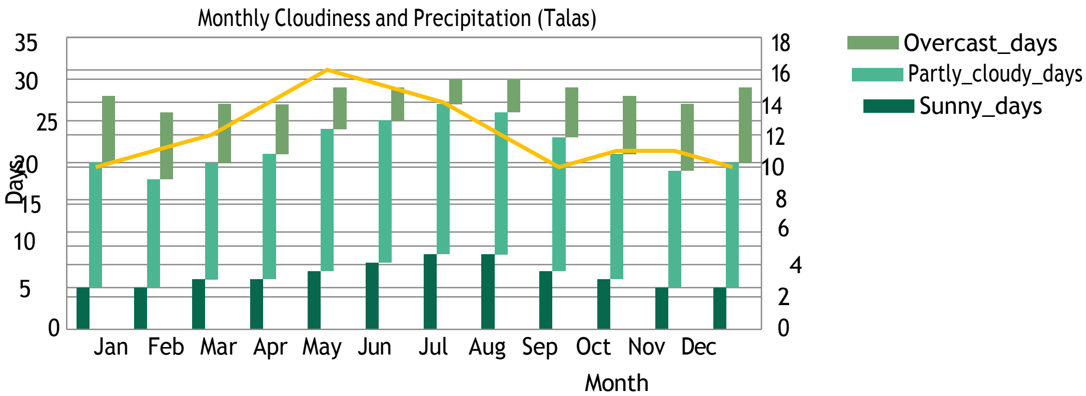


Figure 5. Climate calendar: precipitation and cloudiness by month

Source: Meteoblue (n.d.)

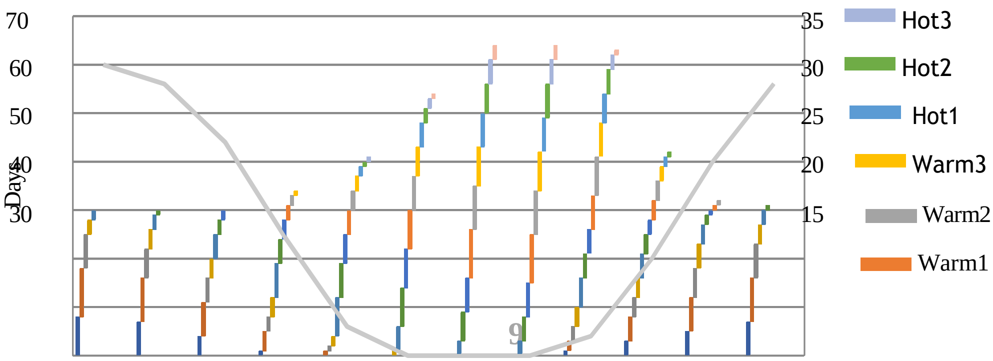


Figure 6. Distribution of temperatures and frost days by month

Source: Meteoblue (n.d.)

This diagram illustrates the distribution of the number of days with different temperature ranges throughout the year. Each colour corresponds to a certain range of air temperature, ranging from severe frosts (-24 to -18°C) to hot temperatures (+32 to +36°C). The grey line shows the number of days with frosts by month. In winter and early spring, the number of frosts is maximum, reaching almost 30 days in January and December. There are no days with frosts in summer, and the number of warm and hot days increases significantly. Autumn is characterisedby a gradual increase in the number of days with low temperatures and frosts (Broka et al., 2016). Figure 7 helps to understand the climatic features of the region, identify seasonal temperature changes and the frequency of frosts.

Figure 7 precipitation for Talas shows on how many days of each month certain amounts of precipitation are reached. In tropical and monsoon climates, these values may be underestimated. Figure 8 shows the distribution of wind speed by month for the city of Talas, according to the ERA5T model.

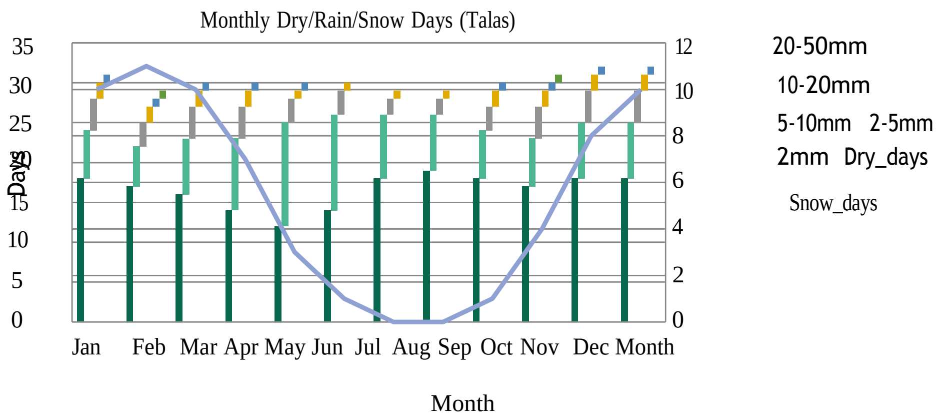
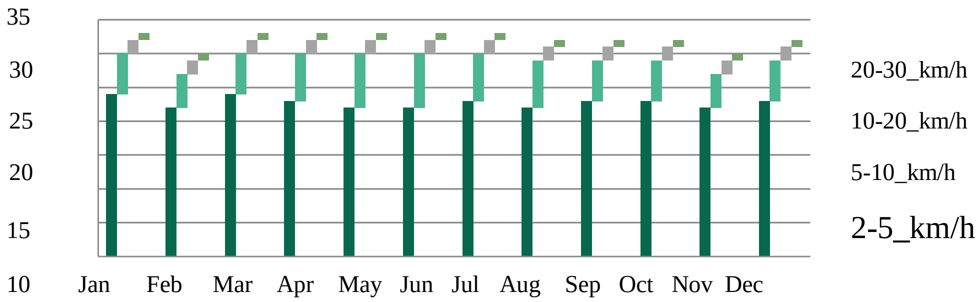


Figure 7. Monthly precipitation ranges (Talas)

Source: Meteoblue (n.d.)



0 Month

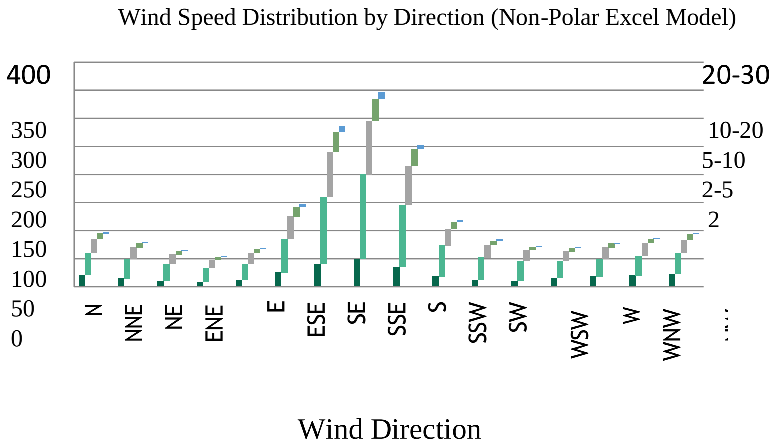
Figure 8. Monthly wind speed categories (Talas)

Source: Meteoblue (n.d.)

The graph shows the average number of days in each month with different wind speed ranges. The most frequently observed winds are of low intensity – from 2 to 5 km/h, which prevail throughout the year. Moderate winds (5-10 km/h and 10-20 km/h) occur to a lesser extent, with the greatest frequency in the spring-summer period (March-July). Strong winds (20-30 km/h) are practically not recorded.

In general, the climate of Talas is characterised by mostly calm wind conditions, which reflects the stability of atmospheric processes and relatively low air turbulence throughout the year. In the summer months (June-August), there is a slight increase in wind speed, which contributes to better ventilation of the air and reduces overheating during daytime hours. In autumn and winter (October-February), wind activity decreases, which can lead to stagnation of cold air masses and, consequently, to frequent frosts. Figure 9 shows the wind rose for the city of Talas, constructed using data from the ERA5T model.

The graph shows that the prevailing wind direction is south and south-east (S and SSE), which indicates the dominance of air flows coming from the southern regions. The most frequent wind speeds in these directions are 2-5 km/h and 5-10 km/h, i.e., moderate and weak winds. Stronger flows (10-20 km/h) are observed much less frequently. Figure 10 shows the verification of meteorological parameters in Talas.



The graph shows a comparison of the predicted and actual air temperature (°C) during the day. The black line indicates the actual temperature, and the coloured areas show forecast errors: orange – the forecast is overestimated, grey – the forecast is underestimated. The temperature rises in the morning to a maximum of approximately 16-17°C during the daytime, then gradually decreases in the evening. Error statistics show a low mean error (0.12°C) and high forecast accuracy: 100% of forecasts with an error of less than 3°C.

The average graph shows the wind speed (km/h). The mean forecast error is 0.19 km/h, the absolute error is 2.02 km/h. The lower graph illustrates the relative humidity (%). Humidity decreases in the morning to a minimum of about 35% in the afternoon, then gradually increases in the evening. The mean forecast error was 3.03%, the absolute error was 4.47%. Humidity and volatility. The air humidity in the Talas region is relatively low, especially in summer, when relative humidity drops to

30-40%. In winter, it increases to 70-80%, which is associated with low temperatures and low evaporation. The evaporation rate in the valley exceeds the amount of precipitation, which leads to a shortage of moisture and the need for artificial irrigation. According to observations, the yearly evaporation rate is 800-1,000 mm, which is almost twice the yearly precipitation. This ratio forms an arid climatic type that requires a developed irrigation infrastructure to support agricultural production.

Climatic anomalies and changes. Observations confirm that the Talas region, like the entire territory of Kyrgyzstan, is under the influence of global climate change. Data analysis by Meteoblue (n.d.) and Google Earth (n.d.) over the past decades shows a number of stable trends: the Talas region has a variety of natural resources that play an important role in the region's economy and determine the specifics of its environmental management. Among the most significant are land, water, mineral, forest, and biological resources. Against the background of global climate change and anthropogenic pressure, environmental problems are increasing, requiring an integrated approach to their solution.

The natural resources of the Talas region have significant potential for the sustainable development of the region. Land and water resources ensure the development of agriculture, mineral resources ensure industry, and forest and biological resources ensure ecological balance. However, under the influence of global climate change and increasing anthropogenic pressure, this potential is gradually decreasing. Rising temperatures, decreasing precipitation, land degradation, and shrinking glaciers pose a threat to the region's environmental sustainability. To preserve natural re-sources and ensure environmental safety, an integrated approach is needed, including: rational use of land and water; development of environmentally sound mining technologies; restoration of forests and pastures; constant monitoring of the environment using satellite and digital data (Google Earth, n.d.; Meteoblue, n.d.). Only with a combination of scientific analysis, government regulation and the participation of the local population is it possible to preserve the natural potential of the Talas region and adapt its ecosystems to the changing climate (Yang et al., 2022).

The Talas region is characterised by a continental climate with cold winters and hot summers. According to Meteoblue (n.d.), the mean yearly air temperature in the region has shown a steady upward trend over the past decades. In the 1980s, the mean yearly temperature was approximately +7.2°C, and by the 2020s it reached +8.6°C. Thus, there has been an increase of 1.4°C in 40 years, which is consistent with global warming trends. The greatest increase in temperature was observed in the winter and spring periods, which indicates a reduction in the duration of the cold season. The average winter temperature increased from -5.5°C (1980s) to -3.2°C (2020s), and the spring temperature increased from +8.1°C to +9.7°C. Table 1 shows the dynamics of average seasonal and yearly temperatures in the Talas region in 1980-2025. The data show steady warming in all seasons, with the greatest increase in summer, and the mean yearly temperature increased from +7.2°C to +8.6°C.

Table 1. Mean seasonal temperatures (Talas region, °C)

Period	**Winter**	**Spring**	**Summer**	**Autumn**	**Yearly mean**
1980-1989	-5.5	+8.1	+22.8	+10.2	+7.2
1990-1999	-4.8	+8.5	+23.1	+10.5	+7.6
2000-2009	-4.3	+9.0	+23.5	+11.0	+8.0
2010-2019	-3.8	+9.4	+23.9	+11.3	+8.4
2020-2025	-3.2	+9.7	+24.2	+11.6	+8.6

Source: compiled by the authors based on Meteoblue (n.d.)

The analysis showed a steady trend towards an in-crease in temperature in all seasons. Winter temperatures increased from -5.5°C in 1980-1989 to -3.2°C in 2020-2025, spring temperatures from +8.1°C to +9.7°C, summer temperatures from +22.8°C to +24.2°C, and autumn temperatures from +10.2°C to +11.6°C. The mean yearly temperature during this period increased from +7.2°C to +8.6°C. The greatest increase is observed in the summer, which indicates the ongoing warming of the climate in the region. These data can be useful for assessing climate change, planning agricultural activities, and forecasting water resources. There is a clear linear increase in temperature, especially pronounced in winter. The warming of winters indicates a decrease in the number of stable snow covers and an increase in the frequency of thaws. This has an impact on the hydrological regime of the region – the spring runoff of rivers decreases and earlier snowmelt occurs in the mountains, as reported by O. Chepelianskaia & M. Sarkar-Swaisgood (2022).

Spatial differences in temperature changes. Ac-cording to Meteoblue (n.d.), temperature changes in the Talas region have a pronounced altitudinal and geographical gradient. In the valley part (Talas city area, 1,200-1,300 m above sea level), the mean yearly temperature reaches +9...+10°C, and in summer it often exceeds +30°C. In the mountainous regions of Talas Ala-Too, the temperature is 5-7°C lower, due to the altitude zone. However, it is the mountainous areas that show the most noticeable warming – approximately +1.6°C over the past 40 years, while in the lowland area the increase was +1.2°C. Long–term observations show a trend towards a slight decrease in precipitation, by an average of 8-10% over the period from 1980 to 2024. If in the 1980s the mean yearly precipitation was about 540 mm, then in the 2020s it decreased to 490-500 mm. Table 2 shows the dynamics of the mean yearly precipitation in the Talas region for 1980-2025. The data indicate a gradual decrease in precipitation, with an overall decrease of 9.3% compared to 1980-1989.

Table 2. Mean seasonal temperatures (Talas region, °C)

Period	**Mean yearly precipitation**	**Change**
1980-1989	540	–
1990-1999	520	-3.7
2000-2009	505	-6.5
2010-2019	495	-8.3
2020-2025	490	-9.3

Source: compiled by the authors based on Meteoblue (n.d.)

Table 2 shows the changes in the mean yearly precipitation in the Talas region over the period 1980-2025. The data show a steady downward trend in precipitation, with precipitation decreasing by 9.3% by 2020-2025 compared to 1980-1989 levels. The main decrease in precipitation occurs in the summer, especially in July and August, when the amount of rain decreased by approximately 12-15%. The spring months (March-April) are characterised by a slight positive trend, which may be due to a change in air circulation and an increase in the number of cyclones from the western regions. Seasonal dynamics of precipitation. Seasonal precipitation distribution in the Talas region is uneven. The main part falls in the spring and summer, which plays an important role for agriculture. Table 3 shows the seasonal distribution of precipitation in the Talas region according to Meteoblue (n.d.). The table shows how precipitation is distributed by season and allows identifying seasonal fluctuations in precipitation over the study period.

Table 3. Seasonal precipitation distribution, mm

Season	**1980-1989**	**2000-2009**	**2020-2024**	**Change (%)**

Winter	85	80	78	-8.2
Spring	165	168	172	+4.2
Summer	195	178	165	-15.4
Autumn	95	85	80	-15.8

Source: compiled by the authors based on Meteoblue (n.d.)

Table 3 shows the seasonal precipitation values and calculates their percentage changes, which allows tracing the trends of seasonal fluctuations and the overall dynamics of humidification in the region. The analysis shows that the increase in spring precipitation is offset by a decrease in summer precipitation. As a result, the total moisture reserve in the soil is reduced during the critical growing season of plants, which leads to increased aridity of the climate and the need for more efficient use of irrigation systems.

Interannual climate variability. Thus, according to A. Islam & M. Hasan (2020), the region is characterised by high interannual variability in temperature and precipitation. According to Meteoblue (n.d.), the amplitude of fluctuations in the mean yearly temperature reaches ±1.5°C, and the yearly precipitation is ±100 mm. Periods of dryness also increased: dry years (with precipitation less than 450 mm) began to recur every 4-5 years, whereas in the 1980s they were observed once every 10-12 years (Kamchybekov et al., 2019). Linear trends in temperature and precipitation were calculated to quantify the changes. Temperature trend: +0.035°C/year, equivalent to an increase of 1.4°C in 40 years. Precipitation trend: -1.2 mm/year, which corresponds to a decrease of approximately 50 mm over the same period. The consequences of the observed changes. Changes in temperature and precipitation have a complex impact on the natural and socio-economic systems of the region: the reduction of glaciers and snow cover in the mountains of Talas Ala-Too, which leads to a decrease in water resources in summer.

Comparison with regional and global trends. The results of the Meteoblue (n.d.) analysis show that the climatic changes in the Talas region correspond to the general picture of the Central Asian region, which has been warming by 1.2-1.8°C over the past 50 years (Mogilevskii et al., 2017). For comparison, in the Chui valley, the temperature increase over the same period was approximately +1.1°C; in the Issyk-Kul region – +0.9°C; in the Naryn region – +1.3°C. Thus, the Talas region is among the territories with the most pronounced warming, which is associated with its continental position and mountainous terrain, which enhances temperature contrasts, according to M. Sydykova (2017).

Environmental consequences of the identified changes. Climate changes in the Talas region lead to a number of environmental consequences, which can be grouped into the following areas: socio-economic con-sequences: reduced crop yields; increased irrigation costs; the need to adapt agriculture and infrastructure to new climatic conditions. Comparison with global and regional trends. The analysis shows that the identified changes in the Talas region are consistent with regional and global trends (Ruppert et al., 2020). Thus, the changes observed in the Talas region fully correspond to the global trend of warming and aridisation, which con-firms the reliability of local observations by I. Bobojonov & A. Aw-Hassan (2014). Table 4 shows the main climate changes in different natural and territorial zones of the Talas region, including temperature increases, precipitation changes, and the impact of these factors on water resources, vegetation, and irrigation load.

Table 4. Climate change and its consequences in various natural and territorial zones of the Talas region

Zone	Nature of the changes	Features

Mountainous part (Talas Ala-Too)	Warming by 1.6°C, reduction of glaciers by 25-30%	Strong impact on water resources, reduction of spring runoff
Foothill zone	Temperature increase by 1.3°C, precipitation decrease by 8%	Vegetation reduction, pasture degradation
Valley part (Talas and Bakai Ata)	1.1°C increase, 10-12% less precipitation	Increased droughts and increased irrigation load

Source: compiled by the authors

Table 4 shows the climatic changes and their con-sequences in various natural and territorial zones of the Talas region. It indicates the zones (mountainous, foothill, and valley), the nature of the observed changes (temperature rise, precipitation decrease, glacier reduction) and the main consequences of these changes for natural resources and economic activity. The dynamics of crop yields in the region confirm their dependence on climatic conditions. Table 5 shows the dynamics of the mean yearly temperature, yearly precipitation and wheat yield in the Talas region for the period 1980-2020.

Table 5. Yearly mean climatic indicators and wheat yield in Talas region

Years	Mean temperature (°C)	Yearly precipitation (mm)	Wheat yield (q/ha)
1980-1990	9.1	500	27
1991-2000	9.7	465	25
2001-2010	10.3	450	22
2011-2020	10.7	435	19

Source: compiled by the authors

Table 5 shows the relationship between the change in mean yearly temperature and yearly precipitation with wheat yield in the Talas region for the period 1980-2020. The table shows the trend towards gradual warming and reduction of precipitation, which is accompanied by a decrease in yields. The data allows assessing the impact of climatic factors on agricultural production in the region. The 25-30% decrease in yields over the past 40 years reflects not only technological, but also climatic reasons: lack of moisture, reduction of snow reserves, soil degradation, and overheating of crops in summer (Ashley et al., 2016).

Animal husbandry is an important component of the rural economy of the Talas region. However, climate warming and decreased precipitation have led to the degradation of natural pastures, especially in foothill and valley areas, as noted by E. Lioubimtseva & G. Henebry (2009). Socio-economic consequences. Climate change in the Talas region has a direct impact on the socio-economic development of the region. Key consequences include: increased risks of crop failures and loss of income for farmers (dry years lead to lower yields and higher prices for products); reduced employment in agriculture (falling land productivity forces some of the population to migrate to cities or abroad); increased irrigation costs (the need to drill new wells, reconstruct canals and pumping stations requires financial resources); increasing water management tensions (increasing competition for water resources between agriculture, the public sector, and ecosystems). Thus, W. Meyers et al. (2012) indicated that climate change is becoming not only a natural, but also a socio-economic challenge to the sustainable development of the region.

Climate change in the Talas region has a multifaceted impact on agriculture and water resources. There is a steady increase in temperature, a decrease in precipitation, degradation of pastures, and a decrease in river runoff. These processes increase the risks of droughts, reduce yields, and pose a threat to the food security of the region. The analysis of climate data for the period 1980-2025 demonstrates a steady warming trend in the Talas region. The mean yearly temperature increased from 7.2°C in 1980-1989 to 8.6°C in 2020-2025, with the greatest increase observed in summer, which increases heat stress for crops. Winter temperatures also show a positive trend, reducing the risk of freezing in low-lying areas (Burkhanov et al., 2024).

Differences in the climatic impact on the natural and territorial zones of the Talas region are reflected in Table 4. In the mountainous part, warming of 1.6°C and reduction of glaciers by 25-30% is recorded, which reduces spring runoff. In the foothill zone, the temperature increase is 1.3°C with a decrease in precipitation by 8%, which leads to degradation of pastures. In the valley area, an increase in temperature by 1.1°C and a decrease in precipitation by 10-12% increases droughts and increases irrigation load. Wheat yield data show a decrease from 27 q/ha in 1980-1990 to 19 q/ha in 2011-2020, which is directly related to rising temperatures and reduced precipitation. These results confirm the need for adaptation measures, including rational water use, changing the timing of sowing, and the use of resistant crop varieties (Reyer et al., 2017).

A comparative analysis with the studies of other authors showed that the climatic trends identified in the study of the Talas region correlate with the previous findings, but they also have their own characteristics. Firstly, Y. Liu et al. (2020) noted that in the southern part of Central Asia, including Kyrgyzstan, rising temperatures and increased aridity lead to increased water scarcity and increased demand for irrigation. This is consistent with the findings of a significant increase in temperature and decrease in precipitation in the Talas region, and increased stress on water resources, especially in valley and foothill areas. Secondly, a regional report by the British meteorological service Met Office (n.d.) highlighted that from 1980 to 2015, Central Asia experienced a steady warming of approximately 0.3-0.4°C per decade, and the frequency of extremely hot days is increasing. These data confirm the area and scale of climate change, although temperature increases in the Talas region have been even more pronounced in recent decades.

Research by K. Standal et al. (2023) identified similar trends in the negative impact of climate on the agricultural sector of Kyrgyzstan, such as a decrease in water resources and threats to food security. The analysis of the climate of the Talas region complements its conclusions with a specific regional assessment: not only the overall temperature increase, but also the spatial heterogeneity of changes, degradation of pastures and reduced yields. Ultimately, the study by L. Wu & H. Zheng (2023) modelled that with a 2°C warming in Central Asia, the need for irrigation water can increase by 10-20%, and irrigation itself can change weather conditions due to the exchange of heat and moisture. These results reinforced the practical significance of the conclusions about the need to modernise irrigation systems in the Talas region as part of an adaptation strategy. Thus, the study revealed a stable trend of warming and decreasing humidity in the region, evaluated the consequences for water resources and agriculture, and provided data comparable to the results of other researchers in similar climatic conditions.

Conclusions

Global climate change in the 21st century continues to have a profound and systemic impact on natural complexes and socio-economic development of various regions of the world. Kyrgyzstan, located in the zone of high-altitude ecosystems, is characterised by increased sensitivity to climatic fluctuations: even small changes in temperature or precipitation regime lead to significant transformations of hydrological processes, soil stability, land use structure, and the state of biological resources. Among the regions of the country, the Talas region is one of the most indicative examples where climate change manifests itself most clearly and consistently. The conducted research, based on the analysis of data from Meteoblue, Google Earth, and Kyrgyzhydromet materials, revealed a number of stable climatic trends. First of all, it has been established that the mean yearly temperature in the region has increased by about 1.4-1.6°C over the past 40-45 years, which indicates a marked warming. However, there is a decrease in yearly precipitation by 10-15%, especially in the warmer months, which increases the processes of aridisation, increases the risk of droughts, and has a direct impact on crop yields. The environmental consequences of these changes are complex: there is a gradual degradation of pastures and arable lands, a decrease in the water content of small rivers, a decrease in glacial reserves of the Talas Ala-Too, a decrease in biodiversity, and an expansion of areas prone to desertification. These processes are already having an impact on agriculture, water supply, public health, and food security, making climate change an important socio-economic challenge.

The use of advanced digital tools Google Earth and Meteoblue has significantly improved the accuracy of monitoring, making it possible to visualise climate changes in the space-time context and form scientifically based conclusions about current trends. Thus, the study confirmed the existence of stable climatic shifts in the Talas region, which require the development of comprehensive adaptation measures to ensure sustainable environmental management and socio-economic stability of the region. The prospects for further research lie in the need to develop local climate models and adaptation maps, including forecast scenarios for the coming decades.

References

[1] Ashley, L., Zhumanova, M., Isaeva, A., & Dear, C. (2016). Examining changes in local adaptive capacity resulting from climate change adaptation programming in rural Kyrgyzstan. *Climate and Development*, 8(3), 281-287. doi: 10.1080/17565529.2015.1034230.

[2] Bobojonov, I., & Aw-Hassan, A. (2014). Impacts of climate change on farm income security in Central Asia: An integrated modeling approach. *Agriculture, Ecosystems & Environment*, 188, 245-255. doi: 10.1016/j. agee.2014.02.033.

[3] Bolatova, Z., & Engindeniz, S. (2020). The economics of climate change in agriculture: A review on Kazakhstan and Turkey. In K. Mattas, H. Kievit, G. van Dijk, G. Baourakis & K. Zopounidis (Eds.), *Sustainable food chains and ecosystems: Cooperative approaches for a changing world* (pp. 1-15). Cham: Springer.

[4] Broka, S., Giertz, Å., Christensen, G., Hanif, C., Rasmussen, D., & Rubaiza, R. (2016). *Kyrgyz Republic agricultural sector risk assessment*. Washington: World Bank, Washington, DC.

[5] Burkhanov, A.U., Yadgarov, A.A., & Tugizova, M.S. (2024). Forecast scenarios of the development of agricultural insurance in Uzbekistan based on econometric models against the background of climate change. In M.P. Eshov, G.K. Abdurakhmanova, A.U. Burkhanov, N.B. Abdusalomova & S.T. Ergasheva (Eds.), *Development of international entrepreneurship based on corporate accounting and reporting according to IFRS: Part B* (pp. 47-53). Leeds: Emerald Publishing Limited. doi: 10.1108/S1877-63612024000033B007.

[6] Chepelianskaia, O., & Sarkar-Swaisgood, M. (2022). *Kyrgyz Republic climate change and disaster risk profile*. Bangkok: ESCAP Working Paper.

[7] Chi, G., Gao, J., Wang, D., Hagedorn, A., Kelgenbaeva, K., Smith, M.L., & Henebry, G.M. (2020). Agricultural production at the oblast level in post-Soviet Kyrgyzstan, 1990-2014: Implications of demographic and climate changes. *Research in Globalization*, 2, article number 100027. doi: 10.1016/j.resglo.2020.100027.

[8] Google Earth. (n.d.). Retrieved from https://earth.google.com/.
[9] Islam, A.H.M.S., & Hasan, M.R. (2020). Characterization of the aquafeed sub-sector in Kyrgyz Republic: A value chain analysis. *Aquaculture*, 524, article number 735149. doi: 10.1016/j.aquaculture.2020.735149.
[10] Kamchybekov, T.K., Atyshov, K.A., & Bakas uulu, B. (2019). Problems of economic sectors of the Kyrgyz Republic.
Journal of Environmental Treatment Techniques, 7(4), 613-622.
[11] Kyrgyzhydromet. (n.d.). Retrieved from https://meteo.kg/ru/.
[12] Liang, L., Zhang, F., & Qin, K. (2021). Assessing the vulnerability of agricultural systems to drought in Kyrgyzstan.
Water, 13(21), article number 3117. doi: 10.3390/w13213117.
[13] Lioubimtseva, E., & Henebry, G.M. (2009). Climate and environmental change in arid Central Asia: Impacts, vulnerability, and adaptations. *Journal of Arid Environments*, 73(11), 963-977. doi: 10.1016/j. jaridenv.2009.04.022.
[14] Liu, Y., Geng, X., Hao, Z., & Zheng, J. (2020). Changes in climate extremes in Central Asia under 1.5 and 2 °C global warming and their impacts on agricultural productions. *Atmosphere*, 11(10), article number 1076. doi: 10.3390/atmos11101076.
[15] Met Office. (n.d.). Retrieved from https://www.metoffice.gov.uk/.
[16] Meteoblue. (n.d.). Retrieved from https://www.meteoblue.com/.
[17] Meyers, W.H., Ziolkowska, J.R., Tothova, M., & Goychuk, K. (2012). *Issues affecting the future of agriculture and food security for Europe and Central Asia*. Budapest: FAO Regional Office for Europe and Central Asia.
[18] Mogilevskii, R., Abdrazakova, N., Bolotbekova, A., Chalbasova, S., Dzhumaeva, S., & Tilekeyev, K. (2017). *The outcomes of 25 years of agricultural reforms in Kyrgyzstan*. Leibniz: Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Halle (Saale).
[19] Reyer, C.P.O., *et al*. (2017). Climate change impacts in Central Asia and their implications for development.
Regional Environmental Change, 17, 1639-1650. doi: 10.1007/s10113-015-0893-z.
[20] Ruppert, D., Welp, M., Spies, M., & Thevs, N. (2020). Farmers' perceptions of tree shelterbelts on agricultural land in rural Kyrgyzstan. *Sustainability*, 12(3), article number 1093. doi: 10.3390/su12031093.
[21] Standal, K., Daloz, A.S., & Kim, E. (2023). A gendered approach to understanding climate change impacts in rural Kyrgyzstan. In R. Sabyrbekov, I. Overland & R. Vakulchuk (Eds.), *Climate change in Central Asia: Decarbonization, energy transition and climate policy* (pp. 123-134). Cham: Springer. doi: 10.1007/978-3-031-29831-8_10.
[22] Sydykova, M. (2017). *Economic growth features in developing countries: The case of the Kyrgyz Republic*.
(Doctoral thesis, University of the Basque Country, Bilbao, Spain).
[23] World Meteorological Organization (WMO). (n.d.). Retrieved from https://www.metoffice.gov.uk/.
[24] Wu, L., & Zheng, H. (2023). Regional climate effects of irrigation under Central Asia warming by 2.0° C. *Remote Sensing*, 15(14), article number 3672. doi: 10.3390/rs15143672.
[25] Yang, J., Wang, Y., Zhang, H., Su, Y., Wu, X., Yan, S., & Yang, S. (2022). Impact of socio-economic and environmental factors on livestock production in Kyrgyzstan. *Frontiers in Environmental Science*, 10, article number 1049187. doi: 10.3389/fenvs.2022.1049187.

[26] Zhunusova, E. (2017). *Agricultural development in the Kyrgyz Republic: The impact of domestic policies, changing macroeconomic conditions, and international migration*. (Doctoral dissertation, Justus-Liebig University Giessen, Giessen, Germany).