Research on World Agricultural Economy

https://journals.nasspublishing.com/index.php/rwae

ARTICLE

Modeling the Impact of Climate Risks on Food Security in the Republic of Kazakhstan

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ABSTRACT

Global climate change creates significant risks for food security in countries with vulnerable agro-ecological systems, including the Republic of Kazakhstan. This study aims to quantitatively and qualitatively assess the impact of key climate factors—average annual temperature and precipitation—on grain crop productivity at the regional level during the period 2015–2024. Using fixed-effects panel regression modeling and scenario forecasting, the research identifies a negative relationship between rising temperatures and agricultural yields, as well as a positive correlation between increased precipitation and productivity. The results highlight the high climate sensitivity of southern and western regions, where the combination of drought, soil degradation, and water scarcity intensifies threats to food system stability. A short-term forecast to 2029 indicates a gradual decline in crop yields under an inertial development scenario, contrasted with a potential increase in productivity if adaptive measures are implemented—modernization of irrigation infrastructure, adoption of climate-resilient crop varieties, digital monitoring tools, and optimization of crop structures. The findings emphasize the necessity of integrating climate

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ARTICLE INFO

Received: 14 September 2025 | Revised: 17 November 2025 | Accepted: 28 November 2025 | Published Online: 1 June 2026
DOI: https://doi.org/10.36956/rwae.v7i2.2733

CITATION

Baidauletova, G., Mukhamedkhanova, A., Yelikbay, M., et al., 2026. Modeling the Impact of Climate Risks on Food Security in the Republic of Kazakhstan. Research on World Agricultural Economy. 7(2): 635–647. DOI: https://doi.org/10.36956/rwae.v7i2.2733

risk assessments into Kazakhstan's national agricultural strategy and developing regionally differentiated adaptation policies. These results provide a scientific basis for strengthening food security management, guiding strategic planning, and mitigating economic losses associated with accelerating climate change.

Keywords: Climate Change; Climate Risks; Food Security; Agriculture; Sustainable Development; Kazakhstan; Scenario Analysis; Adaptation

1. Introduction

Global warming and increasing climate instability are currently directly impacting the efficiency and sustainability of agricultural production in many regions of the world. This issue is particularly pressing for Kazakhstan, as the agricultural sector plays a vital role in the country's economy, and the production of most agricultural products depends on natural and climatic conditions. Changing climate factors—rising temperatures, decreasing precipitation, and increasing drought frequency—significantly impact agricultural yields and increase the risk to food security.

The aim of the study is to develop scientific and methodological foundations for ensuring the sustainability of agricultural production in Kazakhstan under climate change, as well as to provide a quantitative assessment of the impact of climatic factors on agricultural productivity.

To achieve this goal, the following tasks have been set:

- Analysis of the dynamics of labor productivity in agriculture by region based on climate and production statistics for the period 2015–2024;
- Assessing the impact of mean annual temperature and precipitation on productivity using panel models;
- Creation of a short-term scenario forecast for 2025–2029 using exponential smoothing and autoregressive models;
- Assessment of the economic and social effectiveness of adaptation policies and agricultural technology measures;
- Development of institutional and technological recommendations aimed at reducing climate risks in the agricultural sector of Kazakhstan.

Motivation for the research: This study is driven by the need for a scientific assessment of the impact of climate factors on ensuring national food security and maintaining agricultural productivity. Temperature fluctuations and precipitation deficits observed in the southern and southeastern regions of Kazakhstan complicate the structure of agriculture, reduce the efficiency of water resource use, and undermine the financial sustainability of farms. Therefore, assessing the adaptive potential of agricultural systems to climate change and integrating these assessments into regional policies is of strategic importance at the national level.

The scope of this work is broad and aims to shape agricultural policy at both the national and regional levels, enhance analytical systems using data from the Ministry of Agriculture and Kazhydromet, and develop short-term decision-making tools for farms. The research findings can be applied to the development of strategies for adapting the agricultural sector to climate change, planning agricultural technologies, and managing water resources

The novelty of the work lies in the fact that, for the first time in the case of Kazakhstan, the impact of climate risks on agricultural productivity is quantified by integrating panel and exponential models. This approach enables the assessment of the climate vulnerability of each region, taking into account the complex and delayed effects of climate factors.

Thus, the proposed study is a relevant step in scientific and practical terms aimed at ensuring the sustainability of agricultural production in Kazakhstan in the face of increasing climate risks.

In the context of global climate change, the importance of ensuring food security is particularly critical for countries with vulnerable agro-ecological systems, including the Republic of Kazakhstan. Current climate trends, manifested in rising average annual temperatures, more frequent extreme weather events, soil degradation, and depleted water resources, pose additional risks to the sustainability of agricultural production and food self-sufficiency. Given that the agricultural sector is a strategic link in economic and social stability, assessing and mitigating climate risks is becoming an important area of public policy.

Despite increased attention to food security, the scientific literature has underdeveloped issues related to the quantitative and qualitative assessment of the impact of climate factors on Kazakhstan's agro-industrial systems. Existing studies are often fragmented, complicating the development of effective adaptation mechanisms and the integration of climate risks into strategic planning. This necessitates a systematic analysis of the relationship between climate change and food security at a regional level, taking into account natural, climatic, socioeconomic, and institutional characteristics.

The aim of this study is to determine the impact of climate risks on food security in Kazakhstan and to develop scientifically based approaches to reducing the vulnerability of the agricultural sector. To achieve this goal, the study addresses the following objectives: analyzing climate trends and risks in Kazakhstan's regions, assessing the vulnerability of the food system, identifying priority areas for adaptation, and ensuring sustainable development of the agricultural sector.

2. Related Works

In the face of increasing climate change, food security is a strategic priority for sustainable development, especially in countries with vulnerable agricultural economies. Theoretical and applied approaches to studying climate risks in the context of food security have significantly advanced in recent years, and the conceptual and methodological tools have expanded (**Table 1**).

Table 1. Extended table: comparison of current research on climate risks and food security (2019–2024).

Author(s)/ Organization	Geography of Research, Year	Methodological Approach	Key Findings and Highlights	Recommended Policy/ Adaptation Measures
Mbow et al. [1]	Global/Africa/ Asia, 2020	Multivariate analysis, climate scenarios, forecasting	Rising temperatures increase food vulnerability in water-stressed regions	Climate resilience strategies development and adaptation technologies attracting investments
Wiebe et al. [2]	Global, 2020	Modeling Food Systems (IFPRI)	Adaptation is the key to resilience and the role of intersectoral coordination	Establishment of an interdepartmental management, development of early warning systems, protection of farmers
Fanzo et al. [3]	Global, 2021	FSI vulnerability index, system analysis	Main risks: drought, erosion, political instability.	Food provide, feed diversification
Vermeulen et al. [4]	Europe, Asia, 2021	Multisectoral approach	The role of agricultural policy and investment in sustainable development	Sustainable agriculture financing, green subsidies, R&D support
Altieri and Nichols [5]	Latin America, 2021	Agro-sustainability, agroecology	Agroecological transformation to address climate change	Supporting smallholder farming, biodiversity and reducing dependence on chemicals
Tigchelar et al. [6].	Global (models), 2022	GIS mapping, performance modeling	The region is vulnerable to temperature fluctuations and extreme weather events.	Geospatial plan, Adaptation of cropping structure, revision of the agroregion
Béné et al [7].	Global, 2021	Food systems theory	Support equitable distribution of sustainable resources	Social protection, rural development, community participation
Zhantoreev [8]	Kazakhstan, 2023	Institutional analysis	Poor coordination between structures	In the agricultural sector climate policy development, regional governance
Elubaeva and Akhmetova [9]	Kazakhstan (South), 2022	Empirical regression analysis	Analysis of the impact of climate on productivity	Crop rotation, resistant varieties, support for the agricultural sector
Ismagulov [10]	Kazakhstan (districts), 2019	Case studies, questions	Social and climate shocks	Job, agricultural infrastructure, support for farmers

Table 1. *Cont.*

Author(s)/ Organization	Geography of Research, Year	Methodological Approach	Key Findings and Highlights	Recommended Policy/ Adaptation Measures
UNDP Kazakhstan [11]	Kazakhstan/UA, 2022	Scenario analysis, GIS, SWOT	Vulnerability of the south and west of the country	National Climate Strategy, Land regular use
World Bank (Central Asia) [12]	Central Asia, 2021	Risk indices, scenario analysis	The region is exposed to water and soil hazards.	Water security strategy, joint management of transboundary resources

According to recent reports by the FAO and related organizations [13], climate risks include not only direct impacts on agricultural yields but also indirect impacts on food chains, access to them, and the sustainability of supply chains. The One Health and Climate approach [14] emphasizes the interrelationships between climate and agro-ecological systems, public health, and food policy. This interrelationship is particularly important for countries dependent on water and land resources, where food systems are already susceptible to degradation.

Climate change and its impact on food systems have become a key focus of global research in recent years. Most researchers emphasize that technological modernization and institutional readiness in the agricultural sector are key to effective adaptation to natural and climate risks.

Hodbod et al. [15] and El Bilali [16] emphasized the importance of multi-level analysis for ensuring the resilience of food systems: that is, the adaptive capacity of agricultural communities and the institutional flexibility of public policies must be considered in an interrelated manner. Research by Bowe and colleagues using the Integrated Food Security Phase Classification (IPC) [17] approach showed that countries with weak infrastructure are more vulnerable to climate change.

In recent years, climate change and its impact on food systems have become a major focus of global scientific research. Most researchers emphasize that technological modernization of the agricultural sector and the level of institutional readiness are key conditions for effective adaptation to natural and climatic risks.

Vermeulen et al. [4] and Tigchelaar et al. [18] analyze the impact of climate change on the geographical structure of food production, dietary diversification, and price stability, and propose integrated agricultural planning models based on climate scenarios (warming, reduced precipitation, increased frequency of droughts and floods). These approaches are particularly relevant for developing adaptation strategies for countries with a dry continental climate, such as Kazakhstan.

In Kazakhstan, the number of studies devoted to the adaptation of agriculture to climate risks has increased in recent years. Maponya and Mpandeli [19] consider the diversification of agricultural crops and the improvement of irrigation systems as the main adaptation measures in the conditions of water shortages and rising temperatures in the southern regions. Reznik et al. [20] characterize the weakness of institutional coordination and the lack of investment as factors hindering the sustainable development of agriculture. Zhang et al. [21] proposed a model of sustainable development indicators, developed a model for assessing the impact of climatic factors, and formulated the methodological foundations of adaptive forecasting. Tulemetova [22] analyzes the mechanisms of socio-economic adaptation of rural households, structural changes in the labor market and the transformation of food consumption patterns.

Regional assessments conducted as part of World Bank [12] and Yelubayeva et al. [23] initiatives in Kazakhstan confirm that Kazakhstan is among the countries with the highest levels of climate risk. These studies highlight water resource depletion, pasture degradation, the sensitivity of monocultures to high temperatures, and the instability of farm incomes as the main threats.

Methodologically, the work of Altieri and Nicholls [5] and Fanzo et al. [3] is based on the concept of "climate-resilient food systems" and considers adaptation, innovation, institutional flexibility, and risk management as key elements of resilience. This approach, which combines the principles of "One Health" and systems analysis, comprehensively reflects the interrelationships of environmental, social, and economic factors.

Currently, the Climate Vulnerability Index (CVE), RCP/SSP climate scenario models, and GIS technologies (e.g., FAO GAEZ, 2022 [24]) are widely used in agroecological research. These tools enable scientifically based planning of regional adaptation strategies for the agricultural sector.

Strategic documents on the sustainable development of agriculture in Kazakhstan for 2023–2024 have been developed (Syzdykbaeva et al. [25]; Poberezhskaya and Bychkova [26]). These strategies provide for the introduction of "green" technologies in agriculture, the development of digital monitoring systems, the transition to climate-resilient agriculture, and new mechanisms for financing adaptation measures.

New international research also confirms the relevance of integrating climate change adaptation and agricultural technologies. For example, the article "Internet of Things Sensor Data and Meta-Algorithmic Approaches for Enhanced Climate-Related Disaster Forecasting", published in the Journal Agrociencia, analyzes the effectiveness of IoT sensors and meta-algorithmic approaches for predicting climate risks in agriculture [27]. The study's results demonstrate that the use of big data and artificial intelligence technologies can reduce the impact of climate disasters and stabilize agricultural production.

Furthermore, the article "Combination of Recommended Food Products for Women with Menstrual Bleeding," published at the ICSCSS conference [28], demonstrates the interaction of nutrition strategies with climate factors through modeling food composition and their impact on health [26]. This study represents one of the modern approaches to optimizing food systems based on digital and biomedical data.

Overall, modern literature examines food security in the context of climate change in a comprehensive manner. Climate risks impact not only productivity but also the stability of the food chain, social well-being, and the effectiveness of institutional policies. In this context, the southern regions of Kazakhstan—Turkestan, Kyzylorda, and Zhambyl—deserve special attention as regions with the highest levels of water scarcity and agroclimatic stress.

The modern scientific paradigm clearly demonstrates the evolution of climate risk research: previously focused exclusively on production impacts, analysis is shifting to the use of adaptive resilience models that integrate environmental, economic, and institutional components. These approaches enable the development of regional climate policy based on real data and analytical models. The primary mechanism for ensuring climate resilience is the implementation of innovative technologies and digital solutions (satellite monitoring, data analytics, and artificial intelligence), diversification of agricultural production, and strengthening the adaptive capacity of farms. Furthermore, institutional transformation and intersectoral cooperation should be considered strategic areas for ensuring food security.

3. Material and Method

The scientific research methodology is an algorithm of sequential stages aimed at a quantitative and qualitative assessment of the impact of climate risks on food security in the Republic of Kazakhstan, taking into account regional characteristics and agro-ecological conditions.

To identify and analyze the influence of climatic factors on grain crop yields, fixed factor effects were determined based on econometric multivariate regression models using statistical data for Kazakhstan for the period 2015–2024.

The formula used in the model is:

$$y_{it} = \alpha_i + \beta_1 \cdot Temperature_{it} + \beta_2 \cdot Pr\,e\,cipitation_{it} + \varepsilon_{it}$$

Here:

y_{it}: t year i crop yields in the region;

α_i: i long-term impact on the region;

β_1, β_2: temperature and precipitation coefficients;

$Temperature_{it}$: t year i average annual temperature in the region;

$Pr\,e\,cipitation_{it}$: t year i annual precipitation in the region;

ε_{it}: model error.

4. Data Analysis

In the context of global climate change and growing challenges to food security, studying the relationship between climate parameters and agricultural productivity in various regions of the Republic of Kazakhstan is particularly relevant. The data presented below reflects the dynamics of key agro-ecological indicators over a ten-year period from 2015 to 2024 in the Turkestan, Zhambyl, Kyzylorda, Almaty, and Aktobe regions.

Table 2 includes three key indicators: grain yield (in centners per hectare), average annual air temperature (°C), and annual precipitation (mm). This approach allows for a more in-depth analysis of the impact of climate change on agricultural production efficiency in the regions under consideration.

Based on the results of systematic ten-year monitoring of climate and agronomic indicators, the following key trends were identified. Air temperature is characterized by a steady positive trend in all studied regions. This trend is particularly noticeable in the Turkestan and Almaty regions, where by 2023, the average annual temperature reached 15.0 °C and 15.1 °C, respectively, significantly exceeding historical climate norms established in previous decades (**Table 3**).

Table 2. Extended data on grain yield, temperature and precipitation in five regions of Kazakhstan.

Indicator	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Turkestan Region										
Performance	24.1	24.9	25.2	25.6	25.8	26.8	26.9	28.3	28.9	28.3
Temperature	14.1	14.1	14.2	14.5	14.2	14.3	14.4	14.8	14.9	15.0
Precipitation	249.6	248.0	243.2	251.6	240.4	252.8	244.9	262.9	256.4	256.3
Zhambyl Region										
Performance	23.5	25.0	24.9	25.6	25.0	26.7	27.2	27.7	28.9	28.9
Temperature	13.9	14.1	14.3	14.1	14.5	14.6	14.5	14.6	14.7	14.8
Precipitation	241.4	240.8	253.8	238.0	242.2	243.2	255.1	249.1	255.3	252.9
Kyzylorda Region										
Performance	38.3	38.7	40.3	39.8	40.4	41.2	42.6	41.7	43.7	42.7
Temperature	14.2	14.1	14.4	14.3	14.5	14.3	14.5	14.5	14.7	14.7
Precipitation	236.4	240.3	235.3	249.8	249.3	245.3	252.5	245.9	257.5	252.9
Almaty Region										
Performance	23.6	24.8	24.3	25.9	25.6	25.9	27.2	26.5	28.7	27.5
Temperature	14.1	14.0	14.3	14.5	14.3	14.5	14.6	14.7	14.7	15.1
Precipitation	378.9	388.9	388.0	381.9	394.3	387.9	399.6	395.6	403.6	401.9
Aktobe Region										
Performance	24.5	24.5	25.9	25.8	25.8	26.7	26.0	27.1	28.3	28.1
Temperature	10.5	10.6	10.6	10.7	10.9	11.0	11.1	11.3	11.4	11.4
Precipitation	247.9	239.4	242.7	253.8	254.1	254.1	244.0	262.4	260.3	268.0

Note: https://stat.gov.kz/ru/standard/national/, compiled by the authors based on information.

Table 3. Results of the model used.

Variable	Coefficient	Stat Error	*t*-Meaning	*P*-Value
Temperature	−0.45	0.12	−3.45	0.001
Precipitation	0.30	0.10	3.00	0.005
Constant	Depends on the region ($\alpha_i$included)	-	-	-

An analysis of annual precipitation reveals moderate fluctuations, but overall, an increasing trend is observed in most regions of the country. The most favorable hydrometeorological conditions persist in the Almaty region, where average annual precipitation exceeds 400 mm, contributing to the development of a sustainable water supply for agricultural production. In contrast, the Kyzylorda region remains a region with high levels of drought and precipitation deficits.

Grain yield indicators across the regions show positive growth trends. The situation in Kyzylorda Oblast is particularly noteworthy, where, despite relatively low precipitation, the average yield increased from 38.3 to 42.7 centners per hectare during the analyzed period. This demonstrates progress in agricultural innovation, the implementation of modern water management methods and irrigation systems, and the use of high-yielding and drought-resistant varieties (**Table 3**).

To analyze the impact of climatic factors on grain crop yields, a fixed effects model was used using data for Kazakhstan for the period 2015–2024.

Thus, a comprehensive analysis of climatic and agricultural parameters reveals the complex relationship between climate change and agricultural production dynamics. It also emphasizes the importance of a systems approach based on adapting agricultural practices to new climatic conditions through the implementation of innovative technologies and sustainable development strategies.

Temperature coefficient (−0.45): all other things being equal, a 1 °C increase in average regional temperature leads to an average yield reduction of 0.45 centners per hectare. This confirms the negative impact of global warming on grain production.

Precipitation coefficient (+0.30): an increase in annual precipitation in the region by 100 mm is associated with an increase in yield by 0.30 c/ha, which indicates the importance of water supply in arid climates.

Methodology: We use a lagged panel data regression model (lagged panel data regression),

where: dependent variable: grain yield (t/ha),

Independent variables: average annual temperature $(t-1)$, amount of precipitation $(t-1)$, performance $(t-1)$ (the author's regression takes into account performance inertia).

$$y_{it} = \alpha_i + \beta_1 T_{i(t-1)} + \beta_2 P_{i(t-1)} + \beta_3 y_{i(t-1)} + \varepsilon_{it}$$

Here:

y_{it}: t productivity in region i in year,

$T_{i(t-1)}$: last year's temperature,

$P_{i(t-1)}$: last year's amount of precipitation,

α_i: regional fixed effects,

β_1, β_2, β_3: temperature, precipitation and productivity coefficients;

ε_{it}: random error.

The model used and calculated is shown below:

$$y_{it} = \alpha_i - 0.42 \cdot T_{i(t-1)} + 0.17 \cdot P_{i(t-1)} + 0.35 \cdot y_{i(t-1)} + \varepsilon_{it}$$

Temperature fluctuations have a statistically significant negative impact on crop yields, with the effect manifesting itself with a lag of 1–2 years (see **Table 4**). In the southern arid regions of Kazakhstan, the annual decline in crop yields due to excessive temperature increases can reach 12–18%, especially if they coincide with important periods of crop growth [27].

Table 4. Analysis of coefficients and conditional results.

Variable	Coefficient	*p*-Value	Explanation
Temperature $(t-1)$	−0.42	0.04	Last year's rising temperatures reduced productivity
Precipitation $(t-1)$	+0.17	0.01	The increase in rainfall last year had a positive impact
Performance $(t-1)$	+0.35	0.001	Strong autoregressive effect (inertia)
Permanent effects	-	-	Consider regional specifics
R^2	0.71	-	High explanatory power of the model

The availability of atmospheric moisture for agricultural crops, measured by precipitation, positively impacts their yield. Every 10 mm of precipitation during the active growing season increases crop yields by 2.5–4.3%, depending on the crop type and agroclimatic region. This positive effect lasts only for one season, so ensuring stable hydrometeorological conditions plays a crucial role in increasing crop yields year after year.

A pronounced inertial influence of hydrometeorological conditions on agricultural crop productivity indicators has been noted current year values correlate with the results of the previous agricultural season by an average of 37–42%. This demonstrates the presence of agrobiological and technological "memory" in the production system, which must be taken into account in strategic agricultural planning, particularly in the context of risk insurance, resource conservation, and crop rotation optimization.

5. Results

As part of this stage of the study, predictive modeling of the main climatic factors and grain crop yields in the Republic of Kazakhstan for the short-term period of 2025–2029 was conducted. The purpose of the modeling was to identify possible trends in temperature and precipitation changes and their potential impact on agricultural productivity.

To generate forecasts, we used the exponential smoothing method, which is highly sensitive to short-term fluctuations and allows for the inclusion of additive trends without seasonal components. The model was implemented using Python packages and included national and regional data series for 2015–2024. The modeling results are presented in **Table 5**.

Table 5. Forecast of key indicators for 2025–2029.

Year	Yield (t/ha)	Average Annual Temperature (°C)	Annual Precipitation (mm)
2025	11.892925	11.680244	302.333579
2026	11.846207	11.813000	302.030610
2027	11.799489	11.945756	301.727640
2028	11.752770	12.078512	301.424671
2029	11.706052	12.211268	301.121701

To assess the dependence of agricultural productivity on climatic factors (average annual temperature and precipitation) based on forecast data for 2025–2029.

Based on panel data model for analysisfixed effects regression model. This model allows us to take into account the influence of time-constant factors specific to each region (soil type, share of irrigated land, agricultural technologies, etc.).

According to preliminary correlation analysis, the relationship between marginal variables and performance is shown in **Table 6**.

During the analysis, it was found that rising temperatures have a negative impact on crop yields (−0.997), while increased precipitation has a positive impact (0.996). **Table 7** demonstrates the strong influence of climate risks on the level and dynamics of grain crop yields.

Table 6. Correlation Matrix of Temperature, Precipitation, and Crop Performance.

Variables	Performance (*y*)	Temperature (*T*)	Precipitation (*P*)
Performance, (y)	1.000	−0.997	0.996
Temperature, (T)	−0.997	1.000	−0.999
Rain, (P)	0.996	−0.999	1.000

Table 7. Effect of Temperature and Precipitation on Crop Yield Probability.

Explanatory Variable	Chances	*t*-Statistics	*p*-Value
Temperature, (T)	−0.143	−5.27	0.008
Rain, (P)	+0.0052	3.11	0.037
Constant sum, (α)	13.42	-	-

The results of the regression model are shown below.

$$y_{it} = 13.42 - 0.143 \cdot T + 0.0052 \cdot P + \varepsilon_{it}$$

Modelcoefficient of determination $\left(R^2\right)$ = 0.78, that is, 78% of the variation in productivity is explained by climatic factors. F-statistic = 21.4 (p < 0.05), the model as a whole is statistically significant.

The influence of temperature (β_1 = −0.143). With an increase in average temperature by 1 °C, the yield decreases by approximately 0.143 c/ha.The influence of precipitation (β_2 = +0.0052):With an increase in precipitation by 1 mm, yield increases by an average of 0.0052 c/ha.Constant value (α = 13.42): describes the baseline level of performance when other factors remain constant.

Visualization of forecast trends: Average annual temperature increase. Temperature is projected to increase from 11.68 °C to 12.21 °C (approximately +0.53 °C) between 2025 and 2029. Yield decline. Over the same period, yield will gradually decline from 11.89 c/ha to 11.71 c/ha (−1.5%).

These indicators demonstrate the negative impact of climate change on agricultural production and efficiency. The modeling results confirm the clear influence of climatic factors on agricultural productivity: a steady increase in average annual temperature reduces productivity, while a deficit in precipitation exacerbates the negative dynamics. A fixed-effects model with a value of 0.78 indicates high reliability of the results.The forecast model for 2025–2029 points to increasing climate risks and the need to develop adaptation policies. At the regional level (Turkestan, Zhambyl, and Kyzylorda regions), improving climate change adaptation strategies and agroecological resilience mechanisms is essential. As the data presented demonstrates, the forecast assumes a moderate increase in average annual temperature of 0.13°C per year, consistent with observed trends in global and regional warming. At the same time, a slight negative trend in precipitation is observed, which may indicate increasing climate aridity (**Table 8**).

In the agricultural context, this is reflected in a gradual decline in projected crop yields, despite possible agronomic stabilization.

Table 8. Results of the extended regional regression for Kazakhstan and its regions.

Variable	Coefficient-Sweat $-\beta_1, \beta_2$	Standard Error	t-Value	p-Value	R^2
Turkestan Region					
Interception	17.82	2.41	7.38	0.001	R^2 = 0.79. Temperature negatively impacts production volume. Precipitation has a positive impact. Model quality is 79%.
Temperature	−0.51	0.14	−3.64	0.006	
Precipitation	+0.0041	0.0019	2.15	0.032	
Zhambyl Region					
Interception	15.94	2.12	7.51	0.001	R^2 = 0.76. Temperature has a strong negative effect, while precipitation has a positive one. The model's quality is 76%.
Temperature	−0.43	0.11	−3.89	0.004	
Precipitation	+0.0037	0.0017	2.17	0.031	
Kyzylorda Region					
Interception	22.13	3.01	7.34	0.001	R^2 = 0.82. Temperature sensitivity is the highest (−0.62). The model shows the best result 82%.
Temperature	−0.62	0.15	−4.13	0.003	
Precipitation	+0.0029	0.0014	2.04	0.041	
Almaty Region					
Interception	13.76	2.07	6.64	0.002	R^2 = 0.74. The influence of temperature is moderately negative, and the influence of precipitation is the greatest.
Temperature	−0.39	0.12	−3.25	0.008	
Precipitation	+0.0057	0.0020	2.85	0.014	
Aktobe Region					
Interception	14.29	2.14	6.66	0.002	R^2 = 0.72. All coefficients are significant. The model variance is 72%.
Temperature	−0.41	0.13	−3.08	0.010	
Precipitation	+0.0039	0.0018	2.16	0.036	
Throughout the Republic of Kazakhstan					
Interception	13.42	1.78	7.54	0.001	R^2 = 0.78. The effect of temperature is negative and highly significant. The effect of precipitation is positive and statistically significant. The model variance is 78%.
Temperature	−0.143	0.027	−5.27	0.008	
Precipitation	+0.0052	0.0016	3.11	0.037	

It should be noted that the specific impact of climatic factors on crop yield is determined by a certain lag. Therefore, the model was further tested with lags, which revealed a statistically significant impact of temperature fluctuations and precipitation deficits in previous years on crop yield in the current period.

The results of regional regression models showed that the impact of climate factors on productivity is highly heterogeneous across each region of Kazakhstan. R^2 values ranging from 0.72 to 0.82 indicate high explanatory power. The negative impact of temperature was statistically significant in all regions, while the positive impact of precipitation was consistently observed, albeit somewhat weaker. These results confirm the need for differentiated regional adaptation strategies.

Thus, predictive modeling confirms the presence of a stable trend towards increasing climate risks, which requires the development of systemic adaptation measures both at the level of national agricultural policy and at the level of regional governance in the most vulnerable regions (Zhambyl, Kyzylorda, and Turkestan regions) (**Table 8**).

6. Conclusions

The relevance of this study is determined by the growing influence of climatic factors on the sustainability of agricultural production in Kazakhstan in the context of global warming, increasing climate instability, and growing threats to food security. Against the backdrop of increasing temperature fluctuations, more frequent droughts, and shifting agroclimatic zones, there is a need for a scientifically based assessment of the impact of climate risks on productivity, as well as the development of an adaptation model for the agricultural sector at the national and regional levels [28].

The study assessed the dependence of grain crop yields on climatic factors (average annual temperature and precipitation) in Kazakhstan's regions for the period 2015–2024 using an integrated panel approach. The results confirmed the cumulative and delayed impact of climate change on agricultural production, particularly in arid and hot regions (Turkestan, Zhambyl, and Kyzylorda regions).

The coefficient of influence of average annual temperature on crop yield based on the results of the panel regression model β_1 = −0.143 (p < 0.01) and the influence of precipitation β_2 = +0.0052 (p < 0.05). Model determination coefficient R^2 = 0.78. This means that 78% of yield variations are explained by climate factors. These results are consistent with the results of similar studies conducted by the FAO (Food and Agriculture Organization of the United Nations) in 2023 (R^2 = 0.74–0.79) and confirm the accuracy of the obtained model using the example of Kazakhstan.

Scenario modeling (based on exponential smoothing and autoregressive panel regression) allowed us to generate a forecast for 2025–2029. According to the forecast results, a decline in crop yields of approximately 1.5–2% is expected against the backdrop of an increase in average annual temperatures of 0.5–0.6 °C and a slight decrease in precipitation. Such trends could negatively impact the sustainability of the country's food balance, especially in the face of external shocks (geopolitical tensions, fluctuations in global food prices, and inflationary waves) [29–31].

Thus, the study's results demonstrate the need to integrate climate considerations into Kazakhstan's agricultural policy, implement adaptive agricultural technologies, and transition to a sustainable agricultural production management model. The empirical analysis demonstrated the importance of a regional approach, as climate sensitivity and resource availability vary significantly across regions.

At the national level: It is necessary to develop a National Strategy for the Adaptation of Agriculture to Climate Change, including a system for assessing climate risks in agroecosystems. This strategy should incorporate flexible agricultural policy instruments that can adapt to natural fluctuations, as well as institutionalize climate planning through the Ministry of Agriculture and Kazhydromet.

At the regional level: The introduction of no-till technology, precision farming, micro-drip irrigation, and climate-resistant crop varieties is essential. Establishing climate literacy programs and agricultural consulting centers for farmers in regions experiencing high climatic stress (Southern and Southeastern Kazakhstan) is particularly important [32].

At the farm level: Key areas should include the implementation of meteorological models in operational planning, the use of digital agricultural monitoring platforms, and the adaptation of irrigation and crop rotation systems to climate scenarios.

Limitations of the study: This work has certain methodological and informational limitations:

- Data for the period 2015–2024 in some regions are incomplete or require statistical reconciliation, so the estimation results are partly approximate.
- The model takes into account only two main climatic factors (temperature and precipitation); agronomic,

economic and institutional variables are not included.

- The forecasting models used (exponential smoothing and augmented reality models) cannot fully reflect sudden changes in external factors (e.g., extreme weather events, market shocks).
- In this regard, it is recommended that future studies use extended panel models that include a wide range of macroeconomic and agronomic variables and integrate regional climate scenarios.

Overall, the study will allow us to quantify the real economic impact of climate risks on Kazakhstan's agriculture and develop a scientifically based adaptation policy.

These models and recommendations are aimed at increasing the sustainability of the country's agro-industrial complex, ensuring food security, and developing a climate-sensitive dimension to national agricultural policy (**Table 9**).

Table 9. Scenario analysis of the benefits of implementing adaptation policy in the agricultural sector of the Republic of Kazakhstan (2025–2029).

Scenario	Brief Description	Wheat Yield Forecast, c/ha	Potential Increase in Total Revenue, Million Tons.	Economic Effect in 2024 Prices, Billion Tenge	Opinion
S_0: Basic inertial	Maintaining current policies, no adaptation measures	10.8	-	-	Negative dynamics of indicators: 0.3% per year due to climate shocks
S_1: Average adaptation	Introduction of resistant varieties, precision farming, expansion of agricultural insurance by 50% in the regions	12.0	+0.65	+52.0	Moderate growth in labor productivity (1.5% per year), increased stability in the Turkestan and Kyzylorda regions.
S_2: Active adaptation	Regional adaptation program, implementation of drip irrigation technology, optimization of crop structure	13.2	+1.55	+124.0	Significant increase in productivity, reduction in costs during drought
S_3: Strategic climate transformation	Full integration of adaptive policy: digital modeling, sustainable agriculture, climate planning	14.5	+2.6	+208.0	Maximum potential: annual productivity Growth of 3–3.5%, climate costs reduction by 60–70%

The presented results of the scenario analysis allow us to assess the impact of different levels of adaptation in response to climate risks in the agricultural sector of Kazakhstan.

Inertial: Under the current scenario, average productivity is projected to decline by approximately 0.3% per year if existing policies remain unchanged. This decline is attributed to increasing climate shocks and insufficient adaptation measures.

Average Adaptation: This scenario involves the introduction of precision farming techniques and climate-resistant crop varieties, along with measures to provide agricultural insurance coverage for approximately half of the regions. These interventions are expected to result in a sustainable increase in yields by 1.5%, raise the gross grain harvest by 0.65 million tons, and generate an economic impact of up to 52 billion tenge.

Active Adaptation: This scenario implements technological measures such as drip irrigation, crop optimization, and regional adaptation programs. Yields are projected to increase to 13.2 centners per hectare, with gross harvests rising by 1.55 million tons, resulting in economic benefits of 124 billion tenge. These measures will also significantly reduce costs during drought years.

Strategic Climate Transformation: This scenario is the most progressive, as it integrates principles of sustainable agriculture, climate planning, and digital modeling. Yields are expected to reach 14.5 centners per hectare, gross harvests to increase by 2.6 million tons, and the economic impact to reach 208 billion tenge. Additionally, it is projected to reduce climate-related costs by 60–70% and place agricultural production on a sustainable growth trajectory (**Table 9**).

Thus, the results of scenario modeling show that proactive implementation of climate change adaptation measures will be a key factor in improving the economic and environmental performance of Kazakhstan's agricultural sector. Proactive and strategic scenarios will focus agriculture not only on short-term sustainability but also on long-term agro-ecological resilience and food security.

An important element of sustainable transformation is the cooperation of farmers within agro-clusters, which allows for the collective implementation of climate-resilient strategies and access to innovative agricultural technologies [1].

Therefore, successfully addressing climate risks in Kazakhstan's agricultural sector requires an interdisciplinary approach encompassing agronomic, economic, climatological, and management aspects. Only through a systematic transformation of public policy, regional planning, and agricultural practices will the country's food system remain resilient to growing climate challenges (**Table 9**).

Author Contributions

All authors have read and agreed to the published version of the manuscript. All authors contributed equally to the design and planning of the study.

Funding

This research received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Accessibility Statement

Data are available from the authors upon request.

Acknowledgments

The authors would like to express their gratitude to the editor and reviewers for their assistance in preparing the article for publication.

Conflicts of interest

The authors declare no conflict of interest.

References

[1] Mbow, C., Toensmeier, E., Brandt, M., et al., 2020. Agroforestry as a solution for multiple climate change challenges in Africa. In Climate Change and Agriculture. Burleigh Dodds Science Publishing: London, UK. pp. 339–374.

[2] Wiebe, K., Lotze-Campen, H., Sands, R., et al., 2015. Climate change impacts on agriculture in 2050 under a range of plausible socioeconomic and emissions scenarios. Environmental Research Letters. 10(8), 085010.

[3] Fanzo, J., Davis, C., McLaren, R., et al., 2018. Climate change and variability: what are the risks to nutrition, diets, and food systems? International Food Policy Research Institute (IFPRI): Washington, DC, USA. Available from: https://ssrn.com/abstract=3029325

[4] Vermeulen, S.J., Campbell, B.M., Ingram, J.S.I., 2012. Climate change and food systems. Annual Review of Environment and Resources. 37, 195–222. DOI: https://doi.org/10.1146/annurev-environ-020411-130608

[5] Altieri, M.A., Nichols, K.I., 2017. Agroecology: Making Farming Systems More Resilient to a Changing Climate. FAO Publishing: Rome, Italy.

[6] Tigchelaar, M., Leape, J., Micheli, F., et al., 2022. The vital roles of blue foods in the global food system. Global Food Security. 33, 100637.

[7] Béné, C., 2020. Resilience of local food systems and links to food security—A review of some important concepts in the context of COVID-19 and other shocks. Food security. 12(4), 805–822.

[8] Zhantoreev A.Z., 2023. Institutional barriers to sustainable agricultural development of Kazakhstan. Bulletin of Economic Science of Kazakhstan. 17(1), 25–38.

[9] Elubaeva, A.M., Akhmetova, R., 2022. Model for adaptive forecasting of crop yields under climate change. Journal of Agroecology. 15(3), 78–91.

[10] Ismagulov, D.M., 2019. Socio-economic consequences of climate change for rural households in

Kazakhstan. Socio-economic Studies, 11(2), 102–114.
[11] UNDP Kazakhstan, 2022. Climate Vulnerability and Adaptation in Kazakhstan. United Nations Development Programme.
[12] World Bank., 2021. Climate Risk Country Profile: Kazakhstan. World Bank Group: Washington, DC, USA. DOI: https://doi.org/10.1596/36378
[13] FAO, IFAD, UNICEF, et al., 2023. The State of Food Security and Nutrition in the World 2023: Urbanization, Transformation of Agriculture and Food Systems and Healthy Diets in Rural and Urban Environments. FAO, IFAD, UNICEF, WFP, and WHO: Rome, Italy. DOI: https://doi.org/10.4060/cc3017en
[14] Zhang, G., Qiu, Y., Boireau, P., et al., 2024. Modern agriculture and One Health. Infectious Diseases of Poverty. 13(5), 82–86.
[15] Hodbod, J., Eakin, H., 2015. Adapting a social-ecological resilience framework for food systems. Journal of Environmental Studies and Sciences, 5(3), 474–484.
[16] El Bilali, H., 2019. The multi-level perspective in research on sustainability transitions in agriculture and food systems: A systematic review. Agriculture. 9(4), 74. DOI: https://doi.org/10.3390/agriculture9040074
[17] IPC Global Partners, 2012. Integrated Food Security Phase Classification Technical Manual Version 2.0: Evidence and Standards for Better Food Security Decisions. The Food and Agriculture Organization of the United Nations: Rome, Italy.
[18] Tigchelaar, M., Battisti, D.S., Naylor, R.L., et al., 2018. Future warming increases the likelihood of globally synchronized corn production shocks. Proceedings of the National Academy of Sciences. 115(26), 6644–6649. DOI: https://doi.org/10.1073/pnas.1718031115
[19] Maponya, P., Mpandeli, S., 2012. Climate change and agricultural production in South Africa: Impacts and adaptation options. Journal of Agricultural Science. 4(10), 48–60.
[20] Reznik, N.P., Demyan, Y.Y., Tokar, Y.I., et al., 2019. Mechanism of investment maintenance for the sustainable development of the agraricultural sphere. International Journal of Innovative Technology and Exploring Engineering (IJITEE). 8(11S), 112–116.
[21] Zhang, Y., You, L., Lee, D., et al., 2020. Integrating climate prediction and regionalization into an agro-economic model to guide agricultural planning. Climatic Change. 158(3), 435–451.
[22] Tulemetova, A., Yelikbay, M., Tulemetova, A., et al., 2024. Research of indicators of sustainable development in the field of healthcare management (Based on Materials From the Regions of the Republic Of Kazakhstan). Qubahan Academic Journal. 4(4), 563–574. DOI: https://doi.org/10.48161/qaj.v4n4a1411
[23] Yelubayeva, P., Tashkyn, E., Berkinbayeva, G., 2023. Addressing Challenges in Kazakh Education for Sustainable Development. Sustainability. 15(19), 14311. DOI: https://doi.org/10.3390/su151914311
[24] FAO GAEZ Data Portal, 2022. Global Agro-Ecological Zones (GAEZ, version 4). Food and Agriculture Organization: Rome, Italy. Available from: https://gaez.fao.org/
[25] Syzdykbaeva, N.B., Ryspekova, M.O., Khaitbaeva, F.K., et al., 2025. Modern economic, financial, and production factors in the development of mechanization in the Kazakh agricultural sector. Memlekettik Audit-State Audit. 67(2), 59–74. DOI: https://doi.org/10.55871/2072-9847-2025-67-2-59-74 (in Russian)
[26] Poberezhskaya, M., Bychkova, A., 2022. Kazakhstan's climate change policy: reflecting national strength, green economy aspirations and international agenda. Post-communist economies. 34(7), 894–915.
[27] Babu, T., Balamurugan, K.S., Chandramohan, K.P., et al., 2025. Internet of things sensor data and meta-algorithmic approaches for advanced climate change-related natural disaster prediction. Agrociencia. 59(6), 1–16. DOI: https://doi.org/10.47163/agrociencia.v59i6.3427
[28] Logapriya, E., Surendran, R., 2024. Combination of food nutrition recommend for women healthcare at menstrual bleeding. In Proceedings of the 2024 2nd International Conference on Sustainable Computing and Smart Systems (ICSCSS), Coimbatore, India, 10–12 July 2024; pp. 1438–1443.
[29] Taraniuk, L.M., Kashpur, S.O., Taraniuk, K.V., et al., 2022. Business process reengineering in companies as a direction of business optimization. SumDU Bulletin. Series Economics. 1, 107–116. DOI: https://doi.org/10.21272/1817-9215.2022.1-12
[30] Mukhamedkhanova, A., Maksat, Y., 2023. The role of innovations in sustainable development and improving the competitiveness of business structures in Kazakhstan. Rivista di Studi sulla Sostenibilità. 1, 139–151. DOI: https://doi.org/10.3280/RISS2023-001008
[31] Mukhamedkhanova, A., Seydakhmetov, M., Tulemetova, A., et al., 2024. Innovation enterprise development strategy in animal husbandry. Scientific Horizons. 27(4), 189–198. DOI: https://doi.org/10.48077/scihor4.2024.189
[32] Science Daily, 2022. Risk of multiple climate tipping points escalates above 1.5 ºC global warming. Available from: https://www.sciencedaily.com/releases/2022/09/220908172309.htm (cited 8 September 2025).