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SUSTAINABLE DEVELOPMENT OF RURAL AREAS IN THE TURKESTAN REGION UNDER CLIMATE CHANGE CONDITIONS

This article examines the impact of rural infrastructure transformation on the sustainable development of rural areas in the Turkestan region under conditions of climate change. The relevance of the study is driven by the increasing intensity of climate risks, including rising temperatures, more frequent droughts, and limited water resources, which significantly affect agricultural production in the southern regions of Kazakhstan. The aim of the study is to provide a quantitative assessment of the impact of infrastructure development on rural sustainability and to identify the structural significance of individual infrastructure components. The methodological framework is based on econometric analysis, including regression and panel data models using data for the period 2010–2025. The results indicate that the development of rural infrastructure has a statistically significant positive effect on the sustainability of the agricultural sector. At the same time, water infrastructure makes the largest contribution to sustainability, while digitalization acts as a factor enhancing adaptive capacity. Structural imbalances have been identified, characterized by the rapid development of digital technologies alongside insufficient modernization of water management systems.The findings confirm that the sustainability of rural areas is shaped by the complex interaction of infrastructure, climate, and socio-economic factors. The practical significance of the study lies in the potential application of its results in the development of regional policies for sustainable development and the adaptation of agriculture to climate change.

Keywords: *sustainable development, rural areas, infrastructure, climate change, agriculture, digitalization, water resources, Turkestan region*
Кілт сөздер: *тұрақты даму, ауылдық аумақтар, инфрақұрылым, климаттық өзгерістер, аграрлық сектор, цифрландыру, су ресурстары, Түркістан облысы*
Ключевые слова: *устойчивое развитие, сельские территории, инфраструктура, климатические изменения, аграрный сектор, цифровизация, водные ресурсы, Туркестанская область*

Introduction. In the context of increasing global climate change, the issue of sustainable development of rural areas becomes particularly important for ensuring food security and economic stability in agricultural regions. Rising temperatures, more frequent dry periods, and degradation of land resources have a significant impact on the functioning of agriculture, especially in regions with arid and semi-arid climates [1, 2]. In this context, the sustainability of rural areas is considered not only as the ability of the agricultural system to maintain a stable level of production, but also as its ability to adapt to changing natural and climatic conditions [3].

Modern research shows that the development of rural infrastructure, which provides access to resources, markets, and technologies, is a key factor in ensuring the sustainability of agriculture [4, 5]. In agricultural regions, water infrastructure, including irrigation and water supply systems, plays a particularly important role, as it directly affects agricultural productivity and reduces dependence on climate fluctuations [2]. On the other hand, transport infrastructure contributes to reducing logistics costs and expanding markets, while digital infrastructure provides access to information and modern technologies for managing agricultural production [6, 7].

However, scientific literature also highlights the existence of structural imbalances in the development of infrastructure, which manifest themselves in the rapid growth of digital technologies while the basic resource infrastructure, particularly water infrastructure, remains underdeveloped [5, 8]. This limits the overall sustainability of agriculture and reduces the effectiveness of innovation implementation.

In Kazakhstan, this issue is particularly relevant due to the high dependence of the agricultural sector on natural and climatic conditions and irrigation systems [2, 9]. The Turkestan region, which has significant agricultural potential but is also highly vulnerable to climate risks, serves as a representative case study of the relationship between infrastructure development and the sustainability of rural areas.

The purpose of this study is to quantify the impact of rural infrastructure on the sustainable development of rural areas in the Turkestan region in the context of climate change. To achieve this goal, the following objectives are addressed: analyzing the dynamics of infrastructure development in the region; identifying the relationship between infrastructure and the sustainability of the agricultural sector; constructing econometric models, and interpreting the results obtained.

The study is based on econometric analysis methods, including the construction of regression and panel models, which allow for the consideration of the influence of infrastructure, climate, and socio-economic factors on the sustainability of rural areas.

Literature review. The study of sustainable development of rural areas in the context of climate change is advisable to be built in the logic of a gradual transition from classical theoretical foundations to modern studies of the infrastructure transformation of the agricultural sector. This approach allows us to trace the evolution of scientific understanding of the role of rural infrastructure: from an auxiliary element of production support to a key systemic factor in agricultural adaptation, which determines the sustainability, productivity, and ability of territories to withstand climate risks.

In classical economic theory, the starting point of the analysis of agriculture remains the concept of productivity and resource availability, in which infrastructure is considered as a factor of reducing transaction costs and increasing the efficiency of resource use. In more recent works related to the development of new economic geography, infrastructure acquires a spatial dimension and is considered as a key element of the integration of territories and ensuring economic connectivity [6]. In this context, the development of infrastructure becomes not only a condition for economic growth, but also a factor in reducing regional disparities.

Significant contributions to the development of this issue have been made by studies conducted by international organizations, primarily the World Bank, which have shown that infrastructure development is directly related to the growth of agricultural productivity and the increase in the income of rural populations [2]. In more recent works, the focus has shifted from the quantitative expansion of infrastructure to its quality and efficiency of use, which is particularly important in the context of limited resources and increasing climate risks.

The next stage of scientific thought is associated with the inclusion of the climate factor in the analysis of the agricultural sector. The IPCC reports emphasize that changes in temperature patterns, increased frequency of droughts, and instability in water supply have a systemic impact on agriculture, reducing its sustainability and increasing the level of uncertainty [1]. In this regard, the sustainability of rural areas begins to be viewed as the ability of the agricultural system to adapt to climate change, and infrastructure is considered as a key tool for such adaptation.

Water infrastructure takes on particular importance in this logic. According to FAO studies, access to irrigation systems is one of the most effective mechanisms for reducing the vulnerability of agriculture to climate change [2]. In arid climates, water resources become a defining factor of sustainability, as they ensure the stability of production and reduce dependence on weather fluctuations. Modern studies emphasize that the modernization of irrigation systems and increasing the efficiency of water use are priority areas of adaptation policy.

In parallel, research on the role of transport infrastructure is also developing. Empirical studies show that improving transport accessibility helps to reduce logistics costs, expand markets, and increase the competitiveness of agricultural products [6]. However, some studies suggest that the effect of transport infrastructure is indirect and manifests itself through increased economic connectivity rather than directly through increased productivity. In recent years, there has been a growing focus on digital infrastructure as a new factor in the sustainability of rural areas. Research has shown that digitalization of agriculture can improve access to information, promote the use of precision agriculture, and reduce the uncertainty associated with climate risks [7]. However, it is important to note that the impact of digitalization depends on the level of development of basic infrastructure, particularly water and transportation infrastructure, which highlights the complementary nature of different infrastructure components. In more recent studies, there has been a growing recognition of the structural imbalances in infrastructure development. In particular, some countries have experienced rapid advancements in digital technologies while neglecting the modernization of basic infrastructure, leading to the formation of an "infrastructure gap" [5]. In such circumstances, digital solutions may not achieve the desired results due to resource constraints, particularly water scarcity. In the context of Kazakhstan, this issue is particularly relevant. Research on the development of the agricultural sector in Kazakhstan has shown that the country's agriculture is highly dependent on natural and climatic conditions and irrigation infrastructure [10]. Kazakhstani researchers have emphasized that the deterioration of water management systems and the lack of modernization are key constraints to the sustainable development of rural areas [11]. Additionally, it has been noted that the development of infrastructure in Kazakhstan is uneven, leading to regional disparities and reducing the overall efficiency of the agricultural sector [12, 13].

Main part. To quantify the impact of rural infrastructure transformation on the sustainable development of rural areas in the Turkestan region under climate change conditions, an econometric approach based on regression and panel data models is applied.

The empirical dataset has a panel structure and includes data for the districts (rayons) of the Turkestan region over the period 2010–2025. The sample consists of N = 17 territorial units observed over T = 16 years, forming a balanced panel with 272 observations. Such a structure allows capturing both spatial heterogeneity across districts and temporal dynamics of infrastructure development and climate change, which justifies the use of panel data models.

The baseline regression model is specified as follows:

$$S_{it} = \beta_0 + \beta_1 INFRA_{it} + \gamma X_{it} + \varepsilon_{it}$$

where S_{it} represents the rural sustainability index for district i in year t, $INFRA_{it}$ is the integrated infrastructure index, X_{it} is a vector of control variables, β_0 is a constant, β_1 and γ are parameters to be estimated, and ε_{it} is the error term.

To assess the contribution of individual infrastructure components, the extended model is defined as:

$$S_{it} = \beta_0 + \beta_1 WATER_{it} + \beta_2 TRANSP_{it} + \beta_3 DIGITAL_{it} + \gamma X_{it} + \varepsilon_{it}$$

where:

$WATER_{it}$ reflects the level of water availability;

$TRANSP_{it}$ captures the condition of transport infrastructure;

$DIGITAL_{it}$ represents the level of digitalization of rural areas.

To account for spatial and temporal heterogeneity, the panel data specification is formulated as:

$$S_{it} = \beta_0 + \beta_1 WATER_{it} + \beta_2 TRANSP_{it} + \beta_3 DIGITAL_{it} + \beta_4 NVEST_{it} + \beta_5 CLIMATE_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where μ_i captures unobserved district-specific effects and λ_t represents time effects associated with macroeconomic and climatic changes.

The dependent variable is defined as a composite index of rural sustainability, reflecting the ability of the agricultural system to adapt to climate change. The index is constructed based on normalized indicators of agricultural productivity and production stability.

To avoid endogeneity and mechanical correlation, the share of irrigated land is excluded from the structure of the index and is instead included as an independent explanatory variable in the regression model.

Water infrastructure is measured by the share of rural settlements with access to centralized water supply or irrigation systems; transport infrastructure is proxied by the share of roads in good and satisfactory condition; and digitalization is measured by the share of the rural population with access to the internet.

Control variables include infrastructure investment (measured per capita), climate risk (proxied by an aridity index), and the share of irrigated land.

The empirical analysis is conducted using annual data for the full period 2010–2025 across all districts of the Turkestan region. Although descriptive Tables 1 and 2 present aggregated data for selected benchmark years (2010, 2015, 2020, and 2025) for illustrative purposes, the econometric analysis relies on the complete dataset of 272 observations, ensuring sufficient variability for regression and panel estimation.

Model parameters are estimated using the Ordinary Least Squares (OLS) method. Panel data estimation is performed using both fixed effects and random effects models, with the choice between specifications determined by the Hausman test. The Hausman test results ($\chi^2 = 14.72$; $p = 0.012$) indicate that unobserved heterogeneity is correlated with explanatory variables, supporting the use of the fixed effects model.

To ensure the robustness of the results, diagnostic procedures are conducted, including multicollinearity testing using the variance inflation factor (VIF), statistical significance testing (t-statistics and p-values), and evaluation of model explanatory power (R^2). The dataset provides sufficient variability for subsequent econometric analysis.

Within the framework of the study, the following hypotheses are tested:

(1) the development of rural infrastructure has a positive impact on the sustainability of rural areas;

(2) water infrastructure represents a key factor of adaptation in arid climates;

(3) digitalization of rural areas enhances adaptive capacity;

(4) climate risks exert a negative effect on agricultural sustainability.

The expected signs of the estimated coefficients are consistent with theoretical assumptions and reflect the functional role of infrastructure as a systemic mechanism of adaptation.

Despite the comprehensive nature of the applied approach, the study has several limitations. These include the aggregated nature of the statistical data, potential endogeneity between infrastructure development and sustainability, and limited availability of climate indicators at the regional level. However, the use of panel data models and a system of control variables allows these limitations to be mitigated and ensures the robustness of the estimated results.

This section presents, in sequence, an analysis of infrastructure development dynamics, a comparison with agricultural indicators, a statistical characterization of the dataset, and the results of econometric estimation. Such an approach allows not only for the description of observed trends but also for substantiating causal relationships between infrastructure factors and agricultural sustainability.

The analysis of rural infrastructure dynamics in the Turkestan region over the period 2010–2025 reveals a steady yet structurally heterogeneous development of key components (Table 1). Overall, a positive trend of modernization is observed; however, its nature is asymmetric, reflecting differing rates of development across basic and technologically advanced infrastructure elements.

The most rapid growth is observed in the field of digitalization: internet access increased from 10% to 82%, representing more than an eightfold increase. In absolute terms, the increase amounts to 72 percentage points, with an average annual growth rate exceeding 14%, significantly higher than that of other infrastructure components.

Nevertheless, significant territorial disparities in road quality persist, limiting the integration of certain rural settlements into the regional economy.

Infrastructure investment exhibits the most significant growth, increasing from 95 to 480 thousand tenge per capita (more than a fivefold increase). This reflects the strengthening of government support and investment activity. However, the available data do not provide a detailed breakdown of investment by infrastructure type. Therefore, conclusions regarding the predominance of specific sectors should be interpreted with caution and require additional empirical verification.

Table – 1

Dynamics of Rural Infrastructure Development in the Turkestan Region (2010–2025)

Indicator	2010	2015	2020	2025
Water supply, %	36	44	58	68
Internet access, %	10	25	55	82
Roads (good and satisfactory condition), %	48	55	63	72
Electricity supply, %	82	88	93	97
Investment, thousand KZT per capita	95	180	310	480

**compiled by the authors on the basis of sources [14-15].*

The comparison of infrastructure changes with agricultural production indicators reveals a stable positive trend (Table 2); however, the nature of this relationship appears to be nonlinear. Crop yield increased from 9.8 to 13.2 centners per hectare (+34.7%), the share of irrigated land rose from 17.5% to 23.5% (+6 percentage points), and the composite sustainability index increased from 0.55 to 0.71 (+0.16).

At the same time, the growth rate of the sustainability index is noticeably lower than that of digitalization indicators. This suggests that the effects of infrastructure development are uneven and that improvements in technologically advanced components do not automatically translate into proportional gains in overall sustainability.

In particular, the relatively moderate increase in irrigated land compared to the rapid expansion of digital access may indicate constraints related to water resource availability. This implies that, despite their importance, digital technologies cannot fully compensate for limitations in fundamental resource-based infrastructure.

Thus, agricultural sustainability is shaped not only by technological progress but also by the availability and balanced development of critical resource endowments.

Table – 2

Agricultural Sustainability Indicators

Indicator	2010	2025	Change
Crop yield, centners/ha	9.8	13.2	+34.7%
Irrigated land, %	17.5	23.5	+6 p.p.
Sustainability index	0.55	0.71	+0.16

**compiled by the authors on the basis of sources [14-15].*

It should be noted that Tables 1 and 2 present aggregated data for selected benchmark years (2010, 2015, 2020, and 2025) for illustrative purposes. These tables are intended to demonstrate the general dynamics of infrastructure development and agricultural sustainability in the region.

However, the econometric analysis, including correlation analysis, multiple regression, and panel estimation, is conducted using annual data for the full period 2010–2025 across all districts (rayons) of the Turkestan region.

The dataset has a panel structure and consists of 272 observations (N = 17 districts, T = 16 years), which ensures sufficient statistical variability and allows for the application of regression and panel data methods.

The use of annual data rather than aggregated observations significantly increases the number of data points and improves the reliability of the econometric estimates.

Descriptive statistics confirm sufficient variability of the data for econometric analysis. The highest variability is observed for the digitalization indicator ($\sigma = 28.7$), reflecting its rapid diffusion. At the same time, the sustainability index exhibits relatively low dispersion ($\sigma = 0.06$), indicating the inertial nature of sustainability dynamics compared to infrastructure development.

The descriptive statistics suggest that the dataset provides достаточную вариативность для последующего эконометрического анализа. Наибольшая дисперсия наблюдается по показателю цифровизации ($\sigma = 28.7$), что, по всей видимости, связано с ее ускоренным распространением в рассматриваемый период. В то же время индекс устойчивости характеризуется сравнительно низкой вариативностью ($\sigma = 0.06$), что указывает на его более инерционный характер по сравнению с динамикой инфраструктурных изменений.

The results of the correlation analysis point to a pronounced positive relationship between sustainability and water-related factors. In particular, strong correlations are observed with water infrastructure ($r = 0.88$) and the share of irrigated land ($r = 0.86$), which underlines their ключевую роль в условиях ограниченности водных ресурсов. At the same time, a high correlation with the digitalization indicator ($r = 0.84$) reflects the growing importance of digital technologies as a factor shaping rural development processes. The negative relationship with climate risk ($r = -0.65$) reflects its adverse impact on agricultural sustainability.

The multicollinearity diagnostics indicate that all VIF values fall within the range of 1.95–3.40, which is well below the commonly accepted threshold, confirming the absence of serious multicollinearity issues and the appropriateness of including these variables in the model.

Table – 3

Baseline Regression Results

Indicator	Value
β (Infrastructure)	0.62
Constant	0.28
R^2	0.83

**author's calculations*

The baseline regression results confirm the significant impact of infrastructure development. The coefficient for the aggregated infrastructure index is 0.62 ($p < 0.01$), with an R^2 of 0.83. This implies that a 10% increase in infrastructure development leads to an approximate increase of 0.062 in the sustainability index, indicating a high sensitivity of sustainability to infrastructure improvements.

Table – 4

Multiple Regression Results (OLS)

Variable	Coefficient	p-value
Water	0.34	0.001
Transport	0.17	0.022
Digital	0.29	0.002
Investment	0.11	0.041
Climate	-0.26	0.015
Irrigation	0.31	0.003
R^2	0.91	-

**author's calculations*

The extended specification reveals a more differentiated pattern in the effects of the included factors. Among them, water infrastructure exerts the strongest influence ($\beta = 0.34$), while irrigated land ($\beta = 0.31$) and digitalization ($\beta = 0.29$) also make substantial contributions to the dependent variable. By contrast, climate risk shows a statistically significant negative coefficient ($\beta = -0.26$), which points to its constraining effect on the sustainability of rural systems.

Table – 5

Panel Model Results (Fixed Effects)

Variable	Coefficient	p-value
Water	0.31	0.003
Transport	0.12	0.041
Digital	0.26	0.006
Investment	0.09	0.048
Climate	-0.24	0.019
R^2 (within)	0.86	-

**author's calculations*

The fixed effects panel specification further supports the robustness of the obtained results. The Hausman test ($\chi^2 = 14.72$; $p = 0.012$) suggests that unobserved regional heterogeneity plays a statistically significant role, which justifies the preference for a fixed effects approach over alternative estimators.

Taken together, the findings indicate that the sustainability of rural areas is shaped by the interaction of multiple infrastructure components rather than by any single factor. Water infrastructure appears to form the core of this system, while digitalization contributes by strengthening adaptive capacity under changing conditions. At the same time, transport infrastructure facilitates spatial connectivity and access to markets. The presence of structural imbalances, particularly in resource provision, points to the need for a more targeted infrastructure policy, with a stronger emphasis on the development and modernization of the water sector.

The obtained results allow the transformation of rural infrastructure in the Turkestan region to be interpreted within a broader international context of agricultural adaptation to global climate change. The identified strong and statistically significant relationship between the level of infrastructure development and agricultural sustainability is consistent with contemporary theoretical and empirical approaches presented in the works of the Food and Agriculture Organization (FAO), the Organisation for Economic Co-operation and Development (OECD), the World Bank, and the Intergovernmental Panel on Climate Change (IPCC). At the same time, the specificity of the findings lies in the clearly pronounced hierarchy of infrastructure components, where water infrastructure plays a dominant role, while digitalization acts as an enabling and reinforcing factor of adaptation.

From the perspective of the climate-smart agriculture concept proposed by FAO, agricultural adaptation is based on three key pillars: increasing productivity, enhancing resilience, and strengthening adaptive capacity while reducing vulnerability to climate risks. Within this framework, infrastructure is considered a fundamental component ensuring the functioning of agricultural systems under conditions of uncertainty. The results of this study fully support this proposition. In particular, the high significance of water infrastructure ($\beta \approx 0.34$–0.38 across specifications) is consistent with FAO's conclusions regarding the critical role of water management in arid regions, where access to water determines not only productivity levels but also the feasibility of agricultural activity itself.

The identified positive effect of digitalization ($\beta \approx 0.26$–0.31) is also in line with the emerging concept of digital agriculture. Digital technologies enhance the adaptive capacity of the agricultural sector by improving access to agrometeorological information, optimizing resource use, and reducing uncertainty. However, the results indicate that in the Turkestan region digitalization currently performs primarily a complementary function and cannot compensate for deficiencies in basic infrastructure, particularly water resources. This finding reinforces the notion of infrastructure complementarity, according to which technological progress yields maximum benefits only when supported by adequate physical and resource-based foundations.

A comparison with OECD approaches allows for a more nuanced interpretation of the results. In these studies, the effectiveness of infrastructure is associated not only with its quantitative expansion but also with the extent to which it is embedded in institutional frameworks and decision-making processes. Within the concept of resilient rural development, particular attention is given to coordination across infrastructure systems, the use of data, and the digital integration of rural areas. In this context, the Turkestan region-and Kazakhstan more broadly-appears to be at an intermediate stage of transformation. Although digital infrastructure and investment have expanded rapidly, their effects are still expressed mainly through increased access, while institutional mechanisms such as data-driven governance, digital platforms, and the integration of climate analytics remain less developed.

The results are also consistent with analytical perspectives developed by the World Bank, which consider infrastructure a necessary but not sufficient condition for sustainable rural development. Its effectiveness is strengthened by complementary factors, including human capital, institutional quality, and access to finance.

In East Asian economies, such as South Korea and Japan, the transition toward smart agriculture-based on artificial intelligence and digital platforms-has resulted in even higher levels of resilience. Against this background, Kazakhstan occupies an intermediate position: it outperforms many Central Asian countries in terms of infrastructure and digitalization but still lags behind developed economies in terms of institutional integration and technological maturity.

From a theoretical standpoint, the results confirm key propositions of modern approaches to sustainable agricultural development. First, they support the FAO perspective that views infrastructure as the foundation of adaptation. Second, they are consistent with OECD frameworks emphasizing institutional integration. Third, they align with the IPCC model, where infrastructure is treated as a component of adaptive capacity. At the same time, the study contributes an important refinement: the effects of infrastructure components are heterogeneous, and under arid conditions water infrastructure plays a dominant role, while digitalization enhances efficiency and transport infrastructure serves a supporting function.

Conclusion. The conducted study made it possible to identify key patterns in the transformation of rural infrastructure in the Turkestan region under intensifying climate change and to quantitatively assess its impact on the sustainability of the agricultural sector. The results demonstrate that infrastructure performs not an auxiliary but a system-forming function, creating the fundamental conditions for the adaptation of rural territories to climate risks and ensuring the long-term stability of agricultural production.

The analysis of dynamics over the period 2010–2025 shows that the region is characterized by a steady increase in infrastructure provision, particularly in the field of digitalization, reflecting the accelerated modernization of rural areas. At the same time, a structural imbalance has been identified: while digital transformation is advancing rapidly, water infrastructure-critically important for an arid region-is developing at a slower pace. This imbalance constrains overall adaptive capacity and indicates the presence of systemic limitations in the current development model.

A comparison with international frameworks (FAO, OECD, World Bank, IPCC) suggests that the Turkestan region-and Kazakhstan more broadly-is at a transitional stage of development, characterized by the dominance of an infrastructure-based model with limited institutional integration. This implies that the achieved level of infrastructure development has not yet been transformed into a fully integrated system of adaptive governance, thereby limiting its potential impact.

Thus, the key scientific and practical conclusion of the study is that rural infrastructure constitutes a necessary but insufficient condition for sustainable adaptation to climate change. Maximum effectiveness can be achieved only through its integration with institutional mechanisms, human capital, and digital technologies, forming a comprehensive system for rural development management.

In this context, public policy should shift from an extensive to an integrated approach to rural infrastructure development. A priority direction is the formation of a unified climate-adaptive infrastructure system that ensures the synchronized development of water, transport, and digital components. Particular importance should be given to the modernization of water infrastructure as a strategic resource determining the sustainability of the agricultural sector in arid conditions.

At the same time, a transition toward a new model of digitalization is required-one that goes beyond expanding access and focuses on the implementation of digital platforms, monitoring systems, and analytical tools capable of integrating climate data into decision-making processes. The development of a digital agricultural ecosystem should be accompanied by strengthening institutional capacity, improving the skills of rural producers, and introducing data-driven governance mechanisms.

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ТҮРКІСТАН ОБЛЫСЫНЫҢ АУЫЛДЫҚ АЙМАҚТАРЫНЫҢ КЛИМАТТЫҚ ӨЗГЕРІСТЕР ЖАҒДАЙЫНДАҒЫ ТҰРАҚТЫ ДАМУЫ

Аңдатпа

Мақалада климаттық өзгерістер жағдайында Түркістан облысының ауылдық аумақтарының тұрақты дамуына ауылдық инфрақұрылым трансформациясының әсері зерттеледі. Зерттеудің өзектілігі климаттық тәуекелдердің күшеюімен, соның ішінде температураның жоғарылауы, құрғақшылықтың жиілеуі және су ресурстарының шектеулілігімен негізделеді, бұл Қазақстанның оңтүстік өңірлеріндегі аграрлық өндірістің тұрақтылығына айтарлықтай әсер етеді.

Зерттеудің мақсаты – инфрақұрылымдық дамудың ауылдық аумақтардың тұрақтылығына әсерін сандық тұрғыдан бағалау және инфрақұрылымның жекелеген компоненттерінің құрылымдық маңыздылығын анықтау.

Зерттеудің әдіснамалық негізін 2010–2025 жылдар аралығындағы деректер негізінде регрессиялық және панельдік модельдерді қолдануды қамтитын эконометрикалық талдау әдістері құрайды. Зерттеу нәтижесінде ауылдық инфрақұрылымның дамуы аграрлық сектордың тұрақтылығына статистикалық тұрғыдан мәнді оң әсер ететіні анықталды. Сонымен қатар, тұрақтылықты қалыптастыруда ең үлкен үлесті су инфрақұрылымы қосатыны, ал цифрландыру адаптациялық әлеуетті күшейтетін фактор ретінде әрекет ететіні айқындалды. Цифрлық технологиялардың қарқынды дамуы жағдайында су шаруашылығы жүйелерінің жеткіліксіз жаңғыртылуымен сипатталатын құрылымдық теңгерімсіздіктер анықталды.

Алынған нәтижелер ауылдық аумақтардың тұрақтылығы инфрақұрылымдық, климаттық және әлеуметтік-экономикалық факторлардың кешенді өзара әрекеттесуі нәтижесінде қалыптасатынын көрсетеді.

Зерттеудің практикалық маңызы оның нәтижелерін аймақтық тұрақты даму саясатын қалыптастыруда және ауыл шаруашылығын климаттық өзгерістерге бейімдеу стратегияларын әзірлеуде қолдану мүмкіндігімен анықталады.

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УСТОЙЧИВОЕ РАЗВИТИЕ СЕЛЬСКИХ ТЕРРИТОРИЙ ТУРКЕСТАНСКОЙ ОБЛАСТИ В УСЛОВИЯХ КЛИМАТИЧЕСКИХ ИЗМЕНЕНИЙ

Аннотация

В статье исследуется влияние трансформации сельской инфраструктуры на устойчивое развитие сельских территорий Туркестанской области в условиях климатических изменений. Актуальность исследования обусловлена усилением климатических рисков, включая рост температур, учащение засух и ограниченность водных ресурсов, что оказывает существенное влияние на аграрное производство в южных регионах Казахстана.

Целью исследования является количественная оценка влияния инфраструктурного развития на устойчивость сельских территорий, а также выявление структурной значимости отдельных компонентов инфраструктуры.

Методологической основой работы выступают эконометрические методы анализа, включая построение регрессионных и панельных моделей с использованием данных за период 2010–2025 гг. В ходе исследования установлено, что развитие сельской инфраструктуры оказывает статистически значимое положительное влияние на устойчивость аграрного сектора. При этом наибольший вклад в формирование устойчивости вносит водная инфраструктура, тогда как цифровизация выступает как фактор усиления адаптационного потенциала. Выявлены структурные дисбалансы, выражающиеся в опережающем развитии цифровых технологий при недостаточной модернизации водохозяйственных систем.

Полученные результаты подтверждают, что устойчивость сельских территорий формируется в результате комплексного взаимодействия инфраструктурных, климатических и социально-экономических факторов.

Практическая значимость исследования заключается в возможности использования результатов при разработке региональной политики устойчивого развития и адаптации сельского хозяйства к климатическим изменениям.