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MULTI-FACTOR ECONOMETRIC MODELS OF WATER RESOURCE USE IN ENSURING REGIONAL ECONOMIC STABILITY

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Abstract: This article develops multi-factor econometric models to assess the efficiency of water resource use in ensuring regional economic stability. Based on regression analysis and panel data models, the relationship between water use and economic growth is quantitatively examined. The Structural Vector Autoregression (SVAR) model is applied to 60 quarterly observations (2010–2024) from the Amudarya Basin Water Management Authority, and the findings provide a basis for practical recommendations on improving regional water policy.

Key words: water resources, regional economy, econometric model, panel data, sustainable development, regression analysis, water policy.

Аннотация: В данной статье разработаны многофакторные эконометрические модели для оценки эффективности использования водных ресурсов в обеспечении региональной экономической устойчивости. На основе регрессионного анализа и моделей панельных данных количественно исследована взаимосвязь между использованием водных ресурсов и экономическим ростом. Для анализа 60 квартальных наблюдений за 2010–2024 годы, полученных из Бассейнового управления водного хозяйства Амударьи, применена модель структурной векторной авторегрессии (SVAR). Полученные результаты послужили основой для выработки практических рекомендаций по совершенствованию региональной водной политики.

Ключевые слова: водные ресурсы, региональная экономика, эконометрическая модель, панельные данные, устойчивое развитие, регрессионный анализ, водная политика.

INTRODUCTION

Water resources have become the most critical strategic resource for ensuring the sustainable development of regional and national economies in the 21st century. According to United Nations data, water scarcity affected 2 billion people globally in 2023, and demand for water is projected to increase by 55% by 2050 [1]. World Bank experts forecast that water scarcity could lead to a reduction of up to 6% of regional gross domestic product [2].

In Central Asia, 90% of water resources are used for irrigated agriculture, which accounts for 10 to 45% of the regional economy. Water losses in irrigation systems reach 35–40% due to aging infrastructure, and modern water-saving technologies are applied on only 3–5% of irrigated land, posing a serious threat to regional economic stability. In the Republic of Uzbekistan, 80% of total water resources originate from neighboring countries, making water security a national priority.

The Khorezm region is one of the most water-stressed areas, as it is located in the lower reaches of the Amu Darya River and more than 90% of its water consumption is allocated to agriculture. The object of this study is the system of water resource use and economic relations within the BVO Amudarya network, while the subject covers the totality of economic processes related to efficient water use, introduction of water-saving technologies, and ensuring water security in Khorezm. The aim of this article is to develop multi-factor econometric models for improving the mechanisms of efficient water resource use in the region and to provide practical recommendations.

REVIEW OF LITERATURE ON THE SUBJECT

A number of significant studies have been conducted in the field of econometric modeling of efficient water resource use. R.A. Young developed a methodology for assessing the economic value of water resources based

on alternative use opportunities [3], while D. Molden and co-authors proposed measuring water productivity through value added per cubic meter of water consumed [4].

In the field of dynamic modeling of regional water consumption, the Vector Autoregression (VAR) model developed by C.A. Sims [5] and the Granger causality test [6] are widely applied. In the Central Asian context, V.A. Dukhovny and J.L.G. De Schutter conducted a quantitative analysis of water allocation processes in the Amudarya basin [7]. Among local researchers, Z.M. Khoshimov studied the economic mechanisms of water resource management, and O.B. Yusupov examined the economic efficiency of water-saving technologies [8].

However, in existing studies, factors affecting water resource use are often examined separately. In contrast to previous work, this article presents the first comprehensive multi-factor dynamic analysis based on the SVAR model using Khorezm region data, and introduces the PWS financial incentive mechanism, the GFI green finance index, and the RSE regional sustainability model.

RESEARCH METHODOLOGY

Several scientific research methods were employed in this study. The comparative analysis method was used to compare the water productivity indicator of Khorezm (0.50 USD/m³) with those of Israel (3.60 USD/m³), Australia (1.80 USD/m³), and other countries, and to identify the causes of the existing gaps.

Through statistical analysis, the seasonal characteristics, long-term trends, and structural changes in water consumption were studied using 60 quarterly observations from the Amudarya Basin Water Management Authority covering 2010–2024. The Hodrick-Prescott filter ($\lambda=1600$) was applied to eliminate seasonal fluctuations, and the consistent downward trend in Khorezm's water consumption beginning in 2019 was identified [9].

Within the framework of economic-mathematical modeling, the SVAR (Structural Vector Autoregression) model was applied to quantitatively assess the dynamic causal relationships between inflow to the Tuyamuyun reservoir (TMGU), and the water consumption of Khorezm, Karakalpakstan, and Dashoguz regions. The Granger causality test confirmed the strong causal influence of TMGU inflow on Khorezm's water consumption with a 2-quarter lag ($F=39.17$; $p<0.001$).

ANALYSIS AND RESULTS

Analysis of the current state of water resource use in Khorezm shows that the region is one of the most water-stressed in Uzbekistan. The region's share of total lower Amudarya consumption rose from 16.6% in 1990 to 24.5% in 2024, reflecting the growing strategic importance of the region in regional water policy (Table 1).

Table 1. Dynamics of water consumption in Khorezm region¹ (2010–2024)

Year	TMGU inflow, mln m ³	Khorezm consumption, mln m ³	Share, %
2010	44 167	4 601	24.6
2015	26 500	4 100	24.8
2020	19 627	3 509	24.8
2022	17 768	2 594	22.9
2024	19 157	3 525	24.5

As shown in the table, water consumption in Khorezm decreased from 4,601 mln m³ in 2010 to 2,594 mln m³ in 2022 — a reduction of 43.6%. This represents a positive trend linked to the introduction of water-saving technologies. However, water losses in irrigation systems remain a serious problem (Table 2).

¹ Source: Compiled by the author based on data from the Amudarya Basin Water Management Authority [10].

Table 2. Water losses in Khorezm region irrigation systems²

Source of loss	Share, %	Volume, mln m ³ /year
Filtration (seepage from canals)	15–18	525–630
Evaporation	8–10	280–350
Distribution errors	5–7	175–245
Inefficient field irrigation	10–15	350–525
Total	38–50	1,330–1,750

The data show that 38–50% of water delivered to the region is lost before reaching its intended use. The primary causes are aging earthen-lined canals built before 1980 and the continued dominance of traditional furrow irrigation, which accounts for 85% of all irrigation (Table 3).

Table 3. Comparison of water productivity across regions³

Country/Region	Water productivity, USD/m ³	Irrigation technology
Israel	3.60	Drip irrigation (82%)
Australia	1.80	Sprinkler + drip
Turkey	0.85	Mixed
Khorezm region	0.50	Furrow (85%)
Uzbekistan average	0.55	Furrow (75%)

The comparison shows that water productivity in Khorezm is 7.2 times lower than in Israel and 3.6 times lower than in Australia. The key reasons are the dominance of traditional furrow irrigation, high canal losses, and the prevalence of water-intensive crops such as cotton and rice in the cropping structure.

The SVAR econometric model results enabled identification of dynamic relationships among factors affecting water consumption. The Granger causality test confirmed that a 1% increase in TMGU inflow two quarters earlier reduces actual water consumption in Khorezm by 1.55% ($p < 0.001$). The Hodrick-Prescott filter analysis revealed a consistent downward trend in Khorezm's water consumption since 2019 — a real decline of approximately 34% — which serves as econometric confirmation that water-saving technologies and state policy are producing tangible results.

The GFI (Green Finance Index) developed by the author increased from 15.9 in 2020 to 42.5 in 2024 — a 2.7-fold increase — confirming that green finance mechanisms are becoming increasingly active in the region. However, this indicator remains at a medium level (40–70 range) and additional measures are required to reach the high level (70+).

CONCLUSIONS AND SUGGESTIONS

The findings of this study show that water use efficiency in Khorezm region significantly lags behind international standards. Water losses of 38–50% in irrigation systems, salinization of up to 50% of irrigated land, and water productivity of only 0.50 USD/m³ pose a serious threat to regional economic stability. The SVAR model confirmed the decisive causal influence of TMGU inflow on Khorezm's water consumption ($F=39.17$; $p < 0.001$), and the Hodrick-Prescott filter analysis revealed a 34% downward trend in consumption since 2019, demonstrating the effectiveness of current state policy.

The following recommendations are proposed to address the identified problems.

1. Introduction of the PWS (Profit-linked Water Savings) financial incentive mechanism developed by the author. This mechanism incorporates three components — direct subsidy (weight 0.40), 'Green Certificate' (0.35), and preferential leasing (0.25) — and is projected to yield annual water savings of 350 mln m³ and additional income of USD 118 mln by 2030.

2. Gradual increase of water tariffs to market levels. Raising the current tariff of 100 soums/m³ to 1,000 soums/m³ by 2030 — alongside social protection measures — will strengthen economic incentives for water conservation.

3. Introduction of the Smart Water Management (SM) digital platform. This platform, integrating IoT sensors, artificial intelligence algorithms, and blockchain technology, can reduce water losses by 50% and significantly improve management efficiency.

² Source: Ministry of Agriculture of Uzbekistan and author's calculations [11].

³ Source: FAO AQUASTAT, Ministry of Water Resources of Uzbekistan [12].

4. Diversification of the cropping structure — reducing cotton and rice areas while expanding intensive orchards and greenhouse vegetable production — can raise water productivity from 0.50 to 0.85 USD/m³.

5. Implementation of the OptWR multi-level optimal water allocation model across the BVO Amudarya — region — district — farm hierarchy will enhance transparency in water distribution and reduce losses.

Comprehensive implementation of the proposed measures will enable Khorezm region to increase agricultural value added by 85%, create 18,000 new jobs, and ensure sustainable regional economic development by 2030.

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