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DESIGNING A WATER-SAVING AND RESOURCE-EFFICIENT REGIONAL SPECIALIZATION MODEL: THE CASE OF BUKHARA REGION

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Abstract. Water scarcity is becoming one of the major constraints affecting regional economic specialization in arid economies. Traditional specialization approaches mainly focus on production concentration, comparative advantage and employment, while the efficiency of scarce natural resources is often insufficiently considered. This study proposes a Water-Saving and Resource-Efficient Regional Specialization Model for Bukhara region, Uzbekistan. The model integrates regional specialization indicators with economic water productivity and multi-objective resource allocation. The proposed framework evaluates economic activities according to their ability to generate value added and employment while minimizing water, land and energy requirements. Existing regional evidence shows that annual water use in Bukhara declined from approximately 4.95 billion m³ in 2016 to 3.62 billion m³ in 2025. At the same time, the majority of regional water resources continues to be consumed by agriculture. The results demonstrate the need for gradual structural transformation from water-intensive raw agricultural production toward high-value horticulture, agro-processing, resource-efficient industry, tourism and service activities. The proposed model can be used as a decision-support instrument for regional development under increasing water scarcity.

Keywords: water scarcity, regional specialization, water productivity, resource efficiency, optimization, Bukhara region.

1. Introduction. Water scarcity is increasingly influencing the spatial organization of economic activity. This issue is particularly important for arid and semi-arid regions where agriculture, industry, households and ecosystems compete for limited water resources. In such conditions, regional specialization cannot be determined only by historical production patterns or conventional comparative advantages.

Bukhara region represents a typical water-constrained territory. Agriculture remains one of the dominant sectors of the regional economy and, according to existing research estimates, accounts for approximately 89.5% of total water consumption. At the same time, annual regional water use declined from around 4.95 billion m³ in 2016 to 3.62 billion m³ in 2025.

This situation creates a structural contradiction: sectors that consume the largest amount of water do not necessarily generate the highest economic return per unit of water.

Therefore, the main research question is formulated as follows:

How should regional specialization be transformed in order to maximize economic and social returns under a limited water-resource constraint?

Most existing studies on water-resource optimization focus primarily on crop structure, irrigation technologies or agricultural water allocation. Considerably less attention has been paid to the

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optimization of the entire regional economic structure involving agriculture, industry, processing and services.

The purpose of this study is therefore to develop a water-saving and resource-efficient regional specialization model for Bukhara region that combines comparative advantage with economic water productivity and resource-use constraints.

2. Methodology. The proposed methodology consists of three interconnected stages:

1. assessment of existing regional specialization;
2. adjustment of specialization according to water productivity;
3. optimization of sectoral structure under resource constraints.

Traditional regional specialization is measured using the Location Quotient:

$$LQ_{ir}=\frac{GVA_{ir}/GVA_r}{GVA_{i,UZ}/GVA_{UZ}}$$

where (i) represents an economic sector and (r) represents a territorial unit.

An (LQ) value greater than 1 indicates that the territory is relatively specialized in the corresponding activity.

However, a high level of specialization does not necessarily indicate efficient resource use. For this reason, economic water productivity is calculated as:

$$EWP_{ir}=\frac{GVA_{ir}}{WU_{ir}}$$

where (WU) represents water consumption.

To combine specialization and water efficiency, the study proposes a **Water-Adjusted Specialization Index (WASI)**:

$$WASI_{ir}=LQ_{ir}\times RWUE_{ir}$$

where:

$$RWUE_{ir}=\frac{EWP_{ir}}{EWP_{i,UZ}}$$

The interpretation of the proposed indicator is presented below.

Specialization	Water efficiency	Strategic interpretation
High	High	Priority specialization
High	Low	Structural modernization required
Low	High	Potential new specialization
Low	Low	Low-priority activity

This approach makes it possible to distinguish between historically established specialization and economically sustainable specialization under water scarcity.

3. Multi-objective regional specialization model. Let x_{ir} represent the scale of sector (i) in district (r).

The model simultaneously aims to maximize regional economic value and employment while minimizing resource consumption.

The economic objective is:

$$\max Z_1=\sum_r\sum_i VA_{ir}x_{ir}$$

The water-saving objective is:

$$\min Z_2=\sum_r\sum_i w_{ir}(1-\tau_{ir})x_{ir}$$

where w_{ir} is the water requirement and τ_{ir} reflects the effect of water-saving technologies.

Employment is maximized through:

$$\max Z_3=\sum_r\sum_i l_{ir}x_{ir}$$

The most important condition of the model is the absolute regional water constraint:

$$\sum_r\sum_i WU_{ir}\leq W^{CAP}$$

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This condition is particularly important because technological improvements alone may not reduce total water consumption. Higher irrigation efficiency may encourage expansion of irrigated areas and cause a rebound effect. Therefore, water-saving technologies must be combined with an absolute water-use limit.

The model also includes land, employment, food-security and environmental constraints:

[\sum_{i\in AGR}a_{ir}x_{ir}\leq A_r]

[\sum_i l_{ir}x_{ir}\geq EMP_r^{min}]

[Q_c\geq Q_c^{min}]

These constraints prevent economically optimal solutions from causing excessive reductions in employment or strategically important agricultural production.

4. Results and Discussion. Existing data demonstrate significant structural differences in water productivity within Bukhara region.

The regional average agricultural water productivity is estimated at approximately 0.98 kg/m³. Kogon, Jondor and Bukhara districts demonstrate relatively higher productivity, whereas Vobkent, G‘ijduvon and Peshku show lower values.

A particularly important structural problem is observed in the distribution of agricultural land and water resources. Cotton and wheat together occupy approximately 68% of cultivated land and consume more than 70% of agricultural water, but generate only around 45–50% of agricultural output value.

In contrast, vegetables, melons, orchards and vineyards occupy only about 6% of cultivated land and use approximately 10–12% of agricultural water while generating roughly 25–30% of agricultural value.

This comparison indicates that improvement in irrigation technologies alone is insufficient. Structural transformation of production is also necessary.

Based on economic and natural characteristics, Bukhara region can be divided into four specialization clusters.

Cluster	**Main territories**	**Recommended specialization**
Cotton–grain	Jondor, Vobkent, Romitan, Shofirkon, Bukhara	Gradual reduction of water-intensive crops, horticulture and agro-processing
Desert–pasture	Qorako‘l, Olot, Peshku, Qorovulbozor	Livestock, drought-resistant crops and processing
Horticultural	G‘ijduvon and partly Vobkent	Horticulture, viticulture, greenhouses and export logistics
Industrial–urban	Bukhara city, Kogon, Qorovulbozor	Resource-efficient industry, tourism and services

The proposed model therefore does not suggest complete abandonment of traditional agriculture. Instead, it assumes gradual redistribution of scarce water toward activities generating higher economic and social returns.

The main direction of structural transformation can be expressed as:

[\text{Water-intensive raw production}\rightarrow\text{high-value agriculture}\rightarrow\text{processing}\rightarrow\text{services and knowledge-intensive activities}.]

An important potential specialization pathway for Bukhara is the development of horticulture, food processing, tourism, education, digital services and other activities with relatively low direct water requirements.

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5. Scenario framework. Future regional specialization should also take into account uncertainty in water availability.

For this reason, four water-resource scenarios are proposed:

Scenario	**Water availability**
Baseline	100%
Moderate scarcity	90%
Severe scarcity	80%
Extreme scarcity	70%

For each scenario, the model determines a feasible combination of agricultural, industrial and service activities.

As water availability declines, low-value and highly water-intensive activities gradually lose their specialization priority, while activities characterized by higher value added per cubic metre of water become increasingly important.

This approach allows regional policymakers to prepare not only for current water conditions but also for future climate and resource risks.

6. Scientific novelty. The scientific novelty of the proposed methodology consists of integrating regional specialization with water-resource efficiency.

Unlike traditional approaches, the proposed model evaluates economic specialization according to the following interconnected criteria:

[\text{Specialization}+\text{Water productivity}+\text{Economic value}+ \text{Employment}+\text{Resource constraints}.]

The Water-Adjusted Specialization Index makes it possible to distinguish between historically developed sectors and activities possessing sustainable comparative advantages under water scarcity.

Another important contribution is the introduction of an absolute water cap into the optimization model. This prevents improvements in irrigation efficiency from resulting in higher total water withdrawals.

Thus, the proposed approach transforms the concept of regional specialization from **resource-based specialization** into **resource-productivity-based specialization**.

7. Conclusion. Water scarcity requires a fundamental reconsideration of regional specialization policies in arid regions.

The case of Bukhara demonstrates that the largest water-consuming sectors are not necessarily those generating the greatest economic value from scarce water resources. Therefore, regional specialization should increasingly be based on economic return per unit of water rather than production volume alone.

The proposed Water-Saving and Resource-Efficient Regional Specialization Model combines conventional specialization indicators with water productivity and multi-objective optimization.

The results support gradual transformation from water-intensive agricultural raw-material production toward high-value horticulture, agro-processing, resource-efficient industry, tourism and knowledge-intensive services.

At the same time, food security, employment and environmental sustainability should remain binding constraints.

The proposed model can therefore serve as a methodological basis for regional planning in Bukhara and other water-scarce regions of Central Asia.

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