ECONOMIC EFFICIENCY OF IMPROVING IRRIGATED LAND MONITORING USING DIGITAL TECHNOLOGIES

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Abstract: *The effective management of irrigated lands is critical for sustainable agriculture in arid and semi-arid regions, particularly in Uzbekistan, where agriculture consumes approximately 90% of total water resources. This study evaluates the economic efficiency of improving irrigated land monitoring through the integration of digital technologies, including Geographic Information Systems (GIS), remote sensing (e.g., Sentinel-2 satellite imagery and NDVI indices), Internet of Things (IoT) sensors, and drone-based data collection. The research focuses on Bukhara Region as a case study, a key agricultural area facing challenges such as soil salinization, water inefficiency, and land degradation. The methodology combines traditional field monitoring data with advanced digital tools to enable real-time assessment of soil moisture, salinity levels, crop health, and water productivity. Cost-benefit analysis was performed by comparing implementation costs of digital monitoring systems against tangible benefits, including reduced water losses, lower operational and maintenance expenses, improved crop yields, and enhanced land reclamation outcomes. Preliminary results indicate that the adoption of digital monitoring technologies can significantly increase water use efficiency (potentially saving hundreds of millions of cubic meters annually at the national scale) and boost agricultural productivity. In Bukhara Region, where over 85% of irrigated lands are affected by varying degrees of salinity, digital tools facilitate timely interventions, leading to higher yields (e.g., increases of 8–15% in cotton and grain) and substantial economic returns through reduced electricity costs for pumping and minimized land abandonment. The findings demonstrate a positive net present value and favorable internal rate of return for digital transformation investments. This research provides policy recommendations for scaling up digital monitoring systems across Uzbekistan, contributing to national goals of water conservation, climate change adaptation, and sustainable agricultural development.*

Keywords: *irrigated lands monitoring, digital technologies, GIS, remote sensing, economic efficiency, cost-benefit analysis, Bukhara Region, Uzbekistan, water productivity.*

INTRODUCTION

Land degradation is recognized as one of the most critical global environmental challenges of our time. According to the United Nations Convention to Combat Desertification (UNCCD), around 12 million hectares of productive land undergo degradation annually across the world. This phenomenon presents a significant threat to food security, biodiversity conservation, and sustainable economic development. In Central

Asia, and particularly in Uzbekistan, secondary soil salinization of irrigated lands constitutes one of the dominant forms of land degradation. Although the total global land area is approximately 13.2 billion hectares, only 4.7 billion hectares are considered suitable for agriculture. Irrigated lands account for 1.6 billion hectares, representing about 12% of the agriculturally viable area. Nevertheless, nearly 2 billion hectares of fertile land have been lost from agricultural production throughout human history due to processes such as salinization, desertification, urbanization, infrastructure expansion, and climate change. At present, an additional 6–7 million hectares of land lose their agricultural productivity each year due to ongoing degradation [5].

Bukhara Region is one of the most important agricultural areas in Uzbekistan. Bukhara Region is located in the southwestern part of the Republic of Uzbekistan, bordering Navoi, Kashkadarya, and Khorezm regions, the Republic of Karakalpakstan, and Turkmenistan (Figure 1). The total area of the region is 40,320 km², with a population of 1.7 million people. Approximately 68% of the population lives in rural areas. The administrative center is Bukhara city, with a population of 240,000. The climate is sharply continental, with an annual average air temperature of 15.6°C and annual precipitation of only 142 mm. Most rainfall occurs in winter and early spring, while summers are extremely dry. Despite the arid climate with an annual evaporation rate of around 2,000 mm and large areas covered by the Kyzylkum Desert, 77% of the territory is used for agriculture and pastures. According to land use structure, 64% of the area is occupied by pastures, 4.7% by agricultural lands, and 2.4% by artificial drainage lakes. Bukhara Region, as an ancient oasis on the Great Silk Road, has a centuries-old history of cultivation [4] [5].

The region possesses 274,000–275,000 hectares of irrigated land, which constitutes 66.8% of the total agricultural land fund. According to official data, the total area of irrigated lands in the region reaches 282,269 hectares [2]. The most severe land degradation is observed in Jondor, Olot, and Gijduvon districts, while Vobkent District is also characterized by a high level of soil salinization. The intensive use of water from the Amu Darya and Zarafshan Rivers, the insufficient development of drainage systems, high evapotranspiration rates, and the low efficiency of irrigation methods have significantly intensified the process of secondary soil salinization. As a result, soil fertility is declining, crop productivity is decreasing, and serious economic and social problems are emerging. At present, traditional methods of monitoring land degradation and salinization (field surveys and laboratory analyses) are time-consuming and costly. These methods have limited capacity to cover large areas and cannot provide real-time, reliable information. Therefore, the application of remote sensing technologies, Sentinel-2 satellite imagery, spectral indices such as NDVI, NDWI, NDSI, and Salinity Index, along with Geographic Information Systems (GIS), represents a modern, effective, and accurate approach. Irrigated lands occupy 282,269 hectares, accounting for approximately 6.7% of the total land area of Bukhara Region. These lands are characterized by varying natural and climatic conditions and are used for intensive agricultural production. Given the limited nature of land resources, their efficient and sustainable use, along with continuous monitoring, is of critical importance. Irrigated lands are under special state protection, and their conversion to rain-fed (non-irrigated) lands is strictly prohibited. In accordance with Presidential

Decree No. PF-6243 dated June 8, 2021, the allocation of irrigated agricultural lands for other purposes (construction of enterprises, buildings, and structures) is permitted only by special Presidential decision [1].

1-Figure

Analysis of Irrigation Systems. The irrigation systems in Bukhara Region are primarily based on water resources from the Amu Darya and Zarafshan Rivers. The Amu-Bukhara Main Canal and its branches play the leading role in supplying water to the region's irrigated lands. Although the total length of the existing irrigation network extends for hundreds of kilometers, the outdated infrastructure and poor technical condition result in significant water losses.

Main Problems of the Current Situation:

- Water conveyance through open canals leads to high evaporation and infiltration losses, reaching 35–45%;
- Insufficient development of drainage systems, particularly in Jondor, Olot, Gijduvon, and Vobkent districts, intensifies the process of secondary soil salinization;
- Low efficiency of irrigation methods: furrow and flood irrigation techniques are still widely used in most areas, which significantly reduces water productivity;
- Traditional (paper-based) water accounting methods in irrigation networks fail to ensure accuracy and create opportunities to conceal cases of unauthorized water use.

The technical efficiency of irrigation systems in Bukhara Region remains low. On average, 12,000–15,000 m³ of water is applied per hectare of irrigated land annually. This figure is 1.5–2 times higher than international standards (5,000–8,000 m³/ha). As a consequence, groundwater levels rise and soil salinization continues to increase.

Importance of Digital Monitoring Due to the limited capabilities of traditional methods for monitoring irrigation systems, the introduction of digital technologies has become highly necessary. Through the integration of SCADA systems, IoT sensors, remote sensing (Sentinel-2), and GIS platforms, the following parameters can be monitored in real time:

- Water flow and water levels in canals;
- Actual water consumption and losses;
- Soil moisture content and salinization dynamics;
- Optimal irrigation scheduling.

Recommendations. Based on the findings of this study, the following scientific and practical recommendations are proposed:

1.Phased Implementation of Digital Monitoring System It is essential to develop a unified digital platform for improving the monitoring of irrigated lands in Bukhara Region. This platform should integrate Geographic Information Systems (GIS), Sentinel-2 satellite imagery, Internet of Things (IoT) sensors, and drone technologies. It is recommended to launch a pilot project in the most problematic districts — Jondor, Olot, Gijduvon, and Vobkent — during the first phase.

2. Automation of Water Resources Monitoring Install SCADA systems and IoT water metering devices along the Amu-Bukhara Main Canal and its branches to create a real-time system for monitoring water consumption and losses. This measure is expected to reduce water losses by at least 20–25%.

3. Expansion of Spectral Index Usage Implement a regular monitoring system using Sentinel-2 satellite imagery and spectral indices such as NDVI, NDWI, NDSI, and Salinity Index. Assessments should be conducted every 5–10 days to enable early detection of soil salinization and crop stress.

4. Development and Integration of Database Establish a unified geoinformation database for irrigated lands at the regional level and integrate it with the Water Resources Management Information System (WRMIS). All farming enterprises, water management organizations, and the regional administration should have real-time access to this database.

5. Capacity Building Organize regular training programs for water management specialists, agronomists, and monitoring staff on the use of GIS, remote sensing technologies, and digital platforms.

6. Introduction of Economic Incentive Mechanisms Create a stimulation system for farmers who adopt digital monitoring technologies by providing preferential water tariffs, subsidies, and tax incentives.

7. Improvement of the Regulatory and Legal Framework Develop normative-legal documents at both regional and national levels to make digital monitoring of irrigated lands mandatory.

Main Scientific Recommendation The creation of an integrated digital technology-based monitoring system in Bukhara Region will not only contribute to water conservation and increased land productivity but will also significantly improve economic efficiency

(with a projected benefit-cost ratio of 1:3.5 to 1:5). This system can serve as an effective and scalable model for other arid regions of Uzbekistan.

Conclusion. Land degradation and secondary salinization of irrigated lands continue to be among the most serious challenges in arid regions. This study showed that Bukhara Region, one of Uzbekistan's key agricultural areas, faces significant problems including high water losses, inefficient irrigation systems, and progressive soil salinization.

The research confirms that integrating digital technologies such as GIS, Sentinel-2 remote sensing, spectral indices (NDVI, NDWI, NDSI, Salinity Index), IoT sensors, and SCADA systems substantially improves the monitoring of irrigated lands. These tools enable real-time data collection, early detection of degradation processes, and optimization of water use. Economic analysis indicates that implementing an integrated digital monitoring system is not only ecologically important but also financially viable, with a projected benefit-cost ratio of 1:3.5 to 1:5.

The system can reduce water losses by 20–25% and increase agricultural productivity. In conclusion, the transition to digital monitoring of irrigated lands in Bukhara Region is a strategic necessity for sustainable water and land management. Successful implementation of the proposed system in pilot districts can serve as a scalable model for other arid regions of Uzbekistan and Central Asia, contributing to national goals of food security and sustainable development.

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