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ECOLOGICAL CRISIS IN THE ARAL SEA BASIN: RATIONAL WATER USE AS A TOOL TO COMBAT LAND DEGRADATION AND CLIMATE CHANGE

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ABSTRACT

This study examines the escalating ecological crisis in the Aral Sea basin and the urgent need to transition from traditional surface furrow irrigation to modern localized water systems. For decades, extensive furrow irrigation has dominated the region, demonstrating extreme resource intensity and colossal inefficiency. This historically established method has led to massive water losses through deep percolation, provoking artificial rises in groundwater levels and resulting in severe secondary soil salinization. Employing a comparative analysis of empirical data collected between 2016–2018 (traditional irrigation) and 2019–2021 (drip irrigation), the study evaluates agricultural productivity and economic viability using the IPAB cost-to-income ratio. The study concludes that improving irrigation efficiency is no longer an exclusively agrarian task aimed at profit generation. Rather, widespread rationalization of water use is a critical, non-alternative tool for conserving melting water resources, halting soil degradation, and restoring the destroyed ecosystem of the Aral Sea region amidst the severe threats of global climate change.

Keywords: Aral Sea basin; drip irrigation; water use efficiency; soil salinization; sustainable irrigation management; cotton production; climate change adaptation; land degradation.

1. INTRODUCTION

Currently, the Aral Sea basin is gripped by an increasing environmental crisis, which is critically and rapidly aggravated by the factor of global climate change [1]. Over the past 50 years, the total area of high-altitude glaciers, which are the main and irreplaceable source of nutrition for the rivers of the entire basin, has inexorably decreased by 30% [2]. The dynamics of this process is such that,

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according to long-term scientifically sound forecasts, by 2050 the total shortage of fresh water only within the borders of the Republic of Uzbekistan may reach an alarming 15 km^3 [Fig. 1].

Fig. 1: Location of the Aral Sea in Central Asia (United Nations, 2020) [4]

Historically, it was the systemic and excessive intake of water for the needs of extensive irrigation that served as a trigger for a large-scale disaster [1]. This thoughtless exploitation of river runoff has led to the fact that the once full-flowing volume of the sea has catastrophically decreased from an impressive 1,090 km^3 to a critical minimum of only 183 km^3. At the same time, the salinity of the water made a fatal leap from the natural 10 g/l to the dead 70 g/l, which was the direct cause of the complete disappearance of the once thriving industrial fishing industry [5]. Moreover, the exposed drained bottom has become a source of regular toxic salt storms that mercilessly poison vast adjacent territories, making them unsuitable for life and agriculture.

For many decades, extensive surface irrigation by furrows has absolutely dominated the agricultural practice in this region [6]. This method demonstrated its extreme resource intensity: the average irrigation rate reached colossal and unreasonably high values of 7,472.7 cubic meters of valuable fresh water per hectare, which indicates its enormous inefficiency. The main hidden environmental threat of this traditional method lies in the inevitable and massive water losses due to the so-called deep filtration, when excess water flows unhindered deep into the lower layers of the soil [5]. This continuous process provokes an artificial increase in the natural groundwater level, which pulls dissolved salts to the surface, which leads to catastrophic secondary salinization and irreversible degradation of the entire soil cover.

The absolute and indispensable foundation for an effective fight against this crisis is a solid technological framework, the formation of which requires a fundamental revision of historically

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established methods of water use. The main vector of these systemic transformations should be the large-scale replacement of outdated traditional irrigation with modern localized water delivery systems, in particular, drip irrigation technology [7]. The mechanism of operation of drip irrigation systems at the physical level eliminates the very possibility of excessive infiltration of water, providing reliable and long-term control over the quality and depth of groundwater. As a result, the destructive process of secondary salinization of lands stops, serving as the main shield against ecosystem degradation.

However, large-scale implementation of such resource-saving technologies is impossible without a functioning economic mechanism that would motivate farmers to conserve water resources. The preservation of old water use methods leaves agricultural production on the very edge of profitability, while comparison with innovative approaches clearly demonstrates a powerful economic incentive for modernization [8]. The released volumes of fresh water are vital in the current environmental context to restore balance in the region. In this regard, this study is aimed at a comprehensive analysis of empirical data on traditional and modern irrigation systems, assessing their economic efficiency using the IPAB indicator (cost-to-income ratio), as well as demonstrating how improving irrigation efficiency is becoming a key tool for conserving water resources, restoring the Aral Sea ecosystem, and globally combating desertification [9].

2. MATERIALS AND METHODS

The study area was conducted in the Bukhara region, located in the Aral Sea basin. This region is characterized by a sharply continental, arid climate, critically low rainfall and an ever-increasing shortage of water resources. The choice of this location is due to the fact that it is representative for evaluating the effectiveness of various methods of water use in the context of the growing environmental crisis and land degradation [10]. The main object of the study was cotton farms specializing in the cultivation of raw cotton, where historically intensive, water-intensive irrigation methods were used, which led to an increase in groundwater levels and secondary salinization of soils. The research design paper uses a longitudinal comparative study design. Empirical data has been divided into two main chronological periods to objectively assess the impact of the transition to resource-saving technologies.

The first stage covers the years 2016-2018, when traditional surface irrigation by furrows absolutely dominated the fields studied. The second stage includes the period from 2019 to 2021, during which a large-scale introduction of modern irrigation technologies [9].

Data collection and sampling the data was carried out directly in the fields of cotton farms in the Bukhara region during six agricultural seasons. During the field research, key agronomic and hydrological indicators were continuously recorded: the volume of water intake, the average irrigation rate per hectare (m3/ha), the level of groundwater, as well as the final yield of cotton

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(kg/ha). The sample was formed from farmland soils of comparable size and initial quality in order to exclude the influence of side effects and ensure high statistical reliability of the results obtained [9]. To quantify the effectiveness of water use, the EUA (Water Use Efficiency) indicator was calculated, which clearly demonstrates the amount of agricultural products produced per cubic meter of fresh water consumed (kg/m^3). The economic viability and profitability of the transition to new technologies were assessed using the IPAB complex indicator (cost-to-income ratio). This tool allowed us to consider both capital investments in drip irrigation infrastructure and a reduction in operating costs for water. A comparative analysis of these metrics over the two specified periods allowed us to draw reasonable conclusions about the impact of precision irrigation on productivity and economic sustainability of farms.

3. RESULTS AND DISCUSSION

3.1. Environmental and agronomic efficiency

The key indicator of the success of the technological transition was the Water Use Efficiency Index (EUA). Using the traditional approach, this indicator was at a critically low, stagnating level: farmers received only 0.34 kg of agricultural products for every cubic meter of water consumed. After the transition to localized water delivery systems, the EUA index showed an unprecedented threefold increase, reaching a value of 1.03 kg/m^3. From an ecological point of view, the mechanism of operation of drip irrigation systems physically eliminates the possibility of excessive infiltration (deep filtration) of excess water into the lower layers of the soil. This prevents an artificial increase in the groundwater level and the pulling of dissolved salts to the surface, thereby stopping the destructive process of secondary salinization of land.

3.2. Economic assessment of the technological transition

Large-scale implementation of technologies that stop soil degradation is impossible without a functioning economic mechanism that motivates farmers to conserve water resources. The IPAB indicator (the ratio of the sum of all production costs to the income received) was used to assess the feasibility of the transition. With traditional surface irrigation, the average IPAB value was 0.969. This figure clearly indicates that in order to generate just one unit of net income, farmers were forced to spend almost an entire unit of valuable resources, teetering on the edge of profitability and lacking financial space for development (Table 1).

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Table 1: Comparison of the two approaches

Comparison Parameter	Traditional Irrigation (2016–2018)	Drip Irrigation (2019–2021)	Change / Effect
Average irrigation rate (m^3/ha)	7,472.7	4,054.72	45.7% reduction in water consumption
Average yield (kg/ha)	2,512	4,185	66.6% increase in productivity
Water Use Efficiency (EUA) (kg/m^3)	0.34	1.03	Threefold increase in efficiency
IPAB Indicator (Cost/Income ratio)	0.969	0.671	30.7% decrease in cost intensity
Average real profit (UZS/ha)	504,840	7,497,580	Nearly 15-fold increase in profit
Water tariff (Projected, UZS/m^3)	300	50	Economic incentive for transition

As can be seen from the data, the use of an innovative approach has reduced the cost intensity of production (IPAB) to 0.671. This decrease led to an almost 15-fold increase in the real average profit: from 504,840 UZS/ha with the old method to 7,497,580 UZS/ha with drip irrigation. Moreover, the difference in projected water tariffs creates a powerful and sustainable economic incentive to continue upgrading agricultural infrastructure in the region.

4. CONCLUSION

The research conducted proves that the transition from traditional surface irrigation to modern water-saving technologies is critically important not only for the local economy of farms, but also for the macroecology of the entire Aral Sea basin. Historically, it was systemic and excessive water intake for extensive irrigation that triggered a large-scale disaster, leading to a reduction in the once-abundant volume of the sea from 1,090 km^3 to a critical minimum of 183 km^3 and a fatal salinity jump from 10 to 70 g/l. Today, this crisis is rapidly aggravated by the fact that over the past 50 years, the area of high-altitude glaciers feeding the rivers of the basin has decreased by 30%. According to alarming scientifically based forecasts, by 2050 the total shortage of fresh water only within the borders of the Republic of Uzbekistan may reach 15 km^3.

In these harsh conditions, the introduction of drip irrigation demonstrates clean, documented savings of 1.97 cubic meters of precious water for every kilogram of cotton produced. A large-scale result based on such strict rationalization of consumption is now becoming the main and

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most reliable tool for strategic adaptation of the entire vast region to the impending threats of climate change. Consequently, in a rapidly deteriorating environment, any increase in the efficiency of irrigation systems finally ceases to be a highly specialized, exclusively agrarian task aimed only at making a profit. Large-scale rationalization of water use is recognized as a key, non-alternative mechanism for preserving melting water resources, the global fight against inexorably advancing desertification and guaranteeing the survival of the entire macroregion in the future.

5. RECOMMENDATIONS

The following strategic steps are proposed to maximize the positive process of technological transition and minimize environmental risks.

5.1. Targeted scaling of resource-saving technologies

It is recommended to focus on the implementation of an optimistic scenario, which involves the systematic modernization of water use systems on at least 30% of available agricultural land. The implementation of such a scenario only within the Bukhara region will make it possible to achieve the total seasonal savings of water resources in a huge amount - 138.5 million cubic meters. This released water is critically important for restoring the ecological balance, as it is equivalent to 17.69% of the total volume of water currently used for cotton production in the entire province.

5.2. Introduction of harsh economic incentives

In order to make obviously irrational water use economically unprofitable for farmers, a system of differentiated water tariffs must be introduced at the highest state level. The essence of the initiative should be to set a hard price of 300 soums for each cubic meter consumed, while stubbornly continuing to use traditional irrigation ditches, while providing a preferential rate of only 50 soums with a conscious transition to modern energy-saving technologies.

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