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Modeling and evaluation of the effectiveness of the operation of Danube rice irrigation systems taking into account environmental requirements

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Abstract **– A mathematical modeling approach was employed to establish a suite of indicators for assessing the efficiency of Danube rice irrigation systems. The proposed indicators facilitate the identification of rational management strategies, including methods, regimes, and schemes for regulating the natural and reclamation processes of irrigated lands. This takes into account the unique characteristics of rice systems while ensuring compliance with current environmental regulations and principles of sustainable development.**

Keywords – Danube rice irrigation systems, efficiency of functioning, regression analysis, natural and reclamation regimes, ecological requirements.

I. Introduction

For the effective and ecologically safe use of rice irrigation systems (RIS), it is essential to revise approaches to land reclamation and develop scientifically based methods for managing the fertility of irrigated lands. This includes improving their agro-ecological conditions and promoting rational usage. These methods must adapt to natural and anthropogenic changes, ensuring maximum profit while preserving land resources.

Rice systems possess specific characteristics due to the requirement of maintaining a layer of water in the fields, complicating system operations. The effectiveness of RIS is evaluated based on crop productivity, water consumption, and the condition of the irrigated lands.

To evaluate the effectiveness of RIS, it is necessary to assess the impact of a set of indicators. These indicators can be expressed as requirements for factors influencing soil formation and plant development while considering the water-air, salt, and other regimes of rice systems.

II. Statement of the Problem

Rice systems exhibit several features that distinguish them from conventional reclamation objects in the irrigation zone. These distinctions arise from the complex geological and hydrogeological conditions of the territories designated for their establishment, as well as the predominance of flooded rice as the primary crop in the rotation. The specificity of this crop lies in its cultivation technology, particularly the necessity to maintain a layer of water in the fields throughout the growing season [1, 2].

Consequently, the rice irrigation system (RIS) constitutes a complex network of water supply, drainage, regulation, and other elements, all interconnected within a singular technological process alongside rice fields that support both flooded rice and accompanying dry crops in the rotation.

The assessment of RIS effectiveness should consider crop productivity, water resources, and both natural and reclamation regimes. To this end, it is crucial to establish a set of indicators that will facilitate the evaluation of RIS operation effectiveness while accounting for ecological and economic requirements, as well as yield models.

III. Solution Of The Published Problem

The rationale behind this set of indicators is to facilitate the improvement and optimization of rice irrigation system management. This will be achieved by employing a comprehensive suite of predictive optimization models, including crop yield models for rice rotations, to enhance the overall efficiency of RIS while ensuring compliance with current environmental and economic regulations.

Evaluating the efficiency of rice fields necessitates indicators that characterize the water cycle, taking into account the design of the rice irrigation system. These indicators should be obtainable through experiments or predictive models of water management, reclamation, and crop yield.

To assess the ecological efficiency of rice irrigation systems within optimization models, it is essential to investigate the relationships and suitability of these indicators as evaluation criteria.

The concept of "yield as a function of multiple variables" requires the development of a methodology for constructing statistical yield prediction models. This methodology should consider various factors influencing yield and utilize multi-criteria regression analysis for indicator selection.

A correlation matrix serves as the foundation for the multi-criteria regression analysis method, enabling the identification of interrelationships among factors impacting crop yield:

$$|r_{mn}| = \begin{pmatrix} 1 & r_{12} & r_{13} & \cdots & r_{1n} \\ r_{21} & 1 & r_{23} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ r_{m1} & r_{m2} & r_{m3} & \cdots & 1 \end{pmatrix} \quad (1)$$

where r_{mn} is the pairwise correlation coefficient between factors influencing crop yield. This method allows for the gradual elimination of factors with the least impact on yield, thereby increasing the accuracy of the forecasting model. The analysis was conducted using long-term rice production data from the Danube River delta at the Kiliya Rice Irrigation System, covering the period from 1966 to 2018 [5].

Based on the analysis and generalization of data from long-term research and relevant literature, we have identified a set of indicators that highlight various aspects of rice yield formation [1, 2, 3, 4, 5, 6].

This set of criteria, substantiated through multi-criteria regression analysis, includes the following key indicators:

Y – Rice yield: the primary economic indicator of production efficiency.

Hg – Groundwater level depth: a combined indicator reflecting the impact of hydrological conditions.

P – Heat and moisture supply: an indicator of climatic conditions during the growing season.

M – Rice irrigation rate: a reclamation technological resource determining the amount of water required to maintain yield.

A – Indicator of the agro-ecological and reclamation state of soils: an environmental criterion reflecting the conditions affecting yield formation.

V – Filtration rate: a technological indicator characterizing the environmental impact on the yield formation process through the water regime.

These indicators enable a comprehensive assessment of the efficiency of rice irrigation systems and facilitate yield forecasting based on mathematical models.

The results of the multi-criteria regression analysis of long-term rice cultivation data at the Kiliya Rice Irrigation System confirm the significant impact of various factors on rice yield.

The matrix of pairwise correlation coefficients illustrates the relationships between yield and factors such as irrigation rate, heat and moisture supply, agro-ecological and ameliorative state of soils, groundwater depth, and filtration rate (Table 1).

TABLE I. CORRELATION MATRIX FOR RICE IRRIGATION SYSTEM PERFORMANCE

Indicator	*Rice yield, Y*	*Rice irrigation rate, M*	*Heat and moisture supply, P*	*Indicator of the agro-ecological and meliorative state of soils, A*	*Groundwater level depth, Hg*	*Filtration rate, V*
Y	1	0.1939	0.4612	0.9065	0.4613	0.8197
M	0.1939	1	0.2509	-0.1432	0.1662	0.1999
p	0.4612	0.2509	1	0.367	0.198	0.2634
A	0.9065	-0.1432	0.367	1	0.4164	0.7442
Hg	0.4613	0.1662	0.198	0.4164	1	0.4178
V	0.8197	0.1999	0.2634	0.7442	0.4178	1
Standard errors of correlation coefficients						
Y		0.15	0.12	0.02	0.12	0.05
M	0.15		0.14	0.14	0.15	0.14
P	0.12	0.14	_	0.13	0.14	0.14
A	0.02	0.14	0.13		0.12	0.07
Hg	0.12	0.15	0.14	0.13		0.12
V	0.05	0.14	0.14	0.07	0.12	
r^2=0.887, r=0.942						

The strongest correlation with rice yield is observed for the agro-ecological-reclamation condition of soils (correlation coefficient – 0.90) and filtration rate (correlation coefficient – 0.82). This shows that ecological conditions and anthropogenic factors, particularly the soil's water conductivity, are of key importance for productivity.

A weaker but still significant relationship was found with heat and moisture availability during the growing season (correlation coefficient – 0.46) and the groundwater depth during the inter-irrigation period

(correlation coefficient – 0.46). These factors reflect climatic and hydrological conditions, which also influence crop development.

The irrigation rate has a relatively weak correlation with yield (correlation coefficient – 0.19), due to the fact that a significant portion of the water is used to create a water layer and compensate for filtration losses, rather than directly meeting the crop's water demand.

According to the results of the regression analysis, the distribution of the importance of factors influencing rice yield formation is as follows:

- Indicator agro-ecological and ameliorative condition of the soil – 41%;
- Filtration rate from the surface of the check – 25%;
- Heat and moisture supply – 13%;
- Groundwater level depth during the inter-irrigation period – 12%;
- Rice irrigation rate – 9%.

CONCLUSION

The main determining factors influencing rice yield are the ecological condition of the soil and the filtration rate, which underscores the importance of effective management of the natural and reclamation regime of irrigated fields. The results obtained provide a foundation for further implementation of optimization models in irrigation system management, particularly for the development of environmentally safe and economically sound engineering solutions for the design and operation of irrigation systems.

This will enhance the efficiency of irrigation systems, ensuring compliance with modern ecological and economic standards and promoting the rational use of water resources.

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