

CLUSTER-MATRIX TOOLS FOR IRRIGATED AGRICULTURE IN INTERFLUVE

OUTILS «CLUSTER-MATRICE» POUR L'AGRICULTURE IRRIGUÉE EN L'INTERFLUVE

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ABSTRACT

The relevance of the study is explained by the need to improve the tools for assessing and predicting irrigated agriculture in natural and geographical zones – interfluvial areas, which are spaces located **between two adjacent rivers and have a high production potential**. The most famous interfluves are located in **Mesopotamia** in the valley of the Tigris and Euphrates Rivers; **the Argentine Interfluve, located in the provinces** of Corrientes and Entre Rios; the Baraba Lowland, which occupies the area between the Siberian Ob and Irtysh rivers. The genesis of mesopotamia shows that these are areas with a high level of development of many branches of agriculture (crop production, animal husbandry and fish farming). The cluster-matrix tools used in the study made an assessment of the productive agricultural potential and justified the reclamation and ecological stability of the Volga-Don interfluve, located in the south of the East European Plain in the Lower Volga and Middle Don basin. *The methodological basis of the study* was the concept of sustainable development of agricultural landscapes and tools that made it possible to conduct a SWOT analysis of agriculture, suggest vectors for the development of mesopotamia, taking into account the life cycle, and outline cluster integration processes. *The hypothesis of the study* is that a multi-factor assessment of the Volga-Don interfluve will allow us to justify the intensification of production with the formation of a "zone of progressive irrigated agriculture". *The aim of the study* was to strategize the Volga-Don interfluve in ensuring the intensification of agricultural production and establishing an ecological balance. *Conclusions*: The conceptual-scenario approach allowed us to model the future appearance of the Volga-Don interfluve as a "zone of progressive irrigated agriculture" with an estimated coefficient of ecological and meliorative intensity ≥ 0.65 , programmed output of finished products from 81,708 hectares of irrigated land and attracting 2.8 billion rubles. public-private investment. To ensure the ecological sustainability of mesopotamia, we propose the following ratios of the main elements of the regional agricultural landscape: arable land-59 %, perennial stands-0.3 %, hayfields-2.3 %, pastures-32.6 %, forest stands-5.8 %.

The relevance of the study is explained by the need to improve the tools for assessing and predicting irrigated agriculture in the most important natural and geographical areas for agriculture - interfluve areas. The most famous interfluves are located in the Mesopotamia in Middle East, the Argentine Interfluve, the Barabinsk steppe in Siberia, the Volga-Don interfluve in the European part of Russia. These areas are characterized by traditional agricultural industries: crop production, cattle breeding, horticulture, and irrigation systems. The developed a facilities of cluster-matrix tools makes it possible to assess the productive potential and environmental sustainability of agricultural landscapes in interfluve. The object of the study was to determine the processes occurring in the agricultural landscapes of the Volga-Don interfluve of Russia. The methodological basis of the study is based on the methods developed by Russian scientists, including: multi-factor analysis, economic and mathematical modeling, and intelligent forecasting. The study hypothesis was the statement that

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attracting investment to irrigated agriculture using the mechanism of public-private partnership will form a "point of intensification of agricultural production" in the Volga-Don interfluvium. The aim of the study was vector-strategic planning of agriculture in the Volga-Don interfluvium based on cluster-matrix tools. Matrix research tools include SWOT analysis of agriculture and construction of the matrix "Production efficiency-multi-factor risks" with four groups of values that characterize production efficiency and risks, and 16 quadrants for making decisions on the different life cycle stages: decline, stagnation, optimization, development. Cluster tools allowed us to identify functioning integrated associations: vegetable growing cluster, grain - vegetable oil cluster, green cluster and garden intensification. Conclusions: the cluster-matrix tools of economic and mathematical modeling allowed us to identify vectors of strategic development of the Volga-Don interfluvium in the field of agriculture through an increase in the area of irrigated land from 1.2% to 6.9% with an estimated productivity of 7.0 thousand feeding units per hectare and average production profitability about 32%. This study made it possible to establish a "point of intensification of agricultural production" in interfluvium with land reclamation intensity coefficient ≥ 0.65 , a programmed finished products yield (vegetable – 40.0 t/ha, crop (winter wheat) – 6.42 t/ha, fruit and berry - 35 t/ha), an optimal ratio of steppe agrolandscapes structural elements (arable land – 50-60%, perennial plantations – 0.3-0.5%, hayfields – 1.2 - 2.3%, pastures – 30.0- 34.8%, forest plantations – 5.1 – 8.2%).

Keywords: agriculture, interfluvium, irrigated agriculture, cluster-matrix tools, productive and ecological potential.

RESUME

La pertinence de l'étude s'explique par la nécessité d'améliorer les outils d'évaluation et de prévision de l'agriculture irriguée en zones naturelles et géographiques – **l'interfluvium** - espaces situés entre les deux rivières adjacentes ayant fort potentiel de production. Parmi les interfluviums les plus célèbres, on peut citer la Mésopotamie (dans la vallée du Tigre et de l'Euphrate), l'interfluvium argentin (situé dans les provinces de Corrientes et d'Entre Ríos) et la basse terre de Baraba (s'étendant entre les fleuves sibériens Ob et Irtych). La genèse de la Mésopotamie montre qu'il s'agit de zones à fort développement de nombreuses filières agricoles (productions agricoles, élevage et pisciculture). Les outils cluster-matrice utilisés dans l'étude ont permis d'évaluer le potentiel de production agricole et de justifier les mesures de mise en valeur et la stabilité écologique de l'interfluvium Volga-Don, situé au sud de la plaine d'Europe orientale, entre les bassins de la Basse Volga et du Moyen Don. *La base méthodologique de l'étude* était le concept de développement durable des paysages agricoles et les outils qui ont permis de mener une analyse SWOT de l'agriculture, de proposer des vecteurs pour le développement de la Mésopotamie, en tenant compte du cycle de vie, et de définir les processus d'intégration du cluster. L'hypothèse de l'étude est qu'une évaluation multifactorielle de l'interfluvium Volga-Don nous permettra de justifier l'intensification de la production par la création d'une «zone d'agriculture irriguée de pointe». L'étude visait à élaborer une stratégie pour l'interfluvium Volga-Don en assurant l'intensification de la production agricole et en établissant un équilibre écologique. Conclusions : L'approche par scénarios conceptuels nous a permis de modéliser le devenir de l'interfluvium Volga-Don, appelée «zone d'agriculture irriguée progressive», caractérisée par un coefficient estimé d'intensité écologique et d'amélioration de $\geq 0,65$, ainsi qu'une production programmée de produits finis provenant de 81,708 hectares de terres irriguées et attirant 2,8 milliards de roubles d'investissements publics-privés. Pour assurer la durabilité écologique de la Mésopotamie, nous proposons les proportions suivantes des principaux éléments du paysage agricole régional : terres arables - 59%, cultures pérennes - 0,3%, prairies naturelles - 2,3 pâturages - 32,6%, zones forestières 5,8%.

La pertinence de l'étude s'explique par la nécessité d'améliorer les outils d'évaluation et de prévision applicables à l'agriculture irriguée en zones naturelles et géographiques les plus importantes pour l'agriculture - zones interfluviales. Parmi les interfluviums les plus célèbres, on peut citer la Mésopotamie (Moyen-Orient), l'interfluvium argentin, la steppe de Barab (Sibérie) et l'interfluvium Volga-Don (partie européenne de la Russie). Ces zones sont caractérisées par des industries agricoles traditionnelles : production agricole, élevage de bétail, horticulture et systèmes d'irrigation. Le développement d'un ensemble d'outils «cluster-matrice» permet d'évaluer le potentiel productif et la durabilité environnementale des paysages agricoles au sein de l'interfluvium. L'objet de l'étude était de déterminer

les processus se produisant dans les paysages agricoles de l'interfluve Volga-Don, en Russie. La base méthodologique de l'étude multi-factorielle se base sur les méthodes développées par des scientifiques russes, y compris : analyse multifactorielle, modélisation économique et mathématique, et prévisions intelligentes. L'hypothèse de l'étude était d'attirer les investissements dans l'agriculture irriguée en utilisant le mécanisme du partenariat public-privé pour créer un «point d'intensification de la production agricole» dans l'interfluve Volga-Don. L'objectif de l'étude était la planification stratégique orientée par vecteurs de l'agriculture dans l'interfluve Volga-Don basée sur des outils cluster-matrice. Les outils de recherche matriciels comprennent l'analyse SWOT de l'agriculture et la construction de la matrice « Efficacité de production - risques multifactoriels » avec quatre groupes de valeurs qui caractérisent l'efficacité de production et les risques, et utilisent 16 quadrants pour prendre des décisions sur les différents stades du cycle de vie : déclin, stagnation, optimisation, développement. Les outils de cluster nous ont permis d'identifier des associations intégrées opérationnelles : cluster maraîcher, cluster céréales et huiles végétales, cluster vert et intensification des jardins. Conclusions : les outils cluster-matrice de modélisation économique et mathématique nous ont permis d'identifier des vecteurs de développement stratégique agricole de l'interfluve Volga-Don dans le domaine de l'agriculture grâce à une augmentation de la superficie des terres irriguées de 1,2% à 6,9%, avec une productivité estimée à 7 000 unités d'alimentation par hectare et une rentabilité moyenne de la production d'environ 32%. Cette étude a permis d'établir un «point d'intensification de la production agricole» en interfluve, caractérisé par un coefficient d'intensité de mise en valeur des terres $\geq 0,65$, d'un rendement programmé en produits finis (légumes – 40,0 t/ha), culture (blé d'hiver) – 6,42 t/ha, fruits et baies - 35 t/ha), un taux optimal d'éléments structuraux des paysages et de l'agriculture de la steppe (terres arables – 50-60%, plantations pérennes – 0,3-0,5%, prairies naturelles – 1,2 - 2,3%, pâturages – 30,0 - 34,8%, plantations forestières – 5,1 - 8,2%).

Mots-clés : Agriculture; interfluve; Agriculture irriguée; Outils cluster-matrice; Potentiel productif et écologique.

Introduction

The present research is a summary of the generated knowledge and results of field studies that provides an understanding of the importance of irrigation systems, predicting scenario solutions in agriculture for ensuring efficiency and environmental sustainability. The current state policy should encourage the development of land reclamation, taking into account the economic and natural significance for the population. Land areas where all the factors that ensure the functioning of high productive sustainable irrigated agricultural landscapes are very limited. Reference to encyclopedic knowledge shows that they include interfluves with **high production potential on the field of irrigated agriculture development. Each country has its own interfluve's territories that were formed as a result of centuries-old tectonic transformations of river basins.**

The most famous interfluve's regions are: Mesopotamia, located in the valley of the Tigris and Euphrates Rivers, **the Argentine Interfluvial region within the provinces** of Corrientes and Entre Rios, and the Russian interfluvial region-the Barabinsk lowland within the two Siberian rivers: Ob and Irtysh. The object of our research is the interfluve, which is located in the southern part of the East European Plain and is bounded by the Volga and Yergeni hills, the Volga and Don River valleys. The western geographical part of the interfluve is represented by a dry steppe with a chestnut soils predominance; the eastern part is represented by a semi-desert area of light chestnut soils with "solonetz spots". The Volga-Don interfluve is first mentioned in the works of Herodotus and Ptolemy. In the XVIII-XIX centuries, the territory became the object of scientific expeditions organized by the Russian Academy of Sciences under the leadership of I. Lepekhin, I. Guldenstedt and P. Pallas.

In the second half of the twentieth century, **interfluve** became a testing plot for large-scale geomorphological transformations caused by the construction of irrigation channels and hydraulic structures. Today, the Volga-Don interfluve is a center of intensive agricultural production, which used modern adaptive landscape technologies, precision farming and intelligent irrigation. Due to climate change, irrigation with project yield volume and environmental sustainability is becoming a key factor in agricultural development (Figure 1).

Modeling of agricultural landscapes using cluster-matrix tools makes it possible to calculate optimal loads on the environment, estimate the importance of agricultural system's components, the quantity of soil fertility, the water regime of plants, and calculate the level of interdependence between regional economic sectors. A review of foreign and Russian publications that give an idea of the managed irrigated agricultural landscape offers a research tools range that allow to get obviously accurate results. This is becoming increasingly important due to climate change and the need for more efficient use of water and land resources.

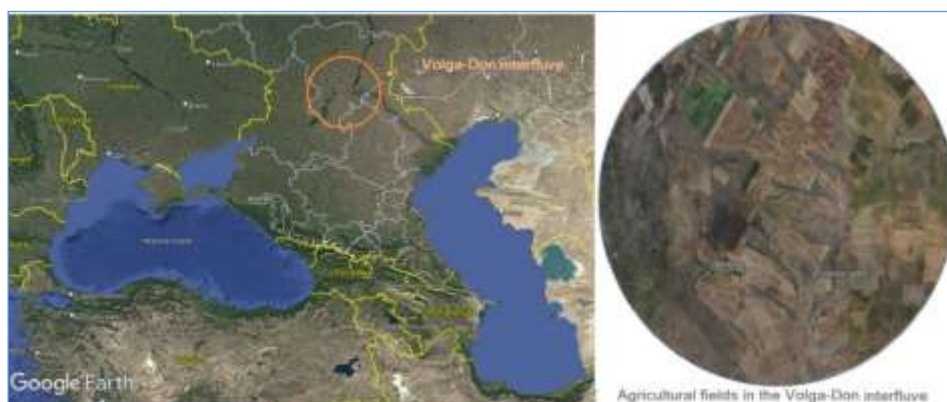


Figure 1. Location of the Volga-Don interfluvium on a geographical map

The main aim of the study was to elaborate the strategy development Volga-Don interfluvium in ensuring the intensification of agricultural production and establishing an ecological balance. The tasks included study of an available tools for assessing natural and anthropogenic factors affecting to irrigated agriculture, conditions for the intensification of production and the formation of agricultural clusters.

Traditional analysis of the current conditions of agricultural production in **interfluvium** doesn't allow us to sufficiently determine the occurrence of certain events, provide economic entities with reliable information, predict risks and obtain programmed profits, taking into account the progressive transformation of food markets.

Under the leadership of Ivan Kruzhilin, Academician of the Russian Academy of Sciences, a water regime management system with programmed crop yields was developed for the Volga-Don interfluvium, and the directions of breeding orientation and conditions of cultivation of agricultural plants are determined, included cultivation of seed grass (Bakhtygaliyev, 1998), alfalfa (Burtseva, 1999), chickpeas (Khabarov, 2005), buckwheat (Ivanova, 2007), soybeans (Zinchenko, 2009), corn (Tikhonova, 2001), potatoes (Gichenkova, 2000), tomatoes (Dementyev, 2004), eggplants (Masharova, 2011), cucumbers (Dmitrienko, 2005), beets (Melikhova, 2007), zucchini (Kovalenko, 2014), carrots (Skorokhodov, 2011), onions (Reznikova, 2003), and rice under periodic irrigation (Nevezhina, 2022).

A scientific factor in increasing the efficiency of agricultural production in the dry-steppe zone of interfluvium is remote mapping, which makes it possible to establish the actual areas of irrigated land and the level of erosion processes. The heterogeneity of irrigated fields reflected on satellite images has a different background, so this interpretation is required confirmation from the field research, which is the goal of VNIIGIM scientists. Currently, in the Volga-Don interfluvium, only 2.5% of the total agricultural land is irrigated.

The hypothesis of the study was the statement that a multifactorial assessment of the Volga-Don interfluvium would justify the intensification of production with the formation of a "zone of progressive irrigated agriculture."

Materials and methods

To conduct research that meet the principles of objectivity, structure and complexity, a program was developed that included the definition of keywords and terms that best reflect the research topic, including "cluster-matrix tools", "production potential", "environmental sustainability", "risk agriculture", "intelligent management" search for scientific information in specialized databases.

To confirm *this hypothesis*, we used cluster-matrix tools and simulation modeling. **The object of the study was the Volga-Don interfluvium with the processes occurring in it.** The subject of the study is relations in the regional economy aimed to development of irrigated agriculture and use of adaptive landscape technologies. To assess the state of landscapes of Volga-Don interfluvium, databases (VNIIGiM, Moscow) were used, including the information presented in Tables 1-4.

Table 1. Soil state of the Volga-Don interfluvium

Soil type	Potential humus reserves, t/ha (G_0)	$G_{\text{гн}}/G_{\text{фк}}$	Mineral elements in fractions of the maximum value			H, mEq 100 g
			N	P	K	
Chestnut	300	1	0,5	0,25	0,7	0,5
Brown semi-desert	50	0,6	0,1	0,15	0,6	0,5

Table 2. Irrigation standards of the Volga-Don interfluvium

Natural area	Soil type	Irrigation rate, mm
Dry steppe	Dark chestnut, chestnut heavy loamy	600-650
Semi-desert	Light chestnut, brown semi-desert loamy	700-800

Table 3. Scale of sustainability of agricultural landscapes of the Volga-Don interfluvium

Crop Productivity	Sustainability Scale
$Y_p \leq (1.7-1.95) \cdot p \cdot K_b < 20\%$	High
$Y_p = (1.4 - 1.8) \cdot p \cdot 20 \leq K_b < 25\%$	Average
$Y_p = (1.0 - 1.40) \cdot p \cdot 25 < K_b < 30\%$	Low
$y_p < A_t \cdot r_p \cdot T_{ov} > 30\%$	Very low

Note: U_r – crop yield, t/ha; K_v – coefficient of variation of agricultural crop yields, by year; U_{RP} – potential crop yield, t/ha.

Table 4. Climatic conditions of the Volga-Don interfluvium

Average indicators	Steppe zone soils
Average annual air temperature ($^{\circ}\text{C}$)	5,5-7,0
Dates of air temperature transition through $+10^{\circ}\text{C}$	23.04
Duration of frost-free period (days)	165-170
Annual precipitation, mm	300-400
Annual evaporation, mm	900-1000

To calculate the economic efficiency of agricultural and irrigated land in the Volga-Don interfluvium, the following formulas were used [12]:

$$\psi(u) = \max_{x_l, y} \left\{ \sum_{l \in L} C_l(y) \cdot x_l - C_0 \left[\left(\frac{y}{\theta} \right)^{4,35} - 1 \right] - \left(C_1 \left(\frac{y}{\theta} \right)^{4,35} + C_2 \right) \cdot \delta \right\}, (1)$$

where $\psi(u)$ is the target function that determines the economic effect of irrigated agriculture, thousand rubles.

i – level of water supply to the irrigation system (IS), m^3 ;

x_l – irrigation area l -crop rotation, ha.

l – crop rotation index.

y – total efficiency of the operating system.

L – set of crop rotations, including subsets $L_i, i \in [1, n]$ types of products;

$C_l(y)$ – production cost per unit of irrigated area for l -crop rotation, rub./ ha.

C_0 – current capital expenditures for the construction of the IS, thousand rubles.

θ – irrigation system efficiency, $\theta \leq y \leq 1$;

C_1 – estimated cost of an irrigation canal construction in an earth channel bed, thousand rubles.

C_2 – estimated capital expenditures for the of an irrigation canal construction in a concrete channel bed in comparable prices, thousand rubles.

δ – binary variable, determined from the dependence:

$$\delta = \begin{cases} 0 & \text{if } \sum_{j \in J^+} u_j u_j \leq u_j^{u_j^0}, \\ 1 & \text{if } \sum_{j \in J^+} u_j u_j > u_j^{u_j^0}, \end{cases} \quad (2)$$

where u_j – throughput capacity of the designed j -th section of the IS, m^3 ;

u_j^0 – throughput of the of the designed j -th section of the IS, m^3 .

Matrix research tools

Monitoring of the irrigated lands state in the Volga-Don interfluvium (hereinafter referred to as the ILVDI) was carried out through the construction of a SWOT model – analysis of agricultural production (Table 5) and the analytical matrix "Productive efficiency of irrigated agriculture-multi – factor risks" (Figures 2, 3).

Table 5. SWOT analysis of agricultural development in the Volga-Don interfluvium

Name – strengths	Name – weaknesses
Sufficient land resources	Constantly increasing wear and tear of production assets
Natural and climatic conditions for agricultural production	Disposal of part of agricultural land from circulation
Experience in ensuring the sustainable state of agricultural landscapes	Insufficient inflow of investment in agricultural production
Developed transport and logistics infrastructure	Relative development of the processing industry
High degree of specialization in agricultural production	Continuous outflow of labor resources
$W = 0,96; \chi^2_{\text{расч}} = 39,01$	$W = 0,59; \chi^2_{\text{расч}} = 21,13$
Name – capabilities	Name – threats
Increasing the competitive status of agricultural producers, incl. export	Climate change, increased likelihood of drought
Favorable natural conditions for business development	High degree of wear and tear of reclamation infrastructure
Availability of unused land and water resources	Shrinking labor market
Prospects for the development of agricultural vertically integrated production	Geopolitical problems (sanctions)
Increasing government support for land reclamation	Insufficient level of investment in fixed assets
$W = 0,65; \chi^2_{\text{расч}} = 26,51$	$W = 0,61; \chi^2_{\text{расч}} = 13,35$

Application to the SWOT analysis allowed to identify "strengths" - 39.01 and "opportunities" - 26.51 in the agriculture development, in assessing the existing natural and anthropogenic potential of the Volga-Don

interfluvial The multi – factor matrix "Productive efficiency of irrigated agriculture-multi-factor risks" was used for assess agricultural land state by the reproduction process in **interfluvial**. The matrix with four axes was divided into several groups: two of them - system-forming factors, and the other two were an agricultural production efficiency and risk assessment.

On the general field of the matrix, consisting of 16 quadrants, blocks of 4 quadrants were formed, representing areas of organizational decision-making. The expert definition was carried out using the formulas (3,4,5):

$$P_i = \frac{\sum_{i=1}^n P_i}{m}, \quad (3)$$

where P_i – average score of the indicator.

P_{Pi} – the expert's rating.

m – the number of experts participating in the study.

$$P_{weighted}^{el} = \frac{\sum_{i=1}^n (P_i^{el} \times R_i^{3n} R_i^{el})}{\sum_{i=1}^n R_i^{el}}, \quad (4)$$

where P_{is}^{3n} – the weighted average estimate of the expert opinion,

where R_i^{el} is the weight of each indicator.

n – number of indicators.

$$P_{weighted}^{el} = \frac{\sum_{i=1}^n (P_{weighted}^{el} \times R_i^{bl})}{\sum_{i=1}^n R_i^{bl}}, \quad (5)$$

where $P_{weighted}^{el}$ – the weighted average block score,

R_i^{bl} – the weight of each element in the block.

A score scale was used to form conclusions: low level - from 0 to 4; medium level – from 5 to 7; high level – from 8 to 9; SMART level-10. When strategizing the irrigated agriculture of the Volga-Don interfluvial on 01.01.2024, the intersecting lines formed an "object state point" located on the border of fields: C3, Y4, which made it possible to conclude that the level of irrigated agriculture development in the Volga-Don interfluvial is insufficient, and that there is a significant unused potential.

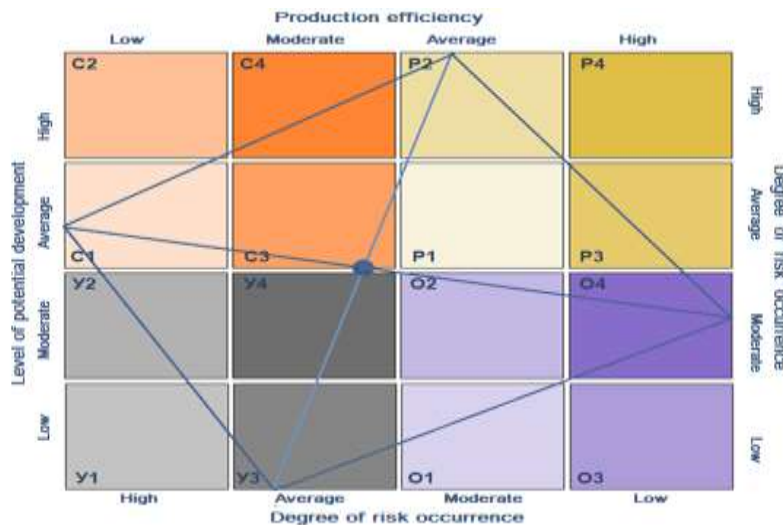


Figure 2. Positioning of irrigated agriculture in the Volga-Don interfluvial, 01.01.2024

Note on the blocks: R – development, U – decline, S – stagnation, O – optimization

Based on the scenario approach, which reflects the focus on increasing the area of irrigated land and assessing the available potential: the level of public and private investments (thousand rubles); the of product volume (rubles/ha); the cluster development index, the «*ILVDI point*» is predicted for 01.01.2040. The estimated location of the " *ILVDI point*" on the *P3 field* indicates an increase of agricultural production on irrigated land and the need to attract public and private investment, including the issue of *water bonds*, the yield of which can be calculated using the computer program "*KOHONEN MAP for determining the yield of water bonds in the implementation of projects in land reclamation*", developed by in VNIIGiM [4].

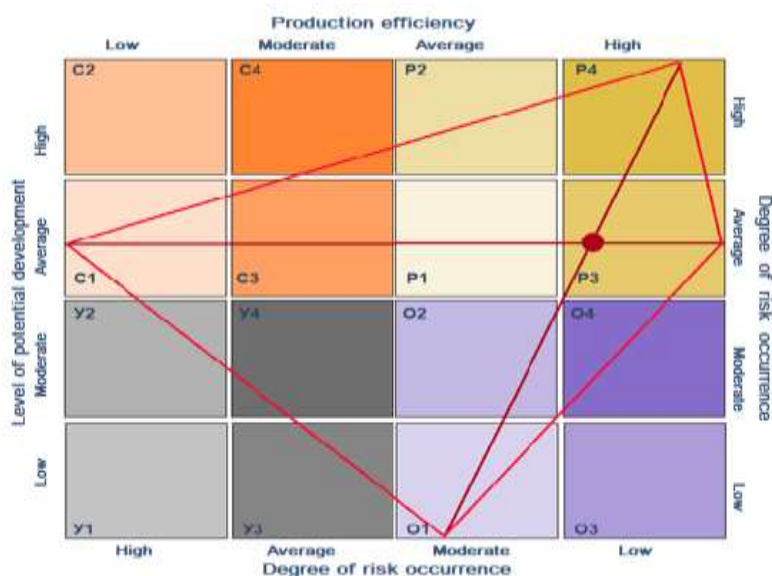


Figure 3. Positioning of irrigated agriculture in the Volga-Don interfluvium for the period up to 2040

Note on the blocks: R – development, U – decline, S – stagnation, O – optimization.

Matrix tools allowed us to form fields for decision-making in the development of irrigated agriculture in the Volga-Don interfluvium (Table 6).

Table 6. Management decisions for agriculture in the Volga-Don interfluvium for the period up to 2040

Field	Action Option
<i>Decline</i>	
Y1, Y2 Y3, Y4	Optimization of available resources, transition to resource-saving technologies, conservation of production. <i>Scenario solution: moving to field U2</i>
<i>Stagnation</i>	
C1, C2 C3, C4	Creation of optimal conditions aimed at preserving business, transition to resource-saving technologies, and search for investments. <i>Scenario solution: moving to field C4</i>
<i>Optimization</i>	
O1, O2 O3, O4	Application of adaptive landscape farming, rational crop rotations, innovative agrobiological and agrotechnical measures, attracting investments. <i>Scenario solution: moving to field O2</i>
<i>Development</i>	
P1, P2 P3, P4	Introduction of new irrigated lands into circulation, increasing the yield of agricultural crops, using different types of irrigation, resource-saving technologies, renewable energy sources, AI. <i>Scenario solution: moving to fields P2, P4</i>

Research Simulation Tools

To develop a standard irrigation system for the Volga-Don interfluvium, we used the calculations of Prof. V. N. Shchedrin, Academician of the Russian Academy of Sciences, based on simulation model of irrigation systems for a sufficiently long period of their operation, as well as research on the application of green technologies in irrigation (Medvedeva L., 2024). For constructing a simulation model based on the "water intake – irrigation system – spillway" profile, data were used that reflect the length and capacity of channels, the efficiency coefficient (COP) of each water supply element, the water use rate (WUR), and the operational reliability indicator of the irrigation system (%deterioration). The scheme of the simulation model for the profile "water intake-irrigation system-spillway" is shown in Figure 4.

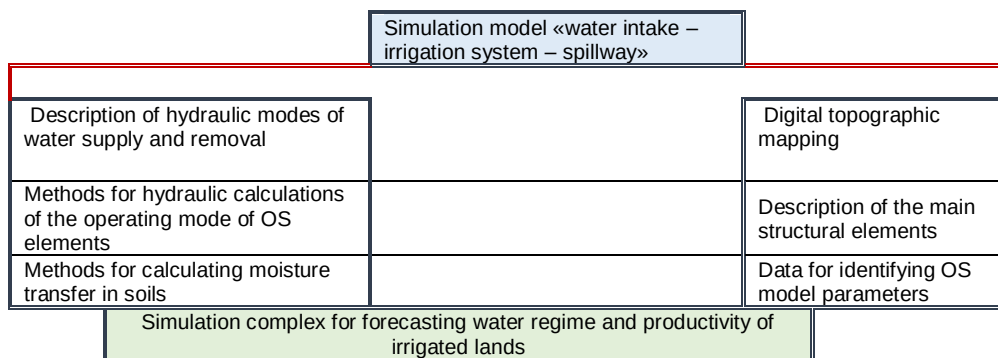


Figure 4. Diagram of the simulation model of the OS for the Volga-Don interfluvium

Cluster approach in research

Cluster analysis is based on research conducted by Prof. M. Porter. The method itself has been actively developed since the mid-twentieth century, when there was a need to process huge amounts of primary data explaining the relationship of industries, regions, and markets. Organizations can gain additional preferences and competitive advantages by ensuring closer interaction with suppliers, partners, and subsidiaries.

When developing a cluster diagram, the general principle is to prioritize manufactured products, followed by equipment and technologies. At the final stage, clusters linked by industry interdependencies are identified. The structural elements of the standard cluster are shown in Figure 5.

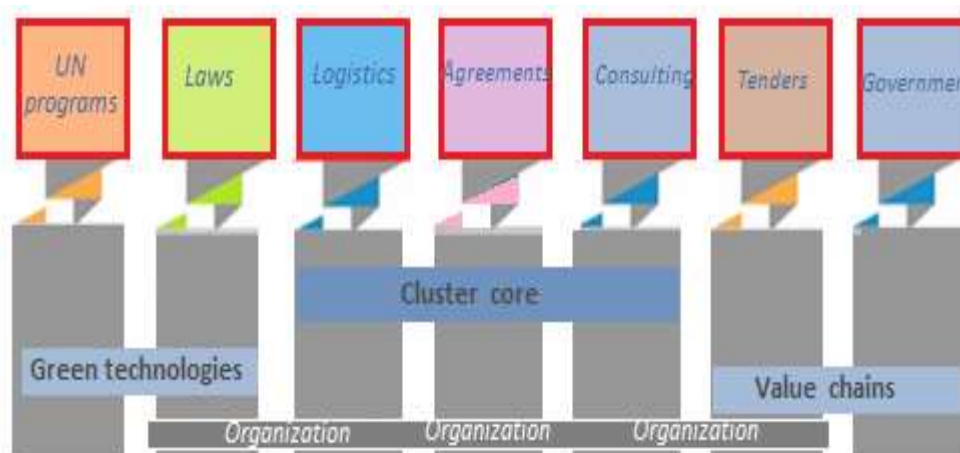


Figure 5. Diagram of a reference cluster using green technologies

Results and discussion

The Volga-Don interfluvium, located in the South of Russia (Volgograd region), covers 22.6 thousand km², of which 1,228,676 hectares are agricultural land, and 34,104 hectares are reclaimed land. The actual area of irrigated land in **interfluvium** is 26,435 ha.³ Scenario solutions for the intensification of agricultural production in the Volga-Don interfluvium require an increase in the area of irrigated land to 81,708 hectares, which will necessitate the modernization of old irrigation systems and the construction of new ones, taking into account the environmental requirements.⁴

Figure 6 shows a typical scheme of an irrigation system with circular wide-reach sprinklers and solar elements. The development of irrigated agriculture in the Volga-Don interfluvium will require 2.8 billion rubles of investments.

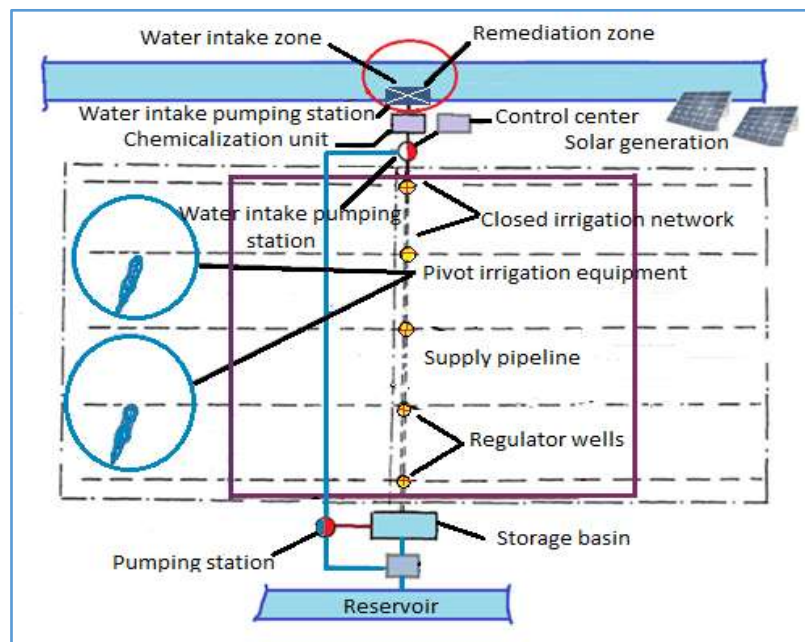


Figure 6. Schematic diagram of a typical model of a new generation irrigation system with wide-coverage irrigation machines for the Volga-Don interfluvium

Using analysis of variance - ANOVA, integration processes were studied in the Volga - Don interfluvium and were identified cluster formations of agricultural producers: vegetable, crop, and berry growing. The scheme of functioning with the allocation of their competitive status is shown in Figure 7.

Economic and mathematical modeling made it possible to establish a green cluster of industrial horticulture in the interfluvium with a consolidated by NPG company "Gardens of Don Region " and established chains of profit formation and product supply. The efficiency of attracted investments of participants of the Volga-Don interfluvium green cluster was calculated using the formula:

$$D_S = \sum_{k=1}^n \gamma_k x_k + \gamma \sum_{k=1}^n x_{n+k} \quad (6)$$

³ **Note.** The boundaries of the Volga-Don interfluvium were determined according to the works of: V. Brylev "Table deposits of the Volga-Don watershed. Issues of geography of the Lower Volga region, Volgograd, 1973, A. Fedyukov "Physico-geographical characteristics of the Volga-Don interfluvium (in the area of the closest convergence of the Volga and Don rivers) Abstract of thesis. for the scientific competition. candidate degree in geogr. Sciences / Univ. M. V. Lomonosov. Moscow 1954. 15 p.

⁴ Order of the Ministry of Agriculture of Russia dated August 28, 2024 No. 495 "Maximum cost of work per hectare of reclaimed land related to the implementation of hydro-amelioration measures"

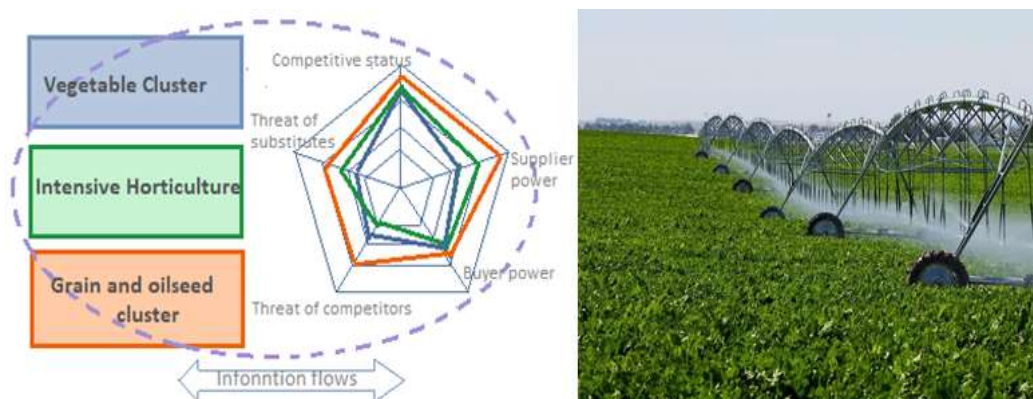


Figure 7. Agricultural clusters of the Volga-Don interfluvium with an estimated competitive status

For different stages of the green cluster life cycle, the efficiency index (D_{Ds}) was in the range: 0.42-0.68, which indicates the relative efficiency of the production process and significant unused potential. Figure 8 shows the competitive status of NPG "Gardens of Don Region" (in terms of product deliveries, product quality, production volumes and revenues received).

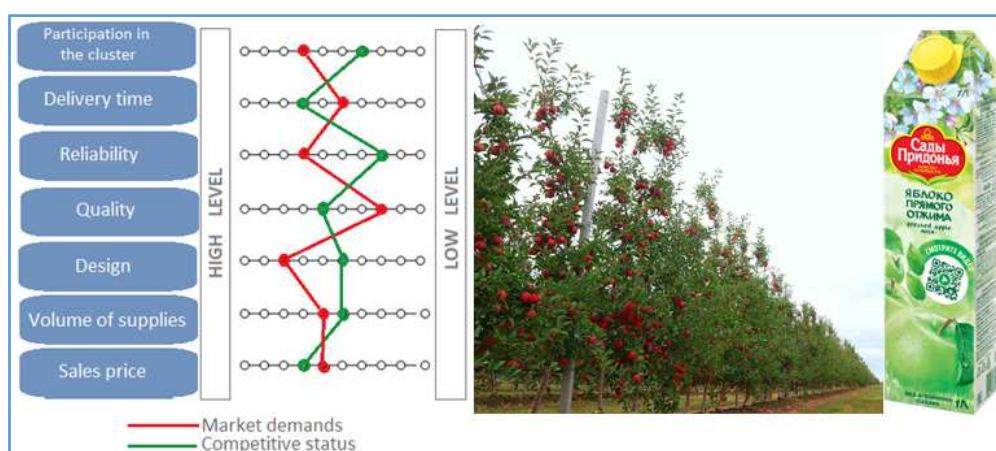


Figure 8. Functional indicators of the green cluster of industrial gardening with the consolidating core of the NPG "Gardens of the Don Region"

Conclusion

The conceptual and scenario approach allowed to model the Volga-Don interfluvium as "zone of progressive irrigated agriculture" with an estimated coefficient of ecological and ameliorative intensity ≥ 0.65 , a programmable output of finished products on irrigated land of 81,708 hectares with a production potential of 7.0 thousand feeding units. For the implementation of this plans, public-private partnership will be required with the involvement of 2.8 billion rubles, including in the water bonds form. On new irrigated lands, it is advisable to use standard design of irrigation systems with elements of green technologies. To ensure the ecological sustainability of the Volga-Don interfluvium, the ratio of the main elements of the agricultural landscape should correspond to the following proportions: arable land-59 %, perennial plantings-0.3 %, hayfields-2.3 %, pastures-32.6 %, forest -5.8 %.

Contributions of the authors: all authors of the present study were intimately involved in the planning, execution and analysis of the study results. Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the research reported in this paper.

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