

Ecological Efficiency Evaluation of Water Regulation of Drained Land in Changing Climatic Conditions

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ABSTRACT

In view of global climate changes, the study of the ecological feasibility of hydromelioration systems and their impact on the natural environment is extremely relevant. Evaluation of the ecological effectiveness of water regulation of drained land for current and forecasted climatic conditions was performed by determining the environmental reliability coefficient, which characterizes the ecological reliability of a reclamation project. The environmental reliability coefficient was determined on the basis of a certain set of physical indicators. The set of physical indicators reflects the extremely complex nature of the formation of water and general natural and ameliorative regimes of reclaimed land as a whole in changing natural, climatic and agro-ameliorative conditions of real objects. Their determining is based on the implementation of a machine experiment based on a complex of predictive and simulation models for water regulation of drained land on a long-term basis. The obtained results showed that ecologically optimal natural, ameliorative and soil regimes of the drained land, subject to compliance with the restrictions $0.5 < k_n \leq 1.0$, are ensured by the application of humidifying sluicing. At the same time, the environmental reliability coefficients are 0.59 and 0.58, respectively, for current and forecast climatic conditions, and the level of ecological reliability of applying humidification to drained land is sufficiently high. The carried out evaluation of ecological reliability of water regulation of drained land confirms the need to increase the role of humidification as a component of effective adaptive measures on drained land in modern and forecasted climatic conditions. Humidifying measures have a decisive influence on the ecological effect and the ecological and amelioration state of drained land.

Keywords: ecological reliability, drained land, water regulation technologies, changing climatic conditions, adaptive measures.

INTRODUCTION

The main task of hydro-technical reclamation is to ensure high and stable yields of cultivated crops. That can be achieved by developing and

implementing a complex of agro-ameliorative measures, technical and technological solutions for regulating the water-air regime as a defining component of the general natural and ameliorative regime. At the same time, the criteria for the

application of hydro-technical reclamation are economic efficiency and ecological feasibility of the impact of hydro-melioration systems on the surrounding natural environment.

The ecological expediency of ameliorative measures to preserve and improve soil fertility in view of rational use of land and water resources as well as environmental protection is becoming extremely relevant. First of all, this is due to the global climate changes, which encourage the adaptation of agricultural production to new climatic conditions [Altieri, et al., 2017; Lipper, et al., 2014; Rokochynskiy et al., 2019].

On the drained land with a close occurrence of groundwater, climatic conditions directly take part in the formation of water regime of soil and groundwater. In addition, climatic conditions determine the course of soil processes in certain growing periods of agricultural crops. Therefore, there is already a need to determine the consequences of predicted global climate changes and make appropriate adaptive decisions regarding these changes, as well as mitigating their consequences in agricultural production [Fiorello et al., 2022; Romashchenko et al., 2020; Kulhavý et al., 2015].

On drained land, adaptive measures should be aimed at: effective regulation of water regime; regulation and accumulation of moisture in the soil profile, as well as within the drainage system; transition from traditional periodic to regular humidification of drained land; improvement of water regulation technologies; improvement of types and designs of drainage systems and their technical elements; introduction of new methods of their design, etc. [Querner et al., 2022; Kovalenko et al., 2019; Morecroft et al. 2019].

The purpose of the scientific research is to determine the impact of climate and its changes

on the ecological efficiency of water regulation and the ecological and ameliorative state of drained land in modern and changing forecasted conditions.

MATERIALS AND METHODS

The substantiation of optimal natural, ameliorative and soil regimes of drained land based on an integral assessment of an indicator set of their ecological efficiency can be effectively performed using the method of B.P. Karuk [1987]. He suggested determining the ecological reliability of the reclamation project by the sum of the indicators of two levels. At the same time, the indicator of the first level takes into account environmental protection requirements within the entire region, while the indicator of the second level takes into account the environmental protection requirements within a specific reclamation object [Rokochynskiy, 2010]. The choice of a rational solution in this case is carried out on the basis of a multi-criteria expert assessment of various indicators of environmental components of the general optimization condition. Conceptually, this process is depicted in fig. 1.

According to [Rokochynskiy, 2010], the characteristics of the ecological reliability of the reclamation project can be presented in the form of a vector – terms H with components H_z

$$H = H_z / z = 1, 2, \dots, N / , \quad (1)$$

where: N – the number of elements (factors) that characterize the ecological reliability of the reclamation project.

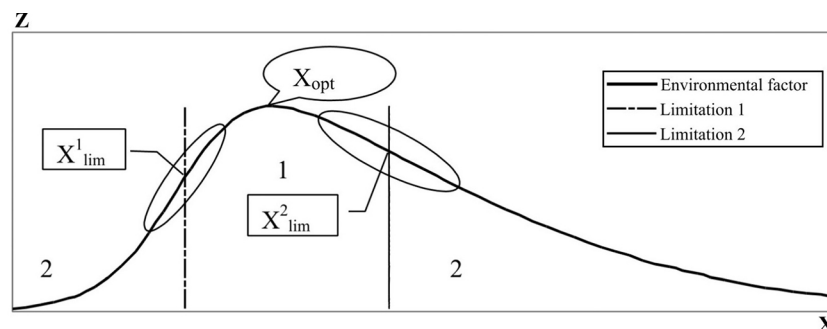


Figure 1. Scheme of finding optimal values of environmental factor X by environmental criterion Z :

1 – zone of ecological optimum; 2 – zone of environmental risk; X_{opt} – ecologically optimal value of the factor; X_{lim}^1, X_{lim}^2 – critical values of X ; \bigcirc – search zone for ecologically acceptable values of X

Here, the components H_z take their respective values provided that

$$H_z = \begin{cases} 1, & \text{if } H_z \leq H_{nz}; \\ 0, & \text{if } H_z > H_{nz}, \end{cases} \quad (2)$$

where: H_{nz} is the normative, critical or permissible value of the z -th element.

Such an approach to evaluating the environmental reliability of the project differs from the classical theory of reliability, where probabilistic values appear. However, this approach is quite simple and universal in nature. This makes it possible to use different evaluation methods and any set of heterogeneous indicators depending on the task.

Assuming that they are all equally important in the system of factors, the absence of a certain element can be considered as a corresponding decrease in the degree of environmental reliability.

Then the coefficient of environmental reliability of the reclamation project can be determined by the formula

$$k_n = \frac{\sum_{z=1}^N H_z}{N} \quad (3)$$

This coefficient represents an approximate evaluation of the environmental sustainability of the project and takes into account the factors of environmental reliability of its functioning. This is especially important for maintaining favorable natural, ameliorative, and soil regimes within the project term of the object's operation.

The values of environmental reliability coefficients of the reclamation object by the recommended scale are given in the Table 1.

Thus, by the considered method, ecologically optimal natural, ameliorative and soil regimes of drained land are provided that the environmental reliability coefficient is in the range of values

$$0,5 < k_n \leq 1,0 \quad (4)$$

The proposed scheme of evaluating the environmental reliability of the reclamation project is universal. That is why any factors, both

Table 1. Scale of environmental reliability coefficients

No.	Environmental reliability coefficient	Level of environmental reliability
1	0.00 – 0.25	Unreliable
2	0.26 – 0.50	Not reliable enough
3	0.51 – 0.75	Reliable enough
4	0.76 – 1.00	Reliable

quantitative and qualitative, characterizing the ecological and ameliorative state of the territory can be the components of reliability.

By model (2), the component H_z takes fixed values $H_z = 1$ or $H_z = 0$. However, as practice and accumulated experience show, such a relationship has a non-linear nature with a pronounced optimum within the limit (optimal minimum and maximum) values of the ecological efficiency indicator of water regulation on drained land.

In contrast to the considered approach, we propose a more flexible tool for determining the value of the component H_z , when it takes all possible values in the range from 0 to 1 by a non-linear dependence based on a dome-shaped empirical formula (see Fig. 1) of the general form

$$H_z = e^{a \cdot H_{fz}^2 + b \cdot H_{fz} + c} \quad (5)$$

where: a, b, c – empirical coefficients that depend on the normalized optimal indicator values of ecological efficiency on drained land;

H_{fz} is the actual value of the z -th element.

The improved approach makes it possible to differentiate the coefficient of environmental reliability of the reclamation project. This approach will also allow for a more objective evaluation of the ecological efficiency of applying an appropriate water regulation technology.

According to [Rokochynskiy, 2010], the ecological consequences of land reclamation projects can be evaluated by groups of physical indicators, selected as criteria for ecological efficiency: groundwater table (GT), moisture content of the estimated soil layer (MC), maintaining a favorable water regime (WR) of estimated soil layer, moisture exchange, irrigation standards, degree of man-made load, etc.

In the zone of excessive and unstable moisture, the recommended indicators of the ecological

efficiency of water, natural and ameliorative regimes of the drained land can be such criteria:

- IW – a moisture supply of the estimated soil layer during the growing season;
- $n(IW)$ – a duration of the optimal moisture supply of the estimated soil layer during the growing season;
- VI – an infiltration during the growing season, m^3/ha ;
- $n(VI)$ – a duration of infiltration during the growing season;
- VP – feeding of the estimated soil layer from WT during the growing season, m^3/ha ;
- $n(VP)$ – feeding duration of the estimated soil layer from WT during the growing season;
- V – a total moisture exchange during the growing season, m^3/ha ;
- IC – a comprehensive indicator of soil moisture supply during the growing season;
- Fr – relative weather and climate risk as to the yield;
- α^m – a share of influence of ameliorative factor during the growing season;
- $E PHAR$ – a actual value of the efficiency of the use of photosynthetically active radiation (PHAR) by the cultivated crop.

The determination of these indicators was carried out based on a machine experiment using the appropriate set of predictive and simulation models regarding: main structural and technological variable parameters of drainage systems; climatic conditions of the area; water regime; water regulation technologies; productivity of drained land for schematized natural, climatic, and ameliorative conditions.

An example of determining the ecological efficiency of various technologies of water regulation of drained land for the drainage system “Birka” of the Volodymyrskyi district of the Rivne region in the area of 544.9 ha was implemented for modern and forecasted changing climatic conditions of the studied object [Scientific and..., 2021; Kovalenko et al., 2019].

The machine experiment based on predictive and simulation modeling was performed under the following natural and ameliorative conditions of the studied object:

- for the calculated by heat and moisture supply growing seasons, the aggregates $\{p\}$, $p=1, n_p$ are following: very wet ($p=10\%$), wet ($p=30\%$), medium ($p=50\%$), dry ($p=70\%$), very dry ($p=90\%$);

- by two schemes for evaluating weather and climate conditions: modern – (recent-1991–2015); forecast – (by the UKMO climate model – the model of the United Kingdom Meteorological Office, which predicts an increase in the average annual air temperature by $6^\circ C$ when increasing CO_2 content in the atmosphere). This model takes into account more critical scenarios of changes in weather and climate conditions when calculating forecast regimes. Such a model is better consistent with the models used by us for the predictive evaluation of the normalized distribution of the main meteorological characteristics both for multi-year and intravegetation periods;
- for two types of drained soil: sod-clay sandy soils ($g = 1$) with a filtration coefficient ($k_f = 0.7$ m/day) and a fractional share of distribution within the system ($f_{gm} = 0.4$) and peat medium-strength and medium-decomposed soils ($g = 2$), $k_f = 1.3$ m/day, $f_{gm} = 0.6$;
- for the crops of estimated crop rotation: winter wheat (estimated yield = 48 t/ha, estimated share of sowing $f_k = 0.3$), potatoes ($Y = 420$ c/ha, $f_k = 0.2$), perennial grasses for hay ($Y = 42$ c/ha, $f_k = 0.5$);
- by the methods of water regulation, the aggregates $\{s\}$, $s = 1, n_s$ are following: D – drainage; PS – preventive sluicing; HS – humidifying sluicing; SD – sprinkler irrigation on the background of drainage, SPS – sprinkler irrigation on the background of preventive sluicing.

RESULTS AND DISCUSSION

As an example, the comparative characteristics of changes in environmental efficiency indicators when applying preventive sluicing, as the most widespread technology of water regulation on drained land, by the entire spectrum of both current and forecast weather and climate conditions of the estimated years are shown in Fig. 2. The relevant indicators are presented by the ratio of their actual values to the optimal values.

The given data characterize the overall efficiency of the application of preventive sluicing. The comparative characteristics clearly show the differentiation of the effect of certain factors in the formation of the water regime of drained land depending on the water supply of the growing season.

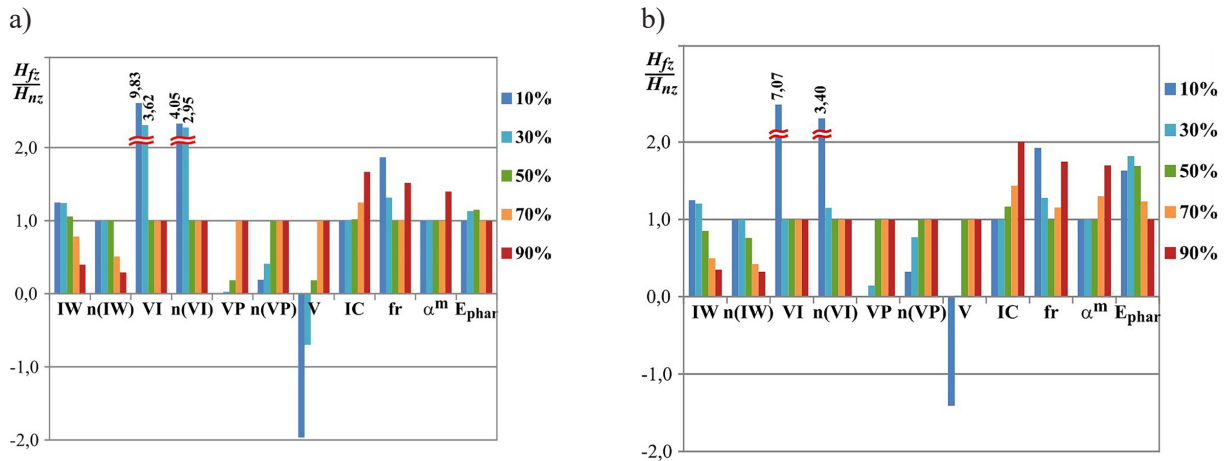


Figure 2. Comparative characteristics of environmental efficiency indicators in a relative form when applying preventive sluicing for the estimated years for variable weather and climate conditions of the studied object; (a) current conditions; (b) forecast conditions

At the same time, the predominant role of the climatic factor in the wet periods of the growing season can be traced both in the current and forecast climatic conditions. At that, the effectiveness of reclamation measures when applying drainage and preventive sluicing deteriorates. Since certain indicators specifying the intensification of washing water regime and the deterioration of ecological and reclamation state of the drained land, significantly exceed their optimal values in some estimated by heat and moisture supply years.

Thus, there is a need to increase the effect of the reclamation factor on the formation of water regime of drained land and the conditions for the development of cultivated crops in dry periods of vegetation by using regular humidifying measures. Such measures have a positive effect on the ecological and ameliorative state of drained land.

For visualization and comparison, the generalized results on the ecological reliability coefficient, determined by the model (3), are presented in Figures 3, and 4.

The presented results show the significant variability of the overall ecological efficiency of applying various technologies of water regulation on drained land for the estimated by heat and moisture supply years in variable both current and forecast weather and climate conditions.

The generalized results on the ecological efficiency of the options of water regulation on drained land for the current and forecast conditions, determined by the model (3), are shown in Table 2.

Figure 5 presents a generalized comparative characteristic of ecological efficiency of various technologies of water regulation on drained land in modern and forecast weather and climate conditions, determined by the model (5).

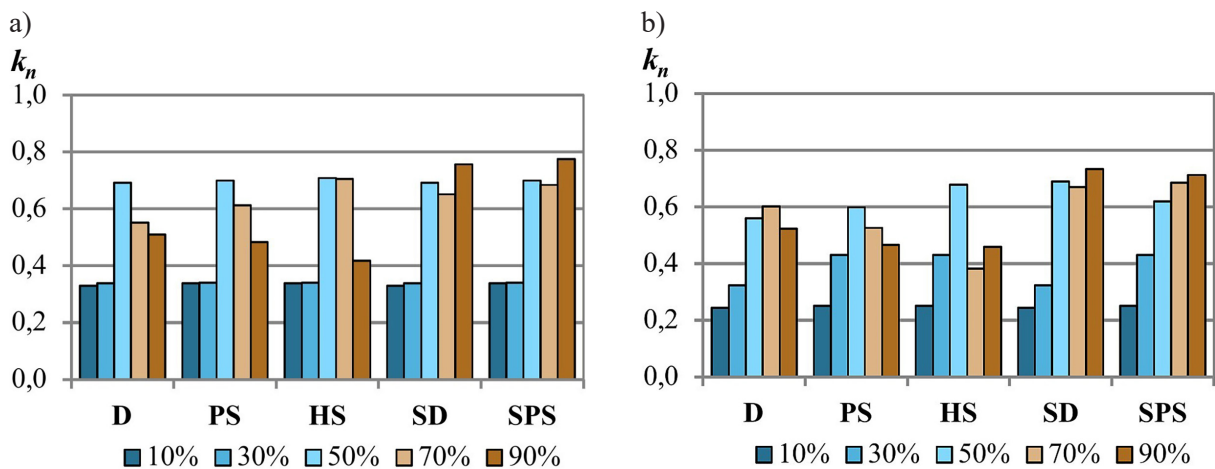


Figure 3. Generalized results on the ecological efficiency of water regulation of drained land in different estimated years by various water regulation technologies in current (a) and forecast (b) weather and climate conditions

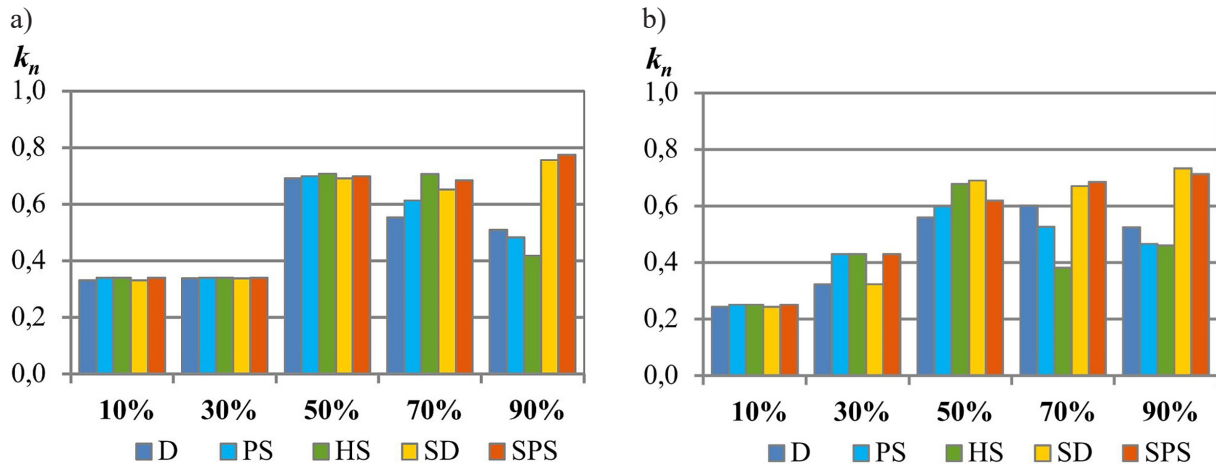


Figure 4. Generalized results on the ecological efficiency of applying various technologies of water regulation on drained land by the estimated years of current (a) and forecast (b) weather and climate conditions

Table 2. Generalized results on the ecological efficiency of the options of water regulation on drained land for the current and forecast conditions

№	Indicator	Optimal value	Indicator value $H_{\phi z}$					H_z by the model (5)				
			D	PS	HS	SD	SPS	D	PS	HS	SD	SPS
<i>Current conditions</i>												
1	IW	0.7–0.9	0.712	0.745	0.785	0.876	0.882	0.64	0.84	0.99	0.72	0.68
2	$n(IW)$	0.8–1.0	0.75	0.77	0.88	1	1	0.41	0.51	0.98	0.67	0.67
3	VI	-200–0	-518	-439	-439	-518	-439	0.03	0.07	0.07	0.03	0.07
4	$n(VI)$	0–0.2	0.34	0.24	0.24	0.34	0.24	0.10	0.32	0.32	0.10	0.32
5	VP	500–1000	316	347	537	242	271	0.22	0.27	0.70	0.13	0.16
6	$n(VP)$	0.8–1.0	0.66	0.76	0.76	0.66	0.76	0.10	0.46	0.46	0.10	0.46
7	V	500–1000	-203	-92	97	-276	-169	0.00	0.00	0.03	0.00	0.00
8	IC	0.9–1.0	1.176	1.133	1.009	1.019	1.006	0.14	0.27	0.87	0.83	0.88
9	f_r	0.0–0.3	0.43	0.383	0.345	0.338	0.32	0.20	0.28	0.35	0.37	0.41
10	a^m	0.0–0.1	0	0.06	0.12	0.14	0.16	0.82	0.99	0.68	0.53	0.39
11	E_{phar}	0.5–1.0	0.9	0.96	1	1	1.04	0.93	0.99	1.00	1.00	0.99
k_n								0.33	0.45	0.59	0.41	0.46
<i>Forecast conditions</i>												
1	IW	0.7–0.9	0.611	0.654	0.708	0.855	0.859	0.13	0.29	0.61	0.84	0.82
2	$n(IW)$	0.8–1.0	0.66	0.69	0.74	0.99	1	0.10	0.17	0.36	0.72	0.67
3	VI	-200–0	-299	-238	-238	-299	-238	0.30	0.46	0.46	0.30	0.46
4	$n(VI)$	0–0.2	0.26	0.15	0.15	0.26	0.15	0.26	0.64	0.64	0.26	0.64
5	VP	500–1000	464	535	868	406	440	0.52	0.69	0.89	0.39	0.46
6	$n(VP)$	0.8–1.0	0.74	0.85	0.85	0.74	0.85	0.36	0.90	0.90	0.36	0.90
7	V	500–1000	165	296	630	106	202	0.06	0.19	0.89	0.04	0.09
8	IC	0.9–1.0	1.332	1.27	1.024	1.045	1.046	0.00	0.02	0.81	0.70	0.70
9	f_r	0.0–0.3	0.457	0.413	0.356	0.327	0.321	0.16	0.22	0.33	0.39	0.40
10	a^m	0.0–0.1	0	0.07	0.17	0.21	0.22	0.82	0.97	0.33	0.14	0.11
11	E_{phar}	0.5–1.0	1.37	1.45	1.54	1.6	1.63	0.35	0.21	0.11	0.06	0.05
k_n								0.28	0.43	0.58	0.38	0.48

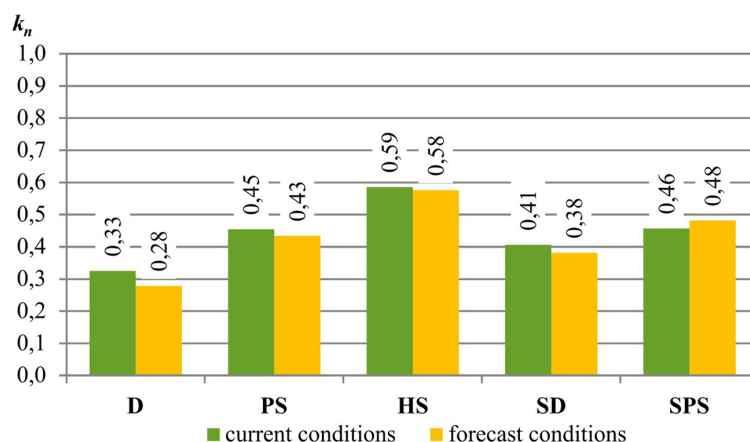


Figure 5. Generalized comparative characteristic of ecological efficiency of various technologies of water regulation on drained land in current and forecast weather and climate conditions

CONCLUSIONS

The obtained results showed that ecologically optimal natural, reclamation and soil regimes of the drained land, subject to compliance with the restriction $0.5 < k_n \leq 1.0$, are ensured by applying humidifying sluicing. At the same time, the ecological reliability coefficients are 0.59 and 0.58, respectively, for current and forecast climate conditions, and the ecological reliability of applying humidification of drained land is sufficiently reliable.

The carried out evaluation of ecological reliability of water regulation on drained land confirms the need to increase the role of humidification as a component of effective adaptive measures on drained land in current and forecast climatic conditions. Humidifying measures have a decisive effect on the ecological and ameliorative state of drained land.

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