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Development of Model for Assessing the Level of Multipurpose Water Use and Protection by Economic-Mathematical Modeling

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***Abstract*—The impact of industrial waste and enterprises' emissions on the chemical composition of water, in particular, the content of phosphate ions in it and the main physicochemical indicators of water (dissolved oxygen, hydrogen index and water temperature) are determined. A model for assessing the level of multipurpose water use and protection using tools of economic-mathematical modeling – fuzzy set theory implemented in MATLAB software is developed. Factors of this model include level of production improvement, adherence to technological discipline; level of average content of phosphate concentration and physico-chemical parameters of the water; full disposal of household, agricultural and industrial waste; rationing of water supply and drainage, rationing of maximum permissible concentration of various substances in the waters for drinking, fishery and other purposes; zero waste water discharge, recirculating water supply; imposing penalties on pollution, littering and water depletion up to the closure of enterprises, factories workshops, complexes-pollutants in accordance with the legislation in force; phytomelioration; subsoil tillage, contour farming. Terms for the linguistic assessment of selected factors of the level of multipurpose water use and protection in hydro-ecosystems based on fuzzy logic theory and the ranges of their changes are proposed. The rules base for the developed model is formed. Input and output parameters defuzzification is carried out according to the "center of gravity" of the Mamdani module of the MATLAB software. The level of multipurpose water use and protection is recorded at 80%, which corresponds to the high level (from 70% to 100%) of the scale and can be improved by increasing the level of each factor of the model. It is established that, when supplementing the input parameters and the rule base, the developed model can be applied to specific industrial enterprises.**

Keywords—hydro-ecosystem, fuzzy set theory, model for assessing the level of multipurpose water use and protection

I. INTRODUCTION

Due to the Ukraine's entry into the European space and changes in environmental standards, industrial enterprises are in need to reorient their development vector taking into account the environmental component. In this regard, it is important to determine the impact of exogenous factors of production and human activity on hydro-ecosystems, assess and adjust ecological parameters.

At present, management of environmental objects is often empirically conducted on the basis of unreliable information on the pollution of hydro-environmental objects by human and industrial activities. Measures aimed at reducing pollution in hydro-ecosystems are usually funded on a residual basis. Therefore, the urgent issue is the application of fuzzy logic models that make it possible to assess the level of multipurpose water use and protection, taking into account both quantitative and qualitative parameters. Implementation of the developed model in modern information resources with elements of artificial intelligence of the MATLAB type will allow, while supplementing and extending databases and rules, to apply it to monitor and manage the content of harmful compounds in specific hydro-ecosystems, to undertake comprehensive measures for their elimination and to determine the volume of these measures financing.

II. LITERATURE REVIEW AND STATEMENT OF THE PROBLEM

A series of works by domestic and foreign scientists is devoted to the study of modeling of ecological and economic systems and protection of water resources. Methods of ecological and economic systems modeling, in particular descriptive and quantitative models, were investigated in [1], but the issue of modeling under uncertainty and instability was not solved. The evolution of the use of ecological-optimization models in the modeling of economic and ecological systems is presented in [2]. The relevance of modeling and forecasting of the ecological and economic systems development is shown, the attention is focused on the importance of the study of negative factors affecting changes in ecosystems. In the reference [3], a methodology for identifying global environmental problems was developed, and the results of data collection and processing on hydro-ecological objects using modern technologies are presented. However, their use for

monitoring factors that have a decisive impact on ecosystems has not been investigated. The possibility of using modeling in ecological systems, which solves the issue of systems management with modern tools, is presented in [4]. Approaches to the application of tools of economic and mathematical modeling for the management of biosystems are disclosed in [5].

However, the question of comparing quantitative and qualitative parameters in the studies has not been resolved, because the existing models are either descriptive or balance models using only the study of quantitative parameters, so development of a model of multipurpose water use and protection based on fuzzy sets theory is an urgent problem.

The application of models that allow to analyze the level of hydropower purification in production areas is especially important for agricultural and raw material extraction and processing regions, as well as for anthropogenically-loaded areas whose active recreational activity generates appropriate anthropogenic pressure, including possible disturbance of phosphorus equilibrium in hydroecosystem. The reference [6] analyzes and summarizes the information available in the professional literature on the pathways of phosphorus pollution and its transformation into aquatic ecosystems, discusses its compounds and their uses, as well as measures by various countries around the world to reduce phosphorus pollution by aquatic ecosystems.

Therefore, to develop appropriate preventive measures, the problem of researching the impact of harmful components of production on the hydro-ecosystems of the region, taking into account the maximum number of quantitative and qualitative factors, is of great importance.

III. AIM AND OBJECTIVES OF THE RESEARCH

The aim of the paper is to apply a mathematical modeling tool to monitor the environmental situation by creating a model for assessing the level of multipurpose water use and protection.

The objective of the research is to determine the control variables and the level of multipurpose water use and protection in hydro-ecosystems based on the analysis of the current state of the object, the use of which allows to monitor its ecological status.

IV. MATERIALS AND METHODS

Samples from the river Zbruch within the Medobory Nature Reserve (Husiatynskyi District, Ternopil Region, Ukraine) were used to study the content of phosphates and physico-chemical indicators of water. Water was sampled from five different points in the river into plastic samplers with the volume of 1 dm3 in the upper third of the total depth. During sampling, the water temperature was measured with a mercury thermometer with a 0.1 °C graduation interval. The hydrogen index (pH) was measured with the use of an ionomer ЭВ -74, and the content of oxygen dissolved in water was determined using the oxygen meter АЖА-101М (country of origin – Ukraine). A spectrophotometric method with ammonium molybdate $(NH_4)_2MoO_4$ was used to determine the concentration of phosphorus in the water [7].

Mathematical modeling using the principles of fuzzy logic requires the choice of a method of constructing membership functions that will ensure the formalization of fuzzy terms. The theory of fuzzy sets makes it possible to use different methods of constructing membership functions. Therefore, it is advisable to identify a number of criteria that would help resolve the issue of their construction. The specific type of membership functions is determined on the basis of additional assumptions about the properties of these functions (symmetry, monotony, continuity of the first derivative, etc.), taking into account the specifics of the existing uncertainty and the real situation.

The membership function is written as follows [8]:

$$\mu(t) = \begin{cases} \dfrac{t - t_{\min}}{t_c - t_{\min}}, \ for \quad t_{\min} \le t \le t_c \\ \dfrac{t - t_{\max}}{t_c - t_{\max}}, \ for \quad t_c \le t \le t_{\max} \end{cases} \qquad (1)$$

where

$\mu(t)$	triangular membership function
$\bar{t} = (t_{\min}, t_c, t_{\max})$	triangular fuzzy numbers
$t_{\min}, t_{\max}, t_c$	the minimum, maximum value and some estimation of the central value (mathematical expectation, thickest value, median, etc.) of a separate parameter respectively

A fuzzy set toolkit and MATLAB software applying the Extended Fuzzy Logic Toolbox were used to develop a model for assessing the level of multipurpose water use and protection. Control model variables (phosphate content and physico-chemical water content) were determined based on an analysis of the current state of the object. The Fuzzy Inference System Editor as well as the Membership Function Editor were used to describe the model's input and output variables. The rules of the fuzzy output system were created by the Rule Editor. In the simulation process, the results were analyzed at different values of the input variables and the model adequacy was estimated using the Mamdani method [9].

The advantage of the proposed method of modeling multivariate dependencies based on fuzzy logic is that it allows to use not only quantitative experimental data (input-output), but also qualitative dependencies formed according to the linguistic rules "IF-THEN". Combination of the expert and experimental data makes it possible to significantly reduce the amount of experiment data required.

V. RESULTS OF THE ECONOMIC-MATHEMATICAL MODELING OF THE LEVEL OF MULTIPURPOSE WATER USE AND PROTECTION ASSESSMENT

The content of phosphate ions in the water of the river Zbruch and its main physico-chemical parameters (dissolved oxygen, pH and water temperature) according to the results of the selected samples are presented in Table I.

The indicators given in Table 1 are used as inputs in the development of a model for assessing the level of

multipurpose water use and protection in MATLAB.

For this purpose the main factors used for simulation (see Table II) have been identified.

Representation of input and output parameters of the model for assessing the level of multipurpose water use and protection is performed with a triangular membership function (see Equation 1).

The terms used for the linguistic assessment of selected factors (model variables) and the ranges of their change are given in Table III.

TABLE I. AVERAGE CONTENT OF PHOSPHATE CONCENTRATION AND PHYSICO-CHEMICAL PARAMETERS OF THE RIVER ZBRUCH WATER (M±M; N=5)

Months	Phosphate ions (PO_4^{3-}), mg 10^{-2}/dm³	Dissolved oxygen (O_2), mg/dm³	Hydrogen index (pH), mol/l	Temperature (t), ˚C
IV	1,2±0,04	10,08±0,007	7,63±0,008	16,5±0,008
V	1,9±0,002	9,76±0,006	8,44±0,007	18,5±0,008
VI	0,7±0,03	9,44±0,006	7,08±0,009	16,5±0,007
VII	1,0±0,03	8,80±0,006	8,24±0,008	19,5±0,008
VIII	1,8±0,04	8,08±0,004	6,87±0,008	16,5±0,008
IX	0,4±0,02	8,48±0,004	7,60±0,008	14,9±0,008
X	0,7±0,04	9,04±0,004	8,61±0,008	11,1±0,008

TABLE II. FACTORS OF THE MODEL FOR ASSESSING THE LEVEL OF MULTIPURPOSE WATER USE AND PROTECTION IN HYDRO-ECOSYSTEMS BASED ON THE FUZZY LOGIC THEORY

Factors	Variable
A comprehensive indicator that determines the level of preventive, procedural and ameliorative methods taking into account the economic efficiency of water use and protection	y
Level of production improvement, adherence to technological discipline	x_1
Level of average content of phosphate concentration and physico-chemical parameters of the water (according to the input data of Table I)	x_2
Full disposal of household, agricultural and industrial waste	x_3
Rationing of water supply and drainage, rationing of maximum permissible concentration (MPC) of various substances in the waters for drinking, fishery and other purposes	x_4
Zero waste water discharge, recirculating water supply	x_5
Imposing penalties on pollution, littering and water depletion up to the closure of enterprises, factories workshops, complexes-pollutants in accordance with the legislation in force	x_6
Phytomelioration	x_7
Subsoil tillage, contour farming	x_8

TABLE III. TERMS FOR LINGUISTIC ASSESSMENT OF SELECTED FACTORS OF THE LEVEL OF MULTIPURPOSE WATER USE AND PROTECTION IN HYDRO-ECOSYSTEMS BASED ON FUZZY LOGIC THEORY AND THE RANGES OF THEIR CHANGE

Variable	Factor	Range of change	Terms (level of the factor's impact)
x_1	Level of production improvement, adherence to technological discipline	0-100%	low (0-29) (l) average (30-69) (a) high (70-100) (h)
x_2	Level of average content of phosphate concentration and physico-chemical parameters of the water	0-100%	low (0-29) (l) average (30-69) (a) high (70-100) (h)
x_3	Level of full disposal of household, agricultural and industrial waste	0-100%	low (0-29) (l) average (30-69) (a) high (70-100) (h)
x_4	Rationing of water supply and drainage, rationing of MPC of various substances in the waters for drinking, fishery and other purposes	0-100%	low (0-29) (l) average (30-69) (a) high (70-100) (h)
x_5	Level of zero waste water discharge, recirculating water supply	0-100%	low (0-29) (l) average (30-69) (a) high (70-100) (h)
x_6	Level of imposing penalties on pollution, littering and water depletion up to the closure of enterprises, factories workshops, complexes-pollutants in accordance with the legislation in force	0-100%	low possibility (0-29) (lp) possible penalties imposition (30-69) (p) high possibility (70-100) (hp)
x_7	Phytomelioration	0-100%	low application rate (0-29) (l) average application rate (30-69) (a) high application rate (70-100) (h)
x_8	Level of subsoil tillage, contour farming	0-100%	low (0-29) (l) average (30-69) (a) high (70-100) (h)
y	Level of preventive, procedural and ameliorative methods and economic efficiency of multipurpose water use and protection	0-100%	low (0-29) (l) average (30-69) (a) high (70-100) (h)

The knowledge base of the model for assessing the level of multipurpose water use and protection is presented in Table IV.

TABLE IV. THE KNOWLEDGE BASE OF THE MODEL FOR ASSESSING THE LEVEL OF MULTIPURPOSE WATER USE AND PROTECTION

Variable	**Rules**											
x_1	l	a	l	l	a	l	l	a	a	h	h	h
x_2	l	l	l	l	l	a	a	a	h	l	h	h
x_3	l	l	l	l	h	a	l	a	h	h	l	h
x_4	l	a	l	l	a	a	l	a	a	h	h	h
x_5	l	l	l	h	h	l	h	l	l	l	h	a
x_6	lp	lp	lp	lp	p	p	p	p	hp	hp	hp	hp
x_7	l	l	h	l	l	a	h	a	a	h	a	h
x_8	l	l	a	l	l	a	l	a	h	h	h	h
y	l	l	l	l	a	a	a	a	h	h	h	h

The level of multipurpose water use and protection in hydro-ecosystems based on fuzzy logic theory is denoted as: G_1 – high, G_2 – average, G_3 – low. Parameters G_1, G_2, G_3 characterize the level of hydro-ecological situation in the region, and the result of the model's experiments is the percentage variable – y (from 0 to 100%) – the level of preventive, procedural and ameliorative methods and economic efficiency of multipurpose water use and protection.

The more complete this rule base is, the more fuzzy sets based model is closer to the real situation.

When changing the environmental situation, it is possible to supplement both the model parameters and the rule base and knowledge base.

Model's input and output parameters defuzzification is performed according to the "center of gravity" of the Mamdani module of the MATLAB software.

A visualization of the developed model input and output parameters simulation is presented in Figure 1.

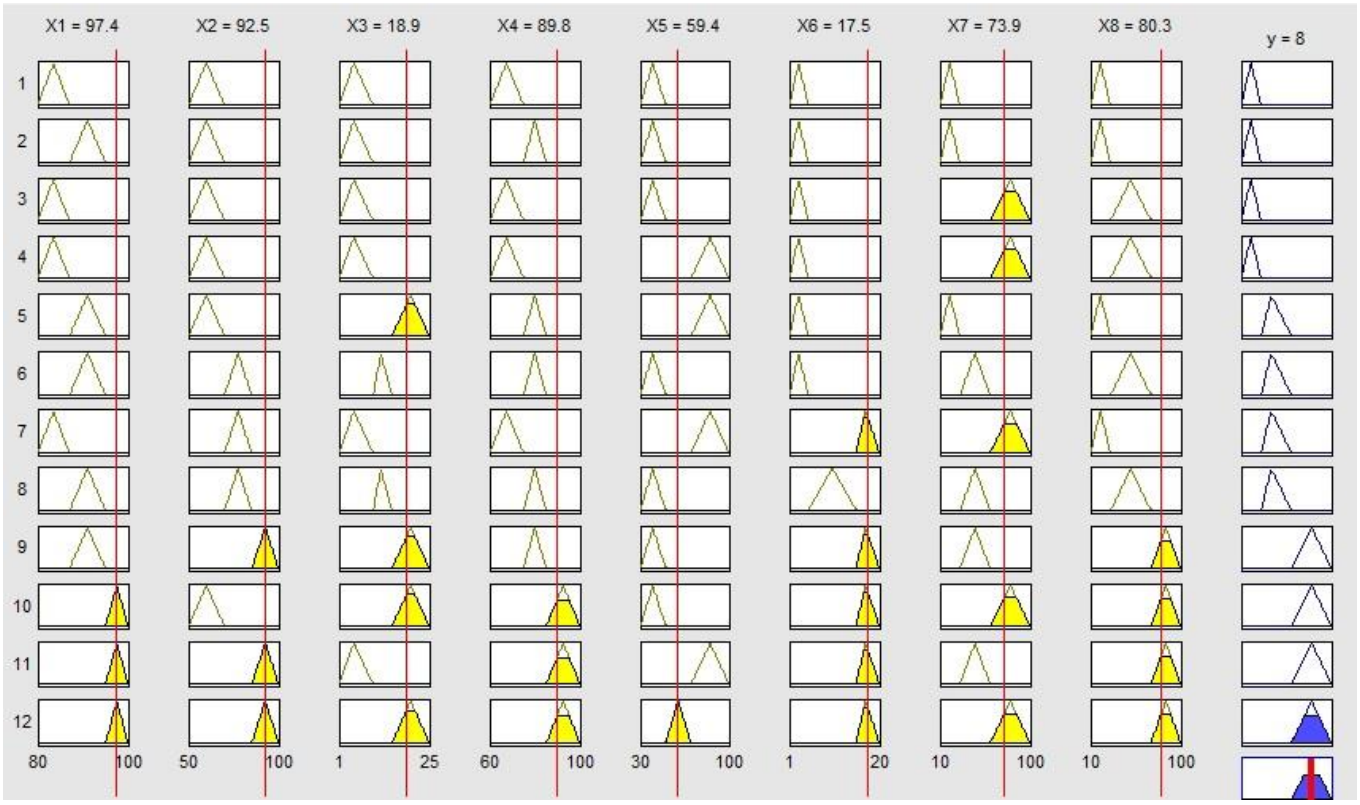

Fig. 1. Visualization of the simulation of the input and output parameters of the model for assessing comprehensive measures to improve the situation regarding water resources

Results of modeling the comprehensive indicator for determining the level of measures to improve the environmental situation are presented in Figure 2.

When applying appropriate comprehensive measures for the use and protection of water resources, it is possible to increase the level of these parameters to the average (30-69%) or high one (70-100%).

The developed model solves the problem of assessing hydro-ecosystems both by quantitative parameters, such as phytomelioration, rationing of water supply and drainage, rationing of MPC of various substances in the waters for drinking, fishery and other purposes, and qualitative ones which include the level of full disposal of household, agricultural and industrial waste, level of organization of waste-free production, level of zero waste water discharge, recirculating water supply and imposing penalties on pollution, littering and water depletion in accordance with the legislation in force.

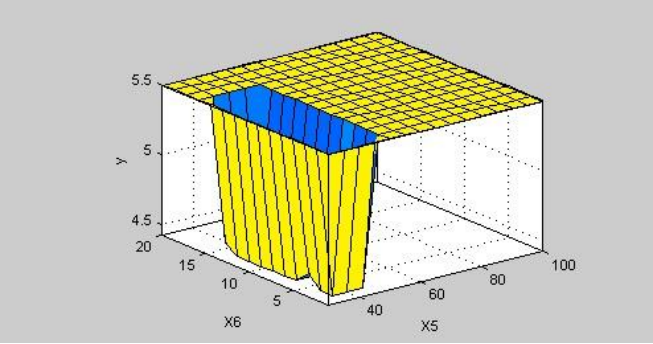

Fig. 2. Graphical representation of the model for assessing the level of multipurpose water use and protection.

The implementation of the model in modern information systems like MATLAB, allows to visualize the results of modeling and to make adequate decisions when monitoring the environmental situation regarding hydro resources.

VI. DISCUSSION OF THE RESEARCH RESULTS

The research results testify that the level of multipurpose water use and protection in the Ternopil region is 80% (high level of the scale), however, the value of this indicator can be improved by increasing the level for each factor of the model. A rather important problem for the studied region is the incomplete utilization of domestic agricultural and industrial waste, since a solid waste processing plant has not yet been built. Waste from rural settlements pollutes the waterways of the region, with a model indicator x_3 of only 18.9%, which corresponds to a low level. Although phosphate levels in the river Zbruch do not exceed the maximum permissible concentrations for fisheries, but there is a tendency for their increase in the spring and summer, when all biotic components of the hydro-ecosystem are activated.

Imposing penalties on pollution, littering and water depletion in accordance with the legislation in force is low – only 17.5%. But penalties imposition on businesses with outdated technologies will encourage their managers to take measures to replace existing technologies for environmentally safe and sound ones.

The level of zero waste water discharge, recirculating water supply (59.4%), which corresponds to the average level, is also insufficient. Measures to be undertaken to increase value of these indicators should be comprehensive and will result in their overall level increase.

Existing models of ecosystems research suggest to apply correlation-regression analysis to study the measure of the indicators impact on the level of eco-pollution when modeling [10], or statistical methods for the collection of input parameters affecting ecosystems [3; 4; 5]. The developed model, unlike the ones mentioned above, is based on fuzzy set theory, which makes it possible to assess ecosystems under uncertainty and stochasticity of processes, to analyze both quantitative and qualitative parameters, which is extremely urgent nowadays.

A limitation of the developed model may be its input parameters and the number of rules in fuzzy sets according to the "IF-THEN" principle.

The model can be improved and expanded with specific tasks to study the corresponding parameters and their ranges. The coding of the model parameters will further develop programming on models for assessing the hydro-ecosystems state with involvement of the cities communities to control the level of pollution and to undertake comprehensive measures to eliminate the factors that cause deterioration of water and ecosystems in general within a specific territorial unit or country as a whole.

VII. CONCLUSIONS

Thus, the use of fuzzy sets toolkit in modeling the ecological situation regarding water resources makes it possible to monitor it on the basis of qualitative and quantitative factors analysis. Identifying low-level factors will allow business managers and municipal authorities to develop measures for their improvement.

It is established that the level of multipurpose water use and protection, using Ternopil region as a case study, is 80% (high), however, there are parameters that need significant improvement, i.e. the level of full disposal of household, agricultural and industrial waste as well as imposing penalties on pollution, littering and water depletion.

The developed model for assessing the level of multipurpose water use and protection when changing input parameters and supplementing the knowledge base can be implemented at specific enterprises and applied to monitor the quality of water resources of a specific territorial unit and other hydro-ecosystems.

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