Modeling of an intellectual system for assessing the environmental safety of irrigated lands using fuzzy logic methods

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Abstract. The article is attempted to use the mathematical apparatus of fuzzy logic for processing the initial data of the model of an intellectual system for assessing the environmental safety of irrigated agricultural land and assessing the risks arising in the course of economic activity in the conditions of differentiated placement of crops. There is a proposed scheme for formalizing indicators set at a qualitative level which is based on membership functions. To determine the form of the membership function, limit, critical and high values of the level of environmental safety are identified. When describing model elements, we use a set of fuzzy situations that characterize the space of possible states of these elements, as well as a set of relationships between them. The assignment of communications that fuzzily characterize the degree of influence between the typical states of pairs of elements allows the formation of production models in the form of a variety of fuzzy rules. The quantitative result of the interaction of elements is determined on the basis of fuzzy inference. The representation of the proposed model allows us to obtain an integrated assessment of the state of environmental safety of land and comparative characteristics of the magnitude of security threats are based on their automated assessment. The implementation of the proposed model allows us to formulate recommendations on the set of necessary measures to prevent damage and minimize losses, as well as to evaluate the effectiveness of their execution in each specific case.

1. Introduction

Nowadays, in Russia and around the world, one of the most current problems are related to the environmental situation of agricultural land. Substantial influence on the environmental safety of irrigated agricultural lands is provided not only by processing enterprises, but also irrigation methods are used in differentiated distribution of crops. Significant impact on the environmental safety of irrigated agricultural lands is provided not only by processing enterprises, but also by irrigation methods used in conditions of differentiated distribution of crops. Therefore, it is particularly important to ensure the sustainable development of natural and economic systems against the...
background of reducing possible threats to their environmental security. To ensure environmental safety, it is necessary to have a clear understanding of the proportions which can have the negative impact, as well as a qualitative and quantitative assessment of damage from environmental pollution, which can be implemented using mathematical tools that allow modeling in terms of the theoretical and probabilistic nature of heterogeneous quantities.

In view of the complexity of modern technical systems and increasing requirements for their environmental safety, the development of a mathematical model of fuzzy inference is undoubtedly relevant.

The purpose of this article is to propose a new method for assessing the environmental safety of irrigated land, implemented with using mathematical tools that allow you to model more specific situations to build an intelligent system that makes recommendations are based on the data obtained, which will allow you to make timely management decisions to prevent the occurrence of negative events.

The working hypothesis is based on a set of scientific assumptions and a system of the following interrelated theoretical provisions, according to which the degree of environmental safety of irrigated agricultural lands depends on endogenous and exogenous factors, the degree of threats from which can be estimated using the fuzzy logic apparatus in artificial intelligence systems, which will allow timely and adequately block the causes of crisis phenomena and situations, as well as offer recommendations for strengthening environmental safety agricultural industry.

Only scientifically substantiated results of the analysis of environmental damage will allow us to develop effective environmental measures, prove the need for environmental protection projects, and thus increase the environmental significance of decisions.

2. Materials and methods
Modeling an intelligent system for assessing the environmental safety of irrigated lands in the conditions of differentiated placement of crops implies the ability to accumulate knowledge of specialists in this subject area and manage this knowledge when making a decision. Among the main requirements of this control system is the possibility of its practical application by a specialist of any level of information training.

When designing the system, we used a method based on a hierarchical block approach, the main goal of which is to decompose functions and hierarchies of systems and subsystems.

Now therefore, mathematical modeling is currently one of the main tools for environmental analysis. A set of tools is not only a specific use of mathematical methods and models, as well as the corresponding technical means for their implementation, but also a methodological approach, a look at environmental processes, at their internal structure, properties, development from the point of view of mathematical modeling apparatus. The use of ecological and mathematical methods and models allows us to obtain new qualitative conclusions about ongoing processes and phenomena.

The mathematical theory of fuzzy sets, proposed by L. Zadeh more than a quarter of a century ago, allows describing fuzzy concepts and knowledge, operating with this knowledge and making fuzzy conclusions. It has been experimentally shown that fuzzy control gives better results than those obtained with conventional control algorithms [1,2].

In conditions of incompleteness, inaccuracy of information, the construction of an accurate mathematical model is problematic. On the other hand, creating a model of complex, poorly formalized objects become difficult to achieve. In such cases, the most effective are fuzzy modeling methods, which are largely based on expert knowledge, on the basis of which positive results can be obtained in the iterative process of refining a consistent model. The system of environmental safety should also be considered as a complex, poorly formalized objects which are functioned uncertainty, also we should be included. Researches provide an interpretation of real processes that characterized the special factors which determined the quality of management decisions.

The identification of fuzzy models is based on observational data, but now it is impossible to exclude the participation of an expert in this process, who solves the following tasks:
- determination of the type of a fuzzy model (Singleton, Mamdani or Takagi-Sugeno);
- the choice of t-normal functions for defining fuzzy logical operations;
- the choice of methods for fuzzy inference (for a model of the Mamdani type: an approximation of Mamdani or a formallogical conclusion).

The choice of model type is determined by the problem which should be solved. If the problem of interpolation or approximation is solved, and accuracy is a determining factor, then the choice should be made in favor of a fuzzy model of the Takagi-Sugeno type.

If the problem of interpolation or approximation is solved, where faithfulness is the determining factor, then the choice should be made in favor of a fuzzy model of the Takagi-Sugeno type. At the same time, a fuzzy model of this type acts as a universal approximator.

If the problem of extracting knowledge from data (in the form of linguistic rules) or searching for associative relations in a data set is solved, then for this purpose it is necessary to use a fuzzy model such as Mamdani. The decisive advantage of such models is their comprehensibility and interpretability.

A model of the «Singleton» type can be used both for solving approximation problems and for extracting knowledge.

Important properties of the model, in addition to accuracy and interpretability, can include the speed of learning, which depends on many factors, such as the type of fuzzy model (the singleton model learns faster than others), from the identification methods which have been chosen, etc.

The theoretical basis for building a fuzzy model is fuzzy logic.

Consider just a few methods of setting logical operations in fuzzy logic. Zade's fuzzy negation is a unary operation which is defined as \( c(a) = 1 - a \), \( \forall a \in [0,1] \).

The negation operation is in accord with the following properties:

\[
c: [0,1] \rightarrow [0,1], \\
c(0) = 1, c(1) = 0, c(c(a)) = a, \\
\forall a_1, a_2 \left( (a_1, a_2) \in [0,1] \right) \Rightarrow (a_1 < a_2) \rightarrow (c(a_1) > c(a_2)) = 1 \\
\]

There are other ways to set the negation operation:

by Sugeno: \( c(a) = (1-a)/(1+\lambda a) \), where \( \lambda > -1 \); \hspace{1cm} (2)

by Jager: \( c(a) = \sqrt{(p \& 1-a^p)} \) where \( p > 0 \). \hspace{1cm} (3)

The function of Zade. For two variables of Zade’s functions are defined in this way:

\[
T(a, b) = \min(a, b), S(a, b) = \max(a, b); \\
\]

for \( n \) variables:

\[
T(a_1, a_2, ..., a_n) = \min(a_1, a_2, ..., a_n); \\
S(a_1, a_2, ..., a_n) = \max(a_1, a_2, ..., a_n). \\
\]

Probability functions. For two variables

\[
T(a, b) = a \ast b, S(a, b) = a + b - a \ast b; \\
\]

for \( n \) variables:

\[
T(a_1, a_2, ..., a_n) = a_1 \ast a_2 \ast ... \ast a_n \\
(a_1, a_2, ..., a_n) = \left( \sum_{i=1}^{n} a_i - \sum_{i=1}^{n} a_i^2 + \sum_{i=1}^{n} a_i \sum_{j>i}^{n} a_j \right) / \pm \prod_{i=1}^{n} a_i \\
\]

An algorithm for procedure t-conormal probability function \( S \) is given below (Data – in. Numerical series (x_1, x_2, ..., x_n) Output. Usage of \( S \): t-conorm:

- step 1. Calculate \( a_1 = M_{lx1}(X_1), A_2 = M_{lx2}(X_2), ..., A_n = M_{lxn}(X_n) \);
- step 2. Calculate \( S = a_n, 1 \leq n \leq 1; \)
3. Results and discussion

The investigation of the intellectual system for assessing the environmental safety of irrigated agricultural lands from the perspective of a systematic approach allows us to consider the process of ensuring it as a kind of integrity which is manifested within the framework of complex formalized systems. Ensuring environmental safety as a system is characterized by: a large number of functions, parameters and functioning results; the complexity of the behavior of the system, which is reflected in the presence of interwoven and overlapping associations between variables; uneven and unstable in time external influences; constant spatial and temporal connection, which appears in the interaction of system elements and is fixed in the form of a certain structure; reflection of the views, goals and values of business entities; lack of dependence of the structure and nature of the relationship between the elements on the level and type of development of the system [3,4].

The first stage of creating an intelligent system for modeling environmental safety was the identification of limit, critical and high values for each indicator. The formalization of indicators set at the qualitative level should also be based on membership functions.

At the next stage of environmental safety modeling, limit, critical, and high values of the level of environmental safety were recognized and determined the form of the membership function associated with each variable; it can be described in the universal form of approximators as:

$$ y(x) = \sum_{i=1}^{N} \left[ \varphi_i(x) \ast \theta_i \right] $$  \hspace{1cm} (10)

Thus, the use of mathematical modeling is based on fuzzy inference made it possible to assess the environmental safety of irrigated agricultural land.

The algorithm which is used describes several successive stages. In this case, each following step receives the input usage in the previous step. The algorithm works on the principle of "black box".

Quantitative values are received at the input, and the same values are received at the output.

In the intermediate stages, the fuzzy logic apparatus and fuzzy set theory are used. This is the elegance of using fuzzy systems. It is possible to transform the usual numerical data, but still use the flexibility provided by fuzzy inference systems.

This approach allows zoning of threats to environmental safety. The environmental safety model represents the main principles and directions of implementation of measures at various levels of operation of irrigated agricultural land, assessment of their environmental safety and implementation of an intelligent decision support system.

The software implementation of the developed complex of fuzzy models was implemented by the MatLab Fuzzy Logic Toolbox system (figure 1). The parameters of the mathematical model are the following linguistic variables: «Pollution coefficient», «Economic effect», having the following fuzzy characteristics: «Suspended substances», «COD», «BOD», «Nitrogen», «Phosphates», «Petroleum products». For each component of the term set T that represents the fuzzy variable \( a_i \) (i=1,2,3), a fuzzy set \( A_i \) should be constructed. Components of this set are the possible values for fuzzy variable \( a_i \).

The belonging of these usages to the set are defined by the semantics of the term \( a_i \), is given by the membership function. Thus, the membership function is a mapping \( \mu_{A_i}(x) \rightarrow [0,1], x \in X \).

The theoretical basis for constructing membership functions is actually a non-trivial task. However, the construction procedure is important for a deep understanding of the nature of the uncertainty described by fuzzy logical systems. The membership function of an element \( x \) to a fuzzy set \( A \) is interpreted as a subjective measure. A subjective measure is defined as the degree of correspondence of element \( x \) to the concept formalized by the fuzzy set \( a \), determined by an expert survey.
The calculation of degrees of membership $\mu_A(x_i), x_i \in X$ is based on the algorithm for processing the matrix of paired comparisons $M=\|m_{ij}\|$. The elements of this matrix are expert estimates of how much the element $x_i$ is more significant for the concept described by the fuzzy set $A$ than the element $x_j$. In accordance with this algorithm, the constructed membership functions for the linguistic variable («K_contaminated», T, X), where: 
$T=\{«low\ pollution», «medium\ pollution», «high\ pollution»\}, X=\{0, 100\} - the basic set, have the form shown in figure 2 [5,6].

![Figure 1. Visualization of the fuzzy output model in MatLab Fuzzy Logic Toolbox.](image1)

![Figure 2. Constructed membership functions for the linguistic variable «Suspended substances».](image2)

Similarly, membership functions are constructed for the remaining elements of many factors. Note that the procedure for constructing membership functions is a stage of fuzzification of a set of premises, the specified values of which determine the usages of consequences that are output in the fuzzy inference procedure. The logical inference mechanism consists of four stages: introducing fuzziness (fuzzification), fuzzy inference, composition, and bringing it to clarity (defuzzification). The scheme fits into the algorithm of the Mamdani inference.

The experimental part of the study was carried out on indicators of the conditional load on the destination soil, which were adopted as indicators of the environmental safety of the agro-industrial complex. The components of the conditional load indicators characterized the level of pollution, the volume of pollutants and their location. Their analysis allows us to differentiate the degree of contamination using conditional load factors [7,8].

Based on the calculated coefficients at three points, the relationship between the cost of soil cleaning and the economic damage from pollution was characterized. The damage function as a function of cleaning costs is generally decreasing and non-linear. As a check on the adequacy of the model, the following parameters were changed: the type of membership function (triangular, trapezoidal, parabolic, Gaussian) and the degree of their fuzziness (basis or alpha-slice), the method of defining the t-operator (Zadeh, probabilistic, Lukasevich, Schweizer-Sklyar), method assignments of the fuzzy inference (Mamdani approximation, formal), the number of terms of input and output variables.

4. Conclusion
The conducted studies allowed us to conclude that the error of approximation of test functions by a fuzzy system, the parameters of which are optimized using fuzzy logic, does not exceed the error obtained during optimization based on standard methods. The formalization of indicators set at the qualitative level should also be based on membership functions (figure 3).
Figure 3. Visualization of environmental safety indicators in MatLab Fuzzy Logic Toolbox.

Based on the above, we propose the main characteristics of the process of ensuring environmental safety of irrigated agricultural land.

Ways to ensure the environmental safety of irrigated agricultural land is a set of measures and a system for organizing their implementation and control, which allow to achieve the highest levels of environmental safety.

The final stage of assessing the current level of environmental safety of irrigated agricultural land is a comprehensive analysis of the feasibility of realized measures to prevent damage and minimize losses, as well as the impact of the effectiveness of measures on the level of profit (income).

It should be noted that all measures are aimed at ensuring a sustainable agro-industrial complex, which allows us to count on a synergistic effect.

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