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Application of artificial intelligence technologies to assess water salinity

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Application of artificial intelligence technologies to assess water salinity

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Abstract. Topical issues of developing theoretical and methodological tools for constructing a fuzzy logical model for assessing water salinity are considered. When constructing a Sugeno fuzzy logical model for estimating water salinity, a rational number of rules and effective values of their membership functions were chosen. Initially, the membership function parameters were obtained from water industry experts. In the future, it is necessary to adjust the parameters of the membership function using neural networks to obtain the minimum number of fuzzy rules.

1. Introduction

In the world, special attention is paid to the improvement of process control systems in the water sector in order to increase agricultural production and the problems of saving water sources through the use of alternative solutions for irrigation water treatment. The problem of shortage of quality water for irrigation necessitates the creation of management systems for water treatment in order to obtain the desired quality. Preservation of soil fertility properties directly depends on the quality of irrigation water. To solve this problem, it is required to create a control system that takes into account the properties of water in the source for further generation of signals for regulating the operation of actuators [1-9].

An important task is to build a fuzzy model based on experimental data, improve the construction of a Sugeno fuzzy logical model for assessing water salinity and using the Sugeno fuzzy algorithm to predict the causes, features of the development of the water salinization process [10-12].

In the process of research, problems arise in solving model problems in the water sector and in solving real life problems, as well as forecasting based on expert data from the water sector. Solving problems of intellectual analysis is characterized by the insufficiency of numerical calculations and the incompleteness of important information about the conditions of the problem [13-19].

2. Methods and models

To build a model for assessing water salinity, a sample was received from experts (X_r, y_r), $r=\overline{1,M}$, where $X_r=(x_{r,1}, x_{r,2}, ..., x_{r,n})$ - input vector of r-pair and y_r - corresponding output vector.

Our task is to build a fuzzy model as follows:

$$\bigcup_{p=1}^{k_j}\left(\bigcap_{i=1}^{n} x_i = a_{i,jp} - w_{jp} \quad \text{with weight}\right) \to y_j = b_{j,0} + b_{j,1}x_1 + \ldots + b_{j,n}x_n + \\ + b_{j,n+1}x_1^2 + \ldots + b_{j,2n}x_n^2 + \ldots + b_{j,n+l-1}x_1^l + \ldots + b_{j,ln}x_n^l. \tag{1}$$

When constructing this model, if l=0, the case is considered as a singleton form model [10-11]. The linear model in the Sugeno representation, consisting of the derivation of fuzzy rules in the case l=1, was studied in [12-13]. The case with l=2 is considered in the work [14].

In the process of building a model, it is necessary to find the values of the coefficients of the fuzzy inference rule as follows

$$B = (b_{1,0}, b_{2,0}, ..., b_{m,0}, b_{1,1}, b_{2,1}, ..., b_{m,1}, ..., b_{1,n} b_{2,n}, ..., b_{m,n}, ..., b_{1,ln} b_{2,ln}, ..., b_{m,ln}),$$
$$i = \overline{1,n},\ j = \overline{1,m}$$

and minimize the following function:

$$\sum_{r=\overline{1,M}} \left(y_r - y_r^f\right)^2 \to \min, \tag{2}$$

where y_r^f - output of input data in *r*- selection line (X_r) in a fuzzy knowledge base - b -parameters.

Solution of problem (1) corresponds to the solution of the following equation $Y = A \cdot B$,
where

$$A = \begin{bmatrix} \beta_{1,1},...,\beta_{1,m}, & x_{1,1}\cdot\beta_{1,1},...,x_{1,1}.\beta_{1,m}, & ..., & x_{1,n}\cdot\beta_{1,1},...,x_{1,n}\cdot\beta_{1,m},..., & x^l_{1,1}\cdot\beta_{1,1},...,x^l_{1,1}.\beta_{1,m}, & ..., & x^l_{1,n}\cdot\beta_{1,1},...,x^l_{1,n}\cdot\beta_{1,m} \\ \vdots \\ \beta_{M,1},...,\beta_{M,m}, & x_{M,1}\cdot\beta_{1,1},...,x_{M,1}\cdot\beta_{1,m}, & ..., & x_{M,n}\cdot\beta_{M,1},...,x_{M,n}\cdot\beta_{M,m},..., & x^l_{M,1}\cdot\beta_{1,1},...,x^l_{M,1}\cdot\beta_{1,m}, & ..., & x^l_{M,n}\cdot\beta_{M,1},...,x^l_{M,n}\cdot\beta_{M,m} \end{bmatrix}.$$

Here in the discrete case

$$\beta_{j,r} = \frac{\mu_{f_j}(X_r)\cdot f_j}{\sum_{k=1}^{m}\mu_{f_j}(X_r)},$$

and in continuous cases

$$\beta_{j,r} = \frac{\mu_f(X_r)\cdot f_j}{\int_{f_-}^{f_+}\mu_f(X_r)df},$$

$$f_j = b_{j,0} + b_{j,1}x_{r,1} + b_{j,2}x_{r,2} + ...+ b_{j,n}x_{r,n} + b_{j,n+1}x_{r,1}^2 + b_{j,n+2}x_{r,2}^2 + ...+ b_{j,2n}x_{r,n}^2 + \\ ....+ b_{j,n+l-1}x_{r,1}^l + b_{j,n+l}x_{r,2}^l + ...+ b_{j,ln}x_{r,n}^l \text{ - output of } j - \text{rule},$$

$\mu_{f_j}(x_r)$ - membership function corresponding to each experimental data for each case:

$$\mu_{f_j}(X_r)=\mu_{j,1}(x_{r,1})\cdot\mu_{j,1}(x_{r,2})\cdot\mu_{j,1}(x_{r,3})\cdot.......\cdot\mu_{j,1}(x_{r,ln})\vee$$
$$\vee\mu_{j,2}(x_{r,1})\cdot\mu_{j,2}(x_{r,2})\cdot\mu_{j,2}(x_{r,3})\cdot.......\cdot\mu_{j,2}(x_{r,ln})\vee$$
$$..$$
$$\vee\,\mu_{j,k_j}(x_{r,1})\cdot\mu_{j,k_j}(x_{r,2})\cdot\mu_{j,k_j}(x_{r,3})\cdot.......\cdot\mu_{j,k_j}(x_{r,ln})$$
$$r=\overline{1,n}.$$

In the process of solving real problems $m(n+1)<M$. In this case, the solution of the system of equations $Y=A\cdot B$ comes down to problem solving $A^TY=A^TA\cdot B$ [17-18].

The membership functions of fuzzy terms used in this knowledge base were chosen by an expert.

Based on the literature data, six groups of soils are considered according to the granulometric composition, with the permissible maximum content of salts in irrigation water in equivalents of chloride ions. Irrigation water quality assessment according to the risk of irrigation soil salinization is given

A fuzzy logical Sugeno model for assessing water salinity has been built.

$$\text{If}\left(x_1=\frac{\sum_{j=1}^{q}\mu(a_{11}^j)a_{11}^j}{\sum_{j=1}^{q}\mu(a_{11}^j)}\wedge x_2=\frac{\sum_{j=1}^{q}\mu(a_{12}^j)a_{12}^j}{\sum_{j=1}^{q}\mu(a_{12}^j)}\wedge\ldots\wedge x_8=\frac{\sum_{j=1}^{q}\mu(a_{18}^j)a_{18}^j}{\sum_{j=1}^{q}\mu(a_{18}^j)}\right)\text{ then}$$

$$y=0,6143-0,0022\frac{\sum_{j=1}^{n}\mu(x_1^{1j})x_1^{1j}}{\sum_{j=1}^{n}\mu(x_1^{1j})}+0,0004\frac{\sum_{j=1}^{n}\mu(x_2^{1j})x_2^{1j}}{\sum_{j=1}^{n}\mu(x_2^{1j})}+0,0006\frac{\sum_{j=1}^{n}\mu(x_3^{1j})x_3^{1j}}{\sum_{j=1}^{n}\mu(x_3^{1j})}-$$
$$-0,0049\frac{\sum_{j=1}^{n}\mu(x_4^{1j})x_4^{1j}}{\sum_{j=1}^{n}\mu(x_4^{1j})}+0,0119\frac{\sum_{j=1}^{n}\mu(x_5^{1j})x_5^{1j}}{\sum_{j=1}^{n}\mu(x_5^{1j})}-0,0018\frac{\sum_{j=1}^{n}\mu(x_6^{1j})x_6^{1j}}{\sum_{j=1}^{n}\mu(x_6^{1j})}+$$
$$+0,0009\frac{\sum_{j=1}^{n}\mu(x_7^{1j})x_7^{1j}}{\sum_{j=1}^{n}\mu(x_7^{1j})}+1,1975\frac{\sum_{j=1}^{n}\mu(x_8^{1j})x_8^{1j}}{\sum_{j=1}^{n}\mu(x_8^{1j})}.$$

$$\text{If}\left(x_1=\frac{\sum_{j=1}^{q}\mu(a_{21}^j)a_{21}^j}{\sum_{j=1}^{q}\mu(a_{21}^j)}\wedge x_2=\frac{\sum_{j=1}^{q}\mu(a_{22}^j)a_{22}^j}{\sum_{j=1}^{q}\mu(a_{22}^j)}\wedge\ldots\wedge x_8=\frac{\sum_{j=1}^{q}\mu(a_{28}^j)a_{28}^j}{\sum_{j=1}^{q}\mu(a_{28}^j)}\right)\text{ then}$$

$$y = 3,8795 - 0,0139\frac{\sum_{j=1}^{n}\mu(x_1^{1j})x_1^{1j}}{\sum_{j=1}^{n}\mu(x_1^{1j})} + 0,0007\frac{\sum_{j=1}^{n}\mu(x_2^{1j})x_2^{1j}}{\sum_{j=1}^{n}\mu(x_2^{1j})} + 0,0243\frac{\sum_{j=1}^{n}\mu(x_3^{1j})x_3^{1j}}{\sum_{j=1}^{n}\mu(x_3^{1j})} +$$

$$+0,0107\frac{\sum_{j=1}^{n}\mu(x_4^{1j})x_4^{1j}}{\sum_{j=1}^{n}\mu(x_4^{1j})} - 0,0202\frac{\sum_{j=1}^{n}\mu(x_5^{1j})x_5^{1j}}{\sum_{j=1}^{n}\mu(x_5^{1j})} - 0,0142\frac{\sum_{j=1}^{n}\mu(x_6^{1j})x_6^{1j}}{\sum_{j=1}^{n}\mu(x_6^{1j})} +$$

$$+0,0538\frac{\sum_{j=1}^{n}\mu(x_7^{1j})x_7^{1j}}{\sum_{j=1}^{n}\mu(x_7^{1j})} - 8,6015\frac{\sum_{j=1}^{n}\mu(x_8^{1j})x_8^{1j}}{\sum_{j=1}^{n}\mu(x_8^{1j})}.$$

If $\left(x_1 = \frac{\sum_{j=1}^{q}\mu(a_{31}^{j})a_{31}^{j}}{\sum_{j=1}^{q}\mu(a_{31}^{j})} \wedge x_2 = \frac{\sum_{j=1}^{q}\mu(a_{32}^{j})a_{32}^{j}}{\sum_{j=1}^{q}\mu(a_{32}^{j})} \wedge \ldots \wedge x_8 = \frac{\sum_{j=1}^{q}\mu(a_{38}^{j})a_{38}^{j}}{\sum_{j=1}^{q}\mu(a_{38}^{j})} \right)$ then

$$y = 4,7979 - 0,0046\frac{\sum_{j=1}^{n}\mu(x_1^{1j})x_1^{1j}}{\sum_{j=1}^{n}\mu(x_1^{1j})} + 0,0185\frac{\sum_{j=1}^{n}\mu(x_2^{1j})x_2^{1j}}{\sum_{j=1}^{n}\mu(x_2^{1j})} - 0,0437\frac{\sum_{j=1}^{n}\mu(x_3^{1j})x_3^{1j}}{\sum_{j=1}^{n}\mu(x_3^{1j})} -$$

$$-0,1253\frac{\sum_{j=1}^{n}\mu(x_4^{1j})x_4^{1j}}{\sum_{j=1}^{n}\mu(x_4^{1j})} - 0,0247\frac{\sum_{j=1}^{n}\mu(x_5^{1j})x_5^{1j}}{\sum_{j=1}^{n}\mu(x_5^{1j})} + 0,0043\frac{\sum_{j=1}^{n}\mu(x_6^{1j})x_6^{1j}}{\sum_{j=1}^{n}\mu(x_6^{1j})} +$$

$$+0,3887\frac{\sum_{j=1}^{n}\mu(x_7^{1j})x_7^{1j}}{\sum_{j=1}^{n}\mu(x_7^{1j})} + 5,9235\frac{\sum_{j=1}^{n}\mu(x_8^{1j})x_8^{1j}}{\sum_{j=1}^{n}\mu(x_8^{1j})}.$$

Here:

Concentration of toxic ions in equivalents of chloride ions by soil groups according to their granulometric composition in the 0-100 cm layer, meq/dm3

x_1 - Sandy;

x_2 - Sandy;

x_3 - Light loamy;

x_4 - Medium loamy;

x_5 - acid loamy;

x_6 - clayey;

x_7 - pH;

x_8 - Consistence CO_3^2, meq/dm3.

The question of constructing membership functions is one of the most important questions in fuzzy set theory.

When constructing membership functions, the main concept is the relative preference of one mode of operation of the system over another. The preference of one mode of operation over another can be caused by technological, economic, reliability, environmental reasons and various subjective reasons caused by informal information that the decision maker has.

The membership function and assigns to each mode a number from the interval [0,1], which characterizes the degree of belonging of the solution to the subset D of effective and feasible solutions.

The requirement of continuity of the function is also natural, which formalizes the intuitive idea that if two solutions of the set X differ from each other only slightly, then the values of the membership functions for these solutions are also close.

The specific type of membership functions is determined on the basis of various additional assumptions about the properties of these functions (symmetry, monotonicity, continuity of the first derivative), taking into account the specifics of the existing uncertainty, the real situation on the object and the number of degrees of freedom in the functional dependence.

For example, the statement "The concentration of toxic ions in equivalents of chloride ions in sandy soils according to their granulometric composition in a layer of 0-100 cm, meq / dm3 should be less than 30" can be represented as follows:

$$\mu(a_{11}^j) = \begin{cases} 1, & a_{11} \le 30, \\ \left[[1 + (a_{11} - 30)]^2\right]^{-1}, & a_{11} > 30. \end{cases}$$

The statement "The concentration of toxic ions in equivalents of chloride ions in sandy loamy soils according to their granulometric composition in a layer of 0-100 cm, meq / dm3 should be less than 26" can be represented as follows:

$$\mu(a_{12}^j) = \begin{cases} 1, & a_{12} \le 26, \\ \left[[1 + (a_{12} - 26)]^2\right]^{-1}, & a_{12} > 26. \end{cases}$$

The statement "The concentration of toxic ions in chloride ion equivalents for light loamy soils in terms of their particle size distribution in the 0-100 cm layer, meq/dm3 should be close to 27" can be represented as follows:

$$\mu(a_{23}^j) = \left[1 + \frac{(a_{23} - 27)^2}{8}\right]^{-1}.$$

The statement "The concentration of toxic ions in chloride ion equivalents for medium loamy soils in terms of their particle size distribution in the 0-100 cm layer, meq / dm3 should be close to 23" can be represented as follows:

$$\mu(a_{24}^j) = \left[1 + \frac{(a_{24} - 23)^2}{7}\right]^{-1}.$$

The statement "The concentration of toxic ions in equivalents of chloride ions in heavy loamy soils according to their granulometric composition in a layer of 0-100 cm, meq / dm3 should be more than 24" can be represented as follows:

$$\mu(a_{35}^{j}) = \begin{cases} \left[1 + \dfrac{(a_{35} - 24)^{-1}}{7}\right]^{-1}, & a_{35} \geq 24, \\ 0, & a_{35} < 24. \end{cases}$$

The statement "The concentration of toxic ions in equivalents of chloride ions in clay soils according to their granulometric composition in a layer of 0-100 cm, meq / dm3 should be more than 20" can be represented as follows:

$$\mu(a_{36}^{j}) = \begin{cases} \left[1 + \dfrac{(a_{36} - 20)^{-1}}{7}\right]^{-1}, & a_{36} \geq 20, \\ 0, & a_{36} < 20. \end{cases}$$

In many practical situations, a membership function must be evaluated from partial information about it, such as the values it takes on a finite set of reference points, for example. In practical applications, methods are used for determining characteristic functions (or constructing their estimates) from samples and based on a priori information, which includes restrictions on these functions.

3. Result

The results of classification according to Sugeno's fuzzy logical model for assessing water salinity were obtained and a comparative analysis was carried out.

Table 1. Accuracy of results calculated using Sugeno's neuro-fuzzy model (%)

№	Value of σ	Term number			
		3	5	7	9
1	0.10	94.25	94.25	94.75	98.92
2	0.20	92.35	93.75	94.25	98.92
3	0.30	92.77	93.87	94.75	97.92
4	0.40	88.47	89.55	95.75	96.92
5	0.50	87.30	88.50	95.75	97.92
6	0.60	86.40	88.40	94.75	96.92
7	0.70	85.30	86.30	94.75	96.92
8	0.80	85.20	86.80	95.75	96.92
9	0.90	86.40	87.40	92.67	95.92
10	1.00	84.92	86.9	92.67	95.92
		94.25	94.25	94.75	98.92

Classification is carried out according to three classes of water salinity:
I - there is no risk of irrigation salinization;
II - - the risk of irrigation salinization is medium;
III - the risk of irrigation salinization of a strong degree.

4. Conclusion

Proposed approach is universal for solving weakly formalized decision-making problems in various objects, where it is possible to attract highly qualified specialists - experts in a particular subject area for the accumulation of knowledge. The system will be able to work with different knowledge bases created for different subject areas.

The implementation of the system provides:

– improving the quality of group decision-making in the conditions of various situations due to computer decision-making and machine experiment with imitation of the corresponding situation;

– the possibility of developing management decisions and recommendations to reduce human and material losses;

– saving resources (material, labor) due to the simulation of collective decision-making on a computer, the multivariance of the decisions obtained and the effective use of pre-prepared decisions in real conditions;

– increasing the effectiveness of training based on the use of modern computer technology and software, mathematical methods and software systems.

The mathematical apparatus used is quite laborious in terms of computational procedures. Therefore, the effectiveness of its use is achieved in the presence of special computer developments.

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