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Forecasting the environmental situation at the purification plants of the enterprise based on fuzzy logic

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Abstract. The study set the goal of improving the efficiency of various technological schemes of purification plants of the enterprise through the development of an expert system based on fuzzy logic methods and the formation of practical recommendations for improving the characteristics of wastewater from the operation of schemes of purification plants.

1. Introduction

The task of assessing the quality of wastewater purification belongs to the type of problems in the solution of which it is necessary to use integral indicators [1].

One of the most common assessment methods today uses the generalized desirability function (GDF) as an indicator that characterizes the integral assessment of wastewater quality, and it is associated with partial desirability functions (PDFs) that characterize the quality of a water body from the standpoint of the value of a specific single indicator [2]:

$$D = \sqrt[k]{(m_1^{a_1 b_1} \cdot m_2^{a_2 b_2} \cdot \ldots \cdot m_n^{a_n b_n})}$$

Due to the fact that it is possible to form many variants of the desirability function itself, therefore, the use of this method in some cases gives inadequate results associated with a too formalized pollution value model.

With the development of intelligent techniques of analysis, the range of possible ways to solve problems of this type has also expanded. Today, assessment and management systems based on fuzzy logic are successfully used and actively improved, and it served as the basis for their use in our study.

2. Materials and methods

Wastewater quality was assessed using statistical research methods in the STATISTICA data analysis application package, standard methods based on the construction of desirability functions and using intelligent analysis methods (fuzzy logic) using Sugeno and Mamdani algorithms implemented in the Mathlab environment.

To assess wastewater, a comprehensive method for analyzing the quality of the functioning of the Purification Plants (PS) was carried out. A three-stage scheme is proposed in the study, including the analysis of the quality of Purification Plants (PS) operation by standard methods, fuzzy logic methods and using an expert system.

In the first phase of the study, a five-month analysis of the quality of the purification plant was carried out using standard methods, using the GDF algorithm (1).

To calculate the PDF and GDF, the average values of the measured values at the inlet and outlet of the treatment plant of each section were taken from two waterways (WW_1, WW_2) with threshold level value (TLV), the data was taken for each month.

Using these data, calculations of the PDF have been made, taking into account the hazard classes of pollutants and the generalized desirability functions for the waterways WW_1 и WW_2 (table 1, 2).

Table 1. Calculation data of PDF and GDF for waterway WW_1 of purification plants.

	Class	AVG	TLV	m_i	a_i	b_i	a_i*bi	PDF	GDF
SM[a]	4	9.95	13.950	1.000	0.25	0.71	0.18	1.0000	
ChOD		10.81	30.0	1.000	**0.25**	0.36	0.09	1.0000	
BOD.5		7.232	2.1	0.536	**1.00**	3.44	3.44	0.1167	
ammonium	4	0.203	0.5	1.000	0.25	0.41	0.10	1.0000	
nitrates	4	2.988	40	1.000	0.25	0.07	0.02	1.0000	
nitrites	4	0.023	0.08	1.000	0.25	0.28	0.07	1.0000	
PC at SS	4	7.450	4.0	0.834	0.25	1.86	0.47	0.9188	
chlorides	4	965.3	300.0	0.567	0.25	3.22	0.81	0.6332	0.0942
refined products	3	0.067	0.050	0.959	0.33	1.34	0.44	0.9815	
fluorides	3	3.930	0.750	0.368	0.33	5.24	1.73	0.1777	
ferrrum	4	0.363	0.100	0.512	0.25	3.63	0.91	0.5450	
manganese	4	0.030	0.010	0.596	0.25	3.02	0.76	0.6770	
nickel	3	0.004	0.010	1.000	0.33	0.37	0.12	1.0000	
cuprum	3	0.053	0.001	0.038	0.33	52.58	17.35	1.3E-25	
zinc	3	0.015	0.010	0.930	0.33	1.47	0.49	0.9652	
lead	2	0.005	0.006	1.000	0.50	0.83	0.42	1.0000	

[a] Suspended Materials.

PC at SS-particle concentration at steady state

Table 2. Calculation data for PDFand GDF for WW_2 of purification plants.

	Class	AVG	TLV	m_i	a_i	b_i	a_i*bi	PDF	GDF
SM	4	12.620	13.950	1.000	0.25	0.90	0.23	1.000	
ChOD		9.820	30.000	1.000	**0.25**	0.33	0.08	1.000	
BOD 5		6.552	2.100	0.581	**1.00**	3.12	3.12	0.184	
ammonium	4	0.213	0.500	1.000	0.25	0.43	0.11	1.000	
nitrates	4	2.458	40.000	1.000	0.25	0.06	0.02	1.000	
nitrites	4	0.021	0.080	1.000	0.25	0.27	0.07	1.000	0.0942
PC at SS	4	6.842	4.000	0.871	0.25	1.71	0.43	0.943	
chlorides	4	963.000	300.000	0.568	0.25	3.21	0.80	0.635	
refined products	3	0.081	0.050	0.894	0.33	1.62	0.53	0.942	
fluorides	3	3.919	0.750	0.369	0.33	5.23	1.73	0.179	
ferrrum	4	0.286	0.100	0.622	0.25	2.86	0.72	0.712	
manganese	4	0.030	0.010	0.601	0.25	2.99	0.75	0.684	

nickel	3	0.003	0.010	1.000	0.33	0.33	0.11	1.000
cuprum	3	0.015	0.001	0.131	0.33	15.23	5.03	0.000
zinc	3	0.013	0.010	0.965	0.33	1.31	0.43	0.985
lead	2	0.005	0.006	1.000	0.50	0.87	0.44	1.000

To compare the efficiency of purification by waterways WW_1 and WW_2 the previously calculated GDF for the water entering the purification plant was used (the value was 0.38).

The primary data analysis of the purification plants section given in tables 2 and 3 showed a sharp deterioration in the quality of the wastewater after passing WW_1 (the value of GDF at the inlet to the purification plant is 0.38, and at the outlet of WW_1 is 0.09) and the deterioration of water quality after passing WW_2 (inlet 0.13 - outlet 0.33). At the same time, analyzing the data of tables 2 and 3, it is obvious that the smallest value of PDF, which reduces GDF, has the “cuprum” parameter. The parameter "cuprum" was excluded from the calculation of the GDF, as requiring additional research. As a result, refined values of GDF were obtained.

Comparison of the values of the generalized desirability function for the waterways WW_1 and WW_2 (0.546 and 0.574 respectively) with GDF of the inlet flow (0.44) suggests a noticeable degree of purification of the flow from pollutants.

The efficiency of their work, taking into account the calculation error (due to the small size of the experimental data array), is the same.

BOD and fluorides have the lowest PDF values for WW_1 and WW_2. At the same time, the PDF of the BOD5 indicator increases several times (more than three for WW_1 and more than five for WW_2 do), i.e. wastewater treatment plants improve this indicator from the standpoint of regulatory requirements, but not effectively enough to achieve TLV. The value of the private function of the desirability of the fluoride indicator practically does not change, which indicates that the operation of the treatment plant according to this scheme has no effect on this pollutant.

The qualification assessment of the wastewater state, based on the use of Harrington's desirability function, allows the quality of the water discharged from this section of the treatment plant to be classified as “satisfactory”. The rating is at the top of this category and is close to the lower limit of the “good” category.

For a more extended description of the analyzed purification process, one can use the conclusions given at the end of the article, taking into account their lower reliability.

Similarly, studies were carried out to analyze the quality of the work of the waterways of the remaining sections.

At the second stage of the research, an analysis of the purification plants work quality was carried out using fuzzy logic methods and an expert system was built, which made it possible to confirm the main conclusions generated from the results of the previous stage of work and form practical recommendations for improving the characteristics of wastewater.

When building this system, we used a database of fuzzy inference rules, created jointly with experts (specialists in the field of wastewater purification), with weight coefficients and membership functions of all input parameters.

At the third stage, the quality of work of technological lines was analyzed using the built system, an integral assessment of the efficiency of individual sections of the treatment facilities of all technological lines was carried out.

3. Results and discussion

As a result, an expert system was created (Figure 1), which showed its suitability at the testing stage.

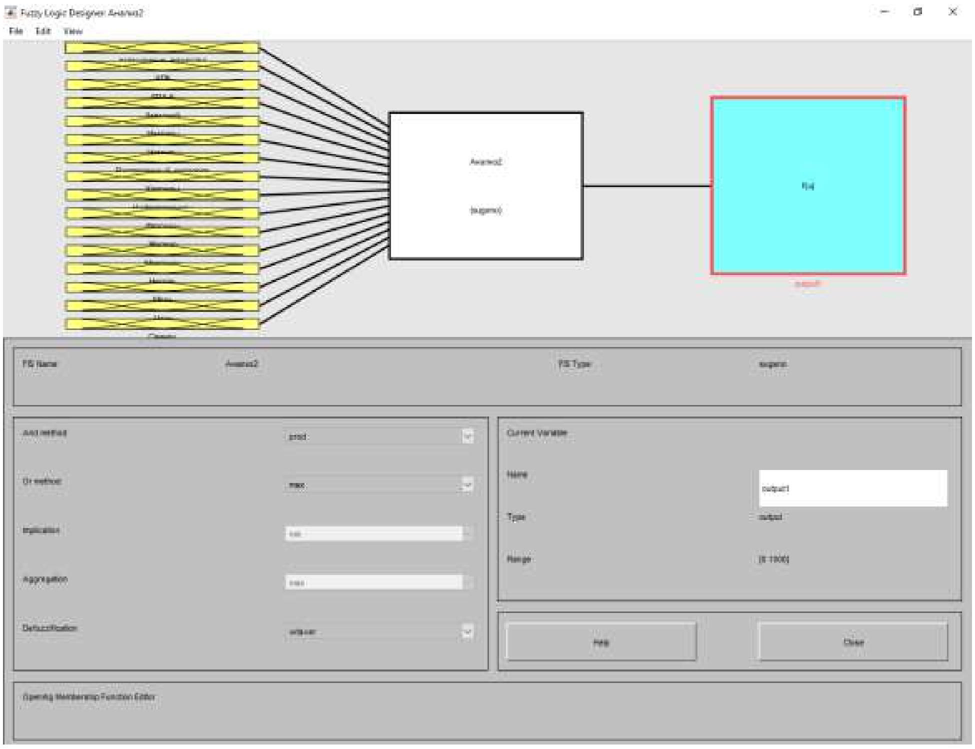

Figure 1. An expert system built using the Sugeno algorithm.

When changing the input values of each of the indicators in the proposed system, the value of the output function for WW_1, WW_2 changes (figure 2,3).

Figure 2. Results of preliminary testing for WW_1.

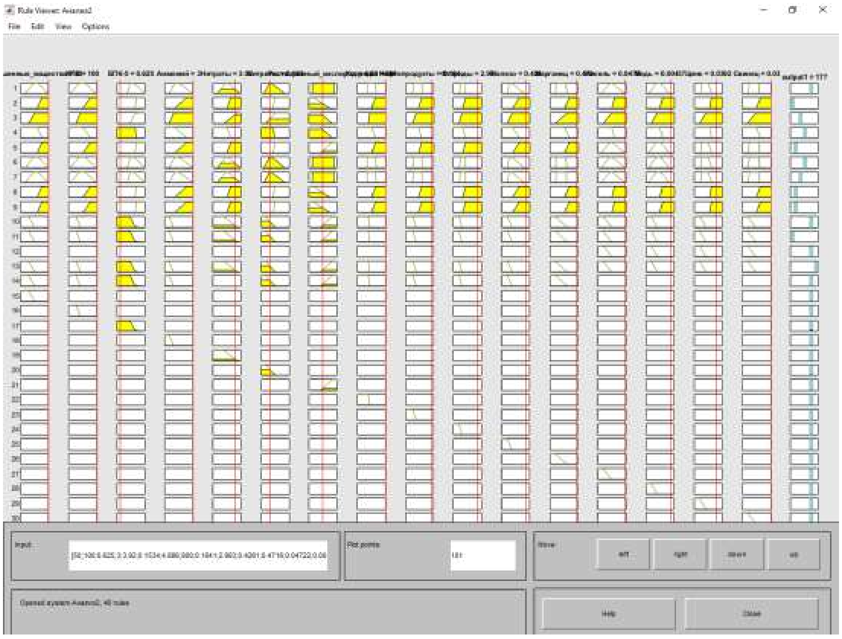

Figure 3. Results of preliminary testing for WW_2

Figures 2 and 3 show the results of preliminary performance testing of the expert system with the Sugeno algorithm

The results of assessing the work quality of the purification plants, carried out based on the application of the methods of generalized desirability functions and the fuzzy inference of Mamdani and Sugeno, are presented in Table 3.

Table 3. Evaluation of purification plants work quality.

Waterways	Power	Scheme 1	Scheme 2	Scheme 3	Scheme K
		GDF assessment*1000			
WW_1	437	524	565	551	546
WW_2		598	600	555	574
		Mamdani scheme assessment			
WW_1	411	486	493	491	468
WW_2		497	482	486	487
		Sugeno scheme assessment			
WW_1	385	463	471	468	444
WW_2		474	458	462	464

The comparison of the obtained results of simulation modeling using the Sugeno and Mamdani systems algorithms with each other and with the results of the evaluation by the GDF method showed the satisfactory operation of both models. At the same time, the results obtained generally coincided with the results of the first stage. However, the identified differences in assessing the quality of work of purification plants emphasized the importance of using the developed integrated approach to data analysis, when the results of one model, on the one hand, are a guide for the work of the other model, and, on the other hand, are verified using additional analysis methods.

4. Conclusions

Because of the work performed a comprehensive method for analyzing the quality of functioning of a purification plant has been formed, which consists in performing the described sequence, which includes statistical research methods, standard methods based on the construction of desirability functions, and intelligent methods of analysis (fuzzy logic).

Carrying out an analysis according to a three-stage scheme makes it possible to increase the reliability of the estimates obtained, to correct them and form conclusions about the reliability of the obtained results, the possibility of using them for further forecasting, and also to offer practical recommendations for improving the quality of wastewater. It is important to note that the introduction of intelligent analysis methods into the scheme of analysis of the work of the purification plant can significantly improve the adequacy of the model due to a more balanced approach, taking into account the importance of specific polluted waters, their allowable ranges of "normality". This approach is much less formalized and allows adjustments to be made during the assessment at various stages of purification, when the requirements for wastewater are different, during the operation of enterprises of various types, when the composition and requirements for wastewater indicators can also differ greatly.

The formulated conclusions and the calculated values of the integral indicators are verified and corrected by fuzzy inference models, are reliable and can be used to predict and form recommendations to improve the quality of purification plants.

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