The inevitability of risk-based water quality assessment

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Abstract. When determining water quality indicators, the assessment is carried out taking into account the possible measurement error and the probability of conformity. If there are disputes regarding the values of the indicators to be determined, the probability of non-conformity with the quality requirements and the risk factors for such non-conformity should be correctly taken into account. Taking into account the fact that the issues of water relations are related to the economic relations of business entities and, consequently, potential contentious situations, the article shows the approaches to assessing conformity, it is justified that one can only trust the results obtained on the basis of a correct risk-based approach that takes into account both a posteriori and a priori data.

1. Introduction
Water quality is almost always a characteristic that requires an assessment of a group of indicators [1]. At the same time, even if a single indicator does not meet the current requirements, it is impossible to consider water of high quality. In this regard, maximum attention should be paid to the correctness of conclusions about non-conformity with quality, the correctness of which should be evaluated from the standpoint of risk-based rationing. This approach to water resources management is increasingly becoming a hot topic of global discussion. [2]. At the same time, the quality of drinking water from centralized water supply systems does not allow any compromises, as associated with human health [3].

2. Methods
The questions are raised about the growing needs of the economy for water of the necessary quality with an increasing shortage of it, about the unpredictability of the appearance of high and ultra-high pollution, about the actual absence of regional and background quality standards in the country, about the too close “step” division of water into quality classes [1,4], etc.

And indeed, by the example of the choice of technological solutions in the field of water treatment, we are guided by the values of the quality of the source and final water, the corresponding structures are designed [4], and the risk of error in choosing the initial parameters is always fraught with significant financial losses.

Unfortunately, the current regulation of the ecological and legal regime of water use does not provide for measures to expand the volume and reliability of information about the composition and properties of water, as well as to develop analysis methods that allow "deciphering" natural laws in order to...
improve water resources management by adapting (adapting) to the composition and properties of natural or wastewater. This is strikingly contrary to other areas of economic development, where the previously existing phenomenological approach to security is replaced by the concept of acceptable risk, which characterizes the possibility of negative events [5]. Water resources management in almost everything provides for "risk-free" regulation, which is economically and environmentally harmful [6].

Taking into account the fact that water industry enterprises in the field of assessing conformity with water quality requirements (both lowercase and potable) are forced to work with discrete samples, the issue of conformity assessment must be solved as correctly as possible. The identification and analysis of risks that accompany almost all types of water use is an urgent problem. However, not enough attention is currently being paid to this issue. Meanwhile, you can only trust the results obtained on the basis of a correct risk-based approach that takes into account both a posteriori and a priori data, as shown in the following example.

3. Results and discussion

Example - waste water quality control case - the company paid great attention to the environmental safety of its activities and the control of the indicators of discharged wastewater. As a result, the post-treatment of wastewater was brought to the maximum economically acceptable level. This guaranteed the regulatory content of pollutants in 99% of the total volume of wastewater. Inconsistencies were possible only in 1% of cases.

Despite such a high level of water and environmental responsibility of the enterprise, the laboratory of the water control authority, which analyzed the wastewater, found a violation of the established requirements for the studied controlled indicator. As a result of the data obtained from the analysis of the selected water sample, the supervisory authority concluded that there was a violation of the water disposal rules (non-conformity with the quality requirements), which gives the right to penalties. Confidence in this was based on the fact that the test laboratory carried out measurements with almost no error – with the risk of error at the level of 0.01. Accordingly, the violation was found almost unconditionally, with a probability of 99%.

However! The management of the enterprise demanded repeated measurements. He insisted on the infallibility of the results of a priori studies of the factory laboratory, indicating a risk of violations of the requirements of only 1%.

Both laboratories, both owned by the control and supervisory authority, and the factory were accredited in a single system, and this obliged us to treat the results of both with equal confidence [3, 4]. Therefore, the a posteriori data obtained by the supervisory authority were adjusted by taking into account the a priori data using probability theory. And it was shown that in this case, the probability of violation is only 50%. This level of probability of violation is no longer 99%, and indicates that the violation is unproven, so to resolve the issue of sanctions, the water analysis should be repeated.

3.1. Proof algorithm

To prove the need for data correction (in order not to fall into the metrological trap), you need to use one of the main theorems of elementary probability theory – Bayes’ theorem, which allows you to determine the probability of an event, provided that another statistically dependent event occurred:

\[ P(B|E) = \frac{P(B) \cdot P(E|B)}{P(E)} \]  

(1)

The notation used in this formula is:

P is the probability of some event,
B is the statement that is being verified, E is the proof,
P(B) is the probability that B is true,
P(E) is the probability that E is true,
P (B|E) is the probability that B is true if E is true,
P (E|B) is the probability that E is true if B is true.
In the problem under consideration:
B - waste water is rejected,
E - the measurement result indicates a violation,
B|E - the water is rejected, since the measurement result indicates a violation,
E|B - the discrepancy is fixed, despite the fact that it actually exists.

3.2. Quantitative assessment.

$P(\text{In}) = 0.01$ - the probability of rejecting waste water, provided that it meets the established requirements in 99%.
$P(\text{E|B}) = 0.99$ is the probability that the discrepancy between recorded, despite the fact that it actually is (the measurement error is 0.01).
$R(E) = (0.01 \times 0.99) + (0.99 \times 0.01) = 0.0198$ - the probability that fixed the discrepancy, which may or may not be.

Here it is taken into account that the risk of non-conformity of the effluents is 1% (a priori information), and the risk of control error is also 1%. Therefore, the probability of a result indicating non-conformity with water is obtained by multiplying the probability of control error and the probability of a priori conformity of water with the established requirements: $0.99 \times 0.01$ plus the probability of correct control, multiplied by the probability that the water is non-compliant: $0.99 \times 0.01$. As a result, substituting the obtained values into equation (1), we obtain the probability of interest:

$$P(\text{B|E}) = \frac{P(\text{B}) \times P(\text{E|B})}{P(\text{E})} = \frac{0.99 \times 0.01}{0.0198} = 0.5 = 50\%$$

Thus, the result becomes not 99%, but 50%, so that the probabilities of conclusions about non-conformity or water conformity are equal, and further analysis is required.

Another typical example is the issue of managing the water treatment process, based on making decisions about the dosage of reagents depending on the quality indicators of the source water. Using the example of the process of disinfection of drinking water, we will show the following scenarios in the general case:

- only a small fraction of the chlorine is used for decontamination;
- the main consumption of chlorine is spent on the oxidation of organic and inorganic compounds.

Thus, the forced overdose of chlorine entails risks of the formation of organochlorine compounds, including trihalomethanes, the rationing of which is very strict [8, 9, 10]. The control of the reagent dosing process depends on the assessment of the quality of the source water. The actual quality in the conditions of manual process control (most of the enterprises of the water treatment plant) depends on the frequency of analyses at the water treatment plant and on the correct interpretation of the results of these analyses to control the dosing of reagents (figure 1, 2).

![Figure 1. Manual control of reagent dosing.](image-url)
The risk-based approach in this case is based either on increasing the number of analyses in order to have the most reliable information about the quality of the selected markers responsible for the potential for the formation of trihalomethanes, or on their correct interpretation. "Total organic carbon" can be used as such a marker. The analysis of such an indicator with a high probability of detection allows us to establish a direct connection with the dosing of decontamination agents, and the process itself can be controlled automatically [7,8,14].

![Figure 2. Proportional control of reagent dosing.](image)

Calculations show that this mode (proportional process control), taking into account the error in dosing, allows you to save up to 10% of the decontamination agent, but this mechanism also needs to be improved, especially when the process control is based on manual sampling, analysis in the test laboratory and data interpretation.

It is useful for water users to refer to a priori information, especially if it is found that the a posteriori result is not at all what one would expect [10,11]. Of course, you also need a posteriori information, but to account for it, it is very useful to use Bayes' theorem, which, by the way, does not allow that at least some event occurs with a probability of 100%. In fact, absolute trust is only possible in the statements of demagogues. In the system of correct assessment of the safety and quality of not only wastewater, errors are inevitable, the risk of which can be established using the Bayes theorem [9,13].

There are other ways to resolve arbitration situations.

For example, in a water user's laboratory (index "1"), the probability of detecting water conformity with the established requirements is R1, and the probability of non-conformity is 1-R1. Similarly, in the laboratory of the control body (index "2"): the probability of conformity with R2 and non-conformity is 1-R2.

In these two laboratories, different results of water quality assessment are possible with the following probabilities:

- Case N1. The water match is detected by both sides: R1 R2.
- Case N2. Mismatch, also detected by both parties: (1-R1)(1-R2).
- Case N3. Found a match by the 1st party, and a mismatch – by the 2nd: R1(1-R2).
- Case N4. Found a match by the 2nd party, and a mismatch-by the 1st: (1 – R1) R2.

Here the total probability Σ=1, however, in cases N3 and N4 there are conflicting results. In case N3, the water user insists on conformity. The probability of such a match is (2) moreover, this creates an arbitration situation.
\[
\frac{R_1(1-R_2)}{R_1(1-R_2)+R_2(1-R_1)}
\]

In case N. 4, the control body detects conformity. The probability of such a situation is equal to

\[
\frac{(1-R_1)R_2}{R_1(1-R_2)+R_2(1-R_1)}
\]

Let, as in the above example, the error risks are 1%, so that R1=0.99 and R2=0.99. In this case:
R1R2=0.9801; (1-R1)(1-R2)=0.0001; R1(1-R2)=0.0099; (1-R1) R2=0.0099 and the total probability \(\Sigma=1\).

At the same time, the value calculated by formula (4) will be exactly 0.5 (50%) (5), as previously shown.

\[
\frac{0.99 \cdot 0.01}{0.99 \cdot 0.01 + 0.01 \cdot 0.99} = 0.5
\]

Thus, the resolution of an arbitration (disputed) situation requires additional studies of water quality.

4. Conclusions

Water quality control has serious economic consequences. Incorrect definition of quality indicators, lack of consideration of real conformity indicators can cause the imposition of fines by the control bodies on economic entities. At the same time, an incorrect conformity assessment can serve as a dispute between interested parties, cause incorrect organizational and technical decisions, and cause further inconsistencies [13].

The article shows the possibility of using the principles of Bayes’ theory in the event of disputes, justifies the need for additional control of the process quality indicators, and shows approaches to the formation of risk-oriented assessment of water quality indicators, both in order to overcome disputes and to optimize the technological process.

The development of tools for the formation of risk-based assessment programs for water quality conformity should be based on the standardization of such approaches, which makes it possible to include the requirements of risk-based assessment in the quality control programs and technical regulations for the operation of water treatment and wastewater treatment facilities. This will contribute to the development of a correct control system and reduce the risks of disputes.

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