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Assessment of ecological safety of a surface water object

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SUMMARY

In the process of calculating water quality indices, the weight of each parameter is usually either not taken into account, and the parameters are considered equivalent, or it is given by experts according to their practical experience, which is subjective and a lot of useful and valuable information about water quality can be lost. These drawbacks can be overcome by using information entropy to assign weights to water quality parameters. As a result of the application of the entropy-weighted water quality assessment index for the section of the Dnipro River, located within the Dnipropetrovsk region, it was established that the quality of the index differs significantly in the warm and cold periods of the year. It should also be noted that one of the key factors in the formation of the entropy index of water quality is the choice of a normative value, therefore, it is promising to justify the choice of the normative value for each specific condition, which can be considered as a separate task.

Introduction

Surface waters used for drinking water supply are vital for the population in industrially intensive regions such as Dnipropetrovsk Oblast, where surface waters constitute the primary source of drinking water. Therefore, the assessment of the environmental safety of surface water sources is a pressing issue. Firstly, humanity faces an increasing demand for drinking water, necessitating the increased withdrawal of water from surface sources. Assessing the environmental safety of surface water sources helps determine their potential water supply capacity and resources that can be used to provide drinking water. Secondly, pollution of surface water sources is becoming a growing concern due to the rise in industrial and agricultural activities, as well as the excessive exploitation of water resources. Assessing the environmental safety of surface water sources helps establish the level of contamination and identify potential sources of pollution. Thirdly, climate change also affects surface water sources, including increased precipitation, runoff rates, and decreased water levels in certain regions. Assessing the environmental safety of surface water sources helps determine how these changes can impact the availability of drinking water and other water resources.

Therefore, the assessment of the environmental safety of surface water sources is crucial for ensuring access to safe drinking water, environmental protection, and sustainable water resource management.

A comprehensive assessment of water quality from such sources provides a large number of physical, chemical, and biological parameters, many of which are integrated into the Water Quality Index (WQI) *(Sutadian, 2018)*. In 1965, the first modern water quality index developed by Horton initiated numerous studies in the field of water quality index research. However, the most crucial stages involved in the development of such indices include selecting parameters, weighting factors reflecting the importance of each parameter, and the final aggregation into a numerical score by establishing a ranking scale for each parameter. In recent years, there has been a growing use of entropy-based approaches for water quality assessment *(Bezsonnyi, Tretyakov, 2022)*. Entropy-based weighting has become a useful method utilizing information entropy to assign weights to water quality parameters *(Amiri, 2014)*. Information entropy deals with identifying uncertainty or chaos within a random process. Assigning weights to a particular parameter in a specific location depends on the uncertainty of its occurrence in that location. Higher uncertainty of occurrence in any location means less weight for the parameters in that location *(Bezsonnyi, 2022)*. The aggregation of weights and the assessment scale of all parameters into an overall numerical score is called the Entropy Weighted Water Quality Index (EWQI).

In the calculation of WQI, the weight of each parameter is usually either not considered, and parameters are treated as equal, or they are assigned by experts based on their practical experience, which is subjective and can result in the loss of valuable and useful information about water quality.

Therefore, the aim of this study is to assess the quality of surface waters used as a source of drinking water supply for the cities of the Dnipro agglomeration based on an improved water quality index with entropy-weighted coefficients.

Method and Theory

Hydroecological systems can be characterized by entropy-increasing and entropy-decreasing processes. The concept of entropy is ambiguous. Along with Clausius entropy, statistical, informational, mathematical, linguistic, intellectual and other entropies appeared. Entropy became a basic concept of information theory and began to act as a measure of the uncertainty of a situation. To characterize the degree of system complexity, first suggested using the concept of entropy *(Ashby, 1959)*. The system interacts with the outside world as a whole. In general, the system does not lose its organization or high orderliness. In order for an ecological system to function and interact with the environment, it must consume information from the environment and convey information to the environment. This process is called information metabolism, which, together with substance and material metabolism, forms a complete metabolism. For the first time, K. Shannon linked the concepts of entropy and information *(Shannon, 1963)*. From its presentation, entropy is the amount of information contained in one elementary message of a source that produces statistically independent messages. Gaining any amount of information equals entropy lost.

The development of the entropy-weighted water quality index (EWQI) involves the following stages *(Amiri, 2014)*:
The first step involves building the initial matrix of water samples and estimated parameters (1).

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

where x_{ij} is the concentration of the *i*-th substance for the *j*-th object, mg/dm^3.

The second step involves the construction of a normalized matrix containing the normalized values of each evaluated parameter in a specific sample in order to eliminate errors caused by different sizes and measurement units.

The third step involves calculating the information entropy (E) of each evaluated parameter according to the formula introduced by Claude Shannon *(Shannon, 1963)* (2):

$$E_n = -\left(\frac{1}{ln\, n}\right)\sum_{i=1}^{m} V_{ij}\, ln\, V_{ij} \tag{2}$$

where n is the number of sampling points, and V_{ij} is the probability of the appearance of the normalized value (v_{ij}) of the estimated parameter *j* in the *i-th* sample, which is determined as follows:

$$V_{ij} = \frac{v_{ij}}{\sum v_{ij}}. \tag{3}$$

The fourth step involves calculating the entropy weights (W) so that parameters with lower entropy or disorder measure are assigned a higher weight as follows:

$$W_j = (1 - E_j)/\sum_{j=1}^{t}(1 - E_j). \tag{4}$$

Parameters with lower entropy are given more weight because they indicate the presence of a more structured system that is more organized and less random and therefore may be more informative for water quality assessment.

Finally, the aggregation of the entropy weights and the quality rating scale into the EWQ-index is expressed as follows:

$$\mathrm{EWQI} = \sum_{j=1}^{n} W_j U_j\,, \tag{5}$$

where EWQI is the entropy-weighted water quality index; U_j for each parameter is given as the ratio of the controlled value of the *j*-th parameter (I_j) to its normative value (S_j):

$$U_j = \left(\frac{I_j}{S_j}\right) \times 100. \qquad (6)$$

According to the water quality classification scale proposed by *(Wu, 2011)*, water quality is defined in five classes: from "excellent water quality" to "extremely poor water quality". The classification standards are given in Table 1.

Table 1 *Water quality scale (Wu, 2011)*

EWQI	Class	Water quality
<50	1	Excellent water quality
50~100	2	Good water quality
100~150	3	Medium or average water quality
150~200	4	Poor water quality
>200	5	Extremely poor water quality

Results

Considering that the processes shaping the ecological condition of water are influenced by temperature regimes, calculations of the entropy water quality index were conducted for both the warm period (April to October) and the cold period (November to March) of the year. The results of the calculations are presented in Table 2 and Figure 1.

Table 2 *Entropy weighted water quality index (EWQI)*

EWQI	p1	p2	p3	p4	p5	p6	p7
Warm period	269.42	269.92	247.03	225.20	301.41	259.50	244.18
Cold period	225.30	202.70	233.31	242.90	223.76	217.14	226.17

According to the scale (Table 1), the water belongs to the 5th class - extremely poor water quality.

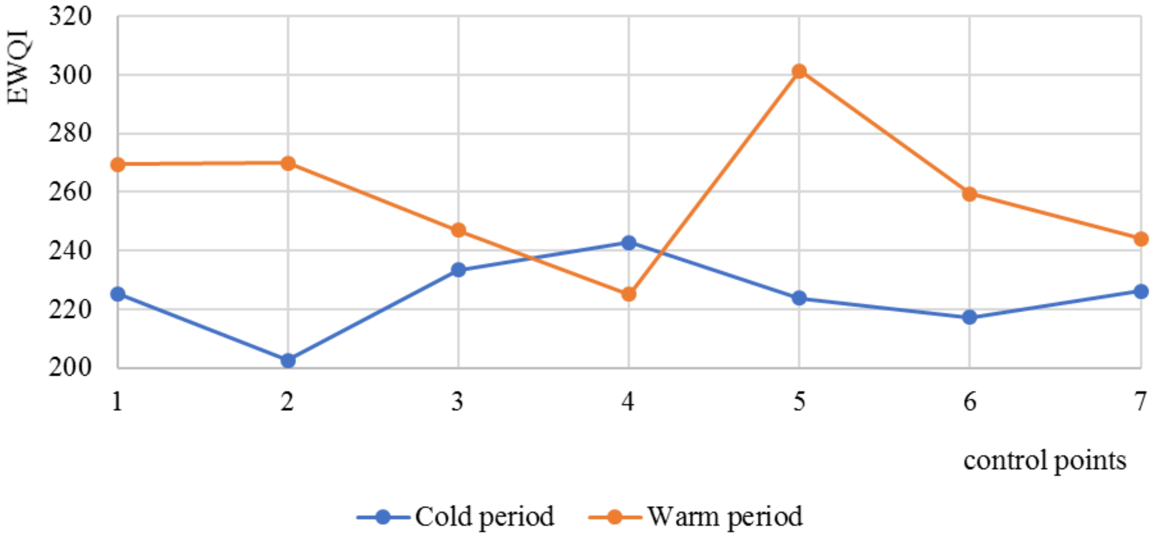

Figure 1 *Dynamics of EWQI by control points*

As can be seen from the graph, the range of EWQI fluctuations is quite wide. For the cold season, the minimum value of EWQI = 202.70 is observed at control point p2 (town Auli, drinking water supply of the city of Dnipro and the city of Kamianske), the maximum - EWQI = 242.90 - in p4 (the city of

Dnipro, left bank, Lomovsky drinking water park). For the warm period of the year, the best water quality is observed in p4 - EWQI = 225.20, and the worst - EWQI = 301.41 - in p5 (city of Dnipro, DTEK "Dniproenergo", drinking water). Territorially, the control point p5 is located below the confluence of the Samara River with the Dnipro River, which can be explained by the significant contribution to the pollution processes of the growth of the leaching of mineral fertilizers into the river basin, especially during the warm season.

Conclusions

Thus, as a result of the application of the improved water quality index with the entropy weighting coefficient for the section of the Dnipro River, located within the Dnipropetrovsk region, it was established that the quality of the index differs significantly in the warm and cold periods of the year. For the cold season, the minimum value of EWQI = 202.70 is observed at control point p2 (town Auli, drinking water supply of the city of Dnipro and the city of Kamianske), the maximum - EWQI = 242.90 - in p4 (the city of Dnipro, left bank, Lomovsky drinking water park). For the warm period of the year, the best water quality is observed in p4 - EWQI = 225.20, and the worst - EWQI = 301.41 - in p5 (city of Dnipro, "DTEK Dniproenergo", drinking water). Territorially, the control point p5 is located below the confluence of the Samara River with the Dnipro River, which can be explained by the significant contribution to the pollution processes of the growth of the leaching of mineral fertilizers into the river basin, especially during the warm season.

It should also be noted that one of the key factors in the formation of the entropy index of water quality is the choice of a normative value, therefore, it is promising to justify the choice of the normative value for each specific condition, which can be considered as a separate task.

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